WASTE VEGETABLE OIL AS AN ALTERNATIVE FUEL

FOR DIESEL VEHICLES

THESIS

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AFIT/GEM/ENS/09-01

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AIR UNIVERSITY

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Wright-Patterson Air Force Base, Ohio

AFIT/GEM/ENS/09-01

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THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Research and Development Management

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March 2009

AFIT/GEM/ENS/09-01

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Abstract

Alternative fuels have become a hot topic in the news as the cost of oil remains volatile. Questions of whether acquiring alternative fuels are worth the cost, logistics, and political implications are being asked. A possible solution may be currently thrown away by Wright Patterson Air Force Base's (WPAFB) dining establishments in the form of Waste Vegetable Oil (WVO).

This study researched the benefits and costs of pursuing the installation of a WVO to Straight Vegetable Oil fuel processing center and using the fuel to power some of the base's diesel vehicles. A pilot program was fielded utilizing the Wright Patterson Club for WVO and the Recycling Center for processing and use. From the pilot program, data was extrapolated to determine the total cost and payback period to operate the system.

It was determined that a cost benefit would be realized if the entire system was fielded at WPAFB. Emissions and the risk of WVO spills would be significantly decreased. Furthermore, the system could be fielded throughout the Air Force at some southern tier large bases.

Acknowledgements

I would like to thank my wife for enduring my endless conversations about grease and the numerous times she came to pick me up and tow home the test vehicle when the experiment didn't go as planned. As a result, I think she could have defended the thesis for me. I want to acknowledge Lt Col Greg Hutson for introducing me to AFIT and inspiring me to strive to get accepted. Colonel Kenneth Fielding (retired) should be recognized for helping my dream of AFIT become a reality. My best friend, Evan Cutler, was always there to back me up, both with off-site storage, positive encouragement, and entertainment during another unexpected result from an experiment. I could not have done this without my mother, who has always been my biggest supporter. I would also like to thank everyone at the Recycling Center and the Civil Engineers, especially Keith Waldron and Charles McCreary for their assistance in making the practical experiment a reality. Without their help, the practical experiment would never come to fruition. Libby Domingue and Bill Meinerding from the 88th Air Base Wing Civil Engineering Group should be recognized for expressing an interest in the project and spearheading the sponsorship effort. Finally, I would like to thank my advisors, LtCol Anderson, Dr. Thal, and Dr. Johnson. Their unbounded enthusiasm and professional opinions made this thesis a truly enjoyable experience.

Harvey S. Gaber

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WASTE VEGETABLE OIL AS AN ALTERNATIVE FUEL FOR DIESEL VEHICLES

I. Introduction

General Issue

Alternative fuels became a hot topic in the news last year when the cost of oil climbed from $90.00 to an all time high of $147.00 per barrel. It was expected to hover around $122.00 for the duration of 2009 (Oil Dashboard, 2008). As the price of oil dropped to the current level of $40.00 per barrel, questions of whether acquiring alternative fuels are worth the cost, logistics, and political implications are being asked all over the Air Force and the government. In the Oval Office, President Obama answered the question by making a reduction on foreign oil dependence a priority in his new administration. He believes that renewable energy is the "foundation of lasting prosperity" (Geman, 2009).

History dictates that alternative fuel should not be forgotten simply because the fuel prices dropped. On July 15, 1979, President Jimmy Carter addressed the nation about the energy crisis that was unfolding during his presidency. He set policies to cap oil importation at 1977 levels. To make up the difference, he was a strong supporter of alternative fuels from coal, shale, and crops (Carter, 1979). This is similar to 2008 when Fisher-Tropsch (F-T), biodiesel, and ethanol are the alternatives being researched. President Carter's initiatives worked for a short period. His initiatives, along with the Iraq/Iran War which limited oil production in those countries and the decreased the supply world-wide, caused the price of fuel to sky-rocket. To mitigate the shortage, Gasahol was developed. It was a mixture of 10% ethanol and 90% gasoline, which is similar to the regular unleaded gasoline sold at a majority of gas stations today. Other initiatives were the development of smaller, economical cars and diesel powered passenger cars. Alternative fuels from coal were close to coming online. These initiatives were eroding the demand for imported fuel. As a result, the Oil Producing Exporting Countries (OPEC) dropped the cost of a barrel of oil almost 50% (Williams, 2007). As fuel prices dropped, initiatives in alternative fuels dropped as well.

President Obama does not want to make the same mistakes by letting alternative fuels progress fall by the wayside. He stated: "We have known for decades that our survival depends on finding new sources of energy" at his first address to congress (Geman, 2009). There are many different fuels being developed along with different propulsion methods to help promote his vision. The development of hydrogen and full electric power is quite promising. However, the technology is many years from maturity and a full working system is even further away. At any time, the cost of fuel could rebound back to the levels of 2008. This would have a severe impact on the Air Force's budget. The Air Force is the largest user of fuel in the government and fuel costs make up the greatest portion of the Air Force's budget. While airplanes get most of the press, there is a large amount of fuel used by ground vehicles. To mitigate a future energy crisis, the Air Force needs a solution to rising petroleum costs today and cannot wait for the new technologies to be acquired. Therefore, the Air Force should consider a fuel source that is compatible with current vehicles utilizing little or no modification.

Executive Order (EO) 13423 and the Energy Policy Act of 2005 (EPAct 05) mandated every agency in the United States Government to reduce the use of petroleum based fuels by 2% per year and increase non-petroleum production by 10% per year for the next seven years (Bush, 2007). The two initiatives replaced President Clinton's initiatives, which date back to 1992. The goals were similar: to limit government use of petroleum fuels. The Air Force declared a victory in 2007 due the large amount of 85% ethanol/15% gasoline (E-85) capable light duty vehicles acquired. However, it was a hollow victory. Alternative fuel use actually decreased by 3.4% (USAF/A4RE, 2007). Part of the problem was the Air Force's strategy of using E-85.

Recently the E-85 infrastructure has improved to where it is a true alternative. The biggest concern with corn fuel is that for every ear of corn made into fuel, there is one less ear for food consumption. If all the corn was converted to fuel using the current methods that American refineries use, it would only comprise six percent of the country's diesel needs or 12% of gasoline needs. Other issues are the fuel is less efficient than gasoline. It burns at a higher temperature and contains approximately 67% of the energy that is in a comparable quantity of gasoline (Bourne, 2007). Also, there are still carbon emissions resulting from the gasoline content.

Gaining momentum in the aviation arena is the Fischer-Tropsch process (F-T). The same process can be used for making diesel fuel. It is currently the most popular and most mature alternative fuel source. It is called a process and not an alternative fuel because it involves using coal, natural gas, and otherwise wasted materials from other refinery products and converts them into non-petroleum based diesel or jet fuel. The advantages are that less toxic gasses are introduced to the environment and materials that would have become toxic waste are recycled into a useful application (Environmental Protection Agency, 2002). The cost savings are realized when crude oil costs climb above $50.00 per barrel (Wisenberg-Brin, 2006).

F-T fuel can be mixed with Jet-A and petroleum based diesel. The mixture can be used in airplanes or ground vehicles without any modifications to the vehicles. Therefore, it is considered a drop-in fuel source. (Hileman, 2007). The concept was proven in 2006. Syntroleum, a new American alternative fuel company, provided 100,000 gallons of F-T fuel to the DoD for testing. The DoD mixed the new fuel with Jet-A and powered a B-52 in flight testing. The results demonstrated reduced soot and sulfur emissions output. Performance was noted as “superior” (Gamino, 2007). A 50/50 mix has been used for several years at Johannesburg International Airport in South Africa without incident. The supplier, Sasol Ltd., is confident it can make 100% unblended synthetic fuel. Sasol is also looking to develop a presence in the United States by developing a coal to liquid fuel plant here (Wisenberg-Brin, 2006). This will definitely improve the development and eventual production of F-T fuel because of competition between Sasol and Syntroleum.

It appears that F-T is the proverbial “silver bullet” that can solve everything. A closer look reveals that it is not the best solution. The major component of F-T is coal. Coal is still a fossil fuel with a finite future. There is more coal than oil in this country, but if it is exploited as the proponents of the fuel want it to be, eventually the supply will wane. In order to make F-T fuel, it requires a coal plant to generate the waste that is converted. Coal is a notoriously dirty fuel. There is health and environmental issues in mining it and emissions from a coal factory are higher than cleaner fuels such as nuclear, solar, or wind power.

Biodiesel is the most popular commercially available alternative fuel. Interestingly, it has been around longer than gasoline and diesel. Henry Ford used a form of it in his first car, and Rudolph Diesel's first engine was powered by peanut oil. Both inventors quickly realized that petroleum based fuels had more energy per gallon than fuels derived from crops. Today, the same still holds true. If refined properly, biodiesel can be used as a drop-in fuel source and the loss of energy is minimal.

Biodiesel costs more to make than conventional diesel. The same holds true for ethanol or any other biofuel. There are actually two costs associated with them. The cost of producing the fuel is one and the impact of taking away food resources is the other. Every day approximately 25,000 people die from hunger. Research shows by 2050 the demand for food and fuel is expected to double (Bourne, 2007). Currently, 14% of the United States corn production is used for fuel. In 10 years, it is expected to rise to 31% (Hileman, 2007).

The actual dollars and cents of biofuel are staggering. Even in Germany, where biodiesel production is about 0.5 billion gallons, it costs 65 cents per gallon (US currency) more to produce than petroleum based fuels. This is based on the 2007 price level of $6.15 per gallon in Germany. Ethanol has a similar price point to gasoline but has less energy per gallon than the petroleum source. To travel the same amount of miles, the quantity of ethanol would be approximately $0.71 more per gallon, assuming a $3.00 per gallon gas price (Bourne, 2007). The government is aware of the issue and has provided lucrative tax credits to ethanol and biodiesel producers. There is a $1.00 per gallon biodiesel tax credit, $0.51 for ethanol, and various incentives to install E-85 pumps and infrastructure (Mufson, 2007). Therefore, not only is the cost of food going up, the tax base is shrinking.

A popular alternative in the consumer sector is Straight Vegetable Oil (SVO) or Waste Vegetable Oil (WVO). After removing water and impurities, SVO and WVO are synonymous. From an outside perspective, it appears SVO is the same as biodiesel. Both fuels are an effort to reduce America's dependence on fossil fuels, they are better for the environment, and are a suitable replacement for diesel. However, the similarities end there. Biodiesel is a drop-in fuel source, requiring no modification to diesel vehicles, while SVO needs a few components. Also, the refining methods are quite different.

There are many different ways to modify a vehicle to run on SVO. The most popular and reliable kits are two-tank systems. As the name suggests, a separate fuel tank for SVO is needed because the alternative fuel starts to turn into a solid when the temperature falls below 160 degrees, making a heating system paramount. Switching valves are equally important. The engine must be started and stopped with diesel, otherwise the SVO will gel inside the fuel lines and the engine will be impossible to restart without a major cleaning of the entire fuel system (Wacker, 2007/2008). Therefore, the original onboard diesel based fuel infrastructure must remain.

SVO is refined differently than biodiesel. The major component of biodiesel is still petroleum-based products. The other main ingredient is some form of food or food-stock (Hileman, 2007). It is formed by a chemical reaction by adding methanol. In addition to fuel, glycerin is produced as a byproduct. The easiest way to dispose of the byproduct is to make soap out of it. SVO, as the name implies, has no additives and is indeed straight vegetable oil (Wacker, 2007/2008). Because of the lack of petroleum additives, SVO produces zero emissions. However, running a vehicle on SVO is not as simple as pouring it straight from the waste dumpster into the vehicle. It needs to be heavily filtered and purified to work.

Even though there is some degree of extra work involved, SVO appears to be a very good option to limit the Air Force's dependence on fossil fuels. Also, collateral positives are plentiful. Most Air Force bases have dining facilities, base restaurants, and Army and Air Force Exchange Services (AAFES) food courts that need to dispose of WVO. The current disposal method involves using an outside contractor. It transports the WVO off base, creating the potential for an environmental incident by spilling the WVO. If the WVO was converted to SVO and used as a fuel, the need for an outside contractor would be eliminated.

Specific Problem

The Air Force needs to find an alternative fuel to cut costs and limit foreign oil dependence. At the same time, it needs to be sound environmental stewards by cutting its carbon footprint and production of waste. This thesis will reveal the positive effects of developing and fielding a WVO infrastructure to include collection, processing, and vehicle use.

Research Objective and Question

The objective of this research is to determine if the Air Force should pursue WVO systems at all major bases. Wright Patterson Air Force Base (WPAFB) will be used as a pilot base to determine the answer. In order to answer the objective question, the following investigative questions must be answered.

- How much WVO is produced by the dining facilities at Wright Patterson Air Force Base (WPAFB)?
- How many vehicles can be powered by the SVO produced?
- At what point does the WVO/SVO infrastructure generate a cost savings?
- What is the amount of emission reduction per vehicle due to operating on SVO?
- Will the new WVO recycling system prevent or eliminate environmental spills?
- Can the WVO infrastructure meet the requirements of the EPAct 2005 and EO 13423 initiatives?

A literature review revealed there is no documentation available regarding the logistics of fielding a WVO to SVO system on a government installation. This thesis will add to the body of knowledge by explaining the methodology used for the research effort and showing the results of the investigative questions.

Scope

The scope of the research will be limited to systems that are currently available. Focus will be centered on SVO from WVO feasibility. Government regulations concerning green initiatives and taxation will be investigated to ensure all federal compliance is achieved. All practical research will be conducted at WPAFB utilizing the resources of the Base Recycling Center and Services eateries.

Summary

Chapter I provided a brief synopsis of the environmental directives mandated by the U.S. Government. The different alternatives available to fuel ground vehicles were defined, and the thesis questions were introduced. Finally, the parameters of the scope of this research were defined.

II. Literature Review

Introduction

Diesel engines have been in use since the late 1800's. The first diesel was developed to run on peanut oil. Once the technology became widely accepted in the 1900's, the abundance and low expense of fossil fuels caused a paradigm shift away from organic vegetable based fuels. At the turn of the current century, the same paradigm was beginning to shift back due to rising fuel costs, the environmental impact, and an abundance of waste feedstock available. Fringe entrepreneurs and environmentalists began developing different methods to harvest the waste grease produced from frying foods. The concept of filtering the grease and removing suspended water particles to make either biodiesel or Straight Vegetable Oil (SVO) was born. At the same time, a renewed interest was found in a Post World War I German process of converting coal to a liquid fuel called the Fischer-Tropsch process (F-T). All three of these options look very promising as a way to reduce the Air Force's dependence on petroleum-based diesel, or petro-diesel. This research will explore SVO derived from Waste Vegetable Oil (WVO) as an option for the Air Force to use to power diesel vehicles in its fleet.

There are many different fuels being developed along with different propulsion methods. The development of hydrogen and full electric power for vehicles has made many advances in the last few years. However, the technology is many years from maturity and a full working system is even further away. Prototype electric vehicles from General Motors, Smart, Toyota, and Tesla were recently unveiled at the 2009 North American International Auto Show. With the exception of Tesla, none of the vehicles are ready for production. Commercial industry is working to make a breakthrough but the manufacturers are keeping most of the information classified. Besides electricity, advances have been made in substituting gasoline with an 85% blend of ethanol to gasoline (E-85) fuel and Compressed Natural Gas (CNG). Both options are viable alternative fuels that have been in use for many years. They have been in use by the government for a few years. Those vehicles are a start to reducing the government's dependence on petroleum but fall short of meeting Environmental Protection Agency mandates. Many vehicles in the Air Force inventory are diesel powered and are being overlooked when it comes to fielding an alternative fuel solution. To utilize this unused capacity and to have a system that could be immediately used, the scope of this research was limited to diesel alternative systems that are available for use today.

There are three dominant alternative fuels:

1. Synthetic fuel derived from Fischer-Tropsch
2. Biodiesel
3. SVO

The research will demonstrate why SVO is the most viable option for the Air Force to pursue.   The costs of petro-diesel to the Government will be compared to the alternatives. Included in the research will be an explanation of the federal tax laws, the current mandates, and alternative fuel incentives provided by the government. All internal combustion engines have emissions. Changing the fuel source has effects on these emissions and changing the collection of WVO provides a benefit to the environment. These changes will be examined. Current WVO to SVO logistical models will be investigated to determine if there is a precedent to fielding a government operated system. The concept of performing a cost benefit analysis is described to form the basis for evaluating the system. The chapter will conclude with a summary of why this thesis is an important study in the decision for the Air Force to pursue SVO derived from WVO as an alternative fuel.

Criteria of Fuels

In order to determine the viability of different alternative fuels, certain criterion should be defined to compare the alternatives to petro-diesel. The criterion consists of the following:

1. Cetane Number
2. Flash Point
3. Pour Point

The cetane rating is "a measure of its [the fuel's] ignition delay with higher cetane numbers indicating shorter time between the initiation of fuel injection and ignition" (Graboski, 1998). Cetane is to diesel as octane is to gasoline. An acceptable rating is 40 to 60. This is the rating when the fuel auto ignites in temperatures characteristic of the combustion chamber of a diesel engine. The goal is to attain ignition when the piston reaches top dead center (TDC). Diesel engines work by compression ignition. There are no spark plugs to ignite the fuel. The compression is how extreme heat is formed to make the fuel auto ignite. It is imperative for the fuel to ignite precisely at TDC. Otherwise, efficiency will suffer and ignition knock will occur (Ramadhas, 2003).

Flash Point is the temperature when a liquid fuel becomes combustible. While not directly related to engine performance, it is important when handling fuel. Diesel has a flash point between 100° and 160° Fahrenheit (What is Diesel Fuel?, 2009). The flash point of vegetable oil is 260°, making it relatively safe to transport and use (Ramadhas, 2003).

Pour Point is the minimum temperature when fuel can move through fuel lines (What is Diesel Fuel?, 2009). Once the temperature falls below this point, gelling occurs. Pour point is closely related to viscosity, or the thickness of the fuel. In order for an alternative fuel to be used in a diesel engine, the viscosity needs to be equal to or better than the viscosity of conventional diesel fuel.

The above characteristics were reviewed to determine if an alternative fuel source exists that can be inserted into a diesel vehicle with little or no modification to the vehicles. The term for this kind of fuel is a “drop-in fuel source”, meaning it can literally be dropped into the fuel tank and the vehicle will run as if it were on petro-diesel (Hileman, 2007). This was a prime reason for limiting the alternatives studied to the F-T process, Biodiesel, and SVO.

1. Synthetic Fuel Derived from Fischer-Tropsch Process

The F-T process is a popular and mature way to refine alternative liquid fuel from coal. The process was developed in 1923 by two German scientists, Franz Fischer and Hans Tropsch, working at the Kaiser Wilhelm Institute. Currently, countries other than the U.S. producing and using the coal-to-liquid fuel include Malaysia and South Africa, with plants being built in the Middle East and China. The F-T process involves using coal, natural gas, and otherwise wasted materials from other refinery products and converting them into non-petroleum based diesel or jet fuel. The product is referred to as synthetic fuel or synfuel. An advantage is that less toxic gasses from particulate matter are introduced to the environment. Materials that would have become toxic waste are recycled into a useful application (Environmental Protection Agency, 2002). The cost savings are realized when crude oil costs climb above $50.00 per barrel and the payback is attained on the initial investment in the refineries. In 2006, the average cost for crude oil was nearing $70.00 a barrel, which led to the U.S. and South African plants to come on line (Wisenberg-Brin, 2006).

While these benefits seem too good to pass up, there are factors battling against coal to liquid production. These factors include: high investment costs for initial production, guaranteed support and demand for the product, and the environmental impact of increased carbon monoxide emissions due to increasing the use of coal. The costs for constructing a large plant producing 80,000 barrels of fuel a day could be upwards of $8 billion. Syntroleum was a company that provided F-T fuel to the Air Force to fly a B-52 on a 50/50 F-T/JP-8 blend in 2007. While the test was a success, Syntroleum had to convert its facility in Oklahoma to biofuel production because there was not enough F-T demand to keep the facility open. If the government cannot provide a demand, interest in the product will wane (Hileman, 2007).

2. Biodiesel

Unlike F-T, biodiesel does not have the same high costs involved in refining the fuel. Its main ingredient can be WVO, SVO, feed stocks, or animal fat. Biodiesel can be produced many different ways. The most accepted method is by taking any of the raw main ingredients listed above and transesterifying the triacylglyerols of the ingredients with an alcohol based catalyst. The result of the transeterification is biodiesel along with a glycerin by-product (Zhang, 2003). Methanol or ethanol is used as the alcohol primarily because of costs and the quick reaction time with the main ingredients. The procedure involves continuously stirring and heating the mixture to at least 149° F for approximately one hour. After the hour, separation occurs by two layers forming. The top layer is what eventually will become the fuel and the bottom layer is the glycerin. The fuel needs moisture removed from it to be usable. This is accomplished by using calcium chloride or sodium hydroxide to dry it (Ramadhas, 2003).

There are numerous biodiesel processors available for purchase. A quick internet search found prices as low as $2695 for a 24-gallon processor at Evolution Biodiesel to $13,299 for a 100-gallon fully automated processor at Northern Tool and Equipment. BioFuels Equipment offers a complete kit for $4495. However, due to the drop in fuel prices in the last quarter of 2008 and the economic downturn, the kit was reduced over $1000. The processor has a 160 gallon capacity, a fuel dryer, and features automatic mixing of the chemicals. The chemicals needed consist of lye (sodium hydroxide) to remove the moisture and methanol to perform the transesterfication. Both chemicals are readily available from many distributors (Freedom Fueler Deluxe with Drywash, 2006). However, sodium hydroxide is extremely toxic. Special handling is stressed when purchasing it due to the caustic nature of the chemical. Rubber gloves, eye protection, and ventilation are mandatory. The cost of a 40oz bag (with shipping) is approximately $25.50 (Sodium Hydroxide/Lye - 2.5 lbs / 40 oz, 2009). Methanol is available locally from various gas and oil distributors. The price changes similarly to other petroleum products. In January 2009, the price of methanol was $2.84 per gallon.

A basic biodiesel recipe calls for approximately 0.87 ounces of sodium hydroxide and 0.20 gallons of methanol along with a gallon of SVO to make 0.80 gallons of biodiesel. The remaining byproduct is the glycerin (Pelly, 2005). After a few calculations, the raw material cost of biodiesel would be $1.40 per gallon. Additional costs would occur if WVO was used. This is due to heating and processing the WVO into SVO and removing the fatty acids. There is an increased use of solvents to perform the removal. The recipe referenced is an alkali-based process. There is another process that involves using an acid catalyst. The benefit of the acid process is the fatty acids do not have to be removed. However, the process uses sulfuric acid to convert the WVO to fuel. The recipe is more complex and sulfuric acid is more dangerous to handle, thus adding increased risk to personnel performing the procedure. Regardless of either method, WVO needs to be pre-filtered to remove particulates and suspended water (Zhang, 2003). The extra processing cost adds to the total cost of the fuel, thus making it comparable to using virgin vegetable oil. Disposing of the glycerin is also an issue. In order to make it usable, the glycerin needs to be boiled and distilled. In this form, it can be used in soap, medicines, or hand lotions (Pelly, 2005).

