SAFETY GEAR SUMMARY

The following gear should be on hand each time you produce biodiesel:

- Chemical-resistant gloves (butyl rubber is best for methanol and lye)
- Chemistry goggles (indirect vented) and face shield
- Dust mask or cartridge respirator
- Eyewash bottle with saline solution
- Small spray bottle with vinegar for neutralizing lye spills
- Access to running water
- Telephone in case of emergency and emergency telephone numbers
- Fire extinguishers (ABC or CO₂)
- Absorbent material and spill-containment supplies
**INTRODUCTION**

This publication addresses processing and safety issues associated with making biodiesel fuel. Biodiesel is a clean, renewable fuel that can be made from various biomass oil feedstocks such as waste vegetable oil, yellow grease, animal fats, and virgin vegetable oils. Small-scale biodiesel production has been growing due to higher fuel prices, a desire for energy independence, and interest in environmentally friendly renewable fuel production.

Although the biodiesel manufacturing process is fairly straightforward, there are several aspects of biodiesel production that need careful attention to detail for a productive, safe, and environmentally sound practice. First, some chemicals used could pose serious risks to the operator or to the environment, unless the proper precautions are taken for storage, process safety, handling, ventilation, and use. Second, disposal of glycerol by-product and waste water generated from biodiesel production could cause environmental harm, unless approved practices are used. Finally, operators need to pay close attention to the quality of the biodiesel produced and proper storage to avoid costly engine problems or excessive emissions during use.

Most enthusiastic newcomers to biodiesel production will find that successfully running a safe and responsible operation is not as easy as it looks. Production of biodiesel on a small-scale carries inherent risks, and careless producers are likely to have mishaps. While the obvious goal of all producers should be to minimize mistakes, it is also important to know how to deal with these mistakes and respond appropriately. Knowledge, attention to safety, and advanced planning are the best approaches to preventing serious accidents.

The objective of this publication is to review some of the accepted practices associated with small-scale biodiesel production to make it a safe, environmentally sound practice that generates a quality product. Prospective biodiesel producers are also encouraged to use this information as they decide whether or not to begin making biodiesel. For the preparation of this document, we have solicited input from a variety of experts including chemists, agronomists, environmental engineers, regulators, and educators in the field of small-scale biodiesel production and use. Please note that this booklet provides references to state regulations for Pennsylvania; biodiesel producers in other states are encouraged to check with their state regulators to ensure that they are in compliance with all regulations. A glossary is provided at the end of the booklet which defines terms used throughout the publication.

**FUEL OPTIONS FROM BIOMASS OIL FEEDSTOCKS**

While early diesel engines demonstrated an ability to run on crude plant-based oils, modern diesel fuel systems are designed for efficiency and low engine emissions and burn fuels of a relatively low viscosity. At average fuel tank temperatures, unconverted vegetable oils are too viscous (too thick) to properly burn in modern diesel engines (especially those with common rail fuel injection systems). Those who wish to run their diesel equipment on raw vegetable oil, used cooking oils, animal fats, or fuels derived from these have the following options: (1) convert the oil to biodiesel, or (2) convert the diesel’s fuel system to run heated oils as illustrated below (Figure 1).

**NOTE:** For simplicity, the general term “vegetable oils” is used and includes virgin vegetable oils, used cooking oil, and rendered animal fats. Some researchers have experimented with blending unconverted vegetable oils into diesel fuel as a fuel additive or extender. While some diesels may tolerate low percentage (5 percent) blends of vegetable oil in diesel, this information is engine-specific, and higher-percentage blends are not advised. In a different approach, some commercially available products promote blending used cooking oils with unleaded gasoline and additives to reduce the viscosity. This practice is not recommended by the authors of this booklet. Numerous studies by the Department of Energy and others have demonstrated that the use of high-viscosity unconverted oils at levels as low as 10 percent may cause engine wear, injector deposit formation, and premature engine failure. Anecdotal reports by diesel service personnel also report several cases of problems with injector pumps and other parts linked to the use of high-percentage blends of unconverted vegetable oils with diesel fuel. Engine manufacturers may not honor warranties if raw oils or any other fuel products not meeting fuel quality specifications are used as fuel.

**FIGURE 1**

![Diagram of biodiesel production process](image-url)
Biodiesel—Converting the Oil

Biodiesel fuel must not be confused with crude, untransesterified vegetable oil. Transesterification is a chemical reaction where certain oil molecules react with alcohol in the presence of a base catalyst such as lye. This somewhat-reversible reaction results in alkyl esters, also known as biodiesel, and a crude glycerol byproduct. The American Society for Testing and Materials (ASTM), a consensus organization of users, producers, and manufacturers, clearly specifies fuel quality standards for biodiesel.

Some people call biodiesel “biodiesel” and “biofuels” interchangeably. In certain regions of the United State, soy-diesel refers to crude soybean oil that is filtered and may be clarified, while in other regions, both terms refer to biodiesel fuel that has been properly processed (transesterified) from soybean oil. In industry literature, FAME is an acronym that is often used for Fatty Acid Methyl Esters (biodiesel). In this document, biodiesel will refer only to transesterified oil from a variety of feedstocks.

Biodiesel fuel can be burned in any diesel engine without major modifications to the equipment. Biodiesel blends readily with petroleum diesel. Fuel blends are referred to by the percentage of biodiesel in the mix (e.g., B20 is 20 percent biodiesel). Biodiesel fuel can also be blended with diesel fuel oil for use in heating appliances. Those who own diesel equipment under warranty are advised to check with their manufacturers regarding recommended percentage limits for biodiesel blends. Manufacturers require that any biodiesel fuels used meet the ASTM D6751 specifications for valid warranty.

“Straight Vegetable Oil”—Converting the Diesel Equipment

The option known as straight vegetable oil (SVO) conversion requires altering the fuel system of the diesel engine to heat the vegetable oil, thereby reducing its viscosity. There are a number of commercially available kits, as well as homemade conversions, most of which function on the same basic principles. This approach is described in Appendix A, but research is ongoing to review potential engine problems and environmental concerns (increased emissions). Although this booklet describes safety and environmental issues pertaining to small-scale biodiesel production and use, some of the regulations and safety information will be useful to SVO system users.

Both biodiesel and SVO systems begin with vegetable oil. In the case of biodiesel, the oil is modified to suit the engine. In the case of SVO, the fuel system of the engine is modified to suit the oil.


Transitional Biodiesel

Whenever switching to biodiesel or a biodiesel blend in an engine or storage tank that had been running on petroleum diesel, it is recommended to monitor or change filter elements on a more frequent basis at least for the first six months after the transition. Biodiesel is an excellent solvent and, as such, it will readily dissolve many of the deposits in a diesel engine, fuel injection, fuel supply lines, and storage tanks that have accumulated over the years of engine operation with petroleum diesel. Continue changing fuel filters on an as-needed basis until the system has been cleaned of the deposits. When high percentage blends of biodiesel are used in road vehicles, it is wise to carry a spare fuel filter and the tools and knowledge to change it on the road.

Fuel Storage

Most of the standard storage and handling procedures used for petroleum diesel can also be used for biodiesel. The fuel should be stored in a clean, dry, dark environment. Recommended maximum biodiesel fuel storage tanks include aluminum, steel, polyethylene, polypropylene, and Teflon, but not concrete-lined storage tanks. If possible, the storage tank should not include any copper, brass, lead, tin, zinc, or rubber fittings if possible (practically speaking, brass ball valves are used with many no major ill effect). Since biodiesel is an organic liquid, the use of an algicide or fungicide additive is recommended whenever the fuel is stored during warm weather. Storage time for biodiesel and petroleum diesel should be limited to six months for best performance. Refer to the sections covering Regulatory Issues and Storage Issues for information on regulations that apply to storage tanks.

Biodiesel in Vehicles/Machinery

Burning ASTM 6751 biodiesel is a recommended, accepted practice consistent with many engine warranty agreements. As discussed earlier in this booklet, the biodiesel that you produce may not meet this standard. Marginal-quality biodiesel may eventually affect engine emissions, longevity, and performance.

Biodiesel can be blended with petroleum diesel fuel in blends up to 20 percent (B20) with relatively few risks. Penn State is doing longterm studies with tractors using B100 (100 percent) biodiesel. The potential for problems with using B100 is expected to include the rubber seals and hoses in the fuel system. As mentioned above, biodiesel is a better solvent than petroleum diesel and may soften or dissolve rubber parts, especially older formulations of rubber. Replacing old rubber lines with newly manufactured rubber is one way to solve biodiesel is a good solvent, it is necessary to quickly wipe any biodiesel spills from painted surfaces to avoid paint removal.

