Community-based solutions for a global energy problem

Producing Biodiesel for Municipal Vehicle Fleets from Recycled Cooking Oil

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In cooperation with the

Energy Division of the Alabama Department of Economic and Community Affairs

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Executive Summary

Biodiesel is a renewable fuel alternative to traditional petroleum-based diesel fuel. Biodiesel is an attractive option for producers who would like to process their own biofuels because it can be made at a relatively small scale using vegetable oils or animal fats. A growing number of municipalities are starting recycling programs to collect and process used cooking oils or waste vegetable oils (WVO) into biodiesel that can be used in the municipal vehicle fleet. This publication provides guidance to municipal small scale fleets on making biodiesel primarily by using cooking oil that has been recycled. Discussion is provided to help the municipality evaluate how much cooking oil might be available in their community; how to develop a recycling program and process the oil into biodiesel; how to test the finished fuel product; and how to store and dispense the fuel. Locally-produced biodiesel will never be able to eliminate our nation's dependence on foreign oil. However, it offers an important opportunity for every citizen to become a participant in recycling a waste product into a useful biofuel, which will, in turn, reduce demands on our landfills and wastewater treatment systems, and stretch taxpayer dollars in challenging economic times.

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Introduction

Pure biodiesel is a biodegradable, nontoxic fuel oil that is essentially free from sulfur and aromatics. It is a renewable resource produced domestically from soybean and other oil crops that are grown each year. It can also be produced from recycled vegetable oil or animal fat, which is generally referred to as waste vegetable oil (WVO). Biodiesel is recognized as an alternative fuel and can be used in compression-ignition engines, from light to heavy duty, just like petroleum diesel. No engine modification or changes in fuel handing and delivery systems are required in order to fuel a conventional diesel engine with biodiesel, however there are different maintenance protocols related to fuel filters and fuel tank cleanliness. Biodiesel is made through a chemical process called transesterification where methanol and a catalyst are added to the oil. The process leaves behind two products – fatty acid methyl esters (the chemical name for biodiesel) and glycerin (a valuable byproduct usually sold for use in soaps and other products). Biodiesel is available nationwide and it can be purchased directly from biodiesel producers and marketers, or petroleum distributors.

Figure 1. Biodiesel produced from WVO.

Small-scale production of biodiesel is possible when an appropriate source of oil is secured, appropriate storage and processing equipment and labor are available, and an acceptable method of disposing of the glycerin byproduct is developed. Interest in small-scale production of biodiesel by municipalities has grown considerably in recent years due to high costs of fuel and due to a desire to implement programs that can prevent improper disposal of used cooking oils. Today, several municipalities in Alabama have developed and implemented recycling programs for both residential and commercial used cooking oils. After obtaining the WVO, it is processed into biodiesel that is subsequently used in municipal vehicle fleets. The cities of Daphne, Gadsden, Hoover, and Montgomery serve as excellent examples of successful programs for recycling WVO and producing biodiesel.

Cautionary Statement

The production and storage of biodiesel involves handling several chemicals that are toxic and therefore potentially dangerous. Before beginning such a program, safe chemical handling practices and all applicable codes and standards should be reviewed and followed. Any municipality evaluating a biodiesel program should consider having fleet management personnel complete courses from accredited organizations to fully understand the chemical processes and their inherent safety issues.

This report discusses some of the issues to be evaluated when municipalities consider initiating their own recycling and biodiesel production programs. Specifically, this document will highlight:

- opportunities for recycling used cooking oils and fats;
- used cooking oil recycling program concepts;
- biodiesel production basics;
- feedstock oil quality and biodiesel production;
- biodiesel quality testing; and
- a case study for the City of Gadsden, Alabama

Opportunities for Recycling Used Cooking Oils and Animal Fats

Used cooking oils and animal fats and the general set of products referred to as Waste Vegetable Oil can be an excellent feedstock for small-scale biodiesel production depending on their condition and quality attributes. Two main sources of WVO may be available in a given community: residential oils and fats, as well as and oils and fats that come from the food industry.

Residential cooking oils and fats, as the names imply, are the used cooking oils or animal fats that may be collected after cooking in the home. Frequently, this oil is placed in the municipal solid waste stream and is deposited in landfills. Unfortunately, some of the oil is poured into sinks and finds its way into the sanitary sewer system and eventually becomes a burden on the municipal wastewater treatment system.

Figure 2. WVO includes used cooking oils generated in the home as well as in the commercial food industry.

Commercial cooking oils and fats may be available from restaurants or other institutional food preparation or processing operations. ***It is important to point out that many restaurants or***

institutional food preparation operations have contracts in place with commercial vendors who pick up their oil and process it further into a commodity that is used in pet and livestock foods. Any municipality considering using cooking oil from commercial entities must be sensitive to business contracts that may be in place between the food industry and the waste oil collection enterprise.