Once the biodiesel is processed, it can essentially be used in the same manner as petro-diesel, thus making it a drop-in fuel source. No modifications to the engine are required. Emissions from the alkali-based process and recipe result in increased particulate emissions over petro-diesel but harmful Nitrogen Oxide (NO_x) emissions are reduced (Ramadhas, 2003). The methanol and lye used in the processing are converted to emissions. Other chemicals found in the final product are methanol, formaldehyde, acrolein, and benzene. There is approximately 1.2 to 3 times more concentration of these harmful substances in biodiesel compared to petro-diesel (Murayama, 2000).

3. Straight Vegetable Oil

The final option studied is SVO. SVO can be purchased in the form of rapeseed oil, sunflower oil, soybean oil, peanut oil, or corn oil. Unfortunately, this is cost prohibitive as the above mentioned oils can cost double or triple the petro-diesel cost. SVO can be refined from WVO. Similar to biodiesel, SVO from WVO needs to be heated and filtered during processing. The systems are much less complex and less expensive compared to biodiesel systems.

Heating WVO to make SVO is performed only to remove suspended moisture. Filtering prevents solid particulates from entering a vehicle's fuel system. The main components of a processor are a vessel to hold the oil, a heater, and a filter. There are no chemicals involved in the WVO to SVO process. The heater needs to be able to heat the WVO up to 140° F. At this point, the water molecules are no longer suspended in the oil and drop to the bottom of the vessel. A filter is needed to remove particulates that would clog up a fuel system (Kattreh, 2008). One micron is the recommended maximum filtration size (F2F Filtration Units, 2008). By processing the oil to that level, a 10 micron filter installed in the vehicle can last up to 9,000 miles (Kattreh, 2008).

Processing systems can be as extravagant or simple as the user wants them to be. A simple 5-gallon processor can be made of a commercial stock pot placed on a stove.

Filtering can be accomplished though a one micron sock. However, this would not be practical for large scale use. Base kits can be acquired for as little as $700, while the most expensive kit is $2000. The advantage of spending more money is the increased refining capacity and the resulting higher quality of fuel. The $2000.00 kit contains two 55-gallon drums for processing, along with a centrifuge (F2F Filtration Units, 2008). The centrifuge provides the advantage of "polishing" the oil. It works similar to a washing machine by spinning out the water and any particulates as the WVO is processed through it. Non-centrifuged SVO has a degree of sludge in it, despite how much filtering is completed. By centrifuging, the oil has a uniform liquid consistency. The result is more usable SVO and the ability to reuse the final SVO storage containers. The non-centrifuged containers contain sludge that is difficult to clean out. They would have a higher probability of ending up in a landfill (Kattreh, 2008).

After processing, SVO has an average cetane rating of 17.7 and is considerably more viscous. The cetane rating of 90% diesel/10% SVO blend yielded a total value of 56.36, well within the standards of conventional diesel (Dorado, 2002). SVO can be used as an additive to petro-diesel in this state. In warmer climates, such as Brazil, SVO was mixed 20% SVO to 80% diesel in a Caterpillar diesel engine without incident. The properties of SVO and diesel allow it to make a complete mixture (Ramadhas, 2003). When the mixture contains more than 25% SVO incomplete combustion issues can occur in colder climates. This leads to poor atomization and carbon deposits. Over time, internal engine components can wear prematurely (Dorado, 2002). Therefore, in this state it is not a complete replacement for diesel, but can be considered a fuel extender. If calculations are made to ensure the percentage of SVO added to diesel fuel is below 20%, the blend could be considered a drop-in fuel source in a warmer climate.

Another option to utilize SVO is heating it in the vehicle before use. Pre-heating the SVO will lower the viscosity and raise the cetane rating to be similar to diesel. SVO's viscosity is about 10 to 20 times that of diesel at ambient temperatures (Demirbas, 2007). However, if it were heated to 70° Fahrenheit, the viscosity drops and the cetane rating increases 40 to 50, about the same as diesel (Calais, 2006). A conventional diesel engine has no spark plugs and relies solely on compression of air to heat the fuel/air mixture to a point where it will auto ignite. This occurs around 500° Fahrenheit (Tang, 2005). SVO has a slightly higher auto ignition point, but will still burn in a diesel engine if the engine is brought up to its normal operating temperature before the SVO is introduced. The same incomplete combustion issue exists if the diesel is diluted over 25% with SVO. Due to the SVO not burning completely, there is a possibility of deposits forming in the fuel injectors along with oil ring sticking and increased carbon deposits (Demirbas, 2007). In order to prevent this, the engine must be purged of all SVO and returned to diesel operation before shutdown. The diesel acts as a cleaner for the lines, injectors, and pistons. Purging virtually eliminates added engine wear. Also, if SVO stays in the fuel lines, it will gel and clog the lines making a restart troublesome. Gelling can occur in as little as 20 minutes from shutdown (GreaseCar Fueling and Filtering, 2008).

Cost of Diesel Fuel

In order to determine if there is a cost benefit to fielding a SVO infrastructure, the cost of the infrastructure should be compared to the current diesel fuel source. The Air Force purchases diesel fuel and biodiesel primarily from the Defense Energy Support Center (DESC). DESC is part of the Defense Logistics Agency. In 1973, DESC went from the wholesale acquisition of fuels to become the all encompassing agency to store, distribute, and sell the fuel up to the "service installation boundary." Additionally, DESC manages all the natural gas, coal, and aerospace energy resources in the continental United States (Defense Engergy Support Center, 2007). The cost of fuel to the user is determined by a Standard Price. The intention is to provide DESC customers stability in budgeting. The Standard Price normally changes once per fiscal year. It is based on predictions made 18 months in advance when the President's Budget is formed. This causes the cost to never be synchronized with what consumers pay on the open market (Defense Energy Support Center).

Over the last calendar year, the cost for a barrel of oil has vacillated tremendously, making forecasting the Standard Price quite difficult. Therefore, DESC had to issue price adjustments twice. In July, 2008, it had to increase the price per barrel of oil from $127.68 to $170.94. By increasing the cost of the raw oil, the cost of all fuels increased proportionally (Roth, Fiscal Year (FY) 2008 Fuel Price Change, 19 Jun 2008). The new price was going to be the Standard Price for Fiscal Year 2009. However, by November 2008, the commercial cost per barrel dipped down to under $40.00. Another adjustment was required. The new and current Standard Price was set at $104.58 per barrel, making a gallon of diesel fuel $2.49. Biodiesel offered by DESC was the same price as petro-diesel through all the adjustments. The cost of both fuels included federal excise taxes (Roth, 20 Nov 2008). While DESC fuels are still higher than commercially available diesel fuel, the cost is quite close. In January 2009, the average commercial diesel cost was $2.29 per gallon.

Taxation of Alternative Fuels

DESC includes the federal excise tax in its costs because the federal government is not exempt from taxation of diesel fuel or alternative fuel if the fuel is used in an on-road motor vehicle (Defense Energy Support Center, 2008). The only exemption is for fuel that would be used in off-road vehicles, such as construction equipment or Aerospace Ground Equipment. Normally, the fuel has red dye added to it to distinguish it as tax-exempt. Fuel taxes are reported to the Internal Revenue Service (IRS) when the fuel is distributed to the "Service Installation Boundary" (Defense Engergy Support Center, 2007). At Wright Patterson Air Force Base, the boundary is the end of the gas nozzle. The fuel inside the fuel tanker trucks and on base storage tanks is the property of DESC. The Air Force owns the fuel when it is pumped into an airplane, motor vehicle, or any internal combustion engine fuel tank (Helber, 2007). DESC pays the federal excise Tax to the government when it refines the fuel and it leaves the refinery, eliminating the need for individual agencies to track fuel usage for tax purposes. Taxes for applicable fuels are collected from the Air Force and its other customers by DESC (Defense Engergy Support Center, 2007). This is analogous to the way excise taxes are collected in the commercial market. The refiner will pay the tax per gallon directly to the

IRS. When the fuel is sold, the end user pays the tax, which in turn is a reimbursement back to the refiner. The current tax rate on diesel fuel is 24.4 cents per gallon (National Energy Information Center, 2008).

Alternative fuels are also taxed. Biodiesel and SVO are taxed at the same rate as petro-diesel. However, the tax is collected when the fuel is "delivered into the fuel supply tank of a motor vehicle" or the fuel is sold in bulk. Taxes are reported and paid on IRS Form 720, Quarterly Federal Excise Tax Return. Just like petro-diesel refiners, the alternative fuel refiner is responsible to pay the tax. The IRS makes no distinction between the biodiesel hobbyist and major refiner (Internal Revenue Service, 2008). The taxes are necessary to pay for America's infrastructure. The funds go to road maintenance and building projects (Wacker, Would You Use Veggie Oil to Fuel Your Vehicle?, 2007/2008). Therefore, if a new SVO infrastructure is fielded, excise taxes need to be calculated and paid by the refiner or processor. Despite the lack of a tax benefit, there are initiatives to use alternative fuels from the government that are described in the next segment.

Alternative Fuel Regulations

Executive Order (EO) 13423 was enacted in January of 2007. The main goals of the order in regards to alternative fuels were for every government executive agency to reduce greenhouse gas emissions by three percent per year. By the end of Fiscal Year (FY) 2015, 30% of the emissions generated by each respective agency should be eliminated. Agencies with 20 vehicles or more need to free themselves of petroleum product consumption at a rate of two percent and increase non-petroleum consumption by 10% per year for the next seven years. Plug-in hybrid vehicles should be used when they become available on the commercial market. The order also states that 50% of new renewable energy sources should be generated on agency properties (Bush, 2007).

This was not the government's first mandate pertaining to alternative fuels. The Energy Policy Act of 1992 (EPAct 92) introduced the federal statutory requirement to acquire alternative fuel vehicles (AFV) within agencies. It set the deadline of FY 2000 to have 75% of new light duty vehicle acquisitions to be AFVs. This equated to 10,000 vehicles per year (Congress 1. , 1992). Differing from the government-wide mandate of the EOs, EPAct 92 limited the compliance to agencies where the vehicles operated predominately in a "Metropolitan Statistical Area or Consolidated Metropolitan Statistical Area." That is defined as an area with 250,000 or more residents. Similar to the EOs, fleet size had to be over 20 vehicles but it only applied to light duty vehicles (under 8,500 pounds gross vehicle weight). "Law enforcement, emergency, and military tactical vehicles are also exempt" (Energy, 2008). The primary alternative fuels were defined as follows:

> methanol, ethanol, or other alcohols, natural gas, liquefied petroleum gas, hydrogen, coal derived liquid fuels, fuels (other than alcohol) derived from biological materials, electricity (including electricity from solar energy), ethers, or any other fuel the Secretary determines, by rule, is substantially not petroleum and would yield substantial energy security benefits and substantial environmental benefits (Congress 1. , 1992).

The bill was approved in January of 1992, but the first EO mandating compliance did not appear until 1998. EO 13101 was one of the first "greening" orders. It was quite ambiguous by stating that the government should procure “environmentally preferable” and “biobased” products. Those were non food or feed products and made by renewable agricultural resources (Clinton, 1998).

EO 13123 was the predecessor to EO 13423 in respect to alternative fuels. It set the same goals for reducing greenhouse gasses. However, it set the 30% reduction as an all or nothing compliance by 2010, almost 11 years after signing the order. Renewable energy was stressed but only solar power was recognized. A goal of installing 2,000 solar systems by the end of 2000 and 20,000 systems by 2010 was made the threshold for compliance. Petroleum products were casually mentioned with verbiage stating that “each agency shall reduce the use of petroleum within its facilities” (Clinton, 1999). At the time, petroleum was not an issue. The 1999 average price for regular unleaded was hovering around $1.00 per gallon or $1.30 a gallon in 2008 dollars after being adjusted for inflation, as Figure 1 demonstrates. However, gasoline started a steady climb of about 50 cents through the next two years. It was one of the biggest jumps since the energy crisis of the 1970s (McMahon, 2008).

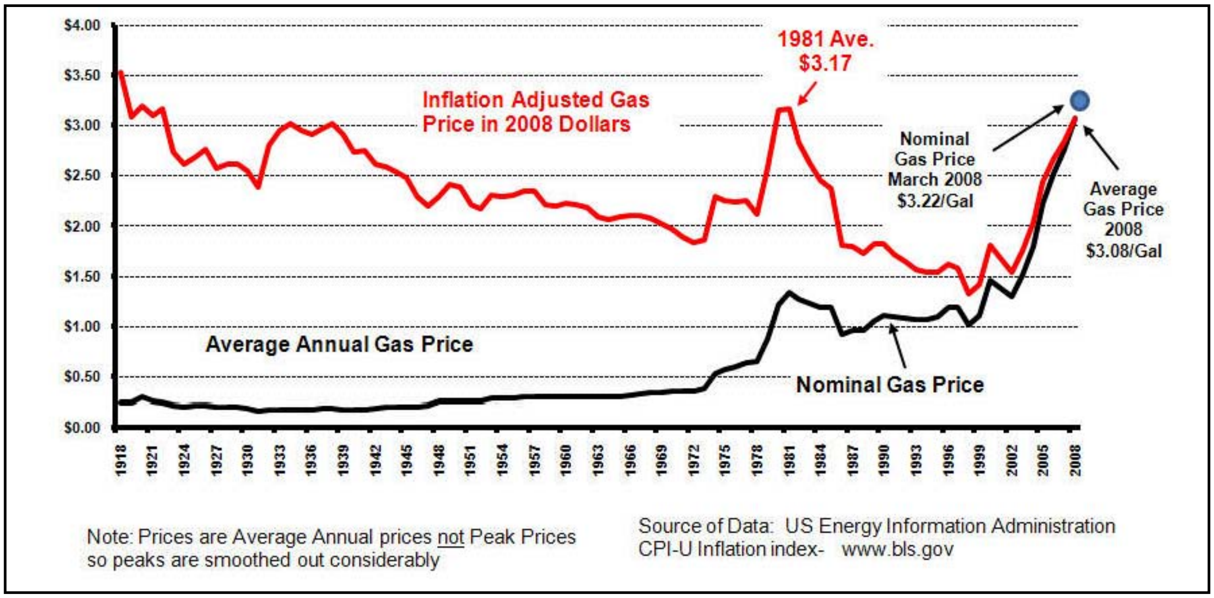

Figure 1: Gasoline Prices 1918-2008, Adjusted for Inflation

Foreseeing the trend, President Clinton signed EO 13149. The order prescribed an aggressive strategy to reduce petroleum consumption by 20% within the next five and a half years. It also placed the government at the forefront of Alternative Fuel Vehicles (AFVs) and alternative fuels by making them a prime user. The strategy served two purposes: to reduce the usage of petroleum and to create a market for AFV developers to sell their products. EO 13149 expanded the mandates of EPAct 92 by making compliance mandatory throughout all agencies with 20 or more vehicles. It used the vehicle reporting credits set up by EPAct 92 for tracking progress (Clinton, 2000).

Due to numerous circumstances, such as the September 11th attacks and Hurricane Katrina, fuel prices continued to escalate to the highest point, even with inflation adjustments, in July of 2008. Also, technology advanced by leaps and bounds in various fields. Therefore, EPAct 92 was updated in 2005, resulting in the Energy Policy Act of 2005 (EPAct 2005). There was still an emphasis on dual fuel vehicles that used natural gas, but electric hybrids were also considered. The act mandated a report by the

Secretary of Energy to Congress (Congress 1. , 2005). Once EO 13423 was signed, it was also included in the Secretary's report.

In 2007, the Air Force reported on the four major vehicle requirements from the two mandates. Unfortunately, the Air Force only met one goal. The performance is shown in Table 1. Due to the writing of EPAct 92 and subsequently EPAct 2005, the Air Force was in compliance due to the AFV credit system (USAF/A4RE, 2007). One credit is allocated for every light duty AFV vehicle that is acquired. If a medium or heavy duty vehicle is procured, than multiple credits are given. However, the vehicles can be dual fueled and never run on the alternative. If a non-petroleum fuel is used, than more credits are allocated. For example, if 450 gallons of biodiesel were used, then one credit was allocated (Congress 1. , 2005). This demonstrates a flaw in the system. The Air Force exceeded the acquisition goal but failed on the usage goal. This caused compliance but did nothing to reduce fossil fuel consumption.

Table 1: USAF's Performance in Meeting EPAct 2005 and EO 13423 Requirements, FY 07

Authority/ Mandate	Performance Measure	Goal/Requirement	USAF Performance in FY07
EPAct 2005	Alternative fueled vehicle (AFV) acquisitions	75% of the covered light-duty vehicles (LDV) acquired in FY07 must be AFVs	Met goal - 119% of the covered LDVs acquired in FY07 were AFVs
	Alternative fuel use in AFVs	Utilize alternative fuels 100% of the time in AFVs	Did not meet goal - Utilized alternative fuels 53.5% of the time in AFVs
E.O. 13423	Reduce fossil fuel consumption	Reduce covered consumption by 2% annually compared to FY05 baseline	Did not meet goal - Decreased covered fossil fuel consumption by 0.04%
	Increase alternative fuels consumption	Increase alternative fuel consumption by 10% annually as compared to FY05 baseline	Did not meet goal - Decreased alternative fuel consumption by 3.4%

The various EOs and the two EPActs state the objectives of the last two presidents clearly. In order to meet the objectives the Air Force decided to use E-85 and CNG powered vehicles. Wright Patterson Air Force Base contributed to the Air Force's alternative fuel credits by adding E-85 to the suite of fuels available in 2004. E-85 is still available and widely used today (Helber, 2007). The primary alternative fuel for diesel vehicles is a 20% blend of biodiesel to petro-diesel, due to the ability to use it with no vehicular modifications and its availability through DESC. It has been on base for at least three years as well (USAF/A4RE, 2007). While biodiesel is providing fuel credits, it is not helping the environment due to its emissions.

Alternative Fuel Emissions

The combustion of diesel yields Nitrous Oxide (NO_x), Carbon Monoxide (CO), and Particulate Matter (PM). NO_x is responsible for ozone depletion and the formation of smog. Presence of CO means there is less oxygen, thus causing detrimental circumstances to humans and animals. PM consists of a variety of chemicals and is the bulk of diesel emissions. It is the source of inhaled pollution along with environmental pollution. Particles can settle anywhere and cause a chemical imbalance. They are very portable. A particle released into the air by a truck in Los Angeles can travel great lengths, ending up in the Grand Canyon (Environmental Protection Agency, 2008). PM is caused by what the fuel is made of. Naturally, if harmful toxins are part of the fuel recipe, the corresponding PM will contain those toxins (Demirbas, 2007).

Synthetic fuel derived from the F-T process utilizes coal as its major contributor. After coal is converted, the resulting synthetic fuel has high cetane and burns cleanly. NO_x, CO, and PM are all reduced. The main reason for PM reduction is due to low sulfur in the recipe, along with no aromatic content (Environmental Protection Agency, 2002).

Biodiesel has many different recipes utilizing different ingredients. As the ingredients change, so do emissions. Some recipes will yield less NO_x at the expense of elevated CO and PM, while others are the inverse. However, no biodiesel recipe has been found to lower all three tested emissions (Ramadhas, 2003).

SVO has no chemical additives. Therefore, the output is the natural ingredients of the SVO. NO_x output is similar to diesel. CO is less than petro-diesel and PM is reduced by 39% (GreaseCar Fueling and Filtering, 2008). While NO_x emissions are similar to petro-diesel, the total process should be considered. Making SVO from WVO involves far less energy use than biodiesel, F-T, or even conventional diesel. If the life-cycle of refining and using the fuels were compared, total NO_x output for SVO would be less than the other two alternatives. (Wacker, 2007/2008).

Environmental Impact of Waste Vegetable Oil

There is a debate over the health effects caused by eating foods cooked in vegetable oil. The actual vegetable oil is not considered toxic, but once it is used and becomes WVO, federal regulations classify it as a pollutant. WVO needs to be disposed in a manner to comply with the Federal Water Pollution Control Act (Quigley, 2009).

The Act regulates the “discharges of pollutants into the waters of the United States.” If the disposal method results in the introduction of pollutants, a permit needs to be obtained (Environmental Protection Agency, 2009).

WPAFB’s disposal system can result in WVO entering clean water streams. Regulations require outside storage containers over 55 gallons to have a secondary containment system to prevent introduction of WVO into the water supply. However, the secondary systems are not in place. It was determined to be impractical to build such a system due to costs. An “impracticality justification” was drafted as an addendum to the Spill Prevention Countermeasure and Control plan. There are two ways to make the base compliant. One way is to store the WVO in containers that are less than 55 gallons. If the drum leaked, the amount of WVO spillage would be minimal. Another way would be to store the WVO inside. If there was a spill, it would go into sanitary drains and not directly into the clean water stream (Quigley, 2009).

Cost Benefit Analysis

Comparing any alternative to the DESC fuel price would require a cost benefit analysis. There should be an advantage to acquiring and fielding a new system. The benefits can encompass more than cost savings. The earliest example of such a cost benefit analysis was the adoption of the U.S. Flood Control Act of 1939. By dredging harbors and building canals, neighboring structures close to the waterways were saved from potential flooding (Guess, 2000). A monetary benefit was realized by determining the amount of dollars that would be saved in relation to the cost of improving the infrastructure. Additionally, collateral benefits would be realized. Businesses close to the waterways would not have to be shut down due to flooding, people would not be inconvenienced by having to evacuate, and the waterways would be a safer means of transportation.

This example could be used when looking at fielding an alternative fuel system in relation to using diesel fuel. Four steps are used in the process. First, the costs and the benefits should be identified. In the case of an alternative fuel system, the costs would be acquisition of the system to include conversion of vehicles if necessary, collection costs for the WVO, and conversion costs of the WVO to fuel. Benefits would include emissions reduction from using the alternative fuel, spill prevention by changing the WVO collection process, and compliance with the government's greening initiatives. Second, the costs should have dollar figures assigned to them. Third, the costs should be applied to the entire life of the project. This involves dividing the one-time costs by their usable life and adding up the recurring costs for every year of operation to determine a total lifecycle cost. Finally, a decision can be made to determine if the system is worth the expenditure (Ascott, 2006). The cost benefit would be if the entire alternative fuel system would cost less than the total expenditure of diesel fuel that it would replace. Collateral benefits would include the reduction of emissions, reduction of WVO spills, and compliance with the government's greening initiatives.