Biodiesel can also be used in residential oil furnaces or boilers, especially if it is blended with petroleum fuel oil. The same issues that apply to vehicle tanks and storage tanks apply here—the deposits in the bottom of the fuel tank are the same as for the addition of biodiesel. It is recommended to start with a low concentration of biodiesel relative to petroleum diesel, changing the fuel filter more frequently to ensure that any dissolved tank-bottom sludge is captured by the fuel filter. Fuel pump seals that are made of rubber will have the same issues of degradation that vehicles and machinery will, particularly at higher blends. Biodiesel should be blended with petroleum diesel prior to filling the fuel tank to ensure adequate mixing. If this is not practical, at a minimum the biodiesel should be added to the tank after the petroleum fuel, as it is slightly denser and some blending will occur as it settles to the bottom of the tank. Since biodiesel burns with a cleaner flame than heating oil, it may confound flame-sensing components in heating appliances. Users who wish to experiment with high-percentage blends are advised to consult a professional heating contractor before doing so. See the References section for more information.

Cold-Temperature Issues

Biodiesel and its blends with petroleum diesel will cloud and gel at higher temperatures than normal winterized petroleum diesel fuel. As temperatures drop, wax-like crystals form in the fuel. These crystals will potentially clog fuel filters or fuel-line inlet screens, causing stalls or failure to start. Plugged fuel filters may strain injection pumps, possibly reducing the longevity of these expensive components. Users are advised to prepare for cold temperatures in advance in order to avoid vehicle and equipment problems associated with cloudy or solidified fuel. The petroleum diesel used in cold climates should be winterized diesel fuel.

A fuel’s cloud point (CP) is the temperature at which it first begins to appear cloudy, as crystals start to form. The pour point (PP) is the minimum temperature at which the fuel can be considered a liquid—below this temperature the fuel will be fully gelled. The cold filter plugging point (CFFP) is usually closely related to the cloud point, thus testing for cloud point may be the most practical way to predict a fuel’s winter performance. Commercial fuel producers are required to notify customers of a given fuel’s pour characteristics, and small-scale producers are advised to be aware of pour points in the biodiesel they produce. The recent introduction of ultra-low sulfur fuel (ULSF) makes this more important, since early indications are the high ULSF can also contribute to the low temperature problem.

Cloud point and pour point of biodiesel will vary according to feedstock. Of the vegetable oils commonly available in the U.S., canola oil is the best for producing winterized diesel fuel, with a cloud point of 20 to 30 degree range (F). Soy biodiesel typically clouds around 32 degrees Fahrenheit (0 degree Celsius). Biodiesel made from animal fats, tallow, or hydrogenated (creamy) vegetable oils will cloud and gel at temperatures above freezing, and thus these fuels perform best in southern regions or summertime.

Freezer Test

Small producers who use oils from multiple sources are advised to test each batch of biodiesel fuel for cold weather performance. A simple test using jars, a freezer, and a thermostat is effective to determine proper winter blending rates. Blends of biodiesel and winterized petroleum diesel fuel of varying proportions (e.g., B10, B20, B50) are made up in small jars and then placed in the freezer. By frequently checking the temperature of each jar, a producer can roughly determine the temperature at which clouding and gelling will occur for each blend. Knowing the expected low temperature, users can then predict which blend will be trouble free. Extreme care must be taken not to spill diesel or biodiesel blends in a freezer that is used for food storage. Use a plastic tub for secondary containment, and mark the tub as a level plate. Do not leave fuel in freezer where others may disturb it accidentally.

A rough version of this test can be performed by leaving marked blended jars of fuel in an outdoor, unheated location during the winter. It is best to start blending biodiesel with petroleum diesel conservatively well before winter to prevent filter plugging in unexpected cold snaps.

Additives

Several fuel additives are available for winterizing petroleum diesel fuel, and a handful are specifically designed to winterize biodiesel blends. A 2005 study at the University of Idaho found several commercial biodiesel additives to be effective at reducing the pour (gel) point of blends, but they had little effect on the pour point of B100. Furthermore, the additives did not significantly reduce the...
cloud point (key to prevent filter plugging) of biodiesel blends, even at several times the recommended usage rates. Some individuals do report successful reduction of cloud points with various unconventional additives, but users are advised to test blends before using in their equipment and to err on the side of caution.

Preparing for Winter Trouble
It is advisable to be familiar with the fuel system in vehicles and machinery using biodiesel in case any winter troubles arise. It is always helpful to carry a spare fuel filter and the tools to change it, especially in winter. If equipment stalls due to fuel starvation, exchanging the waxed filter for a fresh one filled with petroleum diesel may get it back in service. A spare five-gallon tank of fresh winterized petroleum diesel (or kerosene for off-road equipment) can be quite handy. If temperatures drop unexpectedly below the cloud point of biodiesel in the equipment’s fuel tank, adding fresh diesel to top off the tank may help prevent clouding and filter plugging. This is especially effective if the diesel fuel is stored in a heated space. Block heaters are effective at keeping the engine warm enough to start, but if a gel layer forms in the fuel tank, problems will persist. When all else fails, the vehicle can be towed to a heated garage to thaw out. For more information on winter preparations, see References.

Blending for the Cold Season
It is best to blend biodiesel with winterized petroleum diesel fuel (cut with kerosene by the fuel distributor). Small producers will typically “splash blend” by simply pouring the two fuels into a tank at the desired proportions. Biodiesel will mix readily with diesel fuel simply through the agitation generated by driving a vehicle. For stationary tanks, it is best to add biodiesel on top of petroleum diesel, as biodiesel is denser and will settle to the bottom, blending on its way down. When blending, both biodiesel and petroleum diesel should be at temperatures above the biodiesel cloud point, as experience has shown that fuels blended at cold temperatures may not stay mixed. For this reason, small producers working in unheated shops may want to blend up a large batch of winter fuel before outdoor temperatures drop in the late fall. If biodiesel should cloud or gel, it will need to be warmed to well above its cloud point to fully dissolve waxy crystals that formed at low temperatures. Note: When blending fuels, tanks should be grounded to avoid static charge buildup (see Chemical Handling).

Biodiesel—Should I Make It Myself?
We begin this section assuming that you are already committed to using biodiesel, and are deciding if you should make it yourself. Making biodiesel fuel yourself offers many challenges. For some people, the enjoyment of the process and the reward of making your own fuel outweigh the challenges. This is for each person to determine. While converting one gallon of oil into biodiesel is simple and fairly easy to learn, processing and finishing hundreds of gallons of waste fryer oil into fuel will present new challenges with each different batch of oil. Reading to become familiar with the finer details of processing, safety protocols, and new developments in quality testing is essential. This section provides some things to consider when deciding if you want to proceed with small-scale production of biodiesel.

Economics
It is common for new producers to underestimate the time they will invest in the myriad aspects of fuel production. An analysis can be performed of the cost of inputs versus the resultant value of the fuel produced. Whether or not labor cost will be accounted for depends on the individual production facility, and whether biodiesel is made as a hobby, or in place of other income-generating work.

Costs to consider in determining the economics of small-scale biodiesel production include:

- Capital investment in equipment—this may include purchasing new equipment and acquiring a location to produce and store the biodiesel. Capital costs may be negligible if production primarily uses recycled materials in an existing well-ventilated space.
- Feedstock acquisition—procuring the oil, whether fresh for pickup or purchased
- Chemicals—these may be bought in bulk or small quantities
- Disposal cost of by-products
- Permit fees
- Electricity/energy—this includes the electricity to run the process, but may also include heat and ventilation for the facility
- Labor—you may or may not choose to include this in your costs

Since costs and availability of feedstocks vary, your cost should be compared to quality commercial biodiesel fuel before deciding to make your own fuel.

Feedstock Availability
Each finished gallon of biodiesel produced will require slightly over one gallon of feedstock, either raw vegetable oil or filtered waste fryer oil from restaurants. Prospective biodiesel producers should consider the amount of fuel they hope to produce, and then be certain that they will be able to obtain and handle the necessary feedstock oil on a regular basis. As production volumes increase, the logistics of collecting large amounts of waste fryer oil may become more cumbersome. In addition, as more people produce biodiesel, there may be competition for waste fryer oils. Lastly, it should be noted that working with used cooking oil is somewhat more complicated than virgin oils, due to the varying acidity, moisture content, and quality of used oil.

Compliance with Environmental Regulations
Biodiesel production facilities may be subject to regulation by the Department of Environmental Protection (PADEP) and other entities, depending on their size and commercial status. Currently, small-scale, noncommercial facilities are exempt from PADEP permitting, but will be subject to “discretionary enforcement” if problems or complaints arise. Other aspects of small-scale biodiesel production may be regulated. A summary of the regulations which may apply to your facility is given in Regulatory Issues. We strongly encourage anyone who is considering small-scale biodiesel production to carefully review the regulatory requirements in order to avoid any violations of the law.

Time Commitment
While biodiesel that is made from fresh used cooking oil has a reduced materials cost, the time commitment for processing should not be overlooked. To responsibly operate a small-scale biodiesel facility, you should allow time for all of the following:

- Fabrication and maintenance of biodiesel equipment
- Oil collection
- Securing chemicals
- Fuel processing
- Methanol recovery
- Water washing of the fuel or other finishing techniques
- Quality testing
- Disposal of waste products

Those who do not have ample time in their schedule for a new project are not advised to begin biodiesel processing purely as a means of saving money.