Recent research at Auburn University (Wang et al., 2008) provided estimates for the amount of two types of processed grease which may be available in Alabama. Tables 1 and 2, show estimates for the amounts of yellow and brown grease, respectively, which may be available in Alabama. Figure 3 is a graphical depiction of yellow grease available from each county. Yellow grease is a commercial product that is the end result of processing WVO from the food industry. Since cooking oils break down after a period of use and become unsuitable for continued cooking, the waste oils must be discarded. The used cooking oils from the food industry are typically collected by commercial vendors who process it to create yellow grease. Yellow grease is a valuable commodity for the livestock, poultry, and pet food industries as well as for the cosmetic industries. Therefore, the estimates for yellow grease provide a good estimate for the amount of commercial cooking oils and fats that may be available. Brown grease is the sewer and pipe grease that is trapped and collected via waste water treatment facilities. As discussed later in this report, brown grease is not generally considered acceptable for use in biodiesel production; however, the estimated quantities of brown grease may provide a partial estimate of cooking oils and fats that are deposited into municipal waste water treatment systems.

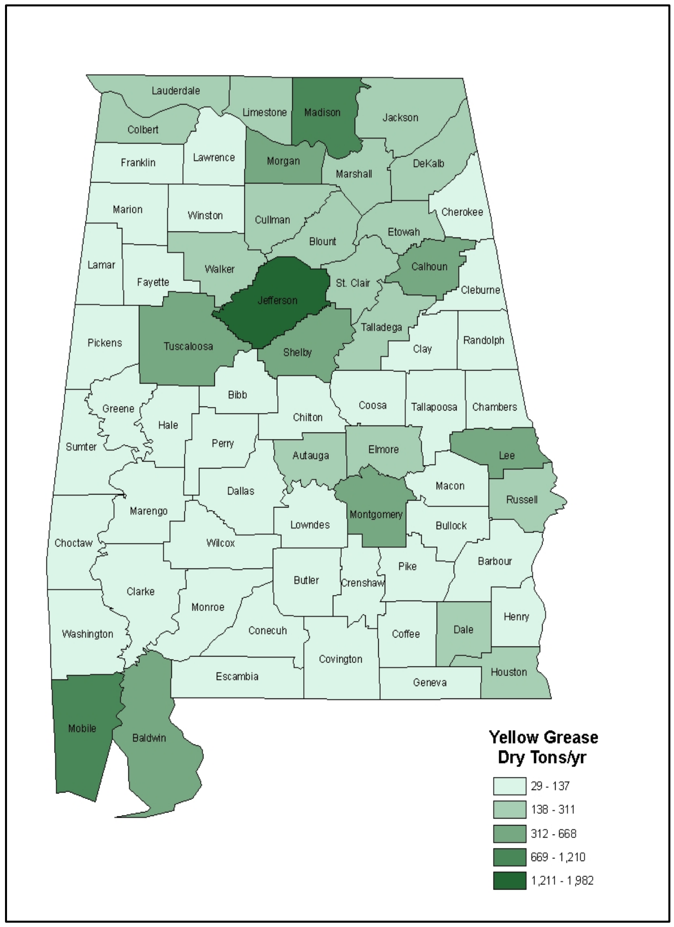

Figure 3. Graphical depiction of estimated yellow grease available annually in Alabama.

WVO can be an attractive feedstock for small-scale municipal biodiesel production, although quality can vary depending on the source of the oil or fat, cooking techniques, storage techniques, etc. The estimates reported by Wang et al. (2008) are based on methods used in the state of Washington and may result in conservative estimates (i.e. lower than what is actually available) in southern states like Alabama since Alabama's dietary preferences appear to favor more fried foods. It is important to note that these estimates do not accurately account for the amount of residential cooking oil and animal fat that may be available. Further research is needed to develop techniques to estimate the amounts of available residential cooking oil or animal fat that might be available. It is also important to remember that most of the commercially produced WVO is already being collected by commercial contractors.

The estimates of yellow grease reported by Wang et al. are a good starting point for the municipality considering recycling waste cooking oils and animal fats. These estimates were based on multiplying the county population by a factor of 6.7 lbs oil per person per year and by an additional factor of 0.9 to account for an assumed 10 percent moisture content of the oil. Overall, Wang estimates that there are approximately 13,743 tons or 3.7 million gallons of yellow grease produced each year in Alabama. Again, this estimate may be conservative due to different dietary habits in Alabama and does not include the cooking oil available from residential sources.

Table 1. Estimated yellow grease available from commercial sources in Alabama, by county. Data from Wang et al. (2008). Estimates are based on a factor of 6.7 lbs/year person and an assumed moisture content of 10%.

Gallons of oil (thousands) by Alabama county. Total gallons = 3.7 million							
Autauga	39	Conecuh	11	Houston	76	Morgan	91
Baldwin	131	Coosa	9	Jackson	43	Perry	9
Barbour	23	Covington	30	Jefferson	529	Pickens	16
Bibb	17	Crenshaw	11	Lamar	12	Pike	24
Blount	45	Cullman	64	Lauderdale	71	Randolph	18
Bullock	9	Dale	39	Lawrence	28	Russell	40
Butler	17	Dallas	36	Lee	99	Shelby	138
Calhoun	90	Dekalb	54	Limestone	57	St.Clair	58
Chambers	29	Elmore	59	Lowndes	10	Sumter	11
Cherokee	20	Escambia	31	Macon	18	Talladega	65
Chilton	34	Etowah	83	Madison	240	Tallapoosa	33
Choctaw	12	Fayette	15	Marengo	18	Tuscaloosa	136
Clarke	22	Franklin	25	Marion	24	Walker	56
Clay	11	Geneva	21	Marshall	69	Washington	14
Cleburne	12	Greene	8	Mobile	323	Wilcox	10
Coffee	37	Hale	15	Monroe	19	Winston	20
Colbert	44	Henry	13	Montgomery	178		

Table 2. Estimated brown grease available in Alabama, by county. Data from Wang et al. (2008). Estimates are based on a factor of 7.44 lbs/year person and an assumed moisture content of 10%.