WVO to SVO System Logistics

Most WVO to SVO systems have been developed by private individuals in garages. The systems are used for personal use (Wacker, 2007/2008). An average system powers one personally owned vehicle. Labor to collect the WVO, convert it to SVO, and use the fuel in a vehicle is performed by the vehicle owner. One particular vehicle owner collects WVO from seven restaurants within a 10 mile radius from his processor. Once WVO is processed into SVO, he uses the fuel to power his late model Volkswagen Jetta over 200 miles a day. There is SVO left over which is sold for $1.35 per gallon to other users. By using the fuel and selling the excess, a payback could be realized after one year of operation (Kattreh, 2008).

There were not any examples of a commercial or government system found in the existing literature. However, the personal systems could be scalable if more vehicles were included and enough WVO outlets were found to make enough fuel to power the vehicles. WPAFB has 13 outlets that produce over 7400 gallons of WVO per year (Dominique, 2007). The Recycling Center on WPAFB uses approximately 5300 gallons of diesel fuel per year (McCreary, 2008). Therefore, there would be enough WVO to power all of the diesel powered Recycling Center vehicles if a WVO to SVO system was fielded.

Summary

This section described the three dominant designs of alternative fuel currently available as a replacement to diesel. Synfuel derived from the F-T process, biodiesel, and SVO were identified as the three alternatives. The necessary criteria to compare the alternatives were defined. The current process to determine how the Air Force is charged for fuel was described. Additionally, taxation, regulations, and emissions were discussed. As a result of this research, it was determined that SVO derived from WVO should be studied further.

The F-T process, biodiesel, and SVO produced from WVO all have definite pros and cons in respect to being used as an alternative fuel. However, when the issues of the environment, ease of production, and costs are factored in, SVO produced from WVO clearly is an alternative that should be pursued. SVO fuel requires far less processing to make it usable and it involves no additional chemicals that would eventually be turned into emissions. Its prime ingredient is an organic base and not a fossil fuel. This makes the emissions output far less than biodiesel. The cost of the processor is less than an F-T system and costs less to operate than a biodiesel refinery.

While synfuel is very clean burning, the emissions gains would be outweighed by the processing of coal. If it were to be used mainstream as a replacement to diesel, it would simply be a transfer of dependence from one fossil fuel to another. While coal is still quite abundant, eventually the supply would wane. Building and running a coal-to-liquid facility is expensive. It requires the expertise of petroleum scientists and needs to be near an operating coal plant to acquire the waste materials to make the fuel.

Biodiesel is an attractive alternative. A processor is needed instead of a full facility and a person with average math and science knowledge can operate it. The acquisition of the WVO can be completed by partnerships with restaurants. Methanol is available through fuel distributors or automobile race tracks, and sodium hydroxide can be purchased from companies via the internet that have reasonable shipping rates. Issues occur when processing occurs. Handling the chemicals requires personal protection equipment. The area must be well ventilated and there is a definite flammability threat. The processing equipment can become costly as well. Additionally, the glycerin byproduct must be disposed of. Once the fuel is in the vehicle, depending on the recipe, it could give off more emissions than petro-diesel.

There is considerably less infrastructure to acquire and process SVO from WVO. To be used effectively in a vehicle, the vehicle has to be modified. However, the cost of one processor and one vehicle kit is quite comparable to a biodiesel processor. Over the long run, the costs will be less than biodiesel because chemicals do not have to be purchased. The waste stream will be less since the only byproducts are food particles from the WVO and non-potable water. The same particles would exist in a biodiesel waste stream. However, the glycerin byproduct would be absent. Emissions are either equal or less than conventional diesel. Running the processor requires minimal instruction. It is as simple as pouring in the product and monitoring the temperature. Once the WVO reaches 140° F, the water is drained and the remaining product is filtered.

SVO is the most viable alternative fuel for the Air Force to pursue. It can be processed by existing Air Force personnel, the infrastructure is relatively inexpensive to acquire, and no hazardous materials are involved. Due to the small expense, the effort should have a relatively short payback time. The carbon footprint will be reduced and the EPAct and Executive Order initiatives for a reduction of greenhouse gasses will be met.

III. Methodology

Introduction

The concept of running a vehicle on Straight Vegetable Oil (SVO) derived from Waste Vegetable Oil (WVO) has been shown in the previous section. However, there is little research in developing an infrastructure that is reliable and cost effective. The thesis question of whether the Air Force should pursue SVO as an alternative fuel will be answered by determining if there is a cost savings versus using DESC provided petro-diesel or biodiesel and analyzing the tangible benefits of using the system. The following investigative questions were asked:

1. How much WVO is produced by the dining facilities at Wright Patterson Air Force Base (WPAFB)?
2. How many vehicles can be powered by the SVO produced?
3. At what point does the WVO/SVO infrastructure generate a cost savings?
4. What is the amount of emission reduction per vehicle due to operating on SVO?
5. Will the new WVO recycling system prevent or eliminate environmental spills?
6. Can the WVO infrastructure meet the requirements of the EPAct 2005 and EO 13423 initiatives?

Four procedures were performed to answer the above questions. First, a source selection was conducted for the WVO processor and the kits for the test vehicles. Second, the complete WVO to SVO infrastructure was operated. This consisted of the following:

1. WVO Collection
2. WVO to SVO Processing
3. Converting Vehicles to Run on SVO
4. Operation of vehicles on SVO

Third, a cost analysis was performed using the data collected from the above procedures to determine where the break-even and payback point is. The cost differential, whether positive or negative, of the SVO system being used versus using conventional diesel or biodiesel will also be calculated. Finally, a benefit analysis was conducted to determine if there are benefits beyond the cost differential. These include:

1. Reduction of emissions
2. Reduction of spills
3. Making disposal of WVO easier for food service workers
4. Compliance with Environmental Protection Act (EPAct) 2005
5. Compliance with Executive Order (EO) 13423 mandates

Investigative Questions

The thesis question can be answered "yes" if there is a reduced cost and increased benefit by fielding and using a WVO to SVO system. To arrive at an answer, the overarching thesis question can be broken down to the following investigative questions. Additionally, the investigative questions can be broken down into the two categories of "Cost" and "Benefits." Below are the investigative questions in their respective categories.

Costs

1. How much WVO is produced by the dining facilities at WPAFB?

   There are 13 different dining facilities on WPAFB that produce WVO. Six were selected to be test facilities for the program. The six facilities were selected based on projected WVO produced, proximity to the Recycling Center, and types of frying equipment used. If all 13 facilities' WVO was collected, there would be more WVO than could be used in the pilot program. The base restaurants produce approximately 7400 gallons of WVO per year (Dominique, 2007). The proposed pilot program called for two vehicles to be operated. Therefore, if the entire amount of WVO was collected, there would be too much unused oil causing increased storage issues. The facilities where the WVO is not collected will be audited for the same information (WVO produced, Recycling Center proximity, and frying equipment used) gleaned by physically collecting the WVO at the pilot facilities. The information was recorded on the Total WVO Collection Costs table.

2. How many vehicles can be powered by the SVO produced?

Once the WVO was collected, it was processed at the Recycling Center. The processing removes water and filters particulates to 1 micron. The SVO output was less than the WVO collected. Initially, two test vehicles were selected to use the SVO. One vehicle used the single-tank system, mixing the SVO and diesel in the same tank, while the other vehicle had a two-tank system, allowing independent operation of either fuel. The miles travelled per gallon of SVO used were recorded. Prior to using the SVO, the diesel miles per gallon (MPG) were recorded as well. By determining the changes in MPG, an estimate can be made for each type of vehicle and system. As the supply of SVO increased and confidence in the logistics system increased, more vehicles were planned to be added. The additional vehicles were planned to be different types ranging from a skid-steer loader to a tractor trailer, allowing further extrapolation of demand.

The information provided insight into the demand required to utilize the available supply of SVO.

An additional limitation could have occurred. Only one WVO to SVO processor was being acquired. Time is involved to heat the WVO to achieve water removal. A possibility existed that more WVO could be collected than could be processed per month. If 36 hours are allotted to process each batch, than approximately 1000 gallons could be processed per month, assuming the processor was run 24 hours a day for seven days a week.

3. At what point does the WVO/SVO system generate a cost savings?

A cost analysis was performed to determine the break-even point of the WVO to SVO system compared to the total cost of the same amount of fuel purchased at the current DESC Standard Price. The list of variables included:

1. Acquisition Costs
2. WVO Collection Costs
3. WVO to SVO Production Costs
4. DESC Fuel Costs

Benefits

4. What is the amount of emission reduction per vehicle due to operating on SVO?

A diesel engine's major emissions are: Nitrogen Oxide (NO_x), Carbon Monoxide (CO), and Particulate Matter (PM) (Environmental Protection Agency, 2008). Emission testing was stopped in the state of Ohio in 2006. Before 2006, diesel vehicles were exempt from testing because they ran cleaner than gasoline vehicles. This made a physical test of emissions not feasible. Therefore, the emissions were calculated using information available from an independent study conducted on similar vehicles and GreaseCar, a commercial provider of SVO kits. GreaseCar claims a 26% reduction of CO and a 39% reduction of PM. NO_x remains constant (GreaseCar Fueling and Filtering, 2008). The findings are consistent compared to other sources (Ramadhas, 2003). These calculations were applied to the emissions to determine the reduced output of PM and CO.

5. Will the new WVO recycling system prevent or eliminate environmental spills? The new system will be evaluated by the WPAFB Civil Engineering spill response specialists. They are responsible for the cleanup of spills that occur on base as a result of the current handling methods. The system will be evaluated based on ease of use for the food service worker and the reduction of spill potential.

6. Can the WVO infrastructure meet the requirements of the EPAct 2005 and EO 13423 initiatives?

The primary objectives of the initiatives are to eliminate greenhouse gasses and increase alternative fuel use by a certain percentage every year. After the amount and mix of vehicles along with the reduction of carbon emissions are determined, the percentages for both variables can be calculated.

Procedures

The four procedures in the order of source selection, operation, cost analysis and benefit analysis were completed to answer the above questions. The procedures consisted of hands-on work along with projections and extrapolations from the hands-on work. The following sections detail each individual methodology along with the data gleaned from performing the procedure.

Source Selection

The first step in developing an infrastructure for the practical analysis begins with a source selection. Different options were considered for the WVO to SVO processor plant and the conversion kits for the test vehicles. Two theories surfaced. One was to build a system from scratch, consisting of different distributors. The other was to purchase a Commercial Off The Shelf (COTS) system from a specialized manufacturer.

There are many different manufacturers offering equipment. After looking at the alternatives, two dominant designs were found. Fryer to Fuel offered complete kits that included everything to become operational. The company offered a processor that transformed the WVO into SVO with remaining particulates at one micron or less. A drum heater is used to heat the WVO up to 140° to separate the oil from the water and features a valve to dispose of the water. Another Fryer to Fuel system offers a processor with a centrifuge to polish the WVO, which essentially removes any water and filters it below one micron. The centrifuge “polishes” the SVO, removing any sludge from the final product (F2F Filtration Units, 2008).

GreaseCar offered only a one micron filtration system and did not include a drum. There were no valves to open to remove the separated water. Pumping out the heated WVO required inserting a hose into the top of the drum (GreaseCar Fueling and Filtering, 2008). This method would make it difficult to remove all the water from the processed SVO and required extra labor from the Recycling Center employees.

The option of building a system from scratch may be very appealing based on cost. However, the total cost of the activity becomes higher due to purchasing everything piecemeal. There would be increased shipping charges from various suppliers and the increased labor time for individuals to engineer and construct the system. There is also an issue of quality. Both GreaseCar and Fryer to Fuel have patented filtration systems. It would be difficult to fabricate a filter system that would be as inexpensive and easy to operate.

The final source selection consisted of four alternatives: two Fryer to Fuel systems (low cost and high cost), the GreaseCar system, and the home-built alternative. Table 2 outlines the criteria used to make the final decision. Cost was calculated based on the total cost of materials to acquire the system. With the exception of the home-built system, the labor to install each processor was comparable in time and effort. User friendliness was rated on a three point scale of easy, moderate, or hard. The classifications refer to the amount of difficulty involved to operate and assemble the system. The risk of spills category used the three point scale of low, moderate, and high. The risk was assessed by the act of operating the system along with possible leaks from connections or valves. Quality of the end-product was evaluated using the same three point scale as risk of spills. The criteria was based on the removal of water and particulate filtration level. The space required category gave preference to systems occupying less space. The completeness of kit category was determined by the number of vendors which pieces had to be purchased from. The winner of each category is listed in boldface.

Table 2: Source Selection Criteria

Manufacturer	**1. High Cost Fryer To Fuel**	**2. Low Cost Fryer To Fuel**	**3. GreaseCar**	**4. Home built**
Criteria (winner in bold)				
Cost	$1239.98 (FOB WPAFB)	**$739.97 (FOB WPAFB)**	*$920.00 (FOB WPAFB) Oil Drum – DRMO	*$1622.29 (FOB WPAFB)
Risk of Spills	**Low – contained system with quick disconnects**	**Low – contained system with quick disconnects**	Moderate – Have to pull pump out of barrel to fill it with grease, more connections due to filer housing	High – same reasons as GreaseCar; in addition the faucet may leak due to being drilled into bottom of 55 gallon drum and everything will be assembled on site
Quality of end product	**High – Filtered down to 1 micron and practically all water removed**	Moderate – Filtered down to 1 micron, most of the water removed	Moderate – Filtered down to 1 micron; risk of water in fuel	Moderate – Filtered down to 1 micron; risk of water in fuel
Space Required	**Size of 1 55 Gallon Drum**	Size of 1 55 Gallon Drum and additional space for filter unit	Size of 1 55 Gallon Drum and additional space for filter unit	Size of 1 55 Gallon Drum and additional space for filter unit
Completeness of Kit	**Everything included**	**Everything included**	Oil Drum not included	Everything must be pieced together

The criteria were weighted differently. User friendliness and quality of end product were considered highly important. If the system is not easy to use, there is a natural human tendency to not want to use it. End-product quality is important because if the product contains water or particulates, it could render a vehicle inoperative. Cost and risk of spills were given medium importance. The cost should be considered but not prohibitive to buying a higher cost system. However, improved benefits should be worth the cost. The risk of spills is important because the WVO and SVO should not be wasted. The Recycling Center has sanitary drains. If there is a spill, it can be contained and the residue will not enter the water stream. Space required and completeness of kit was given the lowest priority. There is ample room in the Recycling Center for any of the systems. If the components are not available through one supplier, there is a high probability they can be easily purchased locally or through internet vendors. Table 3 lists the criteria and the importance of the source selection.

Table 3: Source Selection Criteria and Importance

Criteria	**Importance**
Cost	Medium
User Friendliness	High
Risk of Spills	Medium
Quality of end Product	High
Space Required	Low
Completeness of kit	Low

In addition to the filtering system, containers to shuttle the WVO from the dining facilities are needed. The containers should be heat resistant and convenient to move. An internet search revealed there were many different plastic receptacles available for about the same relative cost. U.S. Plastics in Lima, Ohio was selected due to the proximity to the base, saving on freight charges. Two different containers were selected. An 8-gallon drum (

Figure 2) was acquired for most of the facilities where the grease is lifted out of the fryers.

Figure 2: 8-Gallon Blue Open Drum

The main kitchen in The Club uses a spigot at the bottom of the fryer. Therefore, 6-gallon jerricans that could be placed under the spigot (Figure 3) were acquired for that facility.

Figure 3: 6-Gallon White Jerrican

The cost of the blue open drum is $22.53 each and the white jerrican are $53.88 each.

Operation Procedures

Operation of the WVO to SVO system consists of four procedures. They are:

1. WVO Collection
2. WVO to SVO Processing
3. Converting Vehicles to Run on SVO
4. Operation of Vehicles on SVO

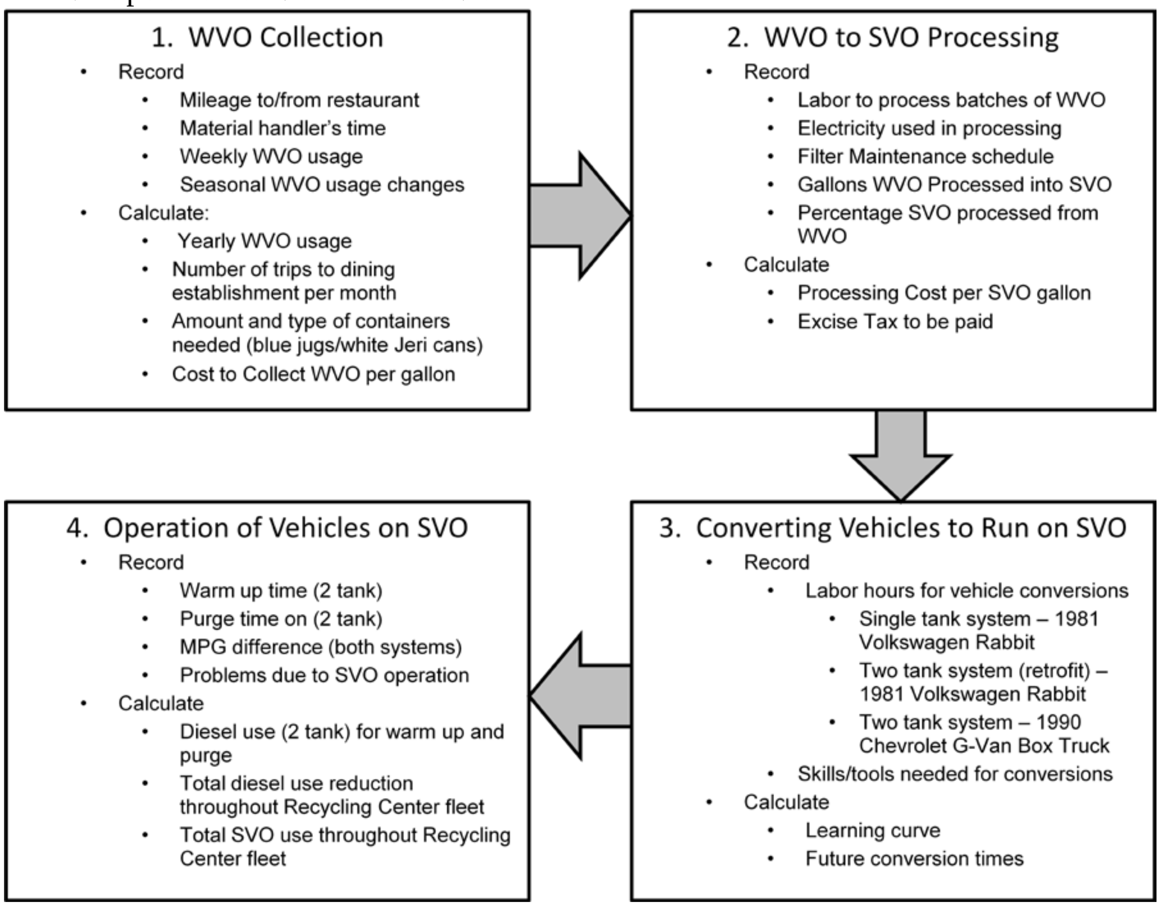

Figure 4 shows the data that was recorded and calculated during each procedure. Most of the recorded data consisted of times and resource usage. The calculations performed will convert the data into dollars spent, total WVO collected, and total SVO production.

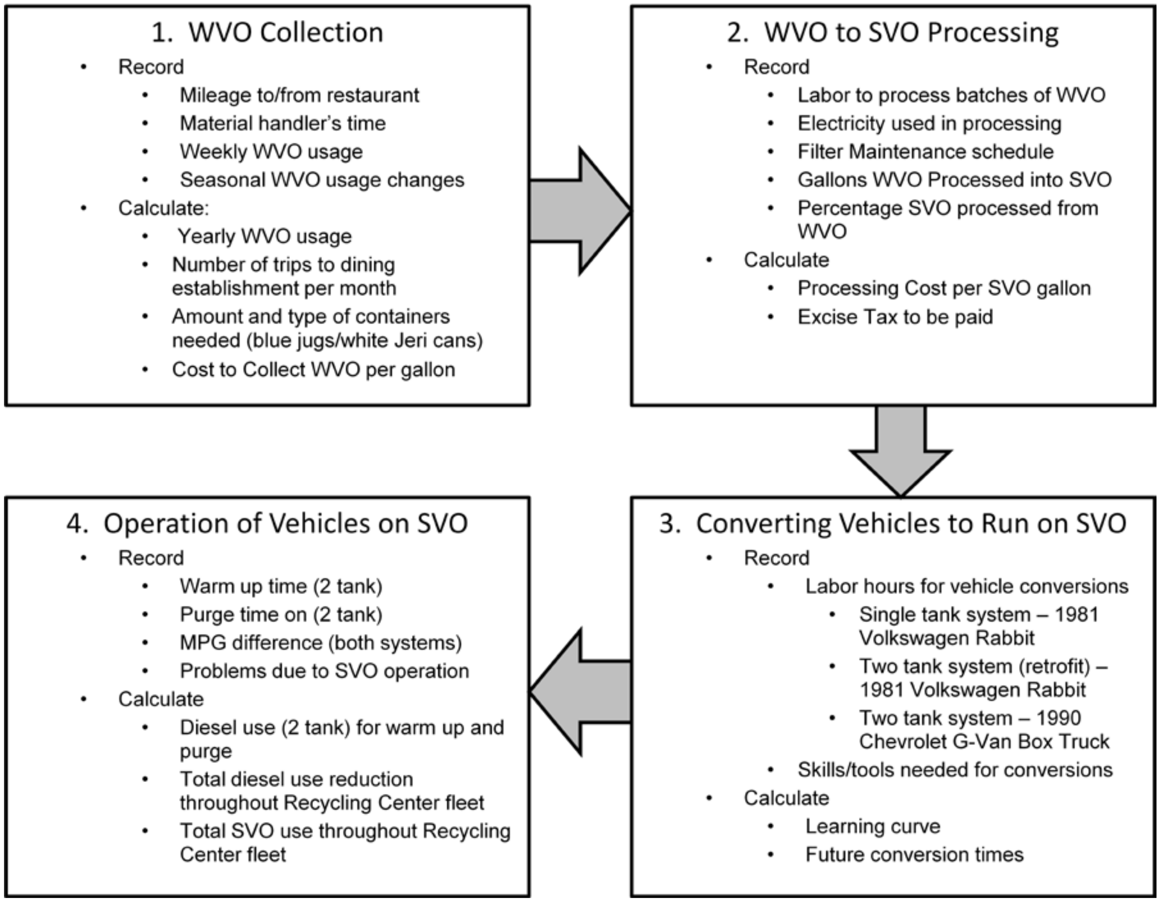

Figure 4: Data Recorded and Calculated During Each Operation Procedure

1. Waste Vegetable Oil Collection

The 88th Air Base Wing Civil Engineer Directorate needs a new solution to the collection of WVO. Wright Patterson's WVO disposal needs are currently handled by an independent contractor. Prior to 2006, the Defense Reutilization Management Office (DRMO) managed the pick up and disposal of the WVO. At the time, the end-product was not producing enough profit for DRMO to consider it feasible. Anamax Corporation, a renderer from Columbus, Ohio, was selected to gather the WVO (Dominique, 2007). Their contract was for a year and expired in 2007. During the contract period, WVO went from being worthless trash to a viable commodity.