Messiness
Despite careful handling, biodiesel processing will commonly result in some “greasy spots on the driveway” or in the farm yard. Collections of oil jugs and barrels can become unsightly unless strictly managed. Leaking or seeping occurs in some plastic jugs over time. In addition, there may be an objectionable odor associated with spoiled used fryer oil. Vehicles used to collect fryer oil, buildings used for housing biodiesel gear, and clothing worn during processing are also likely to be affected by sticky fryer oil over time. Keeping the work area clean adds labor cost to the production of the fuel, but is a worthwhile safety practice.

Chemical, Waste, and Safety Issues
Chemical Exposure and Safety
Methanol (a flammable, toxic alcohol) and lye (a corrosive, caustic base) are two hazardous chemicals required to convert vegetable oil into biodiesel. Overexposure to methanol can cause neurological damage and other health problems; and it presents a serious fire risk. Lye can cause skin and lung irritation. Both methanol and lye can cause eye damage or blindness. Rigorous precautions are necessary to avoid personal poisoning, fire, and contamination of soil and water resources. Before beginning a biodiesel project, please consider whether or not you can responsibly follow the safety protocols outlined in Process Hazards, Safety Precautions, and Handling Issues.

Handling of By-Products
Biodiesel processors generate substantial quantities of crude glycerol by-product (about one gallon of waste product containing glycerol for every five gallons of biodiesel produced). Most processors also use water for fuel purification, and may generate as much as three gallons of waste water for each gallon of fuel produced. Both glycerol and waste water require handling and disposal consideration (see By-Product Handling and Disposal for further information).

Responsibility for Vehicle/Equipment Failure
The moment that a small producer pours the first gallon of homemade fuel into a fuel tank, that producer takes responsibility for the future performance of the equipment in question. While there are thousands of examples worldwide of small producers successfully powering diesel equipment with homemade fuel, users should also understand that problems can and do occur. Careful attention to production chemistry and fuel-quality
Simplified Overview of Processing Steps

1. Collect feedstock: waste oil from restaurants, pressed oil from oilseed crops, render animal fats, trap grease, etc.
2. Check oil for water content (see Biodiesel Quality Test Methods) and de-water oil if necessary. (Settling collected oils in large bulk tanks/drumms, then drawing oil for processing from the top of the tank/drum may be sufficient in warmer weather.)
3. Filter oil to remove food particles and debris.
4. Fill processing equipment with oil and begin heating.
5. Test oil for free-fatty acid content via titration to determine the amount of catalyst (NaOH lye or KOH) to be used per liter of oil (see Biodiesel Quality Test Methods).
6. Make a mini batch with the heated oil (500 mL or 1 liter) to test the accuracy of the recipe being used before proceeding to a large batch. Mason jars make cheap and effective test batch vessels, provided they have tight-fitting lids.
7. When oil has reached the reaction temperature of 120 to 130 degrees Fahrenheit (50 to 55 degrees Celsius) proceed to mix the large batch using the recipe from a successful test batch. Carefully mix lye with methanol, add chemicals to oil, mix for up to two hours, and then allow glycerol by-product to settle.
8. Make accurate records of all variables in each batch of oil source, mixing time, temperature, quantities of reactants, any other processing variables.
9. Drain glycerol by-product and label for further processing, temporary storage, or disposal. The glycerol will contain significant methanol and should be handled as such (flammable and toxic).
10. Recover excess methanol from raw biodiesel. If methanol is not recovered from biodiesel, the raw fuel should be treated as if it were methanol (flammable and toxic).
11. Pump biodiesel to wash tanks and wash.
12. Allow water to settle out over several days or dry biodiesel via “active drying.”
13. Pump through a filter to fuel storage barrels.
14. Test fuel for quality parameters and compare with processing records.
15. Recover methanol from glycerol once sufficient quantities are on hand.
16. Dispose of glycerol and wash water in a safe and responsible manner (see By-product Handling and Disposal).

Regulatory Issues

There are regulations, both state and federal, which cover various aspects of biodiesel production, storage, and disposal. Knowledge of which regulations apply to you is essential. Furthermore, you may be subject to specific requirements from your local municipality, so it is important to check the local regulations and ordinances. You should check with your local County Emergency Management Agency, fire officials, and your local Department of Environmental Protection office prior to initiating any chemical storage, transportation, or handling practices on your premises, and before disposing of any waste materials. The regulations change frequently for these types of activities.

It is critical to realize that your goals and those of the regulators are the same—to protect the environment, your
health, your property, and the general public. Don’t be afraid to report a spill or to ask for assistance. The following list gives a summary of federal and state requirements which may apply to your facility. The acronyms for the regulatory agencies are defined below. Contact information for each agency is listed in References, as is the Web address for Pennsylvania’s regulations.

- Environmental Protection Agency (EPA)
- Occupational Safety and Health Administration (OSHA)
- Pennsylvania Department of Environmental Protection (PADEP)
- Pennsylvania Department of Labor and Industry (PADL&I)
- Pennsylvania Department of Revenue (PAREV)

**Issues and Regulations That May Apply**

**Biodiesel production from used cooking oils or other used animal fats**

- PADEP requires a commercial processor (an entity that produces biodiesel for sale) of used cooking oil, yellow grease, oils and fats from rendering plants, etc., to have a general permit for beneficial use under the residual waste regulations. Farm or home production of biodiesel that is not for sale is exempt from these requirements.

**Storage tanks**

- EPA requires a Spill Prevention, Control, and Countermeasures Plan for aboveground storage of oils (any type including vegetable, petroleum, animal fats, etc.) of 1,320 gallons or more or underground storage of 40,000 gallons or more (Title 40, Code of Federal Regulations, Part 112).
- PADEP regulates aboveground storage tanks that contain hazardous substances (such as methanol) of 250 gallons or more or underground storage tanks of 110 gallons or more (Title 25 Pa. Code, Chapter 245). They also regulate storage tanks at residences or farms that contain biodiesel or blends of biodiesel and petroleum diesel if they contain more than 1,100 gallons. Tanks that contain waste cooking oils which were generated by a residence, municipal building, institution, or commercial establishment (such as a restaurant) and the biodiesel is made by a small-scale noncommercial producer, the Municipal Waste Management storage regulations apply. These require that the aboveground tanks be properly constructed and have secondary containment. Underground tanks must be checked annually for leaks. (Title 25 Pa. Code 285.122). If the oil was generated by a food processing plant or was an agricultural waste product such as on-farm renderings, then Residual Waste Management storage regulations apply. These tank regulations are considerably more complex and biodiesel producers are advised to contact the DEP (Title 25 Pa. Code 299.122).

- PADL&I regulates surface tanks of 30 gallons or more that contain blends of B60 or lower (Flashpoint 200 degrees Fahrenheit (93 degrees Celsius) or lower). Tanks that contain fuels used for heating or generators that are less than 3,000 gallons are exempted. (Note: In Allegheny and Philadelphia counties, this regulation is under the jurisdiction of the county fire marshal, not PADL&I). See Title 37 Pa. Code Chapters 11, 13, and 14.

**Oil and hazardous-material storage**

- PADEP may require a Preparedness, Prevention, and Contingency Plan if hazardous materials and/or oil are stored in quantities of 55 gallons or more without secondary containment and they have the possibility of entering the environment (soil, stormwater drains, surface water, etc.) if spilled or leaked (see References for detail).

**Oil transportation**

- Used cooking oil that has been generated by a residence, municipal building, institution, or commercial establishment (such as a restaurant) must be transported as Municipal Waste (25 Pa. Code 285.201). Used oils generated by food-processing plants must meet the same requirements but must be labeled “Residual Waste” (25 Pa. Code 299.201). See the Storage Issues section for more details.

**Safety**

- OSHA regulates employee safety and provides standards for workplace hazards.

**Oil and hazardous-substance spills**

- EPA regulates spills of 40 gallons of oil or more (this includes used cooking oil and biodiesel) to waterways or where a visible sheen is present; spills of this size must be reported to the National Response Center (Title 40, Code of Federal Regulations, Part 110). Spills of methanol that exceed 5,000 lbs (758 gallons) and potassium hydroxide or sodium hydroxide that exceed 1,000 lbs must also be reported to the National Response Center (Title 40 Code of Federal Regulations, Part 302).

- PADEP regulates spills of hazardous substances and oil that could pollute the “waters of the Commonwealth.” This is interpreted to include groundwater and surface water; all spills must be reported to the regional PADEP office. Prevention of spills from waste materials in storage (including containers) are regulated by Title 25 Pa. Code 285.121

**Air quality**

- PADEP regulates air quality and requires a plan approval for facilities that will have methanol emissions of one ton or more (see the Tracking Emissions section for a discussion of methanol emissions). A Request for Determination (RFD) can be made through the PADEP’s Web site (see the References section). In addition, no malodors can leave the property (Title 25 Pa. Code Chapter 127).