Gallons of oil (thousands) by Alabama county. Total gallons = 4.1 million							
Autauga	43	Conecuh	12	Houston	84	Morgan	102
Baldwin	145	Coosa	10	Jackson	48	Perry	10
Barbour	25	Covington	33	Jefferson	587	Pickens	18
Bibb	19	Crenshaw	12	Lamar	13	Pike	26
Blount	50	Cullman	71	Lauderdale	78	Randolph	20
Bullock	10	Dale	43	Lawrence	31	Russell	44
Butler	19	Dallas	40	Lee	110	Shelby	153
Calhoun	100	Dekalb	60	Limestone	63	St.Clair	65
Chambers	32	Elmore	66	Lowndes	12	Sumter	12
Cherokee	22	Escambia	34	Macon	20	Talladega	72
Chilton	37	Etowah	92	Madison	266	Tallapoosa	36
Choctaw	13	Fayette	16	Marengo	19	Tuscaloosa	151
Clarke	24	Franklin	27	Marion	27	Walker	63
Clay	13	Geneva	23	Marshall	77	Washington	16
Cleburne	13	Greene	9	Mobile	358	Wilcox	11
Coffee	41	Hale	16	Monroe	21	Winston	22
Colbert	49	Henry	15	Montgomery	198		

Used Cooking Oil Recycling Program Concepts

Programs to recycle WVO should be developed to best suit each community and should consider factors such as: potential for use of biodiesel in municipal vehicle fleets; potential for reducing costs in the municipal sewer systems; local dietary preferences and cooking methods; local food industry characteristics; and community commitment to recycling and attributes of existing recycling programs.

Perhaps the first and greatest factor to consider before attempting to develop a biodiesel production program is the ability of the municipal fleet to accommodate such a program. A strong commitment to and ownership of the program by the fleet manager and their employees is critical to its success. Cities in Alabama that have been successful with their biodiesel production programs have the attribute of a fleet manager who initiated the program and has primary responsibility for operating it. Other considerations include: 1) does the municipal fleet have sufficient numbers of diesel powered vehicles that can be switched to biodiesel?; 2) is there sufficient labor available in the existing municipal fleet management operation or other municipal offices to operate the recycling program and to process the biodiesel?; and 3) is the municipal fleet maintenance group confident in their ability to diagnose and address any problems that might arise from use of biodiesel in their engines?

Figure 4. WVO containers placed outside a restaurant.

After insuring the commitment of the municipal fleet management group, some cities have conducted surveys to estimate the amount of cooking oils that may be available. These surveys have been targeted at either or both the commercial food sector or the general population. In the case of the commercial food sector, which usually consists mainly of local restaurants, several cities have found great interest in participation in the recycling program—enough interest that restaurants asked for decals to place on their doors or in their menus indicating that they were participating in the recycling program.

Figure 5. Collection bins used for WVO generated in the home.

The actual collection programs will vary depending on the characteristics of the municipality, but usually involve the distribution of containers to collect the used oils. For commercial entities, containers can be placed at the restaurant where oil is deposited (either 55 gallon or smaller.) These containers can be picked up by personnel from the municipality on a regular schedule or when full. Typically, a clean empty container is left at the same time a full container is picked up. Larger drums can be difficult to handle depending on the labor and equipment available to transport the oil, so 25 or 30 gallon containers are preferred. It is important to make sure that spill containment is provided under or around the oil storage container. Residential programs have involved the distribution of plastic containers (usually no more than one gallon) to citizens for collection of used cooking oils and animal fats in the home. These containers can be distributed at local stores (primarily grocery stores) and either collected at central recycling points or picked up curbside if the program can be integrated into the existing municipal recycling program. Several cities have fabricated collection bins which have been placed at local recycling points or at local businesses where citizens can drop off the full containers.

It is possible for smaller municipalities to work collaboratively with other neighboring communities to share some of the costs. This reduction in cost could be accomplished mainly by sharing the initial capital investment in the biodiesel processing equipment. The biodiesel processor could be mounted on a trailer and moved from one location to another, or multiple neighboring communities could construct a shared facility in one central location. Also, it may be possible to reduce the cost of any recycling containers and bins by teaming with another municipality to purchase or fabricate a larger quantity of the items.

A final important feature of a successful recycling program is some form of accompanying educational program. Such a program is important to communicate to citizens or restaurant workers what can and cannot be placed into the recycling containers. Also, the educational activities can help promote the recycling program by educating citizens about its beneficial effects on the municipal wastewater treatment system and the reduction in operating costs for the municipal fleet.

Biodiesel Production Basics

Biodiesel production involves several steps: (1) preparing feedstocks, (2) titration to determine amount of catalysts needed for the transesterification process (3) transesterification, (4) biodiesel and glycerol separation, and (5) methanol recovery and dry washing.