Therefore, Anamax continued to pick up the WVO without a contract or any compensation (Johnson, 2007). Anamax was absorbed by Sanimax, a Canadian company with corporate headquarters in Montreal. Sanimax uses the WVO to produce various products ranging from animal feedstock to biodiesel (Sanimax, 2007). Without a contract and the renderer being out of town, WVO pick-up is unreliable. The waste receptacles must be stored outside. This creates a need for the dining facilities' personnel to lug containers of used grease out to the receptacles and risk spillage into the storm drains when emptying the containers (Johnson, 2007).

Due to the unreliability of Sanimax, when the decision to move forward with this thesis effort came to fruition, a Memorandum of Agreement (MOA) was drafted to insure success and instill confidence with the base restaurants. The signers consisted of a member of the research team, the Recycling Center Chief, the Services Food and Beverage Manager, and the Base Club Manager. The MOA specified exactly what containers were used. Eight-gallon containers were selected as the maximum size. WVO weighs about seven pounds per gallon (Kattreh, 2008). By using the small containers, the maximum weight will be approximately 56 pounds. Most likely, five gallons (35 pounds) will be stored in the containers because most fryers are filled in increments of five gallons. Also, the original corn oil comes in five gallon jugs. Per the MOA, the original corn oil jugs were saved by the restaurants and acquired by the Recycling Center. The jugs served the purpose of storing the processed SVO in a pre-measured increment for tax and distribution purposes. A copy of the MOA is located in Appendix A.

The WVO was picked up by the Base Recycling Center drivers. Currently, there are two drivers who operate a box truck that has an assigned route through the base.

They pick up recyclable materials such as used aluminum cans and shredded paper from every building on the base. Their route is mostly assigned, but customers can request a pick-up at anytime. The recycling center usually can accommodate the request within 72 hours (McCreary, 2008). Data was captured to determine how much extra time the drivers were using to complete the pick-up of full containers and the delivery of empties. Time was converted to costs based on the employee's hourly rate and how many employees did the run. If the run was part of a scheduled pick-up or the drivers were passing by the pick-up site and it was not a dedicated run, only the time spent actually working on the task of picking up the WVO was counted. Data sheets were located in each truck for calculation. There were limitations to the data collection. The most obvious is the accuracy of time reported by the drivers. Therefore, a member of the research team completed three to five runs to determine a baseline. If the drivers failed to report the time or the time reported was an extreme outlier, than the mean time was used. The number and type of containers were recorded to determine how much WVO is collected. Additionally, the material handlers were instructed to report any spills.

2. Waste Vegetable Oil to Straight Vegetable Oil Processing

The sponsor of this effort, the 88th Air Base Wing, Civil Engineering Directorate, offered full utilization of the Wright Patterson Base Recycling Center. The center had space to install any alternative outlined in the source selection, along with the availability of personnel willing to participate. Electricity, WVO and SVO storage, and sanitary drains were conveniently located. The costs of the various pieces of equipment required to make the plant operational were documented. This included the collection jugs for the WVO, the drums for processing, and any additional safety equipment. All costs were captured for the purpose of setting up a payback baseline.

Once the processing plant was operational, additional data was collected. The Recycling Center's mechanic and research team member were the primary operators of the plant. The time the operators spent operating the plant were documented. Training was minimal. It was completed during the processing of the first batches. Because the training was completed on-the-job, an additional training category was not added to the data collection. Any spills were reported along with clean-up procedures to keep from making the spill an environmental incident. Additionally, electricity use and cost was calculated by using the equipment manufacturer's specifications. The quality of the processed SVO fuel was monitored for water concentration in parts per million, flash point, and contaminants. The Air Force Petroleum Agency (AFPET) lab was used for the measurements.

To demonstrate the concept of implementing a pilot program and to prove or disprove the advantage of building a complete SVO infrastructure, end users of the processed WVO were acquired. A demand needed to be created. To create the demand, vehicles were converted to run on SVO.

3. Converting Vehicles to Run on Straight Vegetable Oil

Vehicle installation was accomplished by the Recycling Center's mechanic and a member of the research team. The Recycling Center mechanic was a willing volunteer with many years of experience as an automobile, material handling equipment, and diesel truck mechanic. The research team member was an Air Force Technical Sergeant who served as an Aerospace Ground Equipment Craftsman for 13 years. In those years, he gained experience in diesel engine repair and theory along with troubleshooting and repair of generators, hydraulic test stands, heaters, air conditioners, and gas turbine compressor powered ground support equipment. Similar to the WVO collection drivers, the mechanic and researcher's time was be monitored, documented, and converted to costs.

There were two test vehicles used for the research. The first test vehicle was a 1981 Volkswagen Rabbit, using a home-made single-tank system and used as the researcher's privately owned vehicle. The second was a 1990 Chevrolet G Series box truck, using a Commercial Off The Shelf (COTS) two -tank system produced by GreaseCar.

The primary task of the conversions was to determine how much labor and materials were required to convert the two vehicles. The data was converted into actual costs to be rolled into the cost analysis. The 1981 Rabbit conversion represented an approach built from scratch, performed with minimal special tools and at the lowest cost. The 1990 Chevrolet conversion utilized COTS parts and detailed directions. It was performed in a repair facility complete with a full set of commercial grade tools. Once the vehicles are converted, they were operated under the same conditions they were used in before the conversion.

4. Operating Vehicles on Straight Vegetable Oil

Operating the vehicles on SVO was the same as normally operating the vehicle with the addition of operating SVO fuel heaters, purging fuel system of SVO before shut-down, and refueling the SVO system. The principle operators of the Box Truck were the material handlers for the Recycling Center. Training of the operators was performed to ensure they were comfortable in the operation of the vehicle and prevent abuse and misuse. Additionally, they were briefed as to what data needs to be collected.

The test vehicles were audited. The Rabbit is driven at least 300 miles a week. The data gained consisted of gallons used and miles travelled before the conversion to determine a baseline. After the conversion, the same records were kept to determine if there was a performance gain or loss due to the blending of SVO and diesel. The mixture percentages were calculated. The Chevrolet Box Truck did not travel very far. Most of the time it was idling or driven a short distance and shut down. Additionally, the truck did not operate the same route every week. Therefore, reaching a baseline was difficult. The data collected from this vehicle consisted of how much SVO was consumed and ease of operation from the driver's and maintainer's viewpoint. From the data collected from the two vehicles, the vehicular SVO demand can be extrapolated to determine how much of the WVO supply can be utilized. The period of collection and operation was for three months. The riskiest time to use SVO is during cold months due to jelling and diesel engines are the hardest to operate in this climate. If any issues from SVO were to manifest, they would manifest in these months. To capture the issues, the data collection period was conducted from November to February.

Cost Analysis

To be able to make an accurate cost analysis, a baseline must be established. If a WVO to SVO infrastructure was not acquired and operated, the default fuel was 100% diesel or a 20% biodiesel blend. In this trial scenario the Rabbit was operated as a POV using fuel purchased from local fuel retailers. The Recycling Center does not purchase fuel from DESC. It purchases fuel from bulk fuel suppliers at the current commercial rate. Under normal circumstances the fuel output of the WVO to SVO infrastructure would go into government vehicles that normally run on DESC-provided fuel. Fuel prices on the commercial market vary on an almost daily basis. To simulate what would be normal operation and to avoid a great number of adjustments for fuel price variations, the cost of diesel fuel was the standard price as set by DESC for the trial period. In November of 2008, the price became $2.49 per gallon, taxes inclusive. The price of diesel or biodiesel was the same (Roth, 20 Nov 2008). Therefore, the baseline was how many gallons of DESC-provided fuel that would not be needed due to the SVO fuel replacing it. For example, if the WVO to SVO refinery produced 100 gallons of SVO fuel, the baseline would be $249 (2.49 per gallon X 100 gallons). The baseline represents where the breakeven point exists and is calculated on volume. Preliminary research revealed that fuel mileage efficiency will not be degraded due to SVO operation.

To attain the breakeven point from the SVO side, the costs were broken down into the following categories:

1. Acquisition costs
2. WVO collection costs
3. WVO to SVO processing costs

One-time costs were broken out over IRS standard lifecycle depreciation time periods. This measure was selected due to the infancy of the systems. There is not any data specifying reliability of the WVO to SVO processor or the vehicle kits. The standard depreciation time periods represent the minimum time between equipment repair and replacement. Recurring costs were extrapolated over 12 months to make a yearly calculation. The two costs together represented a yearly operating cost to compare against the DESC fuel cost.

There were many variables that limited this analysis. Future economic conditions are hard to predict due to the economic downturn that occurred in the early months of 2009. Therefore, determining the future value of the investment was difficult. Adding to the difficulty was the replacement costs of the components. GreaseCar has steadily increased its prices faster than the rate of inflation over the last few years. Conversely, a bio-diesel processor from another vendor is being discounted over $1000, and Fryer-To-Fuel has not had any price increases for at least two years. Fuel prices are a moving target as evidenced by DESC making two Standard Price adjustments within the last fiscal year. Mitigation of the limitations was made by not factoring in future value discounts and inflation. The break-even point is calculated with 2009 costs for fuel, the SVO components, and labor.

Due to the limitations of the breakeven analysis, a second cost analysis was performed. A two and three year payback point was determined. All one-time costs were factored into the first year of operation. Recurring costs were extrapolated over 24 months and 36 months. The costs will be added to determine the total expenditure of the system for two and three years.

By having a total expenditure calculation, the payback point was determined. This was attained by taking the amount of diesel that would be replaced by SVO and dividing the total SVO expenditure by the amount of diesel. The calculation provided a SVO cost per gallon. This would represent the point where the DESC Standard Price would have to be to achieve a two or three year payback point. Cost savings or losses were extrapolated by changing the DESC Standard Price.

1. Acquisition Costs

Acquisition costs consisted of the purchase of the WVO to SVO processor, the containers to collect the WVO, and the vehicle conversion kits. These were considered one-time costs. They were divided by the lifecycle years per the IRS' distinction of class life (in years). The processing equipment consisting of the WVO to SVO processor and the WVO storage containers fall under IRS asset class 20.3, "Manufacture of Vegetable Oils and Vegetable Oil Products." This asset class has a life of 18 years. The SVO kits installed in the vehicles become part of the vehicle. They are classified under IRS asset class 00.241, "Light General Purpose Trucks," with a class life of four years (Internal Revenue Service, 2007). The labor hours spent were added in using the same schedules. For example, the labor to install the processor was calculated and divided by 18 years. The costs are represented on Table 4.

Table 4: Acquisition Costs of Processing Equipment

Name of Equipment	Quantity	Cost	Extension	Total Cost per year
Nomenclature	Amount of Units Required	Dollars per Unit	product of Quantity and Cost	Extension divided by IRS Dep Rate
WVO to SVO Processor	X1	Y1	EXT1=X1*Y1	EXT1/18
6-Gallon White Jerricans	X2	Y2	EXT2=X2*Y2	EXT2/18
8-Gallon Blue Open Drums	X3	Y3	EXT3=X3*Y3	EXT3/18
Labor Hours to Install Processor	X4	Y4	EXT4=X4*Y4	EXT4/18
Vehicle Conversion Kits	X5	Y5	EXT5=X5*Y5	EXT5/4
Labor Hours to Install Kit (Mechanic 1)	X6	Y6	EXT6=X6*Y6	EXT6/4
Labor Hours to Install Kit (Mechanic 2)	X7	Y7	EXT7=X7*Y7	EXT7/4
Total Acquisition Costs			**SUM(ABOVE)**	**SUM(ABOVE)**

2. Waste Vegetable Oil Collection Costs

WVO collection costs were calculated by totaling the labor and materials used to physically pick up the WVO at the base restaurants and deliver it to the Recycling Center. The six test facilities used real data while the audited sites used data extrapolated by performing dry runs to the sites. Data collected consisted of:

1. Material Handler's time (computed from hourly wage)
2. Wear and tear of vehicle (based on IRS business reimbursement rate of $.555 per mile)
3. Number of trips to the facility per month
4. Gallons of WVO collected
5. Amount and type of collection containers needed

The data for each facility is located in Appendix B: Waste Vegetable Oil Collection Audit per Facility.

Table 5 is a sample of the collection table.

Table 5: Sample Table of WVO Collection Costs

WVO Collection Costs Per Month			For "Z Facility"	
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	L	per hour	H	$LC=LH
Vehicle mileage cost per trip	$0.555	per mile	M	$V=$M(.555)
Trips to Facility per month	T	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	G	White	W	
Total cost of all trips	$TC=$LC+$V	Blue	B	
Cost per gallon collected	**$TC/G**			
Legend				
L = Labor Rate	$LC = Labor Cost			
H = Hours	$V = Vehicle Cost			
M = Miles	$TC = Total Cost			
T = Number of Trips				
G = WVO Gallons				
W = Number of White Jerricans				
B = Number of Blue Drums				

The total cost for all WVO collection was added together and placed in Appendix C: Total WVO Collection Costs per Month.

3. Processing Costs

Processing costs were the costs associated with the physical act of running the WVO to SVO processor. This included the time spent by the operators, computed into costs from their hourly wage, allotment for replacing the 1 micron filter, and electricity used to run the equipment. Electricity use was calculated by computing the wattage from each electrical component, determining the amount of time it is in use, then multiplying the time by the kilowatt hour rate charged by Dayton Power and Light. Table 6 shows a sample spread sheet for electricity usage along with the calculations performed.

Table 6: Sample Table Recording Electricity Usage

Electricity Usage for Batch "X"								
Component Name	**Volts**	**Amps**	**Wattage**	**Kilowatts**	**Time in Use**	**KW Used**	**KWH Rate**	**Cost**
Band Heater - Drum 1	V	A	W=VA	KW=W/1000	T	KWU=KW*T	R	KWU*R
Transfer Pump	V	A	W=VA	KW=W/1000	T	KWU=KW*T	R	KWU*R
Centrifuge Pump	V	A	W=VA	KW=W/1000	T	KWU=KW*T	R	KWU*R
Band Heater - Drum 2	V	A	W=VA	KW=W/1000	T	KWU=KW*T	R	KWU*R
Fuel Nozzle Pump	V	A	W=VA	KW=W/1000	T	KWU=KW*T	R	KWU*R
Total Electricity						**Sum(above)**		**Sum(above)**

The collected WVO was processed to attain an average of the costs. The average was extended to project the usage of all the WVO on the base. Due to impurities and water content, there is not a 100% yield from the WVO. The amount of SVO processed from WVO was also calculated. From the calculations, the cost to process a gallon of SVO was attained. Federal Excise Tax was added at this point. Table 7shows a sample of the data captured and calculations of individual batch costs. The data and calculations for each batch produced are located in Appendix D: Waste Vegetable Oil to Straight Vegetable Oil Production Costs

Table 7: WVO to SVO Costs per Batch

WVO to SVO Production Costs		**For**	**Batch "N"**	**Date Completed**
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor	L	per hour	H	LC=L*H
Electricity	R	per KWH	KWU	EC=E*KWU
1 Micron Filter Change Maintenance	$0.014	per gallon	W	M= .014*G
Gallons WVO Processed	W	Gallons SVO Output	S	
Federal Excise Tax Reported	$0.244	Gallons SVO Output	S	T=S*.244
Percent SVO from WVO	S/W			
Total Processing Cost		**per gallon**	**PC/G**	**PC=Sum(LC:EC:M:T)**

Each batch was tabulated on a total WVO to SVO Production Costs spreadsheet. An average cost per gallon and the amount of SVO generated was computed. Also, the percent of SVO from WVO was calculated. All of these costs became the baseline to project full production of all of WPAFB's WVO output. Appendix E: Total Waste

Vegetable Oil to Straight Vegetable Oil Processing Cost, contains the total production costs and the calculation of how much each gallon of SVO would cost to produce.

All of the above data was rolled into a master spreadsheet to calculate a total cost of the system and a per gallon cost. By adding up the above costs and extrapolating to a full year of operation, a cost per gallon was calculated. The cost per gallon can be compared against the baseline of DESC fuel to determine if there was a cost savings. The savings per gallon was extended over the amount of SVO fuel to show how many dollars will be saved if that amount of fuel for the year was used. Additionally, the costs of acquisition, collection, and production were added to obtain a total cost for the first year. Collection and production were added to obtain costs for the second and third years. Table 8 denotes how the final spreadsheet will appear. All values are notional.

Table 8: Cost Analysis Master Spreadsheet

Roll Up of All Costs to Gallons SVO Produced - Recycling Center Use Only					
Name	**Annual Breakdown**	**Monthly Breakdown**	**Total Cost - 1st Year**	**Total Cost - 2nd Year**	**Total Cost - 3rd Year**
Acquisition Costs	$6,209.82	$517.48	$30,286.21		
WVO Collection Costs	$1,776.00	$148.00	$1,776.00	$1,776.00	$1,776.00
WVO to SVO Production Costs	$6,808.00	$567.33	$6,808.00	$6,808.00	$6,808.00
Total SVO Cost	**$14,793.82**	**$1,232.82**	**$38,870.21**	**$8,584.00**	**$8,584.00**
Gallons Produced	7400	617			
			Total Lifecycle Cost	**$47,454.21**	**$56,038.21**

Cost Savings of SVO vs. DESC Diesel or Biodiesel	
Name	**Cost**
Total Cost of SVO Per Gallon	$2.00
DESC Fuel Cost	$2.49
Savings Per Gallon	$0.49
Savings Per Month	$302.68
Savings Per Year	**$3,632.18**

Benefit Analysis

Besides dollars and cents saved, there are other tangible benefits to fielding an SVO derived from WVO infrastructure. These include:

1. Reduction of emissions
2. Lessening of environmental spills

3. EPAct 2005/EO 13423 compliance

Each benefit will be discussed in the following sections.

1. Reduction of Emissions

Diesel engines as a whole are cleaner running than gasoline engines (Bourne, 2007). The perception of diesel being dirty is a result of watching and smelling a diesel vehicle in operation. The smoke and smell is the Particulate Matter (PM) being introduced into the atmosphere. Other major emissions are Nitrous Oxide (NO_x) and Carbon Monoxide (CO). Due to diesels being cleaner, there is a lack of emission testing equipment readily available. Studies have been completed by GreaseCar and independent researchers. The GreaseCar tests revealed a zero reduction in NO_x, a 26% reduction in CO grams, and a 39% reduction in PM grams when operating on SVO (GreaseCar Fueling and Filtering, 2008). Independent research data revealed similar findings (Calais, 2006).

An emissions baseline was acquired from an independent study of comparable diesel vehicles for a biodiesel comparison. Four different Chevrolet pick-up trucks of similar age and a 6.2-liter diesel engine similar to the test box truck, were used. Average PM was measured to be 0.22 grams per mile. Average CO was measured to be 1.97 grams per mile (Durbin, 2002).

The reduction in emissions was calculated using the emissions figures above reduced by the corresponding percentages and multiplied by the total number of vehicles that could be running on SVO fuel. This represents a grams per mile calculation. The total emissions reduction can be calculated by inputting the total amount of miles that the fleet of vehicles would drive if they were powered on SVO.

2. Lessening of Environmental Spills

There are three major situations where WVO can be spilled. The first is transportation to the outside storage drum, the second is the pouring of the WVO into the storage drum, and the last situation is when the WVO is collected by the renderer. Some methods previously used promoted spillage. One facility stored over 80 gallons of WVO in open drums and transported it down two floors to be disposed of. All major facilities were using the Sanimax dumpsters and rely on Sanimax to dispose of the product. Minor facilities, such as the golf courses, transport WVO to the major facilities. While no major spills have been reported in the last five years, there is an issue with runoff and minor spills. The Sanimax dumpster has a covered opening on top of it. The opening is smaller than the top of the dumpster. When pouring the WVO into the opening, it is difficult to keep from spilling some of the WVO. Figure 5 illustrates an average dumpster and the WVO accumulating around it.

Figure 5: Sanimax Dumpster Located at Pitzenbarger Hall (Photo by Harvey S. Gaber)

Due to the dumpsters being located outside, every time it rains a small amount of grease runoff occurs. Also, rodents are attracted to the dumpster, making for unsanitary conditions around the dining establishment. The WPAFB Spill Prevention Control and Countermeasure (SPCC) plan calls for a secondary system to contain the runoff. The 88th Air Base Wing mitigated the requirement by creating an "impracticality justification." It states the current containers cannot practically have a secondary containment system. This was submitted to the inspectors of the SPCC plan. At any time, the inspectors can reject the justification, creating a need for WPAFB to build containment structures (Dominique, 2007).

Fielding a new WVO to SVO system could prevent spills and eliminate the need for the impracticality justification. The benefit was calculated by observing the individual facilities' current methods and implementing the new collection system at the test sites. Experts from the WPAFB environmental spill team monitored the new procedure and provided their opinion as to the reduction of spills ease of use. The food service workers were asked for their opinions of ease of use and spill prevention as well. The variables were scored on a five-point scale with “easy” or “no risk of spills” equal to one and “hardest” or “riskiest” equal to five. The mean values for “ease of use” and “risk of spills” were calculated for the previous WVO disposal system and the current system. The means were compared to determine statistically if the new system was easier and had less risk.