**Disposal of waste products**

- PADEP regulates the waste products generated by the biodiesel process as at least residual wastes, and in some cases, such as pure methanol, as hazardous wastes. Any waste that meets the characteristics of a hazardous waste under Title 25 Pa. Code 261.20 has to be handled as a hazardous waste. The generator is responsible for appropriate chemical testing and recordkeeping.

**Wash Water**

- PADEP does not allow this to be discharged into on-site septic systems or into storm sewers. It is at least a residual waste and may be a hazardous waste, depending upon its characteristics (see above). Disposal to a municipal wastewater treatment plant must be approved by the operating agency of that facility.

- Local municipalities may regulate disposal of wash waters to the treatment plant; best management practices to neutralize this wash water are given in the By-Product Handling and Disposal section and must be approved by the treatment plant prior to disposal.

**Glycerol**

- PADEP does not allow this material to be disposed of by either land application or composting if it contains methanol. It is regulated as a residual waste or possibly a hazardous waste, pending characteristic test results under Title 25 Pa. Code 261.20, and must be disposed at a permitted landfill pending test results and approval from the Landfill Operating Authority and the Waste Management Facilities Permitting Section of the Regional PADEP Office. If the methanol has been removed, the glycerol may be composted or used as a dust suppressant on roads, but a permit from the DEP is required. See By-Product Handling and Disposal, for further discussion.

**Methanol, lye**

- EPA and PADEP regulate these materials as hazardous wastes once they are determined to be wastes (Note: This is not household hazardous waste, it is from a chemical reaction producing combustible fuel, and has nothing to do with a normal household activity). See Process Hazards, Safety Precautions, and Handling Issues for proper storage and disposal of hazardous wastes.

**Bad vegetable oils**

- PADEP regulates this as a residual waste. It may be disposed of in a permitted landfill (with approval from the Landfill Operating Authority) or composted. Consult the Waste Management Facilities Permitting Section of the Regional PADEP Office.

**Public Highway Road Tax**

- PAREV regulates the use of any fuel used in a diesel engine on the road. If a producer makes less than 1,000 gallons of biodiesel per year for road use, the “road tax” is prepaid for 1,000 gallons and reduced at the end of the year based on the actual volume produced. If 1,000 gallons or more are produced per year, the producer must be licensed and bonded and pay monthly fees.

**Federal Excise Tax**

- The IRS requires that biodiesel producers (including small-scale production for personal use) register (Form 637), report, and pay excise tax for biodiesel that is produced for use in on-road registered motor vehicles. The vehicle operator is liable for the federal excise tax of $0.244 per gallon on the B100 fuel using Form 720. A biodiesel producer may claim the biodiesel blenders’ credit if the fuel is mixed with at least 0.01% diesel and/or may claim the biodiesel producer’s credit. For both of these credits the biodiesel must meet the ASTM requirement D6751 and the requirements of the Clean Air Act. In order to meet the Clean Air Act requirements, a small producer would have to join the Nation Biodiesel Board, which is likely too cost prohibitive for most small-scale non-commercial producers. These biodiesel fuel credits may be claimed using Form 8864.
Chemical Handling

Methanol is toxic and must be handled and used in a well-ventilated area. Inhalation or ingestion of methanol can be very harmful at higher concentrations and can lead to death or blindness. It is especially dangerous to the eyes; safety goggles, chemical-resistant clothing, and gloves must be worn whenever handling the material. If concentrations in the air exceed 200 ppm, air-supplied respirators are required, preferably with a full-face mask. (Canister respirators are not effective for regular use in methanol vapors). The level at which the odor of methanol is perceptible all over (farther than 200 ppm). Thus, if one “smells” methanol in the processing facility, unhealthy personal exposure is already occurring. Producers are advised to alter any processing activity that results in perceptible methanol odors.

There have been many instances where methanol was ingested purposely because of its mildly intoxicating effect (much like ethanol). Ingestion has led to numerous cases of death or blindness, and precautions must be taken to keep this chemical away from children and animals. Methanol ingestion, inhalation of high concentrations, and any contact with the eyes requires immediate medical attention. Short-term exposure to methanol vapor can irritate the eyes, nose, throat, and cause headache, nausea, vomiting, dizziness, and trouble breathing.

Other common symptoms of drunkenness, such as lightheadedness, giddiness, blurred vision, and dilated pupils, might also appear. The symptoms depend on the level and length of exposure and can vary from person to person.

Methanol will readily dissolve into water and if released without proper treatment, can get into the water table.

Methanol is flammable and presents a fire hazard. It is heavier than air and can travel a substantial distance to find an ignition source with subsequent flashback to the processing unit or methanol storage tank. Methanol’s flash point is a rather low 52 degrees Fahrenheit (11 degrees Celsius) which is the point whereby sufficient vapor is released to form a potentially flammable mixture. At biodiesel processing temperatures (110 to 140 degrees Fahrenheit), there is enough methanol vapor generated to sustain a serious fire if air is allowed to mix with the methanol.

Sodium hydroxide (NaOH) and potassium hydroxide (KOH) are corrosive and may be fatal if ingested. (These chemicals are both referred to as “lye” or “catalyst” elsewhere in this booklet.) Skin contact can cause severe burns and the area affected should be thoroughly flushed with water or a dilute vinegar solution. Inhalation of the solid NaOH or KOH is possible if the material is reduced to dust-sized particles. Any of these situations is critical, requiring immediate medical attention. Sodium and potassium hydroxide must be stored away from water since water will inhibit the biodiesel reaction as well as cause heat release due to mixing, which can potentially cause a fire in adjacent material. NaOH, KOH, and concentrated solutions should never contact aluminum as they will create explosive hydrogen gas.

Proper safety gear for working with NaOH or KOH includes elbow-length gloves, chemical safety goggles, a dust mask or respirator, long pants, and shoes. An eyewash station and/or emergency shower within 25 feet of the workspace are also highly recommended. (A homemade eyewash station can be as simple as a dedicated garden hose or faucet that runs a constant, gentle stream of water up into the eyes. Design for “hands-free” operation so that an affected person can use the hands to keep eyes open while flushing.) When measuring anything but very small quantities of NaOH or KOH, wearing a dust mask or cartridge respirator is very important to prevent inhalation of caustic particles. A spray bottle of vinegar is handy for neutralizing any small residual catalyst spills in the workplace. Fine particles of NaOH or KOH will produce holes in clothing, thus a protective apron or jumpsuit is also advised. It is also helpful for each person working in the biodiesel shop to keep a spare change of clothes on hand, so that accidentally contaminated clothing can be quickly shed if needed.

Sodium methoxide or potassium methoxide is made during the process by combining the methanol and sodium hydroxide. It has many of the same corrosive and toxic characteristics as methanol and sodium hydroxide, and should be handled similarly. Pure sodium or potassium methoxide is not very stable and can ignite on contact with water or moist air.
Electrical equipment should be installed by qualified service personnel in accordance with the national electrical code and local regulations. Temporary rigging of electrical equipment is inherently dangerous and poses a serious fire risk. Heating elements used in processing fuel should be regulated by appropriate thermostats. Care should be taken when running power to heavy electrical loads (such as heating elements) through extension cords, so that the amperage or wattage rating is not exceeded. If an electrical cord ever feels warm, it is overloaded and should be unplugged immediately. When in doubt, consult a qualified electrician.

Fire extinguishers should be conveniently located throughout the biodiesel shop, and all users should be familiar with their operation. Avoid blocking access to extinguishers with clutter or equipment. Remember the acronym PASS:

**P**ull the pin from the fire extinguisher
**A**im the nozzle at the base of the fire
**S**queeze the trigger device
**S**weep from side to side of the flame as you extinguish the fire

A twenty-pound ABC fire extinguisher is recommended. It is a good idea to run occasional “fire drills” in the biodiesel shop to be prepared in case of an actual emergency.

**Safety Gear Summary**

The following gear should be on hand each time you brew biodiesel:

- Chemical-resistant gloves (butyl rubber is best for methanol and lye)
- Chemistry goggles (indirect vented)
- Face shield
- Dust mask or cartridge respirator
- Plumber’s eye or station
- Small spray bottle with vinegar for neutralizing lye spills
- Access to running water
- Telephone in case of emergency and emergency telephone numbers
- Fire extinguishers (20lb ABC)
- Absorbent material and spill-containment supplies

### Process Safety and Handling Issues

#### The Production Facility

An ideal space for biodiesel production will be well-ventilated yet protected from weather, and lockable to prevent unauthorized people from accessing chemicals and equipment. Adequate ventilation is an absolute must due to serious health hazards associated with methanol fumes, and lye dust. Ventilation can be provided mechanically, via fans or chemical fume hoods, or by working outdoors in the open air. Storage space for vegetable oil, chemicals, and processing equipment should be ample, and should not cramp the working space. Electrical and water service are also required for most processing systems. A secondary containment system is advisable in case of large spills of oil, biodiesel, wash water, etc.