Converting vegetable oils and animal fats to biodiesel is achieved through a process known as chemical transesterification. All plant and animal oils have a similar chemical structure, consisting of triglycerides, which are compounds formed from one molecule of glycerol and three fatty acids. Fatty acids are chains of hydrocarbons that vary in carbon content depending on the source of the oil or fat. Chemical transesterification of oils and fats, which was originally used to make soaps, involves the reaction of oils with an alcohol in the presence of a catalyst to produce Fatty Acid Methyl Esters and glycerol. The Fatty Acid Methyl Esters, also known as biodiesel, can be burned in a diesel engine just like petroleum-based diesel fuel.

The typical biodiesel reaction is described by:

5 parts of vegetable oil or fat + 1 part methanol = 5 parts of biodiesel + 1 part glycerol

Figure 6. Commercially-available biodiesel processor shown with WVO storage tank in background.

Chemical Safety Considerations. Fleet managers producing biodiesel should be familiar with the Material Safety Data Sheet (MSDS) for each chemical used in the biodiesel production process. The MSDSs should be provided by the chemical vendors or can be found in on-line databases. When handling chemicals, it is important to always wear proper personal protection equipment (PPE) such as protective gloves, a mask, an apron, and eye protection. Workers should also guard against inhaling vapors. The workspace should be thoroughly ventilated, provided with a supply of tap water, and equipped with emergency eye wash units, emergency showers, and appropriate fire suppression equipment. Safe working practices would suggest having at least two workers present when mixing chemicals.

Workers should exercise caution when handling methanol and methanol-catalyst mixes (methoxide). Methoxide is very caustic and can result in chemical burns. Methanol is a poisonous chemical that can cause blindness. It can be absorbed directly through the skin or inhaled as a vapor. For detailed safety instructions on methanol use, please refer to safety guidelines provided by chemical suppliers. Local and state code officials should be consulted for any special permitting issues related to storage, handling, and use of methanol.

Preparing Feedstocks. Prior to biodiesel production, used WVO is collected from restaurants and households, brought to a central holding facility and then filtered to remove any food debris in the oil. During cold weather, the WVO may need to be warmed to allow it to flow easily. Different techniques can be used for storage and filtration. In general, the oil is stored long enough (one to two weeks) to allow food particles to settle to the bottom of a storage container and then the oil near the top of the container (with lower concentration of solids) is pumped through a filter and into the biodiesel processor. Typical filtration is done using 250 to 400 micron filters. Recycled cooking oil and animal fat is also rich in water. At some point, either in storage, or in the biodiesel processor, the oil will be heated to remove water.

Figure 7. Chemical storage tote used for storage of WVO before processing into biodiesel.

In the bulk storage tank shown here, WVO is pumped into the tank and solids are allowed to settle. The WVO is then pumped from the top through a filter into the biodiesel processor. (Note the spill containment under the bulk tank, the 55 gallon drums, and the biodiesel processor.)

Titration. The transesterification process usually relies on a base, sodium hydroxide (lye), to act as a catalyst to cause the exchange of glycerin for methanol molecules. Before processing the oil to convert it to biodiesel, it is critical to determine the amount of catalyst required for transesterification. A chemical titration is performed on the oil to determine its free fatty acid (FFA) content and in turn, determine the amount of catalyst needed in the transesterification reaction. References such as Kemp (2006) provide details on titration of the feedstock oil.

Transesterification. To complete the transesterification process, several commercial small-scale biodiesel processing systems are available for purchase. While it is entirely possible for a municipality to fabricate their own biodiesel processor, it appears that most would prefer to purchase one of the commercially available units.

During the transesterification reaction, 5 parts of cooking oil are mixed with 1 part of methanol in the presence of sodium hydroxide catalyst. Different processors have different features and protocols for how the methanol and lye are mixed, etc.; however, the basic steps are the same. In general, the process of mixing the oil and the methanol-lye mixture takes about 1 hour to allow the chemical reaction to proceed to completion. Once the reaction is complete, the mixture will be allowed to sit two to 24 hours (depending on the processor) during which time biodiesel and glycerin will separate due to differences in their specific gravities. Since the glycerin and unreacted catalyst are heavier than the biodiesel, they will sink to the bottom of the reactor vessel they can be easily drained, leaving what some refer to as “raw” biodiesel.

Figure 8. Commercially-available biodiesel processor. Transesterification reactor vessel shown on the left with storage, dry-wash vessel shown on right.

Final Biodiesel Processing. Raw biodiesel contains a small amount of unused catalyst and methanol, as well as suspended glycerin. The suspended glycerin can clog fuel filters and affect fuel injector spray patterns. Also, "raw" biodiesel can have high pH, due to unreacted catalyst, and unreacted methanol which can corrode fuel system components and degrade fuel system seals and hoses.

Glycerin, methanol, and the catalyst can be removed by various "washing" methods depending on the biodiesel processing unit. Many older biodiesel processors use a water wash method of misting water into the raw biodiesel. The water droplets have a higher specific gravity than biodiesel and therefore fall to the bottom of the tank holding the biodiesel, absorbing any free glycerin and unused catalyst as they fall. After several washing periods, the wash water can be drained for further processing before disposal (wash water is considered toxic and must be treated before disposal.) Some of the newer biodiesel processors use a "dry wash" technique by employing an Amberlite® resin to remove the unused catalyst and the remaining glycerin. The benefit of this dry wash is that it does not require any water for washing. A small amount of methanol is also recovered during the process. Washing and methanol recovery could take several hours.