EPAct 2005 and Executive Order 13423 Compliance

EPAct 2005 EO 13423 compliance were measured by determining if the fielded WVO to SVO system met the goals set forth by the orders. The four main goals considered for this study are:

1. Reduction – Reduce Fossil Fuel Consumption by 2% annually (EO 13423)
2. Addition – Increase Alternative Fuel Consumption by 10% Annually (EO 13423)
3. Acquisition – 75% of new vehicle purchases should be Alternative Fuel Vehicles (EPAct 2005)
4. Usage – utilize Alternative Fuels in Alternative Fuel Vehicles 100% of the time (EPAct 2005)

The study was limited to the WPAFB Recycling Center. To determine a baseline, the fuel consumption of only the WPAFB Recycling Center was used to determine the reduction objective. Currently, the Recycling Center is not using any alternative fuels. Even one gallon of SVO used should meet the addition objective. The acquisition objective would not be met. The Recycling Center fleet consists of vehicles reclaimed from other base entities. Its budget does not warrant new vehicle acquisitions. A single-tank system would utilize the alternative fuel 100% of the time, meeting the usage objective. A two-tank system would not meet the usage objective due to the vehicle's need of being started and stopped on pure diesel. The WVO to SVO system was considered a benefit in respect to EO 13423 if both of its objectives were met.

EPAct 2005 compliance is determined by assignment of fuel credits. Every 450 gallons of fuel used constitutes a credit. Also, acquiring Alternative Fueled Vehicles (AFV) constitutes a credit. If the vehicle is a heavy truck, two credits are assigned. The WVO to SVO system was considered a benefit if the Recycling Center can earn credits for the fuel use.

Summary

This chapter outlined the methodology to answer the thesis question "Should the Air Force pursue SVO derived from WVO as an alternative fuel?" To arrive at a solution, investigative questions were presented. By dividing the questions into the two categories of Costs and Benefits, four procedures were developed to answer the questions. The procedures of source selection, operation, cost analysis, and benefit analysis were explained in detail. The necessary data that should be collected was described. The results of the procedures will be documented in the next chapter.

IV. Results and Analysis

Introduction

The acquisition, operation, and analysis of the selected Waste Vegetable Oil (WVO) to Straight Vegetable Oil (SVO) system was described in the previous chapter. The acquisition and operation occurred from August 2008 through February 2009. Analysis occurred from February through March of 2009. In concept, the operation of the processor and subsequent powering of a vehicle on the SVO fuel appeared to not be a challenge. Reality was much different. This section will cover the results of the experiment.

The results and limitations are divided by the six investigative questions. The questions are divided into two sections, Costs and Benefits. Each question will be answered by providing the data that was collected and the analysis of the data. Limitations for each question will also be addressed in each question's section. The chapter will wrap up with the answer to the thesis question: should the Air Force pursue SVO derived from WVO as an alternative fuel?

Costs

The first questions answered will cover the costs to acquire and operate the WVO to SVO system and determine if there is a monetary savings. The calculation of the savings requires knowledge of how much WVO is produced and how many vehicles can be operated with SVO. The three investigative questions are:

1. How much WVO is produced by the dining facilities at Wright Patterson Air Force Base (WPAFB)?
2. How many vehicles can be powered by the SVO produced?
3. At what point does the WVO/SVO infrastructure generate a cost savings?

1. How Much Waste Vegetable Oil is Produced by the Dining Facilities?

All 13 base WVO generating facilities were visited and WVO production was audited. Most facilities were on a weekly or bi-weekly schedule of changing the vegetable oil in the fryers while others changed the oil on an as-needed basis. The Pitzenbarger Dining Hall and the golf courses had seasonal schedules. The total output equates to an average of 982.5 gallons per month or 11,790 gallons per year. Figure 6 illustrates the total amount of WVO production (adjusted for seasonal differences) broken down by each dining establishment. The amount of oil collected was recorded on the tables listed in Appendix C. The dining facilities that were audited and not part of the test group are denoted by "(proj)" for projected.

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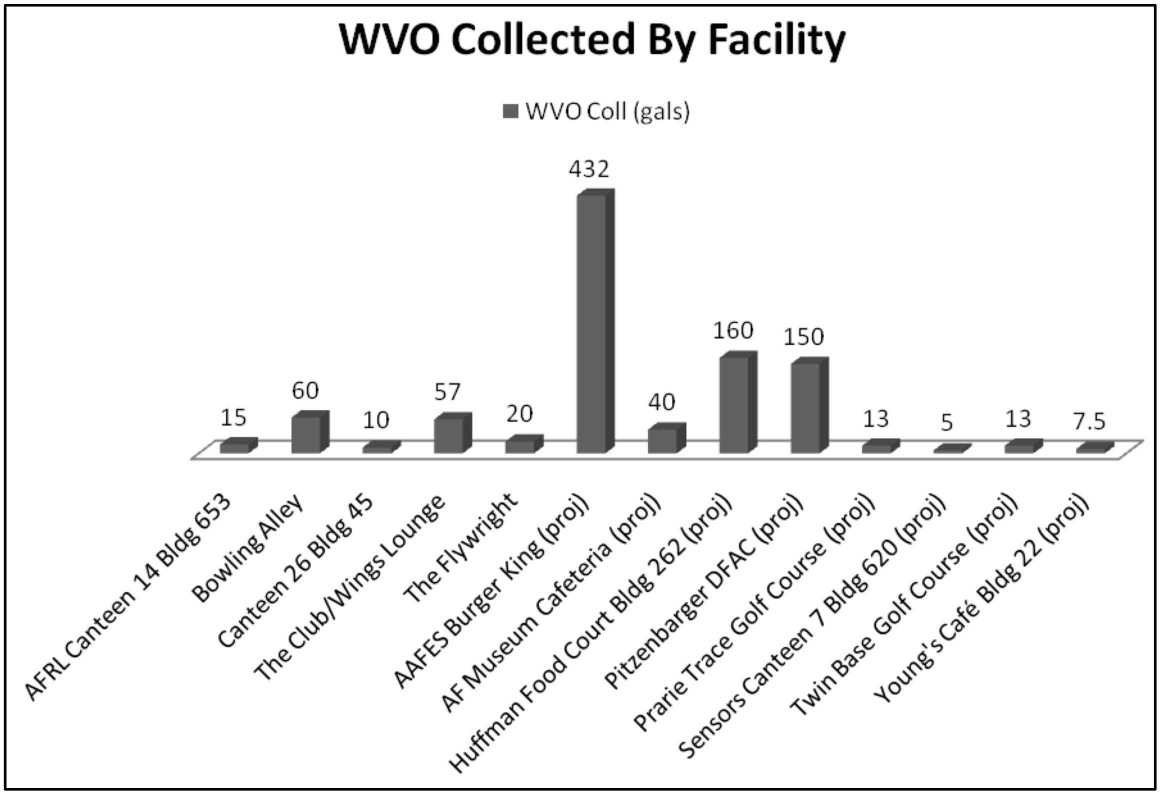

Figure 6: Waste Vegetable Oil Collected by Facility

This data is limited by the amount of extrapolation that had to occur. While the biggest contributor of WVO, AAFES Burger King, is on a set schedule, all of the other projected sites had seasonal changes. The seasonal use was taken into account but could not be 100% verified.

Initially, the test facilities consisted of the ones listed on the Memorandum Of Agreement located in Appendix A. The Bowling Alley was added because it had an immediate problem disposing of the WVO. It was stored outside and rats were gnawing into the containers. Once the manager heard of this thesis project, she contacted the research team to become part of the test group. Sensors Canteen 7 was eliminated due to the small amount of WVO it produced, and accurate data for travel times was collected by using the Flywright and AFRL Canteen 14.

2. How Many Vehicles Can Be Powered By The Straight Vegetable Oil Produced?

Two procedures were performed to determine the number of vehicles that could be powered by SVO. First, the WVO was processed into SVO. Second, the vehicles that were converted were monitored to determine how much SVO they could use. There were many limitations in answering this question that need to be addressed before the findings can be presented. The methodology stated that additional vehicles would be added as confidence and the SVO supply increases. Unfortunately, there was a lack of resources to field additional base vehicles. At the same time, the 1981 Rabbit became inoperative due to complications from running a one-tank system.

Rabbit Test Vehicle Limitations

It quickly became evident that there were numerous flaws in the operation of the single-tank system. First, calculating the proper mixture of SVO and diesel proved troublesome. The mixture should have been a complete mixture. When the weather was colder, the SVO would separate from the diesel and gel as if there was no mixture at all. Second, the amperage draw of running two heaters created numerous battery failures. When the car became inoperative, there was no fail safe to run the vehicle on straight diesel such as in a two-tank system. If the SVO was compromised by not having enough water removed from it, the car would become inoperative. The only way to restart the vehicle would be to drain the fuel tank, dilute the fuel mixture with more diesel, or add fuel dryer into the fuel filter and fuel tank. After fixing the fuel issue, restarting was still difficult. Restarting after a fuel failure required many minutes of cranking the engine, using a lot of battery power.

The 1981 Volkswagen came standard with a 65-amperage alternator. In stock configuration, there was plenty of power available to run all the electrical accessories and charge the battery. Under normal driving conditions the battery achieved 13.60 volts. However, once the two heaters were actuated, voltage dropped to 10.00 volts or lower. A brand new battery, with stock specifications, failed to start the car without jump starting or using a battery charger. In order to start the car with a 33% mixture, the heater needed to be actuated. Therefore, considerably more power was required than normal to jump the vehicle. Most other vehicles that were used to attempt to jump start the Rabbit didn't have enough power for the job.

An attempt to mitigate the issue was made by installing a 90-amperage alternator and a battery with increased cold cranking capacity. This alternator provided more voltage and amperage, thus providing a small amount of reserve to start the vehicle under optimum conditions. Unfortunately, it was not enough if the vehicle didn't start quickly. There was not enough reserve to continuously crank the vehicle, run the heaters, and power the glow plugs.

A bigger issue was the mixing of diesel and SVO in the single tank. On an extended trip to New Jersey a 33% mixture was introduced. As soon as it was introduced, the Volkswagen stalled. The heaters were engaged to heat it slightly above 100° and the car returned to operation. The vehicle was operated for short trips over the next two days for approximately 70 miles. After a two hour stop, the vehicle failed to start. Troubleshooting revealed the fuel filter appeared contaminated with water. Once the fuel filter was replaced, the vehicle ran sluggishly, but was operational. Over the next two hours at highway speeds, operability diminished until eventual failure. The vehicle required towing to a repair facility where additional troubleshooting revealed the 90 amperage alternator had failed. A new alternator was installed and the battery recharged. The vehicle ran well until nightfall. Once the headlights, fuel heaters, and passenger heat were turned on, the new alternator could not provide enough power. The vehicle became inoperational again.

Based on the findings above, the single-tank system is not recommended. The Rabbit ran well on a 20% or below mixture in temperatures above 40° without the use of the fuel heaters. However, finding the proper mixture was troublesome. The SVO did not mix 100% with the diesel. Adding the same ratio of diesel and SVO during refueling actually increased the amount of SVO in the tank. This was discovered by looking at the clear Fleetguard fuel filter bowl. Diesel has a lighter color than SVO. As the SVO was added, the color of the fuel increased in darkness. Due to these issues, single-tank usage was discontinued. Mixing of SVO and diesel was not attempted on any other vehicles.

Box Truck Limitations

There were additional limitations pertaining to the Chevrolet Box Truck test vehicle. The odometer was unreliable making a Miles Per Gallon (MPG) calculation of SVO or a diesel baseline impossible. Also, the heater core was leaking. This issue was not related to the conversion but became an issue as the weather got colder. The Materials Handlers refused to drive the vehicle, causing it to not get used regularly.

Members of the research team used it as much as possible but it was not enough to use the SVO that was being produced.

Mitigation of Limitations

Acquiring the data to determine if there was a difference in fuel mileage required the Rabbit test vehicle to be converted to a two-tank system, similar to the Chevrolet. There was an additional benefit. The learning curve for performing two-tank installations was defined. Once converted, the SVO usage was monitored and no change was noted in fuel mileage between running on SVO or diesel. Similar tests were previously conducted on a late model Volkswagen Jetta in Michigan over thousands of miles. The test confirmed there is no noticeable change in fuel mileage (Kattreh, 2008).

To mitigate the lack of data that would have been gleaned by calculating MPG, the fuel records of the Recycling Center were audited. The Center is a unique entity. It does not participate in the DESC program and purchases fuel on the open market. All of its vehicles are essentially recycled as well. They are acquired before being turned into the Defense Reutilization Management Office. They are not government Service Agency (GSA) vehicles (McCreary, 2008). Because of this unique situation there is a closed loop for fuel. The Center used 5,262 gallons of diesel fuel from January 2008 to December 2008. The fuel was used to power 11 vehicles. They ranged from a Bobcat skid steer loader to an over-the-road Ford tractor trailer. All of the vehicles would be capable of running SVO as a fuel if they were converted.

Operating SVO Powered Vehicles

Vehicles running on the two-tank system need to start and stop on diesel. The Chevrolet Box Truck was operated in temperatures ranging from 50° to 5° Fahrenheit.

On the 5° day, it took 26 minutes to warm the SVO to the proper viscosity and flow point of 68°. As the air temperature increased, the SVO warm up time decreased. On a 50° day, five minutes of warm up time was needed. The GreaseCar computer uses engine temperature as the switch over point. It is programmed to switch from diesel to SVO when engine coolant temperature reaches 150°. This ensures the SVO is heated to approximately 68°. Even if the ambient temperature is over 68°, the minimum run time on diesel is five minutes due to having to warm up the engine. Driving the vehicle immediately after starting, versus idling, to warm it up has negligible effects. The warm up and consequent switch over times are practically unaffected. When the switch over occurs, it is seamless to the user. The only indication is the computer displays "VegOil" instead of "Diesel." At shutdown, the fuel lines have to be purged. If SVO is left in the fuel lines and allowed to cool, it will gel. Restarting is next to impossible and there is a risk of damage to the engine. For the Chevrolet, a proper purge took six minutes. The Rabbit in two-tank configuration took slightly less time to warm up and purge than the Chevrolet.

Fuel Consumption

The average low temperatures in Dayton are normally above 40° from April through October. The highs are above 50° from March to November. The assumption was made that average warm-up times would be approximately 10 minutes throughout the year. Without an accurate odometer, and being unable to record how much diesel is used in the start up and purge processes, the following calculation was made. The known figure is 5,262 gallons of diesel fuel was used by the Recycling Center fleet. The fleet size is 11 vehicles. The operators of the vehicles work a nine hour shift five days a week with a half hour break for lunch and two 15-minute breaks throughout the day. There are also numerous times when the vehicle's engine is turned off, such as loading and unloading materials. Using those figures, the average vehicle run time would be seven hours. Purging only needs to occur if the vehicle is shut off for more than 20 minutes. It was assumed that the vehicle would have to be purged at least once during the day and once at the end of the day. This means the vehicle would be started on diesel twice a day. By using this assumption, and the assumption that it takes 10 minutes on average to start the vehicle on diesel and six minutes to purge, the vehicles would be run on diesel for 32 minutes out of the seven hours it is operated per day. Therefore, the run time on diesel would be 7.6% of the total run time if the vehicles were operated on the two-tank system. This equates to about 400 gallons of diesel fuel that would still be required annually.

Processing Straight Vegetable Oil

Five batches of SVO were processed at the Recycling Center. Each batch is documented in Appendix E: Total Waste Vegetable Oil to Straight Vegetable Oil Processing Cost. An average of 87% of the WVO was turned into SVO. If all 982.5 gallons of WVO were used, 854.78 gallons of SVO could be processed per month. The monthly capacity of the WVO to SVO processor is approximately 1000 gallons of WVO per month. This is calculated by looking at the most time consuming step, heating the WVO to remove water in the first drum. Figure 7 shows that the longer the WVO was heated, the less water, measured in Parts Per Million Water (ppmw), would be in the finished product, but there is a diminishing return. This happens between 30 and 40 hours of heating.

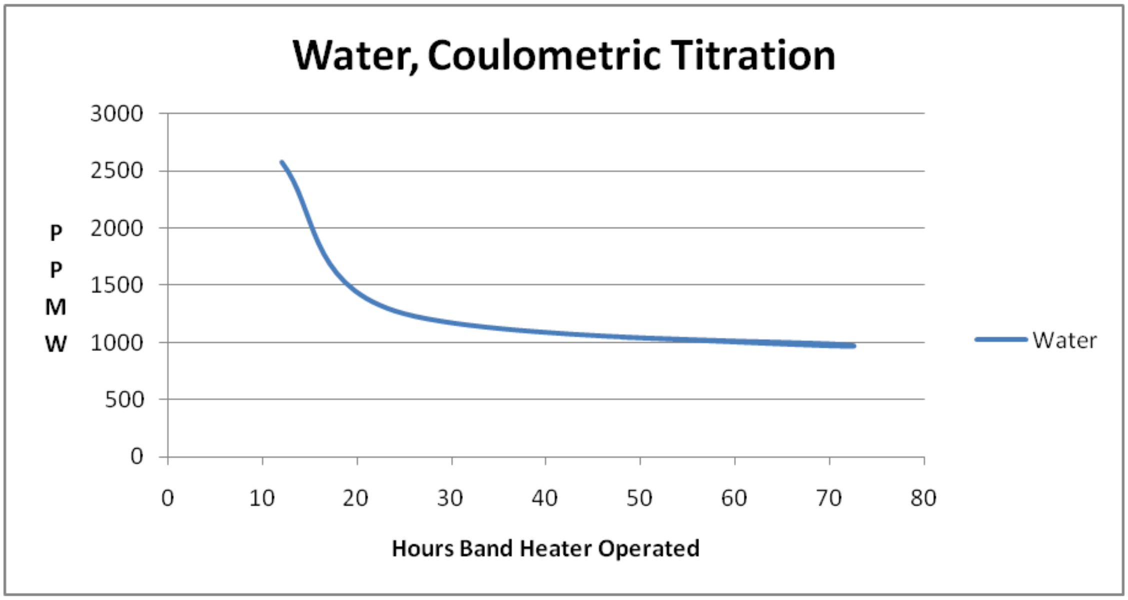

Figure 7: Water, Coulometric Titration

If the average time to heat the WVO is 35 hours and 50 gallons are processed per batch, it would take 689.5 hours to heat 982.5 gallons of WVO per month. The heaters can be run around the clock without constant monitoring. There are 720 hours in a 30-day month. Therefore, there is enough time to process all of the WVO with one processor. This would result in 10,257 gallons of SVO processed per year and an excess capacity of approximately 5,395 gallons if the Recycling Center was the sole user of the fuel.

Answering the Question

Due to the problems encountered with single-tank operation in the winter, the SVO should be used in two-tank operation when the weather is cold. Enough SVO would be available to operate the 11 Recycling Center vehicles year round if they were converted to a two-tank system. There would be 5395 gallons of SVO left over per year. WPAFB uses approximately 12,000 gallons of diesel fuel per month (Helber, 2007). If the SVO was mixed at a conservative blend of 10% SVO to 90% diesel, the excess fuel could be consumed during the warmest 4.5 months of the year.

3. At what point does the WVO/SVO infrastructure generate a cost savings?

This investigative question required multiple procedures to be completed. First, the acquisition procedure was completed. This included the source selection, installing the WVO to SVO processor, fitting the two test vehicles with SVO fuel systems, and documenting the labor hours for the installation processes. Second, the WVO collection procedure was performed and documented. With a source of WVO, the five batches of SVO were processed and data was collected for the WVO to SVO procedure. Finally, all the costs were calculated and compared against the DESC Standard Price of $2.49 for a gallon of diesel or a 20% blend of diesel and biodiesel (B-20).

Source Selection

The source selection process yielded the higher cost Fryer to Fuel system. It was selected based on user friendliness and completeness of the components. According to the web site, it was extremely easy to install and everything is included to start processing. Operating the centrifuge is as simple as turning valves and pushing a button (F2F Filtration Units, 2008). However, once the unit arrived, it was apparent more components were needed. There was not a cover for the drum. The centrifuge and pressure gauge protruded from the top, prohibiting installation of the needed 200 micron pre-filter. The Recycling Center mechanic put a screen on the drum to try to keep dust from entering but it proved futile. Figure 8 is the complete high cost Fryer to Fuel system.

Figure 8: High Cost Fryer to Fuel WVO to SVO System (Photo by Harvey S. Gaber)

In order to make the system operational, the low cost system had to be purchased additionally. It added the capability of pre-filtering the WVO to 200 microns, storing an additional 55 gallons of WVO, and intermediately filtering the WVO down to one micron. Intermediate filtering provided the benefit of reduced centrifuge cleaning intervals and wear on the centrifuge. Figure 9 is the complete processing system.

Figure 9: Complete WVO to SVO Processing System (Photo by Harvey S. Gaber)

The total cost of both systems, along with shipping was $1978.97. Installation was quite easy. The Recycling Center mechanic had the original system operational within an hour. A second hour was used to install the second system and link the two together.

Another expense of the processor was the acquisition of the containers to transport the WVO to the Recycling Center. Two types of containers were selected. The blue open drums (Figure 2) were used for a majority of facilities. They were selected for the ease of pouring hot WVO out of the fryers and directly into the jugs. This solution worked for the smaller fryers that held five to 10 gallons of vegetable oil. The WVO is stored in a deep pan and is emptied by pulling the pan out of the fryers and pouring the WVO into the drums. For the larger fryers, such as the ones located in The Club, white jerrican style containers (Figure 3) were selected. The larger fryers have a spigot at the bottom of the grease tank to allow a container to be placed under it. The blue containers are too high to fit under the spigot.

The number of needed containers was estimated by the type of fryers each dining facility used, the amount of WVO the facility generated, and the frequency of pick-ups. If the entire WVO supply on WPAFB were utilized, 60 blue open drums and 68 white jerricans would need to be acquired. The pilot infrastructure used 12 drums and 9 jerricans. The original containers that held the vegetable oil were also recycled. The SVO fuel was pumped back into them. This made it easy to track the SVO going out of the Recycling Center for tax and usage purposes. Once the system was operational, attention was focused on the test vehicles.

Installation of Single-Tank System

The first vehicle converted to run on SVO was the 1981 Rabbit. The single-tank system was installed using Commercial Off The Shelf (COTS) parts that were acquired at a plumbing supply store, a hose supplier, and a “big box” hardware store. Heating the fuel was provided by a primitive aluminum block that transferred heat from the coolant lines to the fuel lines. Before the coolant was hot enough, heat was generated by two glow plugs installed into the block. Additional heating was provided by a Vegtherm inline heater. The original fuel filter was replaced by a Fleetguard seven micron water separator/filter. The total installation was completed in a household garage by a research team member with 13 years of diesel automotive knowledge and average mechanic’s tools. It took approximately 45 hours to convert the car.

Installation of First Two-Tank System

The second SVO kit was installed in the Recycling Center by the research team member and the Recycling Center mechanic. It was installed on the Chevrolet Box Truck and took 59 hours to complete. The system was much more complex than the

Rabbit's. The complete two-tank system from GreaseCar, with a computer to switch between diesel and SVO operation, was used. The time differential between the two vehicles was due to the additional complexity of the two-tank kit. There was considerably more plumbing required, along with wiring the computer and the solenoids. Also, the test vehicle was a van, which has limited space to work and install components.