A “best practice” is to have a separate space dedicated to biodiesel production, apart from other buildings that serve multiple purposes. Biodiesel processors in existing multi-use buildings risk the loss of assets in case of an unforeseen fire or other accident. Users are cautioned to absolutely avoid producing biodiesel in quantity inside their personal residences. Making biodiesel inside a production greenhouse or livestock barn is also not advised. Fires due to biodiesel production may not be covered by home or farm insurance policies.

A typical solution for small-scale producers would entail erecting an appropriately sized shed apart from other buildings on the property. Inexpensive modular metal buildings of various sizes (such as those sold as carports) are now commonly available throughout Pennsylvania. Such buildings, when equipped with retractable walls and doors, would make an ideal site for small-scale biodiesel production. It is essential that the facility not be located immediately adjacent to waterways that could be impacted by spills of chemicals, oil, or biodiesel.

A good processing safety plan starts with a schematic flow chart for the proposed facility. Where and how will lye and methanol be stored and in what quantity? How will they be handled? Where will vegetable oil enter the building and where will it be stored? How will the materials involved in various processing steps move through the building? How will fuel and by-products exit the facility and where will they be stored? Be sure to note the location of safety gear. Once a schematic is made, it can be applied to the physical space under consideration for biodiesel production.

#### Processing Equipment

All of the problems associated with processing biodiesel can be handled with a properly engineered design. However, some Web sites suggest that you can build something with “what’s lying around the house.” This can be very dangerous and should be avoided. Please consult with experienced biodiesel producers or industrial personnel when designing your facility.

While there are a side variety of processor designs that will effectively convert vegetable oil into biodiesel, for safe and energy efficient production, a closed system that minimizes opportunities for escape of methanol vapors into the workspace or environment must be used. Although early efforts on biodiesel popularized the use of open-top barrels for mixing oil with methanol and lye, these irresponsible designs result in increased fire risk, increased worker methanol exposure, and reduced fuel quality due to evaporation of methanol from the reaction tank. Additionally, any pouring of large quantities of methanol or mixtures that contain methanol should be avoided in the process design. For this reason, a closed system, wherein oil, chemicals, and end products can be safely transferred using pumps, tubing, and valves is ideal. Use of devices with sparking electric motors, such as drills or paint mixers, near open containers of methanol also presents a fire risk and must be avoided.

A successful closed-system design that is widely used is the water-heater-based processor (popularly known as the “Appleseed” reactor). Electric water heaters, whether purchased new or recovered from plumber’s salvage yards, have the following desirable features: they are scalable, factory insulated, and come equipped with electric heater elements, thermostat, a drain, and several inlet ports at the top of the tank. Reliable information and plans for building a biodiesel reactor from a water heater can be found in References. The water heater reactor uses a centrally located pump for recirculation of the reacting biodiesel. This eliminates the need for a mechanical mixer/stirrer, simplifying the system while improving overall safety.

Sealed reactors must be equipped with a temperature-pressure relief valve that is compatible with the tubing used to plumb the reactor (most water heaters are sold with 150-PSI valves, and these should be replaced with a 30/PSI valve if using any poly or plastic tubing). A manually operated vent valve, plumbed to the outdoors, is also essential, as described below. A sealed system based on a metal tank also allows for the recovery of excess methanol from biodiesel fuel and the glycerol by-product, which saves money and reduces handling and environmental complications after processing.

When plumbing a reactor of any design, stainless-steel or black iron tubing should be used wherever possible, as they are most compatible with the chemicals involved in processing. Galvanized fittings and any copper parts will reduce the oxidation stability (shelf life) of biodiesel, while hard-plumbed PVC tends to break down over time. Aluminum should also be avoided, as it will violently react with lye to form explosive hydrogen gas. Many systems use brass ball valves with no major ill effects.

Wherever plastic, poly, or HDPE is used in biodiesel equipment, its proximity to heat sources should be considered. For example, early works on small-scale equipment popularized the use of conical-bottomed plastic tanks for the main reactor vessel. While they do possess some advantages, plastic vessels present an increased fire and spill risk in the event of an unforeseen overheating situation, structure fire, or other accident. In the event of a fire in or near the processing space, any plastic tanks will likely rupture and release their contents, potentially adding fuel to the fire. Heating elements should never be installed in plastic tanks. Most conical-bottomed plastic tanks are not 100 percent airtight, and thus will result in some methanol release if used as a main reactor. These tanks also will not tolerate the high temperatures needed to use the reactor as a methanol recovery device.

While homemade wooden stands are commonly used to support biodiesel equipment, these also present a weak link in overall plant fire safety. In the event of a fire in the plant, a wooden, oil-soaked stand will likely burn, dumping whatever liquid is in the tank it supports into the fire. An ideal firesafe biodiesel plant will use metal tanks supported on secure metal stands.

**Ventilation, Methanol Fumes, and “Make-up Air”**

The main reactor and other processing equipment will be laden with methanol vapors at various times during biodiesel production. Whenever fluids are added or drained from a sealed reactor, make-up air must be allowed to flow into or out of the reactor to prevent pressure or vacuum buildup. Air leaving the reactor should be vented through tubing to the outdoors at a minimum, as it may contain toxic or flammable vapors. Simply running a temporary flexible hose from a valved port on the reactor to the outdoors may be sufficient, while hard-plumbed venting is desirable for regular processing. A best practice is to vent all methanol vapors through a condenser for collection, as described in Methanol Recovery.

Methanol fumes will also be present when glycerol is drained from the reactor, and when raw biodiesel is pumped from the reactor to wash tanks, especially if these fluids are drained while hot. Gas analysis in
one Pennsylvania biodiesel facility found methanol concentrations in excess of the lower explosion limit (and personal exposure limit) when splash-pumping warm biodiesel into an open wash tank. Remember, if you can smell methanol in the workspace, there is a problem with your process design to be corrected. A best practice is to transfer all methanol-laden fluids via tubing into closed vessels, and to vent all vessels to the outdoors. (Figure 5). One innovative design drains glycerol into a sealed container, which has air-vent tubing temporarily plumbed to the main reactor, so that air pressures between the two vessels can stabilize without methanol release into the workspace or environment. Periodic venting of the reactor to the outdoors is still necessary due to thermal expansion and contraction associated with heating and cooling. However, if this occurs through a condenser, methanol release is minimized. Such a "fumeless" design is very attractive for air-quality considerations. For further information on fumeless processing, see References.

Operator’s Quick Reference
Basic processing equipment developed in the home or farm shop can become complicated with multiple valves and switches for various purposes. Even experienced operators can make mistakes, and opening (or failing to open) certain valves during processing stages may result in spills or accidental release of dangerous chemicals into the workspace. A best practice is to develop a well-thought-out process diagram, including step-by-step guidelines for the state of valves and switches during different stages of production (Table 1 and Figure 6). This diagram should be posted on or near fuel-making equipment, to serve as a reference for all trained operators. In the sample diagram below, each “X” represents an open valve, or electrical component turned on during a given process step.

**Step-by-Step Process Protocol**
In biodiesel shops where multiple operators use shared equipment (co-ops, educational facilities, etc.), it is helpful to print off and post a standard processing protocol. Such a document ensures that all personnel follow proper safety and fuel quality procedures during each step. In addition, a “batch step checklist” that follows a batch of fuel from the reactor to the outdoors is still necessary due to thermal expansion and contraction associated with heating and cooling. However, if this occurs through a condenser, methanol release is minimized. Such a “fumeless” design is very attractive for air-quality considerations. For further information on fumeless processing, see References.

**Washing Fuel**
Wash tanks are considered essential equipment by most producers. They are used to “finish” biodiesel by cleaning it with water. Raw biodiesel straight from the reactor typically contains soap, residual catalyst, traces of glycerol, and residual methanol if a methanol recovery stage was not performed. While a few small-scale producers run unwashed fuel in their equipment, for high quality biodiesel that approaches the ASTM standard, washing or mist washing (mist nozzles rain very fine water) is very attractive for air-quality considerations. For further information on fumeless processing, see References.

### Table 1

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- **OPEN** or **ON**: Pump should only run periodically
- ***Pump should only run periodically**

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Biodiesel Drain Source

will contain significant methanol and should be handled with care. Typically, warm water equal to 5 percent of the original volume of oil will be added to reaction, then mixed for another 15 minutes or more. (For example, in a 50-gallon batch reaction, 2.5 gallons of water would be added at the end of the normal mixing time). When the fluid is drained and water mixture is allowed to settle, most of the water will settle in the glycerol layer, taking soap with it. The resulting biodiesel may be easier to wash, requiring less water, and producing less waste water for disposal. (Note: The water must be added while glycerol is still in the reactor, or else emulsification will result from vigorously mixing water and biodiesel together.) Adding water to the reaction will complicate methanol recovery steps, and achieving high-purity (dry) methanol becomes more of a challenge. See References for further discussion.