After washing, some biodiesel processors will dry the biodiesel by heating it or blowing hot air through it. This process can remove excess water from the fuel, improve its oxidative stability for storage, and reduce the tendency for microbial growth during storage. The finished biodiesel is usually pumped through a 5 micron filter (more restrictive than most vehicle fuel filters) into a storage tank.

Glycerin disposal. Glycerin, a byproduct, contains catalyst and soap, and in large scale production, it is neutralized by an acid and sent to storage. The reaction between a base and an acid produces salt, which can be recovered to use as a fertilizer or left in the crude glycerin. In some cases, methanol and water are removed to produce 80-88% crude glycerin. In a sophisticated operation, glycerin is distilled to produce 99% purity or higher and can be sold for use in cosmetics and/or for pharmaceutical use. In municipal biodiesel production facilities, one common method for disposing of crude glycerin has been composting it for use as a fertilizer amendment. Care must be taken before attempting a composting program since the glycerin may contain unused methanol. It is important to note that composting is not necessarily an acceptable process in all states or municipalities. Consult with local environmental officials before composting glycerin.

Biodiesel storage and blending. Finished biodiesel can be stored as other petroleum-based diesel fuel in approved fuel storage tanks with appropriate spill containment. The main concerns for storage are water absorption into biodiesel, sediments, bacterial growth in biodiesel, and contamination from old fuel in storage tanks. The biodiesel industry recommends against storing the biodiesel for more than six months before use.

Biodiesel is rarely used as a 100% biodiesel fuel (or B100). Usually, biodiesel is blended with petroleum-based diesel fuel for use. For example, a B10 blend consists of 10% biodiesel and 90% petroleum-base diesel fuel. Different engine, equipment, and vehicle manufacturers provide recommendations on biodiesel blends. Each fleet manager should study these recommendations and consult with their equipment suppliers to make an informed decision on what blend of biodiesel to use in their fleet.

Feedstock Oil Quality and Biodiesel Production

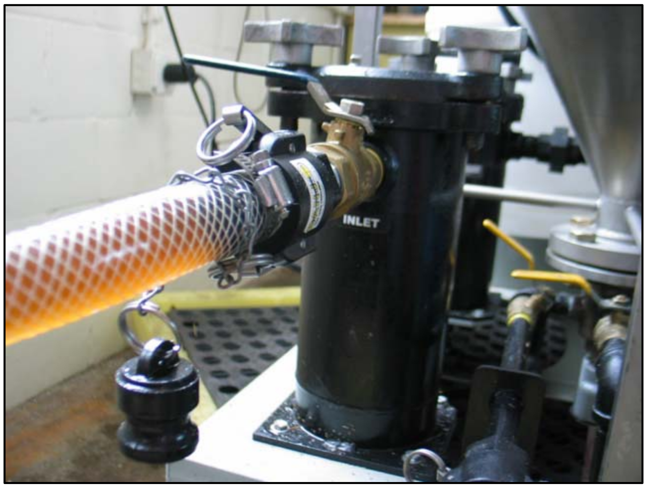

Figure 9. WVO supply line to 400 micron filter.

The quality of oil used to produce biodiesel can affect final characteristics of biodiesel. Special attention is required when the biodiesel is produced from low quality feedstocks such as animal fat, recycled cooking waste oil, trap and yellow grease. As discussed previously, if WVO is used, the oil must be filtered to remove any debris. If there is excess water, it has to be removed prior to transesterification. If oil used for biodiesel production contains relatively high levels of free fatty acids, the free fatty acids in the oil will react with the alkaline catalyst to form soaps. This is undesirable because soap binds the catalyst and impedes the reaction that forms biodiesel. Furthermore, soap acts as an emulsifier which makes it difficult to separate the biodiesel from glycerol at the conclusion of the transesterification reaction.

R-OH (FFA) + KOH (catalyst) >> K-OR (soap) + H_2O

Since various feedstocks may be used in biodiesel production, FFA composition can vary significantly as shown in Table 3. Animal fats and recycled cooking oils have much higher levels of free fatty acids than refined or crude vegetable oils that have not been use for cooking. Yellow grease typically contains 15% free fatty acids. Trap greases can contain between 50 and 100% free fatty acids, which is why this is not a suitable feedstock for biodiesel production.

Table 3. Free Fatty Acid contents of various potential biodiesel feedstocks from Van Gerpen (2001).

Biodiesel Feedstock	Free Fatty Acid Content
Refined Vegetable oil	<0.05%
Crude vegetable oil	0.3-0.7%
Restaurant waste grease	2-7%
Animal fat	5-30%
Trap grease	40-100%

The maximum amount of FFA acceptable for base catalyzed transesterification is less than 2%, preferably less than 1%. If the FFA level is less than 0.5%, the issue of soap formation can be ignored. If the oil contains higher FFA, further pretreatment is necessary before starting the transesterification process. One approach would be to use more catalyst and let the FFA react to form soap and then separate the soap using a centrifuge.

The accurate amount of catalysts for transesterification can be determined by following the titration methods discussed earlier. However, the water formation during saphonication can still pose a problem. When water is present, especially at high temperatures, it can hydrolyze the triglycerides to diglycerides and form a free fatty acid.