Installation of Second Two-tank System

The third kit was a retrofit of the Rabbit. After the single-tank system was scrapped, it was converted to run on a two-tank system. The research team member performed the conversion in the household garage. The system consisted of GreaseCar solenoids, a converted fuel tank from a surplus ammunition box, and various COTS components. The GreaseCar computer was not installed. The Cummins fuel/water separator and the Vegtherm heater were retained from the single-tank installation. However, the entire system had to be removed and the vehicle returned to its original configuration before the two-tank system could be reinstalled due to different routing and sizes of the fuel lines. The total time to install the new system was 18 hours.

Installation Times

From the above data, it can be observed that a learning curve was forming. Installing the second and third SVO systems are quite comparable. If the installation time of the computer was estimated at two hours, there would be a 66% reduction in installation time. This time should be adjusted for the complexities of working on a van. A conservative estimate would be a 50% reduction in time for the next van installation. Therefore, it can be estimated that the next van installation would be 29.5 hours total.

Without further data, it would be difficult to extrapolate a learning curve for a third or any further installations into a comparable vehicle.

The Recycling Center has a variety of vehicles that would pose different challenges. The tractor trailer has a lot of room for the components and two tanks for diesel fuel. It could be predicted that this vehicle would take less time to convert than the Bobcat Skid Steer which is quite compact. Therefore, subsequent installs were estimated at half of the 59-hour initial install rate or 29.5 hours. If all 11 Recycling Center vehicles were converted, the two mechanics would have split the workload. The total hours for each mechanic would be 177 hours. This includes the time to install the original two-tank system on the 1990 Chevrolet. The Rabbit was not included in the estimate because it is a personally owned vehicle and not part of the Recycling Center's fleet.

From the above data, the total acquisition cost to field the infrastructure would be $32,334.10. Figure 10 shows the acquisition costs broken down. The largest cost is the installation kits. They cost $1650.00 each and 11 are required to install in each Recycling Center vehicle. Both mechanic's times are based on the Recycling Center mechanic's wage of $14.50 per hour. Another notable cost is the WVO collection containers. While the cost appears high, over time the containers will pay for themselves. There are enough containers budgeted to allow the materials handlers to swap out the full ones with empties when collecting the WVO. This will save trips to each dining establishment.

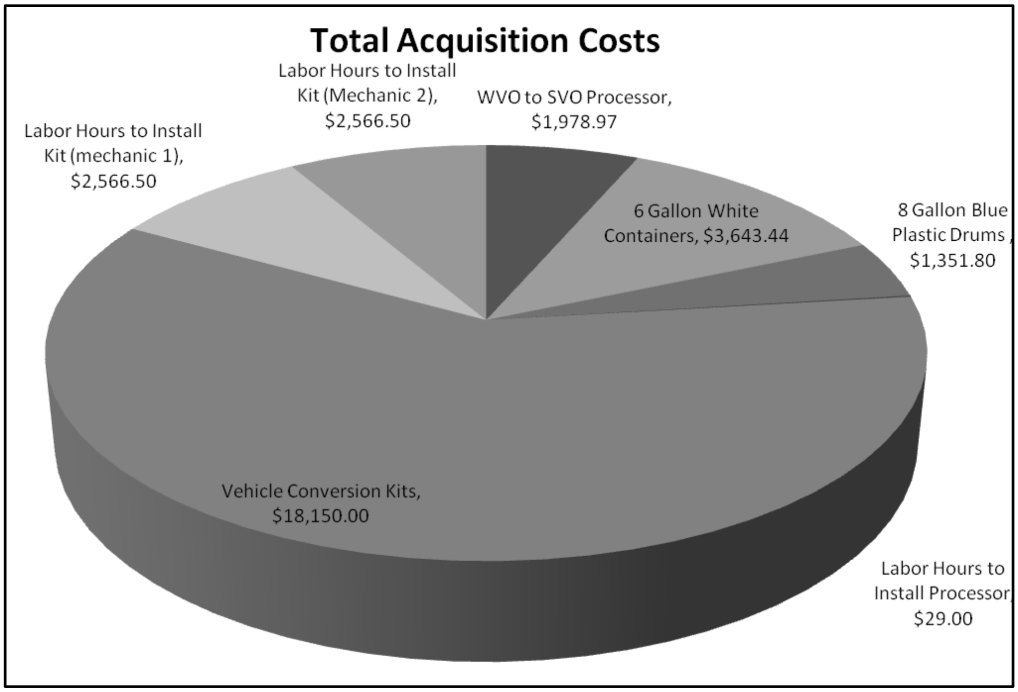

Figure 10: Breakdown of Acquisition Costs

If the acquisition costs were divided by the corresponding lifecycles of 18 years for vegetable processing equipment and four years for equipment installed in vehicles, the costs for acquisition would break down to $5,568.19 per year. This figure will be used for the final calculations to determine the total cost per gallon.

WVO Collection Costs

Once the vehicles were running and the WVO to SVO processor was online, the WVO was collected from the test facilities. The mileage from the Recycling Center was noted along with the time to collect the WVO and drive to and from the collection point. For the projected sites, the collection time was estimated by walking into the kitchens and determining how many trips to the vehicle it would take to collect all of the WVO. Costs were calculated for each facility by multiplying the time the materials collection worker spent for each facility by his or her hourly wage of $8.50 per hour. The vehicle operation costs were estimated by the miles travelled to complete the trip from the Recycling

Center to the dining establishment and back. The two costs were multiplied by the number of trips to the restaurants per month, then divided by the amount of WVO collected (actual or projected).

There is a limitation to this calculation. Due to the amount of data extrapolation and the neglect of the materials handlers to document when they picked up the WVO, the highest calculations of labor times and mileage had to be made. The assumption was made that each trip to each facility was an independent event. In reality, multiple dining establishments would be routed together to eliminate multiple trips to sites relatively close to each other, such as the Sensors Canteen and the AFRL Canteen. The weighted average of all WVO collected was $0.24 per gallon.

Figure 11 represents the cost per gallon to collect the WVO at each establishment.

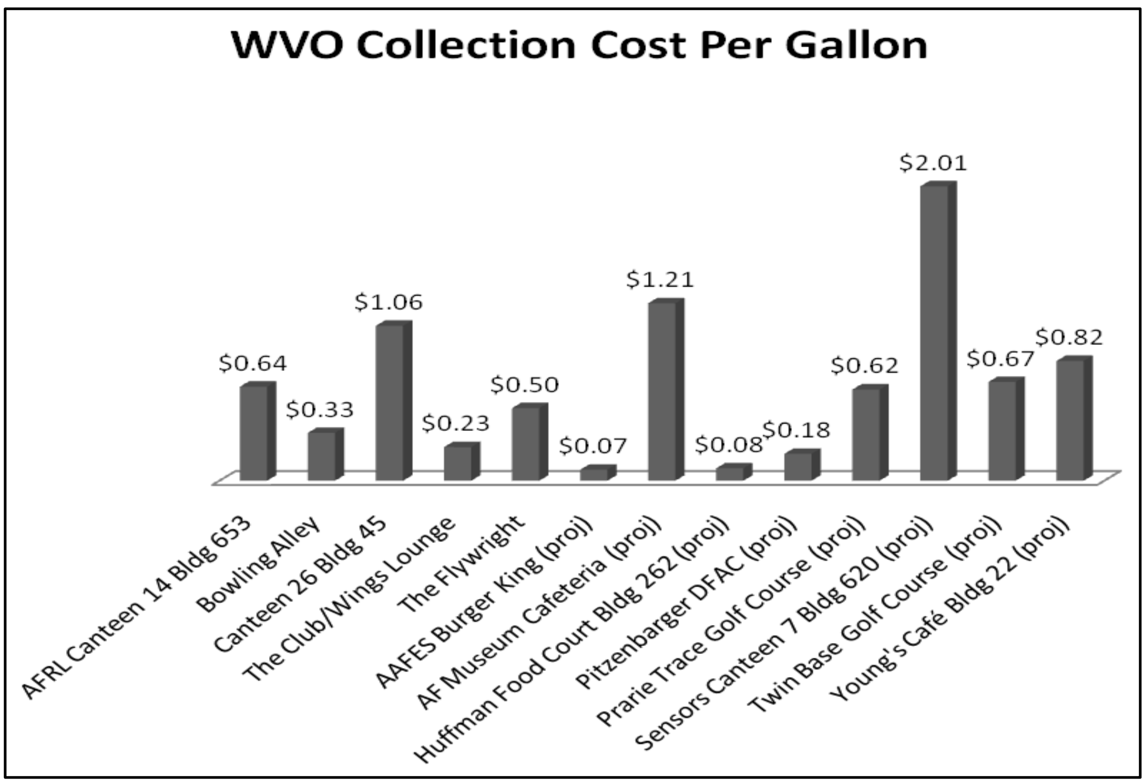

Figure 11: WVO Collection Cost per Gallon

WVO Processing Costs

After the WVO arrived at the Recycling Center, the WVO to SVO processing began. There was enough WVO collected to make five batches. The batches of SVO were processed and times for each step of the processing were noted. The Recycling Center mechanic completed two of the batches and the research team member did the other three. The times that the band heaters, pumps, and centrifuge were in operation were documented and kilowatt hour consumption was calculated. The one micron filter has a lifecycle of 550 gallons. The cost to replace the filter was calculated by dividing the cost of a replacement filter by the lifecycle of 550 gallons. Additionally, the excise tax was added. A weighted average of $0.92 was calculated to be the cost of processing a gallon of SVO. Figure 12 shows the cost breakdown. Labor was the largest expense. This was due to the mechanics running the system. Costs could be lessened by training material handlers who have a lower wage. The largest time use was pouring the WVO through the 200 micron filter. The second largest cost was electricity. This cost could also be lessened as the last batch used the band heater for 144 hours. As Figure 7 showed, there is little added benefit to heating the WVO over 35 hours. Excise tax and filter maintenance are fixed costs.

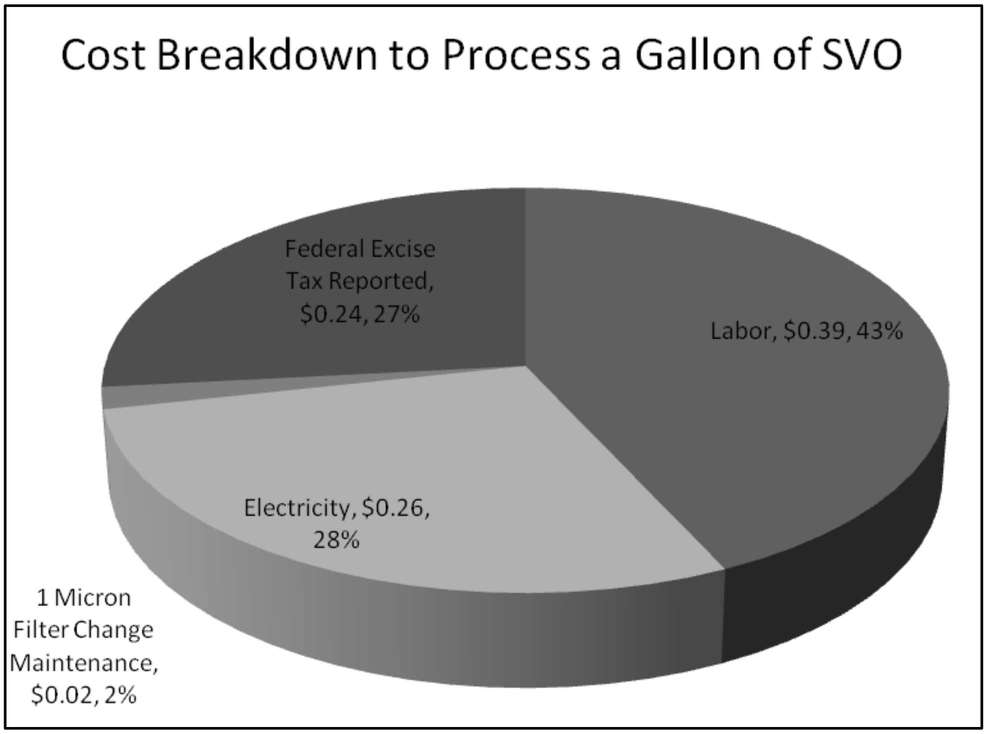

Figure 12: Cost Breakdown to Process a Gallon of SVO

Total Cost of WVO to SVO System

With the costs for the complete system fully calculated, the total operation cost can be compared to the DESC Standard Price. There were two scenarios to calculate the total cost. The first was to compare the costs with the maximum amount of WVO. The maximum amount of processed SVO available is 10,257 gallons. This would leave approximately 5,400 gallons of processed SVO after the 11 Recycling Center vehicles use the fuel. The excess SVO could be used by other base entities or sold to civilian SVO users. This scenario would yield a total cost of $1.77 per gallon. This cost also represents the breakeven point for the system. By running the system at maximum capacity, the acquisition costs are absorbed through more gallons of processed SVO. The current DESC Standard Price is $2.49 per gallon, so $1.77 per gallon yields not only a breakeven, but also a cost savings. The total cost roll up and savings are located in Appendix F. Figure 13 shows how the cost would break down per gallon.

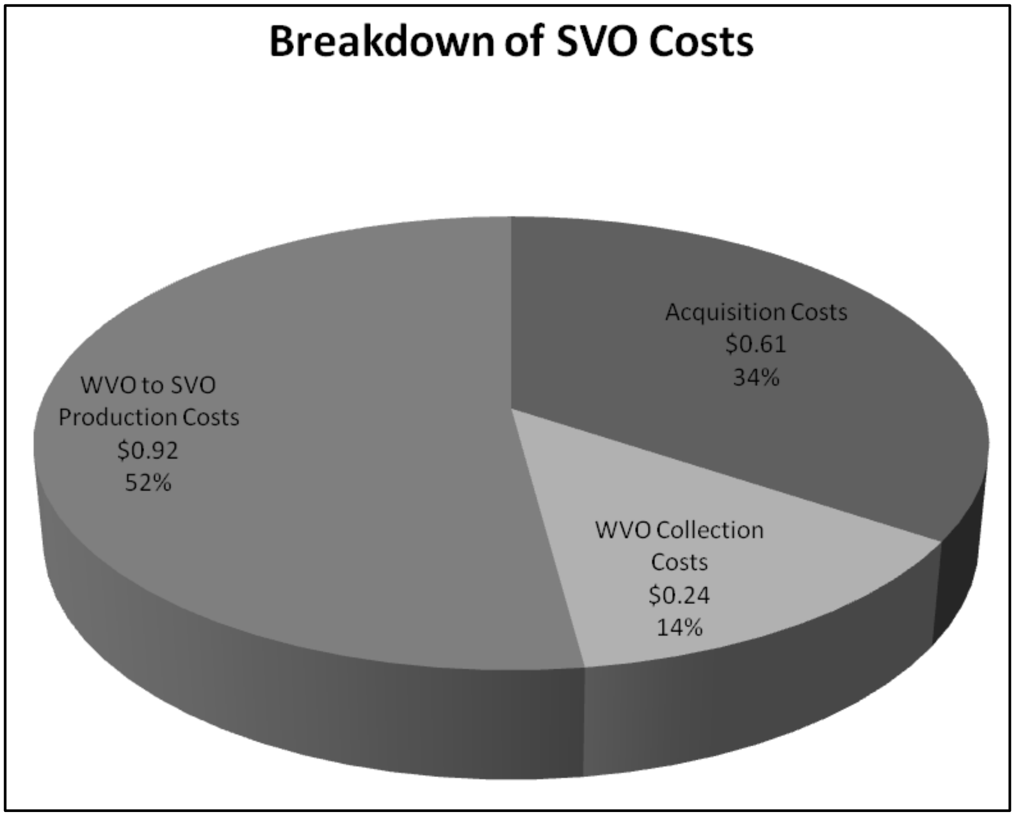

Figure 13: Breakdown of SVO Costs - Maximum Capacity

The breakeven point is calculated by using the entire 18-year life-cycle for the WVO to SVO processor and the four year lifecycle of the vehicle kits. Another way to consider cost savings is to look at when the cost savings are enough to pay for the system. If a two year payback is desired, the DESC Standard Price would have to reach $2.64 a gallon. The DESC price is already above the three year payback price. It would have to stay above $2.15 per gallon. Figure 14 represents the payback points for the two and three year scenarios of converting 11 vehicles and processing all of WPAFB's WVO. It would be naïve to assume DESC Standard Fuel Costs are going to remain the same. As the costs rise, so would the savings. The steeper line on the chart represents the amount of money that would be saved after the system is paid off in three years. The other line is the money saved after the system is paid off in two years.

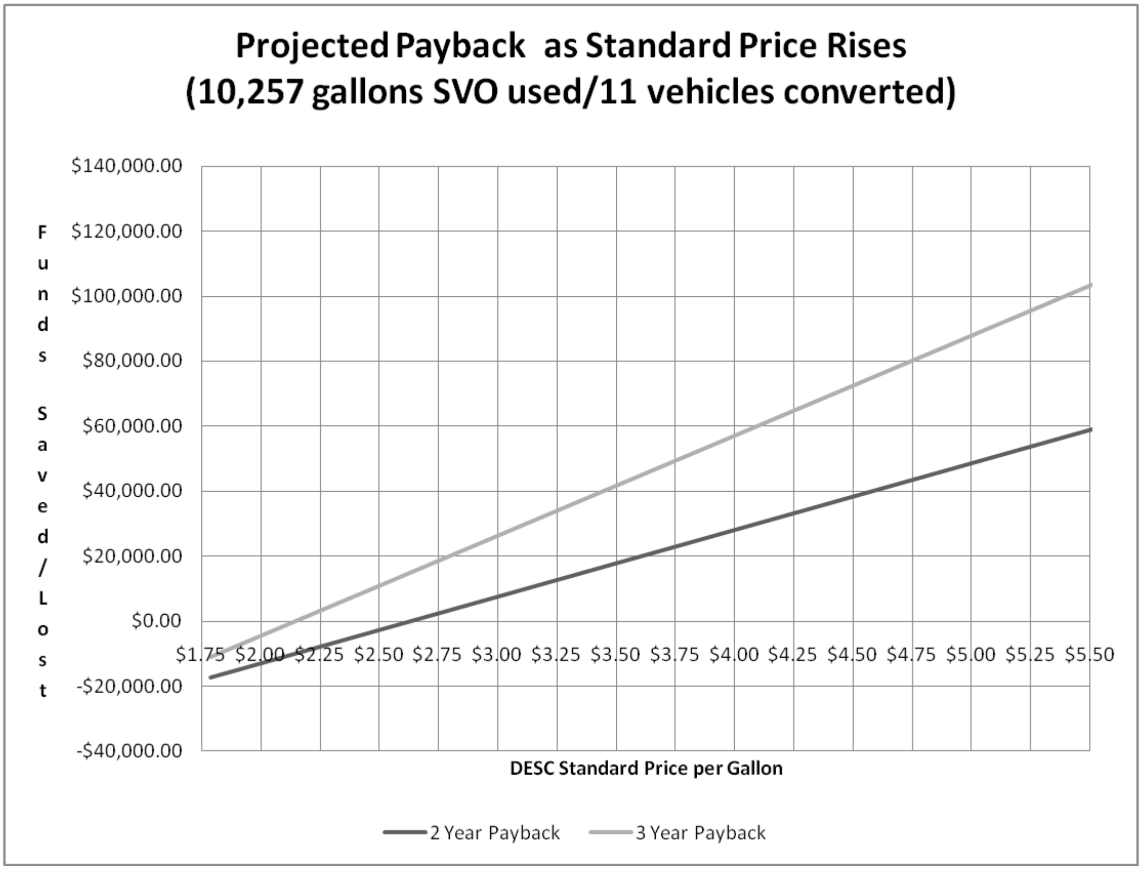

Figure 14: Projected Payback - Maximum Capacity

Another scenario involved processing only enough SVO to power the Recycling Center vehicles. The Center used 5,262 gallons of diesel in the last calendar year. Diesel is needed to start the vehicles and purge the fuel lines before shut down. The total amount of SVO the Recycling Center could use would be 4,862 gallons. Total costs are listed in Appendix F. By not utilizing the entire capacity of the processors, the cost rises to $2.44 per gallon of SVO. By looking at Figure 15, it can be seen how maximizing capacity lessens the percentage of acquisition costs. This is key to the first scenario having a quicker payback point.

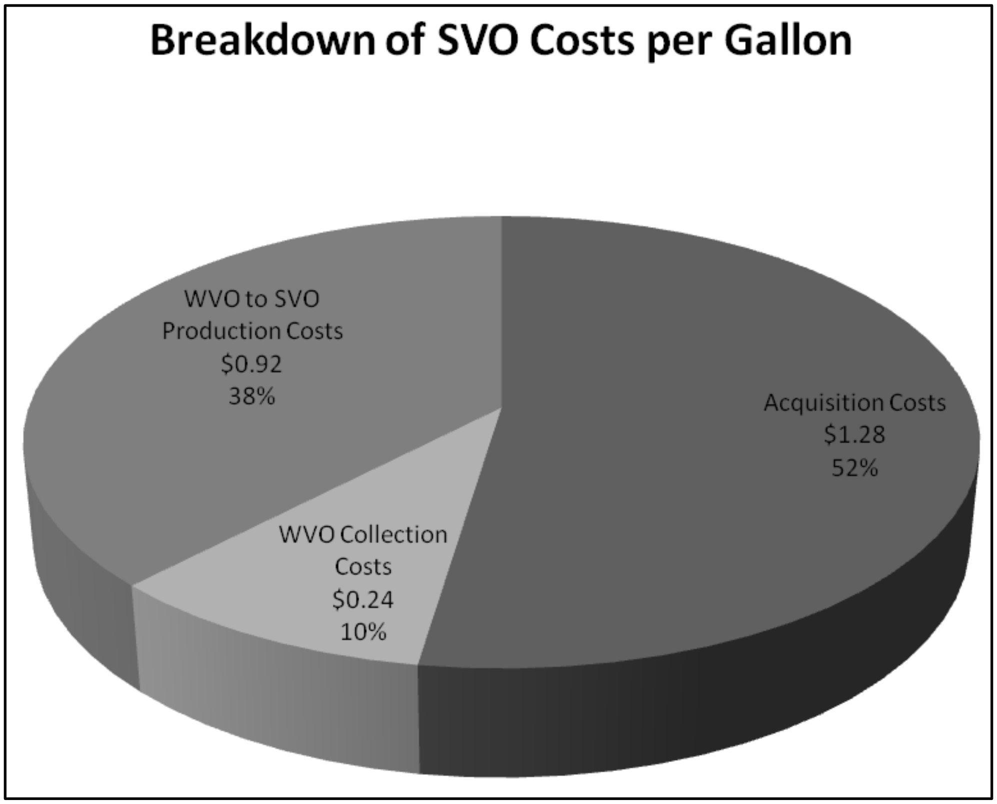

Figure 15: Breakdown of SVO Costs - Recycling Center Use Only

A payback point would still occur with the second scenario. As Figure 16 shows, the DESC Standard Price would have to rise to $4.28 per gallon for a two year payback and $3.24 for a three year payback. The slopes are not as steep as the Standard Price goes up due to less gallons being used in the system.