Drying Fuel

During the washing process, biodiesel will become cloudy with suspended water droplets (sometimes referred to as having an "orange-juice-like" appearance). Washed fuel must be thoroughly "dried" before use in equipment or transfer to storage. Water in fuel can cause serious damage to diesel system components, and biodiesel may be easier to wash, requiring less water, and producing less waste water for disposal. Several hours, and the risk of fuel overflow in a forgotten tank. Affordable water shutoff timers or more sophisticated devices also provide redundancy in case one should fail. Threaded float switches are also advisable to prevent accidental fuel tank. Ion-exchange resins, such as Amberlite or Purolite beads, are used by some commercial producers for removal of impurities instead of water washing. These beads, which absorb soap, water, glycerol, and some methanol, are packed in columns through which unwashed biodiesel fuel is passed. After flowing through a series of columns, the biodiesel is then filtered and pumped to storage.

Waterless Soap Removal

Due to the inherent challenge of proper wash water disposal in rural areas, waterless washing methods may also be attractive. Some small-scale producers have managed to achieve ASTM-quality fuel with no washing. This process is most effective following the "prewash" technique described above for initial soap reduction. The majority of the contaminating soap, residual catalyst, and glycerol are not soluble in biodiesel, but are suspended in biodiesel because they are soluble in methanol. If methanol is driven out of the fuel (see Methanol Recovery), soap and other contaminants will settle out of the fuel over a period of several days. Soap separation from biodiesel happens more reliably if sodium hydroxide is used as the reaction catalyst (rather than KOH). After the soap is removed, the fuel can then be passed through a series of filters and put directly into storage without water washing. A soap test (described in Biodiesel Quality Test Methods) is helpful to determine that the cleaning process is working correctly.

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transport food or animal feed. Spill-free collection and transportation will ensure a lasting good relationship with restaurants and regulatory agencies. Keeping a bucket of an absorbent “oil dry” material and a spill kit in the collection vehicle is advised in case of spills. Secondary containment in the collection vehicle is desirable, as is securing any buckets or barrels to prevent spills during transportation. Take care not to overload the rated hauling capacity of your vehicle with heavy oil drums or totes. While a vehicle may physically carry more weight than it is rated for, braking ability may be increased when overloaded, presenting an accident hazard.

Oil can be stored for six months to a year before processing, ideally stored in a container with minimal air space. Large heavy duty plastic totes (300- to 350-gallon cubes) equipped with drains at the bottom make handy oil storage containers. These must be well-supported. 300 gallons of oil weighs about 2,100 pounds without adding the weight of the container.) Oil can be rough-filtered by pouring it through a screen when transferring from the collection vehicle to storage. Water and food particles will naturally fall to the bottom of the container over time, and can be periodically drained. Oil for processing should be drawn off or in the top of the container to avoid any water layer below.

Chemical Storage
All hazardous chemicals (and any contaminated processing gear) should be kept in locked storage containers when not in use. A best practice is to use an approved metal fire cabinet for storage of flammable liquids. Heavy duty 5-gallon plastic carboys are handy for methanol storage and transportation. Handling of methanol is reduced if using carboys that can be plumbed directly to the biodiesel reactor for chemical addition to the feedstock oil. Chemical storage containers should be clearly identified with safety labels to advise fire or safety personnel and others in case of an emergency.

Labeling Stored Fluids
A best practice is to label all storage containers, from buckets of glycerol by-product to large tanks of used cooking oil. It is very easy to lose track of which “unidentified brown fluid” may be in an unmarked container. Labeling prevents accidental issuance of fluids, and will help emergency service personnel know what they are dealing with in case of an accident. Paper tags with strings or wires sold at office-supply stores are easily affixed to jug and bucket handles. (Pencil or permanent marker is the most reliable for marking tags in oily conditions). Figure 8

Container labels should indicate the type of fluid, any distinguishing characteristics, and the date the fluid was produced or stored. Dating waste containers is particularly important to be sure that storage does not exceed the one-year limit regulated by the PADEP. Methanol containers should be labeled “flammable” and by K or KOH containers should be labeled “corrosive.” Stickers for labeling may also be available from chemical suppliers.

Spills
Spills of hazardous materials or oil are easiest to clean up if they are kept to paved or concrete areas. If the spill occurs on these areas, great effort should be made to keep it on these surfaces and not allow it to migrate to soil, into storm sewers or manholes, or other surface water. If a spill enters surface water or the storm water system, it becomes a high-impact spill and must be reported to 911 for emergency cleanup response. Typically this will involve the county-designated Hazmat team.

For smaller spills and releases (those that can be safely handled by the biodiesel producer and do not enter storm sewers, manholes, or other surface water), the following procedures should be used:

• Identify the problem.
• Stop the source of the spill/release.
• Contain the spill/release by using absorbent socks, or prevent the spill/release from migrating to other areas such as soil, drains, or surface water by using the absorbent socks or constructing a dike.
• Recover the spilled/release material and affected soil or gravel by covering it with absorbent materials (pads, pillows, or loose absorbent material). Other materials can be used as needed including shopping bags, sawdust, etc. All free product must be absorbed. If the spill/release is to soil or gravel, excavate all material that is affected. Use both visual observations and odors to determine the extent of material to be excavated.
• Properly dispose of the used absorbent materials and excavated soil/gravel. Used cooking oil spills and small wipe-ups of hazardous materials such as methanol may be disposed of as municipal waste. Spills of methanol, or other chemicals that saturate the absorbent material, should be disposed of as hazardous waste.
• Report the spill to the PADEP if it occurs outdoors or enters any storm-water drains, manholes, or surface water. Provide information on the location of the spill, the material spilled and its volume, and the affected media (water, soil, etc.).

It is helpful to have a spill kit on hand to easily deal with spills. The kit should contain some loose absorbent material such as kitty litter, as well as pads that are designed to absorb oils and other chemicals. Secondary containment around oil and fuel storage areas is a highly recommended management practice in anticipation of spills. A short painted or sealed concrete curb or dike around oil storage tanks should be sized to accommodate potentially spilled oil, or a sturdy wooden enclosure lined with pond liner or heavy-duty plastic may suffice for a temporary solution. For small-scale producers, plastic children’s pools are an affordable option for spill prevention around barrels.

Containerment of any kind should be sized to accommodate at least 110 percent of the volume of the single largest container in the containment area. Using the figure 1 gallon equals 7.48 cubic feet, you can calculate the appropriate size of your containment area for your largest tank. It is possible to make the entire shop floor into one large containment area using a short wall around a concrete floor.

By-Product Handling and Disposal
Glycerol
The answer to the question “What do you do with the glycerol and wash waters?” is a moving target. Rules and recommendations regarding legal and environmentally responsible by-product disposal are likely to change over time as research is carried out, and the regulatory agencies consider the applications of the law. What follows is the author’s best possible synopsis of the available information at the time of publication. Biodiesel producers are advised to stay in contact with local regulatory agencies (PADEP office) and biodiesel production networks for the latest on this evolving issue. Suffice it to say that responsible glycerol disposal is a major sticking point for small-scale producers.

The opportunity for innovators to take advantage of this “waste” product for a yet-to-be-determined beneficial use is profound. Biodiesel production will result in significant quantities of residual glycerol byproduct. For each gallon of biodiesel produced, approximately 1/5 gallon of glycerol will result. Refining crude biodiesel glycerol into pure, marketable glycerin is technologically difficult, expensive, and is not considered practical on a small-scale. New producers should give ample consideration to how they will dispose of their by-product before beginning construction. Storage of glycerol byproduct should be done in accordance with applicable sections of Title 25 Pa. Code Chapters 285 and 299, as it presents a health and fire risk. Glycerol stored in plastic fryer oil jugs will leak over time. Storage cannot exceed a one-year period, as this is considered on-site disposal. See References for a link to the Pennsylvania Code, which provides the regulations regarding storage of residual and municipal waste materials.

Crude glycerol byproduct is contaminated with methanol (approximately 25 percent by volume) and as such may be considered hazardous waste. Contrary to popular belief, methanol will not evaporate from stored glycerol at ambient temperatures sufficiently to consider the glycerol uncontaminated. Raw, methanol-laden glycerol by-product should be handled as if it were methanol. This includes wearing gloves and goggles and avoiding any concentrated vapors.

Land application of glycerol that is contaminated with methanol may result in methanol leaching into ground water, leaving biodiesel producers liable for any damages to drinking water sources. Land application of contaminated glycerol will certainly result in air emissions of methanol. Methanol is a listed hazardous air pollutant by the EPA and PADEP due to its impact on human health and other organisms.

A best practice is to recover the methanol from the glycerol by-product via distillation, prior to disposal or further use. Methanol recovery reduces environmental pollution and allows producers to reuse methanol, thereby reducing costs and improving energy balance. Methanol recovery has some inherent safety concerns, and should only be carried out by advanced producers who fully understand the safety issues involved with handling methanol and hot liquids. However, the authors of this booklet strongly recommend that all biodiesel producers incorporate methanol recovery systems into their long-term plant designs. New producers may consider stockpiling a modest amount of glycerol until they are ready to advance
Anaerobic Digestion: Crude by-product has been added permitting requirements. With regulators in your state for the latest information and allowed, as well as incorporation into landfills. Please check farm composting or anaerobic (biogas) digestion may be become available. In other states, use as a feedstock for on- processing and would require a permit from PA DEP.