Triglyceride + water >> Diglyceride + Fatty acid

Biodiesel Quality Testing

Biodiesel that will be blended with diesel fuel or used a substitute for diesel should meet ASTM standard D6751-08 (ASTM, 2008), which includes the specific standards listed in Table 4. Testing biodiesel for compliance with ASTM standards can be done by commercial fuel testing laboratories. It is advisable to conduct periodic full tests of the biodiesel produced using small-scale units in the municipal facility. These full ASTM tests should be performed at least twice per year to fully verify the performance of the biodiesel processing equipment.

Water and sediment content, flash point, sulfated ash content, and total glycerin content are the most critical tests to conduct to insure proper fuel quality. Water and sediment content is a measure of the cleaniness of biodiesel. It is important because water can react with esters and produce FFA in the biodiesel. The presence of water can support algae growth during storage which then clog filters. Residual methanol in the fuel can affect seals and elastomers in the engine and also erode metal components. The residual methanol in the biodiesel can also make the fuel product dangerous to store and handle. The sulfated ash test will give an indication of the presence of some metals from unused catalysts in the biodiesel. If not recovered fully, these metals may damage the engine. Total glycerin content tests measure free and bound glycerin. Bound glycerin is the portion of 'mono', 'di' and triglyceride molecules in the oil. Elevated numbers of triglycerides are an indication of an incomplete reaction during transesterification.

Table 4. Applicable ASTM standards for biodiesel testing.

Parameter	**Testing for**	**Engine problem**	**Official test method**
Overall biodiesel test standard			ASTM D6751
Residual Glycerin	Free and total glycerin	Injector coking, filter plugging, shortened shelf life, sediment formation,	ASTM D6584 (Gas chromatography)
Residual Catalyst	Sulfated Ash	Injector plugging, filter plugging, ring wear issues with lubricant	ASTM D874 (gravimetric)
Residual alcohol	Flash point or % methanol	Degrades some plastics and elastomers, corrosive, can lower flashpoint (fire safety)	ASTM D93 (Pensky-Martens Closed Cup Tester)
FFA	Acid number	Poor cold flow properties, deposits on injectors and in cylinders	ASTM D664 potentiometric titration
Water and Sediment		Accelerated oxidation, filter plugging	ASTM D2709 (centrifuge)
Cloud point		Reduced fuel flow in cold climates	ASTM D2500 (visual test)
Bacterial growth (in storage tanks)		Clogs filters, deteriorates fuel	ASTM D6974-04 (membrane filter)

Testing the fuel can be daunting for small-scale biodiesel operations, such as municipal producers. However, there are several relatively simple testing methods on the market to make sure that the product could potentially pass ASTM standards. Nonetheless, these methods cannot replace ASTM testing protocols and most of the procedures are qualitative rather than quantitative. Crude methods that are available in the market are pHLip test, Fleet Biodiesel test, Wilks Infraspec, 3/27 test and i-SPEC Q-100 handheld analyzer. This is not an exhaustive list and their mention here does not imply endorsement by Auburn University or the Alabama Department of Economic and Community Affairs.

pHLip Test. The pHLip test can be used as a quick check in the field for detecting traces of catalyst, mono/di/triglycerides, soaps, acids and oxidized (aged) fuel for 100% biodiesel. This test does not require any technical expertise and takes about 10 minutes. The test can be performed by simply adding B100 to a test vial, mixing the biodiesel with salts supplied in the test kit, and allowing the mixture to create two distinct phases. The quality of fuel is measured by visual inspection. Glycerides and oxidized fuel are seen as concentrations at the biodiesel-glycerin interface whereas fatty acids, triglycerides, and soap are seen as turbidity. This process serves as a rapid go/no-go test but does not replace lab testing for ASTM standards.

Fleet Biodiesel Test. Fleet biodiesel Inc. has developed test kits that can be used to provide immediate indicators of fuel quality. The kits are designed for use with all blends of fuel from B2 through B100. Kits are available for total glycerin, water, microbial contamination, and acid number tests.

Wilks Infraspec. This infrared instrument can help to determine total glycerin content of the finished biodiesel. This instrument also has been used to determine the blend percentage.

The 3/27 Test. This is a very basic test and can be performed on washed or unwashed fuel and does not require any special expertise. This process works on the basis that biodiesel dissolves in methanol whereas triglycerides do not dissolve in methanol. In this process, 3 mL of biodiesel are mixed in 27 mL of methanol and shaken for a few seconds. If the biodiesel completely dissolves and no oil settles at the bottom of the container, it can be assumed that the transesterification reaction achieved a high conversion efficiency. A failing sample often appears as cloudiness or as a pool of unreacted feedstock.

Water Analysis. This method can be used to quantify the amount of water in the feedstock and biodiesel. The test marketed by Utah Biodiesel Supply works by reacting water in biodiesel with a reacting agent such as calcium hydrate. The reagent converts the water to hydrogen gas which increases the pressure inside a sealed container. The increase in pressure inside the container is correlated to the percentage of water in the sample.

A Case Study of Municipal Biodiesel Production: Gadsden, Alabama

Figure 10. One gallon residential WVO container used by Gadsden, Alabama.