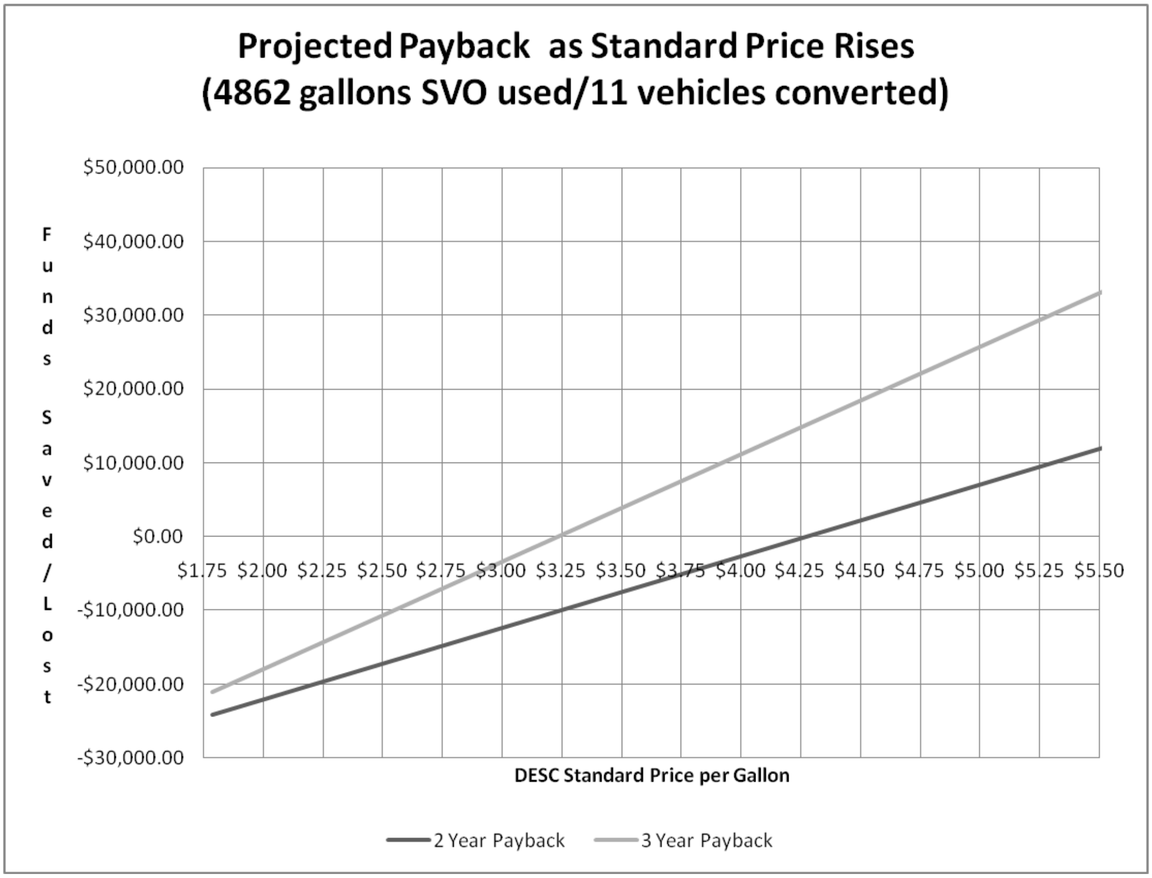

Figure 16: Projected Payback, Recycling Center Use Only

From the figures above, there is a definite cost savings if WPAFB pursued SVO derived from WVO. The more SVO that is used throughout WPAFB generates greater savings. Similarly, if the DESC Standard Price rises, the savings goes up and could reach over $100,000.

Benefits

Cost savings alone are not the only benefit to fielding the infrastructure. The WVO to SVO system could provide benefits to the environment, reduce WVO spills at restaurants, and help the government comply with its greening initiatives. The next set of investigative questions address the additional benefits. Those questions are:

4. What is the amount of emission reduction per vehicle due to operating on SVO?
5. Will the new WVO recycling system prevent or eliminate environmental spills?
6. Can the WVO infrastructure meet the requirements of the EPAct 2005 and EO 13423 initiatives?

4. What is the amount of emission reduction per vehicle due to operating on SVO?

Using the information available from the manufacturer of the SVO conversion kits, there is no reduction in Nitrogen Oxide (NO_x). Particulate Matter (PM) is reduced by 39% and Carbon Monoxide (CO) is reduced by 26%. Vehicles that were similar to the Chevrolet Box Truck were used for an independent study for biodiesel. Through this study, a baseline with conventional diesel was attained. The figures were 0.22 grams per mile for PM and 1.97 grams per mile for CO (Durbin, 2002). For every mile that SVO is used, the reductions would be 0.09 PM grams and 0.51 CO grams. Another way to examine the data is by looking at the overall reduction of emissions. Four vehicles operating on SVO would provide the same emission reduction as taking a similar diesel vehicle out of service.

5. Will the WVO recycling system prevent or eliminate environmental spills?

A representative from the WPAFB Environmental Spill Response Team and a member of the research team toured the six pilot facilities where the WVO collection occurred. The opinions of the food service workers who dispose of the WVO and the Spill Response Team member pertaining to the previous and the current disposal methods were recorded. Different numbers of food service workers were surveyed at each location. They discussed the systems amongst themselves and arrived at a consensus. Their rating was given the same weight as the Spill Response Team member. Therefore, two points of data were collected for each dining facility. The Spill Response Team member and the food service workers rated the two systems on five point scales for two categories: ease of operation and risk of spills. One was the best score which represented "easiest" for ease of operation and "slight risk" for spills. Five was the worst score which represented "physically impossible" for ease of operation and "spill every time" for spills.

Ease Of Use

Ease of operation for the previous disposal system had a mean score of 2.67. The individual scores for each facility are located in Appendix G. The scores are listed as the average between the food service workers and the Spill Response Team member. The new system improved the mean to 1.75. The reduction of "ease of operation" scores shows that the new system is easier. The food service workers were very happy with the new system. The workers at the Flywright were impressed with the ability to dump the WVO directly into the blue open drum without cooling. They also liked the Recycling Center picking up the WVO. Previously they had to transport it to The Club, approximately a 14 mile-round trip. The workers estimated the time savings to be 1.5 hours.

Risk of Spills

The risk of spills had similar results. The mean for the six facilities was reduced from 3.75 to 1.92. Most food service workers could not say enough good things about the new system. They liked the large opening of the drums and the ability to place the white jerricans directly under the drain spigots in the large fryers. Praise was given for not having to dump the WVO in the large 300-gallon dumpsters.

Limitations

The only facility that had a gain in scores was the Bowling Alley. The employees were transferring the WVO from the fryer to a square pan underneath it. They take the pan to a large plastic drum with a spigot on it. Then they move the WVO into the original vegetable oil containers. The WVO is hot when it goes into the large drum, which is not constructed to withstand the high heat. This caused leakage. Mitigation could occur by fully training the workers. The Bowling Alley was added after the pilot sites were selected. It did not get briefed or provided a Memorandum of Agreement. When the research team member visited the site, the blue open drum was stored under the sink and not being used. This is the reason the ease of use and risk of spills scores went up at that facility.

Impracticality Justification

The Spill Team member agreed with the opinions of the food service workers. Additionally, she looked at the sites to determine if the impracticality justification to the Spill Prevention Control and Countermeasure (SPCC) plan can be removed. Because the WVO is stored in drums less than 55 gallons and the 300-gallon cube dumpsters will be eliminated, the justification can be removed for all facilities. This will remove any doubt that WPAFB is compliant with the Clean Water Act (Quigley, 2009).

A collateral benefit of the elimination of the 300-gallon cube dumpsters is the elimination of using Sanimax. They are responsible for collecting the WVO that is not recycled. There was a consensus that the quality of service was poor. The complaints ranged from spilling the WVO without cleaning it up to sporadic service. There are also issues with the Sanimax drivers getting on base. Numerous instances have been documented when the driver arrives at WPAFB without proper credentials. They are turned around at the gate and do not return for days or months (Allen, 2009).

There are definite benefits to fielding the WVO collection procedure throughout all 13 base dining establishments. The majority of food service workers found time savings and their job was easier by using the new system. Spills would practically be eliminated. The base would finally have a SPCC plan without any waivers and the poor service of the collection company would no longer be an issue.

6. Can the WVO infrastructure meet the requirements of the EPAct 2005 and EO 13423 initiatives?

The sections covering vehicles in EPAct 2005 and EO 13423 have guidance that can be divided into four categories. They are:

1. Reduction – Reduce Fossil Fuel Consumption by 2% annually (EO 13423)
2. Addition – Increase Alternative Fuel Consumption by 10% Annually (EO 13423)
3. Acquisition – 75% of new vehicle purchases should be Alternative Fuel Vehicles (EPAct 2005)
4. Usage – utilize Alternative Fuels in Alternative Fuel Vehicles 100% of the time (EPAct 2005)

Unfortunately, the system will only meet one of the objectives of the two acts. If all 11 Recycling Center vehicles use the two-tank SVO system, there would still be a requirement for 7.6% of the current diesel amount. This would clearly meet the objective of reducing fossil fuel consumption by 2%. SVO is not recognized by the Department of Energy as an alternative fuel. There is plenty of reference to biodiesel, but nothing about

SVO. The reason is because there is no political lobby for SVO. Biodiesel has a lot of support from prominent figures such as Willie Nelson and Neil Young. SVO does not have the support, due to the intricacies of converting vehicles and it not being a drop-in fuel source (McConahy, 2009). Therefore, it cannot be eligible for increasing the Alternative Fuel consumption by 10% annually. The WVO to SVO system involves using older vehicles for the conversion to run on SVO. No new vehicles were planned to be purchased. This makes attaining the acquisition objective of 75% of new vehicles not viable. Finally, if SVO was considered an Alternative Fuel, the other EPAct mandate of using alternative fuel 100% of the time in an alternative fueled vehicle would be unfeasible. The two-tank vehicles require diesel to start and purge before shutdown. Previous calculations showed that the vehicle would be running on diesel 7.6% of the time. This eliminates the SVO infrastructure from both EPAct mandates.

Summary

This section answered the six investigative questions that will ultimately answer the thesis question of whether the Air Force should pursue SVO derived from WVO as an alternative fuel. The results from the procedures clearly demonstrated that there is an advantage to having a WVO to SVO infrastructure. The dining facilities on WPAFB produce over 10,000 gallons of WVO per year. This is more than double the amount of diesel that is currently used by the Recycling Center to power 11 vehicles. The left over SVO can be sold by the Recycling Center or other on-base entities could utilize it. From a cost stand point, the system could be fully paid for in two or three years with money left over. If the price of diesel fuel rises to the record price of over $4.00 per gallon as it did in the summer of 2008, the cost savings would be tens of thousands of dollars. From an environmental position, SVO used in diesel vehicles will reduce PM and CO emissions. Every four vehicles converted to run on SVO would be equivalent to operating one less diesel vehicle on the road for CO output. PM emissions are reduced even further. The new WVO collection system has been recognized by environmental spill experts and food service workers as a definite improvement to the current system. The new system will make WPAFB's Spill Prevention Control and Countermeasure Plan compliant without any waivers. The WVO to SVO infrastructure will not help the Air Force meet EPAct 2005 or EO 13423 initiatives. However, the current usage of vehicles by the Recycling Center is not providing compliance either. There would be no federal deterrent by adopting the new system. The concept was proven at WPAFB but could be easily done at other bases. Southern bases, such as Robbins AFB in Georgia or Lackland AFB in Texas, would be prime candidates. They are both large bases with many dining establishments. Also, the temperature is much warmer year round, mitigating the cold operation issues. Therefore, the Air Force should pursue SVO derived from WVO as an alternative fuel.

V. Conclusion

Introduction

The preceding chapters outlined the methodology and results of fielding a Waste Vegetable Oil (WVO) to Straight Vegetable Oil (SVO) infrastructure at Wright Patterson Air Force Base (WPAFB). This infrastructure can be used as a model for other large bases with comparative WVO generation throughout the Air Force. Many positive findings came out of this research along with some challenges. This section will highlight the results and make recommendations for future research.

Results

Six investigative questions were asked to determine if the Air Force should pursue SVO derived from WVO as an alternative fuel. Below are the answers to the questions.

1. How much WVO is produced by the dining facilities at Wright Patterson Air Force Base (WPAFB)?

   Originally, the estimate of WVO produced was 7,400 gallons. Actual research revealed that the total amount is an estimated11,970 gallons. This question was asked to determine if there was enough WVO generated on base to justify fielding a system to collect and reutilize it. The answer is "yes."

2. How many vehicles can be powered by the SVO produced?

The Base Recycling Center used 5,262 gallons of diesel in the 2008 calendar year. After the WVO is processed into SVO, there would be more than enough to power the 11 diesel vehicles operated by the Recycling Center, as well as having 5,395 gallons for use by other base entities or to be sold. The 88th Air Base Wing Civil Engineers expressed interest in using the SVO in the summer as a fuel extender by diluting diesel with 10 to 15% SVO. This demonstrates that the supply of WVO can be used by an the Recycling Center for its diesel fuel needs. An abundance would be left over for other uses, such as a fuel extender or as a primary fuel if more vehicles are converted.

3. At what point does the WVO/SVO infrastructure generate a cost savings?

Once the processor was put online and if all 11 Recycling Center vehicles were converted and ran on SVO, a cost savings would be recognized. By breaking the costs of the processor over its entire lifecycle of 18 years, the costs of the vehicle kits to four years, and only processing enough WVO to power the Recycling Center vehicles, the savings would be minimal. A breakeven point would be obtained and surpassed. However, if all the WVO on base was converted to SVO and users were found for the finished product, the savings would be $7431.99 per year, compared with acquiring diesel fuel at the current Defense Energy Support Center (DESC) Standard Price of $2.49 per gallon. At these figures, the system would pay for itself in three years.

4. What is the amount of emission reduction per vehicle due to operating on SVO?

Previous research proved SVO usage would reduce Particulate Matter (PM) and Carbon Monoxide (CO) emissions by 39% and 26% respectively when compared to diesel. Nitrogen Oxide (NO_x) emissions are not reduced. SVO is one of the cleanest burning alternative fuels due to the lack of chemical additives and petroleum content. A benefit to the environment would occur.

5. Will the new WVO recycling system prevent or eliminate environmental spills?

After the new WVO system was fielded at a sample of base dining establishments, opinions of the food service workers and an expert from the WPAFB Spill Response Team were recorded. The answer was almost unanimous that the new system will prevent spills better than the current system. However, benefits can only be attained if the system is easier to use. If the system is more difficult to use than the current system, it is human nature to use the old system. A majority of food service workers found the new WVO disposal system much easier to use and expressed interest in keeping the new system long after the research effort is complete. This is considered a highly positive benefit to having the infrastructure.

6. How can the WVO infrastructure meet EPAct 2005 and EO 13423 initiatives?

Unfortunately, SVO is not recognized as an alternative fuel. Even if it was, the wording of the EPAct 2005 and EO 13423 initiatives precludes the WVO to SVO system from being eligible. New vehicles are not being acquired and alternative fuels would not be used 100% of the time in alternative fueled vehicles. However, fossil fuel would be reduced by over 2% if the SVO system was fielded, meeting one of the EO 13423 objectives. Due to only meeting one of the four government objectives, compliance of EO 13423 or EPAct 2005 objectives cannot be considered a benefit from fielding the WVO to SVO system.

Summary

From the data above, the thesis question, "should the Air Force pursue SVO derived from SVO as an alternative fuel?" can be answered as a definite yes. Five out of six criteria are met as Table 9 demonstrates. Each question is listed and a grade of "P" for pass or "F" for fail is shown. Passing grades were assessed by meeting the objectives. The first two questions of how much WVO is produced and how many vehicles can be powered were given passing grades because there is enough WVO to fuel the entire fleet of Recycling Center vehicles. The third question addressing when a cost savings occurs is given a passing grade because once the system is operational and the scenario of using less SVO is realized, the cost per gallon of SVO is less than the current DESC Standard Price. Emissions reduction and spill prevention gained passing grades because it was proven that both objectives would be met. The government greening initiatives were given a failing grade due to only meeting one out of four objectives. The thesis question was given a pass because five out of six investigative questions were given a passing grade.

Table 9: Answers to Investigative Questions and Thesis Question

Answers to Investigative Questions		
Criteria	**Answer**	**Grade**
How Much WVO is Produced?	11,970	P
How Many Vehicles Can be Powered?	11 +	P
When is there a Cost Savings?	Once Operational	P
Emissions Reduced?	Yes	P
Prevent Spills?	Yes	P
Meet Gov't greening initiatives?	1 out of 4	F
Should the Air Force Pursue SVO derived from WVO?	**Yes**	**P**

Recommendations for Further Research

The pilot infrastructure consisting of the WVO to SVO processor, one test vehicle, numerous WVO collection containers, and the Recycling Center mechanic will remain at WPAFB after this research effort is complete. There is a considerable amount of enthusiasm from both the Services employees, who are using the system for WVO collection, and the sponsor of the effort, the 88th Air Base Wing Civil Engineering Group. This infrastructure and dedication makes a perfect opportunity for further research in the field of SVO. Four distinct future research opportunities can be considered. First, the existing infrastructure could be utilized and the processed SVO could be used as an extender in non-converted vehicles. Second, the complete infrastructure could be fielded involving all 11 Recycling Center vehicles, additional Civil Engineering vehicles, and all 13 dining establishments. Third, the filtered SVO could be the main ingredient in a biodiesel system. Fourth, the effort could be fielded at another base.

Use Current System

The current system has the potential to make more SVO than the one test vehicle can use. Everything has already been paid for. Future research can involve utilizing the fuel as an extender. Previous research revealed that SVO can be mixed with diesel in quantities up to 20% in warmer climates such as Brazil. When SVO was operated in a single-tank system during the colder months in Dayton, Ohio, it proved troublesome. The Rabbit test vehicle had to be towed many times due to electrical problems and gelling. Finding the correct mixture for the climate would be a viable research effort. Additional opportunities exist to do a longer term evaluation of the test vehicle, improving the logistics of collecting and using the WVO, or finding other ways to exploit the WVO source.

Procure Complete System

Procuring the complete system would help WPAFB by eliminating the impracticality justification plaguing the Spill Prevention Control and Countermeasure Plan. The complete system would eliminate the need for the 300 gallon cubes and the need for a secondary containment system. Sanimax would no longer be needed to dispose of WVO. The excess processed SVO could be the source of research similar to the future research opportunities of using the existing infrastructure. There would be issues with this effort. To set the effort up for success a substantial investment from the sponsor would be required. An additional ten SVO conversion kits need to be acquired and installed, and many more collection containers would have to be purchased. At least one more material handler or mechanic would need to be hired in order for the system to operate successfully. The Recycling Center has very little excess labor capacity in the current employee structure to dedicate the necessary time to run the infrastructure. If this effort was considered, the research team should attain full commitment of the Recycling Center or the Civil Engineers to provide full funding and an additional dedicated employee. This research would prove very valuable to the sponsors by eventually saving funds. The Standard Fuel price will most likely rise in the following years, making for the possibility of larger cost savings.

Convert to Biodiesel

The WVO to SVO system could be converted to biodiesel. This option was not considered due to the higher costs of the infrastructure, along with the issues of using chemicals. However, due to the high cost of converting vehicles to SVO and the recent positive public opinion towards biodiesel, support for the refinery may be easier. Biodiesel is considered an alternative fuel source per EO 13423 and EPAct 2005. McGuire Air Force base recently received $3.2 million worth of defense funding for a bio-fuel plant. The plant will convert waste materials into synthetic fuel to power up to 40 homes on base (McGuire Biofuel Project Gets Funding, 2009). Preliminary research proved a biodiesel system at WPAFB could be acquired and ran for a fraction of that cost. While there is more risk in using hazardous chemicals and the Recycling Center is not equipped to store them, the reward of making a fuel that is usable in any diesel powered vehicle is worth investigating.

Field System at Another Base

The cold weather at WPAFB revealed difficulties in using SVO in single-tank applications. Additionally, the largest expense was converting vehicles to the two-tank system. If the system was fielded at bases in the southern tier where temperatures remain above 68°, the fuel could be used exclusively as an extender. The home of Basic Training, Lackland AFB, first came to mind as the best option. Inside every Basic Training squadron is a Dining Facility (DFAC) that feeds hundreds of recruits. The squadrons are located close to each other, reducing travel time for WVO collection. Other bases that could be used would be Robbins or Nellis, due to the similar climate and training missions as Lackland.

Conclusion

Alternative fuels are a hot topic even with the recent price drop in oil. Unfortunately, public support is starting to wane, despite the Obama administration making it a priority to reduce America's dependence on foreign oil along with improving the environment. History has shown over time that many good alternative fuel concepts are investigated when fuel costs are considered high but are scrapped as soon as the costs dip. This phenomenon happened during the Carter administration and appears to be repeating itself in the present day. History also shows that fuel costs will eventually rise again. When the rise occurs, it will be swift, as evidenced by the rises in the summer of 2007 and 2008.

A way to reduce some of the demand for fossil fuels, provide a cost stable fuel, and an environmentally friendly fuel source, is to utilize the abundant supply of WVO. Enough WVO is disposed of to be converted into over 10,000 gallons of SVO fuel on WPAFB. This resource is currently a burden to dispose of and is a commodity that could be reutilized. This research has been conducted to prove there are numerous benefits and cost savings to fielding a system to collect, process, and use the fuel. The Air Force should implement this system and begin the pursuit of using SVO derived from WVO as an alternative fuel.