Glycerol Contaminated with Methanol

Currently no easily attained options for disposal of glycerol with methanol are allowed by the PADEP. Some options are under investigation and may be allowed as more data become available. In other states, use as a feedstock for on-farm composting or anaerobic (biogas) digestion may be allowed, as well as incorporation into landfills. Please check with regulators in your state for the latest information and permitting requirements.

• Anaerobic Digestion: Crude by-product has been added to anaerobic biogas (methane) digesters with success in several locations, including farm-scale manure digesters and municipal waste water treatment plants. In controlled anaerobic digestion, microbes decompose animal manures and/or human waste, producing methane gas that may be used for power generation. These microbes are capable of breaking down methanol and glycerol into more benign compounds. The addition of biodiesel glycerol by-product may actually boost biogas production. The glycerol by-product typically has a high pH and a high carbon to nitrogen ratio, which may also make it attractive as a digester additive. Dilute additions of small amounts of glycerol by-product should be tested while carefully monitoring the response of the digester. For a listing of farm-based manure digesters in your area, contact your county Penn State Cooperative Extension office.

Glycerol After Methanol Recovery

• Industrial Combustion as described above. The Air Quality section of the PADEP needs to be apprised of any fuel-burning situations with this material. The Waste Management section should also be consulted for permission to designate glycerol as a co-product for use as fuel.

• Composting. After methanol removal, glycerol can be safely composted with reduced concern for environmental contamination. Glycerol by-product is a high carbon, high-pH, wet feedstock, and should be combined with a bulking agent (straw, hay, leaves) and some nitrogenous materials (manures or fresh green yard wastes) for proper composting. Glycerol should be added to compost piles in dilute amounts to prevent wet saturation leading to anaerobic conditions. Frequent turning of piles will promote speedy aerobic decomposition and an even distribution of glycerol into the mix. Glycerol compost piles should be constructed far away from any water source to prevent runoff contamination. Covering piles with commercially available compost fabrics will prevent water saturation and reduce runoff potential. Soils where compost is applied should be tested regularly for any salt buildup from residual biodiesel catalyst in the glycerol by-product. The PADEP requires a permit for this method of disposal, so consult your local office. Until further research into the action of crude biodiesel glycerol in the compost pile can be conducted, the authors do not recommend adding glycerol to compost piles used to fertilize food gardens.

• Soap. Glycerol can be processed into a crude hand or body soap using simple recipes (see References). It is imperative that all methanol has been removed from the methanol soap. Glycerol should be heated slowly to 212 degrees Fahrenheit (100 degrees Celsius), which is the boiling point of water. If bubbling occurs in the glycerol pot before 212 degrees Fahrenheit (100 degrees Celsius) is reached, then some methanol is still present. Heating should continue until no bubbling occurs at temperatures below 212 degrees Fahrenheit. When making soap, use only stainless steel, glass, or ceramic pots (no aluminum). Heating should occur outdoors over an electric burner to prevent any concentration of fumes or ignition of stray methanol vapors.

• Degreaser: A simple but effective engine degreaser or floor cleaner can be made by making a 50/50 blend of water and glycerol after methanol removal. Individual biodiesel producers report a strong demand for glycerol degreaser in some locations.

• Dust Suppressant. After methanol recovery is complete, glycerol by-product has been blended with water and sprayed on roads and dirt tracks as a dust suppressant. Glycerol tastes sweet to animals and may draw wildfowl to roads, so caution is advised. Avoid spraying near any waterways to prevent contamination. Any land application of waste material must have permission from your Regional PADEP Office and the township or state if they have jurisdiction of the road.

• Animal Feed Additive. Early experiments show some success with adding glycerol to animal feed after methanol recovery. Glycerol is a sweet, high carbohydrate energy source that may be added to grain feeds in dilute quantities. Further research is needed to determine proper blending rates and the possible effects of potassium or sodium salts and high pH of the by-product. For more information, see References.

Wash Water

Wash water from biodiesel processing presents a significant disposal and handling challenge in rural areas. Those who have access to a public sanitary sewer may be permitted to dispose of wash water by their local water treatment authority. Contact your water treatment authority for permission before disposing of wash water to the sanitary system.

Wash water may be contaminated with any of the following: methanol (first wash, if methanol recovery step was not carried out on fuel), soap, excess catalyst, glycerol, vegetable oils, free fatty acids, and biodiesel. Wash water will typically have a high, alkaline pH. The pH of the water should be tested prior to disposal in a sanitary sewer. Local regulations vary, but any liquid with a pH higher than 9.5 or 10 is of concern due to its corrosive nature. The alkalinity of wash water may be neutralized in batches using vinegar or dilute muriatic acid. However, “pretreatment” or neutralizing a waste prior to disposal is regulated under PADEP Permit-By-Rule regulations for neutralization, pending test results for waste determination as hazardous or residual. Each case will be handled separately by the PADEP, depending on the test results of the waste and the needs and type of treatment plant involved. At the very least, the treatment facility operator and local PADEP Water Quality section should be consulted prior to receiving water.

Methanol-laden wash water will have a high biological oxygen demand (BOD), which is of concern to water treatment plants. Some treatment plants are very wary of flammable liquids in sewer water. Local regulations for methanol in sewer water may vary. Vegetable oil or biodiesel in wash water can also confound water treatment and sewer systems—many plants have very low tolerances for fats, oils, and grease. A best practice is to pass wash water (and water from sinks where biodiesel lab ware is cleaned) through a grease trap. Commercially available grease traps will prevent excessive oil contamination of the waste water stream. An effective grease trap can also be made from plumbing parts and a large plastic tote (Figure 9).

FIGURE 9

Grease Trap Flow Rate: 4GPM ~ 5th Grease Capacity

12’’

22 1/2’’

FIgure 9
Any land application that results in foul odors affecting neighboring properties is likely to be prohibited.

- Application to gravel/dirt farm roads for dust suppression and "paving." Many farmers report effective control of dust using dilute additions of vegetable oil to unimproved roads. Care must be taken to avoid application where runoff could enter any storm sewer, stream, or other water source. Vegetable oil may draw pets or wildlife to roads. Keep accurate records of the date, time, location, and quantity of vegetable oil applied to roads. Consult your local PADEP office prior to application.

- Compost. Vegetable oil will compost if small amounts are added to absorbent material (straw, hay, leaves, wood, etc.) in a large compost pile. Oils tend to slow the composting process, but may also help to tie up soluble nitrogen. Keep accurate records of the date, time, location, and quantity of vegetable oil applied to compost piles.

- Burning in bonfires/wood furnaces. This use may require a permit from the air quality section of the PADEP.

- Mix with absorbent material and landfill. Consult with your landfill administrator or trash hauler before disposing of large quantities of oil in this manner. Oil-soaked sawdust presents a dangerous spontaneous combustion fire hazard and must not be allowed to linger in or around buildings. Oily sawdust should be wetted down with water and packed in sealed containers to avoid starting a dumpster fire.

**Tracking Emissions: Where Does the Methanol Go?**

Methanol is an air pollutant of concern for the PADEP and the United States EPA due to its potentially harmful impact on humans and other organisms. In Pennsylvania, facilities that emit into the air one ton (2,000 lbs) or more of methanol per year are required to obtain a permit from the PADEP. Facilities that emit less than one ton per year are not required to obtain a permit. If the reactor is sealed (which is strongly advised for safe and efficient production), unbound methanol amounting to approximately 2 to 4 percent of the oil volume will be present in the biodiesel layer. If methanol is not recovered from the biodiesel, it will be burned as fuel. That leaves about 1 to 1.5 gallons of methanol in the glycerol by-product. If methanol is recovered, it will be burned as fuel. The remaining unbound methanol, amounting to approximately 5 percent to 10 percent of the starting oil volume, will be in the glycerol layer. For example, consider a 50-gallon batch reaction, using 20 percent methanol (10 gallons), with no methanol recovery. Roughly 6.5 gallons of methanol (13 percent of the oil volume) will become a part of the biodiesel molecules and will be burned as fuel. That leaves about 1 to 1.5 gallons of residual methanol in the unwashed fuel, and 2 to 2.5 gallons of methanol in the glycerol by-product.