The City of Gadsden, Alabama initiated a WVO recycling program and biodiesel production program in the fall of 2007. Like many similar municipalities, they were faced with soaring fuel costs. They were also faced with another common problem of municipalities: high maintenance costs in their wastewater treatment system due to grease that had been introduced into sewers from households and restaurants. After expressing their intention to start a WVO recycling and biodiesel production program, the city was designated as an Auburn University Energy Partner. In this relationship, personnel from the City of Gadsden municipal fleet worked together with personnel from Auburn University's Center for Bioenergy and Bioproducts and the Alabama Cooperative Extension System to establish the biodiesel production system. The City of Gadsden is currently recycling used cooking oils that are available from local restaurants and households to produce biodiesel, thereby minimizing fleet fuel expenditures and wastewater treatment system maintenance. Additional financial support for this program was provided by the Energy Division of the Alabama Department of Economic and Community Affairs.

Program initiation. At the start of the program, the biodiesel processing equipment and associated oil collection and processing equipment were procured by Gadsden fleet management personnel. This equipment included the following major items:

- biodiesel processor capable of producing 55 gallon batches of biodiesel (manufactured by Biodiesel Logic, Inc.);
- 4 – 275 gallon chemical storage "totes" for storing WVO before processing;
- 2 – 150 gallon fuel tanks, pumps, and meters for storing and dispensing finished biodiesel;
- 20 – 55 gallon steel drums for WVO collection at restaurants;
- 4500 – 1 gallon plastic jugs for residential WVO collection;
- 7 – collection bins for residential WVO jugs;

- Miscellaneous lab supplies for titration of WVO; and
- Expendable supplies for biodiesel production (methanol, sodium hydroxide catalyst)

The collection bins for residential WVO jugs were fabricated internally by personnel in the fleet management group in Gadsden. Other municipalities have purchased similar commercially available units. The one gallon jugs were fitted with preprinted labels that have information on procedures for recycling the WVO.

After the system was configured and ready for rollout, a public media event was held at the municipal fleet facility to publicize the start of the program. At this event, political leaders, fleet management personnel, and Auburn University personnel spoke to local media outlets about the program and the basics of producing biodiesel. Education and public awareness are keys to a successful recycling program. As a separate activity, fleet management personnel made contact with local restaurants to inform them of the new program to recycle WVO. In these visits, the fleet representatives stressed the importance of not violating any contracts with commercial enterprises that pick up and process WVO.

Figure 11. WVO containers placed at restaurants.

Program operation. As the program started, 55 gallon drums were distributed to participating restaurants. Fleet management personnel checked the drums once each week, and generally picked them up when the drum contained about 35 gallons, or every other week, whichever came first. A clean drum was left at the restaurant when the full drum was picked up.

Figure 12. Storage bins fabricated for residential WVO collection.

The residential WVO jugs were placed in the storage bins, which were located at seven community centers in Gadsden. While other cities have chosen to place the collection bins at grocery stores, Gadsden chose to use their network of community centers. The bins are configured so that empty, clean containers are placed on the top shelf, while full containers are placed on the bottom shelf. Also, the bins are designed so that larger containers of WVO (such as those two gallon containers used for turkey frying, etc.) can be placed on the bottom shelf.

Once the oil is picked up and transported to the fleet management facility, it is poured (in the case of the one gallon jugs) or pumped (in the case of the 55 gallon drums) into the chemical storage totes. If water is detected in the WVO, the oil is heated and then allowed to cool to separate the water from the oil. Since there are several of these 275-gallon totes, there is a rotating procedure where the oil is allowed to settle for nearly one week before being used for biodiesel production. The WVO is pumped from the top portion of the tank through a filter and into the biodiesel processor.

Figure 13. Biodiesel Logic, Inc. BDL-55-PPS processor used in Gadsden.

After the oil is pumped into the biodiesel processor, minimal labor is required by the fleet management personnel to perform the transesterification process. The Biodiesel Logic unit is a relatively self-sufficient processor that will conduct most of the transesterification process automatically. Before starting the transesterification reaction, the WVO is heated to 140^{o}F and a sample of oil is removed for the titration procedure, in order to determine how much catalyst is is required for biodiesel production. After the titration process is complete, methanol is added to a separate methanol tank and the catalyst is then poured into a methyl/oxide mixer drum. After starting the reaction process, it will take approximately 1.5 hours for glycerin to begin separating from the biodiesel and another 1.5 to 2 hours for the glycerin to be completely separated. The Biodiesel Logic system uses a dry wash process that requires another 3 hours to complete. After being allowed to cool, the finished biodiesel can then be filtered through a 5 micron filter, and pumped into the fuel storage tank. Biodiesel is splash blended with petroleum-based diesel to create blends of B10 or B20 for various fleet vehicles or machines.

Glycerin that results from the process is drained from the reactor vessel into a clean 55 gallon drum for later disposal. Disposal options used have included composting and transferring to a nearby business that manufactures soaps.

Program results. At the time of publication of this report, the Gadsden program has operated for over one year. During this one year of operation, approximately 2000 gallons of biodiesel have been successfully produced. The fleet manager reports that much more fuel could be produced (as much as one 55 gallon batch each day) if more WVO was available in the community. The fleet manager indicated that the collection and processing operations do not place any undue burden on fleet personnel.