Appendix A: Memorandum of Agreement For Waste Vegetable Oil Collection

DEPARTMENT OF THE AIR FORCE
88th Air Base Wing
WRIGHT PATTERSON AFB, OHIO

MEMORANDUM OF AGREEMENT

BETWEEN

88 ABE/CEVY (Base Recycling Center), 88 MSG/SVB (Base Restaurants) and 88 MSG/SVBO (Wright-Patterson Clubs)

1. This Memorandum of Agreement establishes the procedures for selected base restaurants (herein called "the facilities") and the Recycling Center to participate in the Waste Vegetable Oil (WVO) recycling program and the Recycling Center's commitment to the program. The following facilities were selected for the program:

The Club	Canteen 7
Canteen 14	Canteen 26
Flywright Club	National Museum of the USAF Food Court

2. The Recycling Center agrees to furnish drums to the facilities for the purpose of collecting WVO out of the fryers. The containers shall be 5 to 8 gallons to allow for ease of handling. WVO weighs about 7 pounds per gallon. Therefore, a full container will weigh 56 pounds, maximum. After the facilities fill the containers, they will call the Recycling Center at 7-4889 to schedule a pick up. The Recycling Center shall pick up the containers and the original corn oil containers within 72 hours.

3. The facilities agree to drain the fryers into the Recycling Center furnished containers. The main kitchen in The Club shall use 5 gallon jericans by draining the hot WVO directly into them. The other kitchens shall use the blue open drums. The canteens shall also drain the WVO directly from the fryer into the drums. Wings Lounge, located in The Club, and Air Force Museum shall use the current draining method, then transfer the WVO into the drums. The drums and jericans shall be stored inside. Also, the original plastic containers in the cardboard will be saved and stored with the drums/jericans.

4. The WVO recycling program will be fielded in increments. This is the initial stage in a pilot program and a thesis project for Capt Harvey Gaber, an AFIT Masters Student. If you have any questions, please contact him at (310) 702-3974 or Harvey.Gaber@afit.edu.

Date 7 Sept 08
WILLIAM MEINERDING, DAF
Environmental Program Manager
88 ABW/CEVY

Date 2 Sept 08
KEITH I. ALLEN, DAF
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88 MSG/SVB

Date 3 Sept 08
HARVEY S. GABER, Capt, USAF
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AFIT/ENV

Date 2 Sept 08
VONZELLA M. ALLEN, DAF
General Manager, Wright-Patt Clubs
88 MSG/SVBO

Appendix B: Waste Vegetable Oil Collection Audit per Facility

WVO Collection Costs Per Month		Projected	For	AAFES Burger King
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	3/5	$5.10
Vehicle mileage cost per trip	$0.555	per mile	5.40	$3.00
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	432	White	44	
Total cost of all trips	$32.39			
Cost per gallon collected	**$0.07**			

WVO Collection Costs Per Month		Projected	For	AF Museum Cafeteria
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	11/15	$6.23
Vehicle mileage cost per trip	$0.555	per mile	10.60	$5.88
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	40	Blue	4	
Total cost of all trips	$48.47			
Cost per gallon collected	**$1.21**			

WVO Collection Costs Per Month		Projected	For	Huffman Food Court Bldg 262
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	1/3	$2.83
Vehicle mileage cost per trip	$0.555	per mile	1.00	$0.56
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	160	Blue	16	
Total cost of all trips	$13.55			
Cost per gallon collected	**$0.08**			

WVO Collection Costs Per Month		Projected	For	Pitzenbarger DFAC
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	5/12	$3.54
Vehicle mileage cost per trip	$0.555	per mile	6.00	$3.33
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
*Gallons WVO Collected	150	White	15	
Total cost of all trips	$27.49			
Cost per gallon collected	**$0.18**	*6 months WVO output is 50/other 6 WVO output is 25 gals		

WVO Collection Costs Per Month			For	Prarie Trace Golf Course
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	11/30	$3.12
Vehicle mileage cost per trip	$0.555	per mile	5.60	$3.11
Trips to Facility per month	1.3	**Type Collection Jug**	**Qty**	
*Gallons WVO Collected	13	Blue	4	
Total cost of all trips	$8.09			
Cost per gallon collected	**$0.62**			

WVO Collection Costs Per Month		Simulated	For	AAFES Burger King
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	3/5	$5.10
Vehicle Wear per trip	$0.555	per mile	5.40	$3.00
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	432	White	44	
Total cost of all trips	$32.39			
Cost per gallon collected	**$0.07**			

WVO Collection Costs Per Month		Simulated	For	AF Museum Cafeteria
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	11/15	$6.23
Vehicle Wear per trip	$0.555	per mile	10.60	$5.88
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	40	Blue	4	
Total cost of all trips	$48.47			
Cost per gallon collected	**$1.21**			

WVO Collection Costs Per Month		Simulated	For	Huffman Food Court Bldg 262
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	1/3	$2.83
Vehicle Wear per trip	$0.555	per mile	1.00	$0.56
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	160	Blue	16	
Total cost of all trips	$13.55			
Cost per gallon collected	**$0.08**			

WVO Collection Costs Per Month		Simulated	For	Pitzenbarger DFAC
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	5/12	$3.54
Vehicle Wear per trip	$0.555	per mile	6.00	$3.33
Trips to Facility per month	4	**Type Collection Jug**	**Qty**	
*Gallons WVO Collected	150	White	15	
Total cost of all trips	$27.49			
Cost per gallon collected	**$0.18**	*6 months WVO output is 50/other 6 WVO output is 25 gals		

WVO Collection Costs Per Month			For	Prarie Trace Golf Course
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	11/30	$3.12
Vehicle Wear per trip	$0.555	per mile	5.60	$3.11
Trips to Facility per month	1.3	**Type Collection Jug**	**Qty**	
*Gallons WVO Collected	13	Blue	4	
Total cost of all trips	$8.09			
Cost per gallon collected	**$0.62**			

WVO Collection Costs Per Month		Projected	For	Sensors Canteen 7 Bldg 620
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	31/60	$4.39
Vehicle mileage cost per trip	$0.555	per mile	10.20	$5.66
Trips to Facility per month	1	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	5	Blue	2	
Total cost of all trips	$10.05			
Cost per gallon collected	**$2.01**			

WVO Collection Costs Per Month		Projected	For	Twin Base Golf Course
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	7/15	$3.97
Vehicle mileage cost per trip	$0.555	per mile	5.00	$2.78
Trips to Facility per month	1.3	**Type Collection Jug**	**Qty**	
*Gallons WVO Collected	13	Blue	4	
Total cost of all trips	$8.76			
Cost per gallon collected	**$0.67**	Fryer in use 8 months/yr - 5 gallons/week		

WVO Collection Costs Per Month		Projected	For	Young's Café - Bldg 22
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor per trip	$8.50	per hour	19/60	$2.69
Vehicle mileage cost per trip	$0.555	per mile	6.20	$3.44
Trips to Facility per month	1	**Type Collection Jug**	**Qty**	
Gallons WVO Collected	7.5	Blue	2	
Total cost of all trips	$6.13			
Cost per gallon collected	**$0.82**			

Appendix C: Total WVO Collection Costs per Month

Name of Facility	Total Trip Costs	WVO Coll (gals)	Time Req'd (hrs)	Cost Per Gal	Blue Jugs Req'd	White Jugs Req'd
AFRL Canteen 14 Bldg 653	$9.63	15	0.47	$0.64	6	
Bowling Alley	$19.60	60	1.00	$0.33	6	
Canteen 26 Bldg 45	$10.58	10	0.50	$1.06	4	
The Club/Wings Lounge	$13.08	57	0.83	$0.23	4	9
The Flywright	$9.91	20	0.50	$0.50	8	
AAFES Burger King (sim)	$32.39	432	2.40	$0.07		44
AF Museum Cafeteria (sim)	$48.47	40	2.93	$1.21	4	
Huffman Food Court Bldg 262 (sim)	$13.55	160	1.33	$0.08	16	
Pitzenbarger DFAC (sim)	$27.49	150	1.67	$0.18		15
Prarie Trace Golf Course (sim)	$27.49	13	0.48	$0.62	4	
Sensors Canteen 7 Bldg 620 (sim)	$10.05	5	0.52	$2.01	2	
Twin Base Golf Course (sim)	$8.76	13	0.61	$0.67	4	
Young's Café Bldg 22 (sim)	$6.13	7.5	0.32	$0.82	2	
Totals	**$237.12**	**982.5**	**13.55**	**$0.24**	**60**	**68**

Appendix D: Waste Vegetable Oil to Straight Vegetable Oil Production Costs

Electricity Usage for Batch 1								
Component Name	**Volts**	**Amps**	**Wattage**	**KWH**	**Time in Use**	**KW Used**	**KWH Rate**	**Cost**
Band Heater - Drum 1	115	13	1495	1.495	12.00	17.94	0.11	$1.97
Transfer Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Centrifuge Pump	115	6	690	0.69	1.50	1.035	0.11	$0.11
Band Heater - Drum 2	115	9.5	1092.5	1.0925	1.50	1.63875	0.11	$0.18
Fuel Nozzle Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Total Electricity						**20.96**		**$2.31**

Electricity Usage for Batch 2								
Component Name	**Volts**	**Amps**	**Wattage**	**KWH**	**Time in Use**	**KW Used**	**KWH Rate**	**Cost**
Band Heater - Drum 1	115	13	1495	1.495	24	35.88	0.11	$3.95
Transfer Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Centrifuge Pump	115	6	690	0.69	2	1.38	0.11	$0.15
Band Heater - Drum 2	115	9.5	1092.5	1.0925	2	2.185	0.11	$0.24
Fuel Nozzle Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Total Electricity						**39.79**		**$4.38**

Electricity Usage for Batch 3								
Component Name	**Volts**	**Amps**	**Wattage**	**KWH**	**Time in Use**	**KW Used**	**KWH Rate**	**Cost**
Band Heater - Drum 1	115	13	1495	1.495	72	107.64	0.11	$11.84
Transfer Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Centrifuge Pump	115	6	690	0.69	2	1.38	0.11	$0.15
Band Heater - Drum 2	115	9.5	1092.5	1.0925	20	21.85	0.11	$2.40
Fuel Nozzle Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Total Electricity						**131.22**		**$14.43**

Electricity Usage for Batch 4								
Component Name	**Volts**	**Amps**	**Wattage**	**KWH**	**Time in Use**	**KW Used**	**KWH Rate**	**Cost**
Band Heater - Drum 1	115	13	1495	1.495	48	71.76	0.11	$7.89
Transfer Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Centrifuge Pump	115	6	690	0.69	2	1.38	0.11	$0.15
Band Heater - Drum 2	115	9.5	1092.5	1.0925	2	2.185	0.11	$0.24
Fuel Nozzle Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Total Electricity						**75.67**		**$8.32**

Electricity Usage for Batch 5								
Component Name	**Volts**	**Amps**	**Wattage**	**KWH**	**Time in Use**	**KW Used**	**KWH Rate**	**Cost**
Band Heater - Drum 1	115	13	1495	1.495	144	215.28	0.11	$23.68
Transfer Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Centrifuge Pump	115	6	690	0.69	3.5	2.415	0.11	$0.27
Band Heater - Drum 2	115	9.5	1092.5	1.0925	3.5	3.82375	0.11	$0.42
Fuel Nozzle Pump	115	6	690	0.69	0.25	0.1725	0.11	$0.02
Total Electricity						**221.86**		**$24.41**

WVO to SVO Production Costs		For	Batch 1	Completed 31 Oct 2008
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor	14.5	per hour	1.50	21.75
Electricity	0.11	per KWH	20.96	2.31
1 Micron Filter Change Maintenance	$0.014	per WVO gallon	45	0.63
Gallons WVO Processed	45	Gallons SVO Output	35	
Federal Excise Tax Reported	$0.244	per gallon SVO	35	8.54
Percent SVO from WVO	78%			
Total Processing Cost		**per gallon**	**$0.95**	**$33.23**
Water, Coulometric Titration (ppmw)	**2576**			

WVO to SVO Production Costs		For	Batch 2	Completed 17 Nov 2008
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor	14.5	per hour	1.25	18.13
Electricity	0.11	per KWH	39.79	4.38
1 Micron Filter Change Maintenance	$0.014	per WVO gallon	45	0.63
Gallons WVO Processed	45	Gallons SVO Output	35	
Federal Excise Tax Reported	$0.244	per gallon SVO	35	8.54
Percent SVO from WVO	78%			
Total Processing Cost		**per gallon**	**$0.90**	**$31.67**
Water, Coulometric Titration (ppmw)	**1277**			

WVO to SVO Production Costs		For	Batch 3	Completed 8 Jan 2008
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor	14.5	per hour	1.10	15.95
Electricity	0.11	per KWH	131.22	14.43
1 Micron Filter Change Maintenance	$0.014	per WVO gallon	50	0.70
Gallons WVO Processed	50	Gallons SVO Output	45	
Federal Excise Tax Reported	$0.244	per gallon SVO	45	10.98
Percent SVO from WVO	90%			
Total Processing Cost		**per gallon**	**$0.93**	**$42.06**
Water, Coulometric Titration (ppmw)	**980**			

WVO to SVO Production Costs		For	Batch 4	Completed 14 Jan 2009
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor	14.5	per hour	1	14.50
Electricity	0.11	per KWH	75.67	8.32
1 Micron Filter Change Maintenance	$0.014	per WVO gallon	45	0.63
Gallons WVO Processed	45	Gallons SVO Output	42	
Federal Excise Tax Reported	$0.244	per gallon SVO	42	10.25
Percent SVO from WVO	93%			
Total Processing Cost		**per gallon**	**$0.80**	**$33.70**
Water, Coulometric Titration (ppmw)	**1048**			

WVO to SVO Production Costs		For	Batch 5	Completed 26 Jan 2009
Name of Cost	**Rate**	**per unit**	**units used**	**total cost**
Labor	14.5	per hour	0.75	10.88
Electricity	0.11	per KWH	221.86	24.41
1 Micron Filter Change Maintenance	$0.014	per WVO gallon	50	0.70
Gallons WVO Processed	50	Gallons SVO Output	49	
Federal Excise Tax Reported	$0.244	per gallon SVO	49	11.96
Percent SVO from WVO	98%			
Total Processing Cost		**per gallon**	**$0.98**	**$47.94**
Water, Coulometric Titration (ppmw)	**Not Tested**			

Appendix E: Total Waste Vegetable Oil to Straight Vegetable Oil Processing Cost

Total WVO to SVO Production Costs				
Batch Number	**SVO Gallon**	**Cost per Gallon**	**Total Cost**	**Percent SVO from WVO**
1	35	$0.95	$33.23	78%
2	35	$0.90	$31.67	78%
3	45	$0.93	$42.06	90%
4	42	$0.80	$33.70	93%
5	49	$0.98	$47.94	98%
Total	**206**	**$0.92**	**$188.60**	**87%**

Appendix F: Total Costs for WVO to SVO System

Roll Up of All Costs to Gallons SVO Produced - Maximum Capacity				
Name	**Annual Breakdown**	**Monthly Breakdown**	**Total Cost - 1st Year**	**Total Cost - 2nd Year**
Acquisition Costs	$6,209.82	$517.48	$30,286.21	
WVO Collection Costs	$2,461.68	$205.14	$2,461.68	$2,461.68
WVO to SVO Production Costs	$9,436.44	$786.37	$9,436.44	$9,436.44
Total SVO Cost	**$18,107.94**	**$1,508.99**	**$42,184.33**	**$11,898.12**
Gallons Produced	10257	855		
			3 year lifecycle	**$65,980.57**

Cost Savings of SVO vs. DESC Diesel or Biodiesel	
Name	**Cost**
Total Cost of SVO Per Gallon	$1.77
DESC Fuel Cost	$2.49
Savings Per Gallon	$0.72
Savings Per Month	$619.33
Savings Per Year	**$7,431.99**

Roll Up of All Costs to Gallons SVO Produced - Recycling Center Use Only				
Name	**Annual Breakdown**	**Monthly Breakdown**	**Total Cost - 1st Year**	**Total Cost - 2nd Year**
Acquisition Costs	$6,209.82	$517.48	$30,286.21	
WVO Collection Costs	$1,166.88	$97.24	$1,166.88	$1,166.88
WVO to SVO Production Costs	$4,473.04	$372.75	$4,473.04	$4,473.04
Total SVO Cost	**$11,849.74**	**$987.48**	**$35,926.13**	**$5,639.92**
Gallons Produced	4862	405		
			3 year lifecycle	**$47,205.97**

Cost Savings of SVO vs. DESC Diesel or Biodiesel	
Name	**Cost**
Total Cost of SVO Per Gallon	$2.44
DESC Fuel Cost	$2.49
Savings Per Gallon	$0.05
Savings Per Month	$21.39
Savings Per Year	**$256.64**

Appendix G: Scores for Ease of Use and Risk of Spills for WVO Collection System

Previous System Ease of Use	
Location	**Score**
The Club	3.00
Wings Lounge	3.00
Flywright	4.00
AFRL Canteen	4.00
Bowling Alley	1.00
Bldg 26 Cafeteria	1.00
Σ	**16**
μ	**2.666666667**

Current System Ease of Use	
Location	**Score**
The Club	2.00
Wings Lounge	1.50
Flywright	1.50
AFRL Canteen	1.50
Bowling Alley	3.00
Bldg 26 Cafeteria	1.00
Σ	**10.5**
μ	**1.75**

Previous System Risk of Spills	
Location	**Score**
The Club	4.00
Wings Lounge	4.00
Flywright	4.00
AFRL Canteen	4.50
Bowling Alley	5.00
Bldg 26 Cafeteria	1.00
Σ	**22.5**
μ	**3.75**

Current System Risk of Spills	
Location	**Score**
The Club	1.50
Wings Lounge	1.50
Flywright	1.50
AFRL Canteen	2.00
Bowling Alley	4.00
Bldg 26 Cafeteria	1.00
Σ	**11.5**
μ	**1.916666667**

Appendix H: Blue Dart

Every month at Wright Patterson Air Force Base, over 900 gallons of cooking grease is thrown away. A Canadian company comes to the base and takes the grease away to use it as they see fit. If the company can get the grease off the base without spilling it into our waste stream or becoming a wild animal's gourmet feast, some of it is used as feedstock to fatten up cows that are eventually consumed by the public. Other uses of the grease are to make biodiesel, a fuel that actually produces more emissions than conventional diesel. There is a solution that will reclaim our grease. A grease to fuel system will prevent harmful pollution to the environment, reduce our dependence on fossil fuels, and save the government money.

A pilot system was fielded at Wright Patterson Air Force Base from August 2008 until March 2009. Six restaurants were selected to recycle the grease from their fryers by pouring it into special 6 or 8-gallon containers, instead of dumping it outside in a 300-gallon dumpster. The opinions of the food service workers were quite positive. They were very happy to participate because using the smaller containers was much easier. The containers were stored inside, eliminating any possibility of the grease accidentally ending up in the fresh water supply or inside animal's bellies. Once the grease was collected, the food particles were filtered out and the water was removed. It was reused as a fuel in specially equipped diesel vehicles. The vehicles demonstrated reduced emissions and no loss in fuel efficiency. The reduction of spills and emissions proves that grease as a fuel would be positive for the environment.

Diesel vehicles can be specially equipped to run filtered grease via a two-tank system and a computer. The vehicle starts on diesel until the filtered grease reaches 68°, where it has the proper qualities to power the vehicle just like diesel fuel. The computer automatically switches the fuel from diesel to filtered grease. The switch is so seamless that drivers cannot tell when the switchover takes place. At Wright Patterson, the Recycling Center operates 11 diesel vehicles that use about 5400 gallons of diesel per year. This system would reduce the diesel usage to about 410 gallons per year.

Besides fossil fuel savings, there is monetary savings as well. The grease to fuel system requires conversion kits for the vehicles to operate year round on filtered grease. If the entire fleet of 11 Recycling Center vehicles was converted and operated on filtered grease and all the grease from Wright Patterson was filtered into fuel, there would be an excess of about 5000 gallons of fuel. The fuel could be used in the summer as an extender. If the air temperature remains above 68°, it could be safely mixed in a 20% filtered grease/80% diesel blend. This blend could be used in unconverted diesel vehicles. If all the grease was used, and all costs were added up, the total cost would be $1.77 per gallon. Currently, the government is paying $2.49 a gallon for diesel fuel. At these prices and usage, the system could pay for itself in two years.

This article outlined three important reasons why grease should be recycled into a usable fuel. A pilot system was fielded at Wright Patterson to prove the concept. The environment would be cleaner due to elimination of spills and reduced emissions. Our dependence of fossil fuels would be reduced. Most importantly, the system will save the government money. Therefore, the time is right to field a grease to fuel system at bases across the world.

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Vita

Captain Gaber received his B.A. in Business Management from Stockton State College in December of 1990. He has completed over 20 years of Military Service with the first 13 years in the Air National Guard. His first assignment was with the 177th Fighter Interceptor Group in Atlantic City, New Jersey as an enlisted Aerospace Ground Equipment Mechanic. He completed his Air National Guard and enlisted service in the 235th Air Traffic Control Squadron at Selfridge Air National Guard Base, Michigan as the Power Production Shop Chief. Captain Gaber began his commissioned service in Los Angeles with the Range and Network Systems Program Office as a Program Manager specializing in Acquisition Logistics. He moved to the 554th Electronic Systems Group where continued program management. After a deployment to Saudi Arabia to work overflight clearances for coalition aircraft, Capt Gaber returned to the 554th to become the Executive Officer. His follow-on assignment is back to Los Angeles to become the Space Vehicles Flight Chief for the Defense Meteorological Systems Program. Captain Gaber resides in Dayton, Ohio with his wife and five cats.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
03-26-2009	**Master's Thesis**	Sep 2008 - Mar 2009

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
Waste Vegetable Oil as an Alternative Fuel for Diesel Vehicles	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Gaber, Harvey S., Captain, USAF	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Street, Building 642 WPAFB OH 45433-7765	AFIT/GEM/ENS/09-01
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
ASC/QI Attn: Mr. John R. Smith 1865 4th Street DSN: 785-4539 WPAFB OH 45433-7765 e-mail: John.Smith@wpafb.af.mil	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Alternative fuels have become a hot topic in the news as the cost of oil remains volatile. Questions of whether acquiring alternative fuels are worth the cost, logistics, and political implications are being asked. A possible solution may be currently thrown away by Wright Patterson Air Force Base's (WPAFB) dining establishments in the form of waste vegetable oil (WVO). This study investigated the benefits and costs of pursuing the installation of a WVO to Straight Vegetable Oil fuel processing center and using the fuel to power some of the base's diesel vehicles. A pilot program was fielded utilizing the Wright Patterson Club for WVO and the Recycling Center for processing and use. From the pilot program, data was extrapolated to determine the total cost and payback period to operate the system. The benefits of reducing spills and emissions were also realized.

15. SUBJECT TERMS
Alternative Fuel, Straight Vegetable Oil, Vehicle Logistics

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Bradley E. Anderson, Lt Col, USAF
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
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Prescribed by ANSI Std. Z39-18