Of the 2000 gallons of WVO collected, approximately 80% of the WVO has been collected from restaurants and other food industries while 20% has been collected from residential sources. The restaurant program has served approximately 10 restaurants during this period and most of these were either new businesses or relatively small businesses that did not have existing contracts with WVO processors. The residential program has been successful; however, the fleet manager reports that there is a continuing need to educate the public on the opportunity to recycle their WVO. The mayor and fleet manager both give presentations to civic groups and take the one gallon jugs with them to pass out to citizens. Also, local news media have been very willing to mention the program periodically. The fleet manager reports that any mention of the program in the media results in an increase in oil collected at the community center bins.

The fleet does not conduct a formal fuel testing program, but has had no vehicle maintenance problems since initiating the program. They do conduct periodic fuel tank cleaning to prevent algae growth. Also, they will conduct the 3/27 test periodically to determine if there is any unreacted WVO in the biodiesel. The only problems they report have been with excess water in the WVO. This appears to have been the result of leaving the tops off of the 55 gallon drums while at the restaurants. Heating the WVO has been a successful method of removing water from the oil.

Figure 14. City of Gadsden fleet vehicle operated on biodiesel and used to collect WVO.

Handling the glycerin byproduct has also been successful. While initial phases of the program composted the glycerin, the city has now developed a relationship with a nearby company that produces industrial soaps. This business comes to the fleet maintenance facility and picks up the glycerin for further processing, thereby alleviating the need to dispose of the glycerin.

The costs of the program also have been quite satisfactory for the municipality. The initial cost of the system (biodiesel processor, storage tanks and bins, and WVO drums and jugs) was approximately \$ 28,750. If this fixed cost is spread over a five year period, accounting for depreciation, and if 13,750 gallons of fuel could be produced per year when the program is fully operational, this results in a fixed cost of \$ 0.33 per gallon of biodiesel. Changing the production rate higher or lower will either lower or raise, respectively, the cost per gallon. The variable costs (methanol, sodium hydroxide, amberlite resin, and electricity) are listed in Table 5 and result in $ 1.09 per gallon of biodiesel. Therefore, a total cost of producing the fuel could be approximately $ 1.42 per gallon at the production rate of 13,750 gallons per year.

Table 5. Variable costs of biodiesel production.

Ingredient	**Cost**	**Cost, $/gal biodiesel**
Methanol	$3.43 /gal	0.69
Sodium Hydroxide	$0.36 /lb	0.02
WVO	$0.00/gal	0.0
Amberlite	$10.5 /lb	0.04
Electricity cost	$0.14 /kWh	0.34
Total cost		**$ 1.09 / gal**

Overall, the fleet manager, mayor, and city council have been very happy with the program. Benefits from this program include fuel and cost savings to the city (and taxpayers), improved air quality from using the biodiesel, and reduced sewer maintenance costs. The fleet manager is strongly committed to continuing and expanding the program into the future. For additional information in a video format, visit http://farmenergy.blogspot.com/.

Concluding Remarks

Small-scale production of biodiesel by municipalities has been conducted successfully by several cities in Alabama and appears to be a concept that can be successfully duplicated in other municipalities across the state and nation. These programs use recycled WVO as their primary feedstock for biodiesel. The WVO can be obtained from the food service industry or from local citizens.

By using commercially available biodiesel processors and relatively simple oil collection and storage equipment, the municipal fleet management team can produce high quality biodiesel for use in municipal vehicles and equipment. While there are technical challenges to overcome in any such program, challenges such as WVO quality assurance, fuel quality assurance, and glycerin disposal have all been successfully overcome by municipal fleet operators.

The most important aspect of these programs is the successful involvement of local businesses and citizens in creating a community-based recycling and biofuel production program. Such programs alone will not solve our nation's energy security problem; however, they can build community awareness for environmental protection and its relation with the production of renewable biofuels. In short, these programs allow the local citizen to have a part in producing renewable fuels in their own community.

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Van Gerpen, J. 2001. Biodiesel production and fuel quality. University of Idaho internal report. http://www.uiweb.uidaho.edu/bioenergy/biodieselED/publication/01.pdf

Wang, Y., L. Teeter, K. Muehlenfeld, L. Samuelson, S. Taylor. 2008. Biomass inventory for Alabama. Draft report by the Auburn University Natural Resources Management & Development Institute and Center for Bioenergy and Bioproducts.

Additional Information on Biodiesel Production or Bioenergy

National Biodiesel Board: http://www.biodiesel.org/

Auburn University Natural Resources Management & Development Institute: http://www.nrmdi.auburn.edu/

Alabama Department of Economic and Community Affairs, Energy Division: http://adeca.alabama.gov/Energy/default.aspx

Alabama Department of Agriculture and Industries, Center for Alternative Fuels: http://www.agi.state.al.us/alternative_fuels

Alabama Clean Fuels Coalition: http://www.alabamacleanfuels.org/

Information on Biodiesel Testing

Fleet Biodiesel Testing: http://www.fleetbiodiesel.com/

Wilks Infraspec Analyzer: http://www.wilksir.com/vfa-spectrometer.htm

3/27 Biodiesel test: www.biolyle.com/docs/gc_3_27pass_fail.doc

Biodiesel water test: www.utahbiodieselsupply.com/biodieselwatertestkit.php

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Disclaimer

This report discusses considerations for municipalities interested in implementing WVO recycling programs and small-scale biodiesel production systems. This type of program is not meant to be a replacement for or a competitor to commercial distributors or retailers of biodiesel. For large-scale fleet use of biodiesel, any organization should consult with commercial producers and distributors of biodiesel.

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