<table>
<thead>
<tr>
<th>Oil processed (gal)</th>
<th>Methanol (percent of oil volume)</th>
<th>Total methanol used (gal)</th>
<th>Methanol recovery?</th>
<th>Potential emissions (gal) *</th>
<th>Potential emissions (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>22</td>
<td>220</td>
<td>N</td>
<td>90</td>
<td>514</td>
</tr>
<tr>
<td>3,366</td>
<td>22</td>
<td>741</td>
<td>N</td>
<td>303</td>
<td>2,000</td>
</tr>
<tr>
<td>1,000</td>
<td>25</td>
<td>250</td>
<td>N</td>
<td>120</td>
<td>792</td>
</tr>
<tr>
<td>2,525</td>
<td>25</td>
<td>631</td>
<td>N</td>
<td>303</td>
<td>2,000</td>
</tr>
<tr>
<td>2,525</td>
<td>25</td>
<td>631</td>
<td>Y</td>
<td>strays emissions only</td>
<td>strays emissions only</td>
</tr>
</tbody>
</table>

* Potential emissions from glycerol and unwashed fuel based on methanol in the amount of 13 percent of oil volume being incorporated into the fuel.
### Methanol Recovery

Methanol in excess of the actual amount required for the transesterification reaction is added to drive the reaction further to completion. If the excess methanol is recovered, it can be used for processing additional batches. If not recovered, most of the excess ends up in the glycerol and some in the water wash. This is not only wasteful of a valuable component, but can further complicate the disposal of these two waste streams, as discussed above.

Using simple distillation technology, it is possible to recover as much as 30 percent of the methanol added to the original reaction, which results in cost savings, increased energy efficiency, and significantly reduced environmental impact. Depending on processing techniques, in a typical 50-gallon batch of biodiesel, there may be 2 to 2.5 gallons of unrecovered methanol in the glycerol, and 1 to 1.5 gallons of unrecovered methanol in the raw fuel.

Methanol recovery can take place from the fuel after the glycerol is removed, and it can be distilled from the separated glycerol. Fuel or glycerol is heated to temperatures over the methanol boiling point, 148 degrees Fahrenheit (64.6 degrees Celsius), and vapors are directed to a wash tank if desired. Hot methanol gas exiting the boiler is directed through the interior copper pipe, where it is cooled by the water jacket, and condenses into liquid methanol before flowing into the collection vessel as low as practical to reduce the amount of vapor escaping through the vent.

The rate at which methanol will distill is a function of the temperature and the rate at which heat can be added to the liquid. Methanol can be distilled at atmospheric pressure and at temperatures between the boiling point of methanol (148 degrees Fahrenheit, 64.6 degrees Celsius) and the boiling point of water (212 degrees Fahrenheit, 100 degrees Celsius). Some more complex distillation systems also use vacuum to increase efficiency and reduce the chance of fuel scorching at high temperatures.

An effective water cooled condenser can be made by any moderately skilled plumber using copper pipe and readily available fittings (Figure 10). A popular design appropriate for water-heater based reactors uses a ¼-inch copper pipe to carry methanol. This methanol pipe is soldered inside of a ¾-inch copper pipe fitted with a tee at each end. One leg of each tee is adapted to garden hose fittings. The other two legs are soldered inside of a copper pipe to carry methanol. This methanol pipe is soldered inside of a ¼-inch copper pipe fitted with a tee at each end. One leg of each tee is adapted to garden hose threads to carry cooling water. Cool water enters the bottom of the condenser, and methanol vapor will continue vapor will condense on the packing material and drip back into the condenser. Since water has a higher boiling point, water vapor will condense on the packing material and drip back down into the boiler, while methanol vapor will continue to pass through and out to the main condenser.

Since there will usually be some water in the reaction mixture, the distilled methanol may contain a small amount of water. Purity of recovered methanol should be assessed to provide feedback on the distillation process. Using a thermometer, graduated cylinder, and the established unit weight of pure methanol at various temperatures (see Table 4, below), one can roughly assess the purity of recovered methanol by weighing a 1 liter sample, then entering the result into the following equation:

\[ \text{% purity} = \left( \frac{1000 - \text{weight of 1 liter of distillate}}{1000} \right) \times 100 \]

Example: A 1-liter sample of recovered methanol weighs 805 grams at 60 degrees Fahrenheit. From the chart, a liter of pure methanol weighs 796 grams at 60 degrees Fahrenheit:

\[ \frac{1000 - 805}{1000} \times 100 = 20\% \]

Water contamination is more of a problem if producers are adding water to the fuel and glycerol during the “prechase” step described in Process Safety and Handling Issues. To reduce water contamination, heating of the fuel or glycerol should occur slowly, and care should be used as fuel or glycerol temperatures approach the boiling point of water (212 degrees Fahrenheit). Some producers will separate their “dry” methanol recovered in the early low-temperature stage from “wet” methanol recovered as the boiler temperature nears 212 degrees Fahrenheit. More sophisticated setups may add a reflux column to improve purity. This is essentially a vertical tube packed with some nonreactive material (e.g., stainless steel kitchen scrubbers, glass beads, or marbles) that will cause high boiling point liquids to condense. Hot gases exiting the boiler pass through the reflux column prior to reaching the methanol condenser. Since water has a higher boiling point, water vapor will condense on the packing material and drip back down into the boiler, while methanol vapor will continue to pass through and out to the main condenser.

### Table 3

<table>
<thead>
<tr>
<th>Date</th>
<th>Batch #</th>
<th>Oil Volume</th>
<th>Methanol, %</th>
<th>Methanol bonded in fuel, gal</th>
<th>Methanol recovered from fuel, gal</th>
<th>Free methanol recovered from glycerol, gal</th>
<th>Potential emissions, gal</th>
<th>Potential emissions, lbs (gal x 6.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-May</td>
<td>07-001</td>
<td>50</td>
<td>22</td>
<td>11</td>
<td>6.5</td>
<td>0</td>
<td>0</td>
<td>4.5</td>
</tr>
<tr>
<td>10-May</td>
<td>07-002</td>
<td>50</td>
<td>20</td>
<td>10</td>
<td>6.5</td>
<td>0</td>
<td>0</td>
<td>3.5</td>
</tr>
<tr>
<td>10-Jun</td>
<td>07-003</td>
<td>50</td>
<td>22</td>
<td>11</td>
<td>6.5</td>
<td>1.5</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>25-Jun</td>
<td>07-004</td>
<td>50</td>
<td>22</td>
<td>11</td>
<td>6.5</td>
<td>1.5</td>
<td>3</td>
<td>19.8</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Temp, degrees Fahrenheit</th>
<th>50</th>
<th>60</th>
<th>75</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of 1 liter pure methanol, grams</td>
<td>802</td>
<td>796</td>
<td>787</td>
<td>784</td>
<td>779</td>
<td>773</td>
</tr>
</tbody>
</table>
KOH or NaOH catalyst, which could present a safety hazard. (Water in the reaction also increases soap formation.)

Depending on biodiesel reactor design, the main reaction can also be handled as a methanol recovery still (provided that it is sealable and the tank and tubing are capable of handling high temperatures). Methanol can be recovered from each batch of fuel immediately after glycerol separation. Glycerol is typically stored in a sealed container until sufficient quantities are collected, then it can be pumped back into the reactor for distillation. More sophisticated plants have separate equipment for distillation, as some distillation units are commercially available.

Extreme caution should be used when distilling methanol to avoid fire and personal exposure. Adequate ventilation and the absence of ignition sources are a must. All fluids and gases should be transferred via tubing rated for the relevant temperatures expected. Methanol collection vessels should be vented to the outdoors to avoid vapor accumulation in the workshop, or recovery gear can be located out of doors with appropriate spill containment. Given the high temperatures involved, accidentally opening the wrong valve at the wrong time could lead to burns or concentrated methanol gas escaping into the workspace. Care must be taken to ensure that untrained personnel cannot inadvertently cause a mishap. Producers are advised to research the design of methanol recovery equipment appropriate to their operation and thoroughly think through all safety considerations. While methanol recovery is no more complicated than the basic biodiesel reaction, due to the inherent safety risks producers should not proceed to this advanced step until they adequately understand how to do so responsibly. For further information on methanol recovery, including equipment examples, see References.

**Biodiesel Quality Test Methods**

Biodiesel fuel can be made from a number of starting materials (feedstocks) including vegetable oils, used cooking oils, and animal fats. The end product (biodiesel) is a blend of triacylglycerols plus free glycerol. In addition to deposit-forming tendencies, lacquer-like deposits can occur (vegetable oil). It is a measure of the mono-, di-, and tri-acylglycerols plus free glycerol. In addition to deposit-forming tendencies, lacquer-like deposits can occur in heated parts of the fuel system. These deposits will affect the combustion spray patterns, resulting in higher emissions and possibly poorer performance. Both free and total glycerol are measured by ASTM Method D6584. The specification for total glycerol is less than 0.240 wt.

There are currently several specifications for biodiesel in the world depending on the location where the product is made. For the most part the standards are similar, but in some cases they are designed around the country’s or area’s primary feedstock and the temperature zone of the area. In all cases, it would be expensive and economically not feasible for the small manufacturer (farmer, fleet operator, etc.) to conduct a complete analysis of each small batch produced. For example, commercial ASTM testing currently costs in the range of $1,800 per batch. Some labs will test individual samples (for example, glycerol content), allowing a producer to pretest a batch of fuel at reduced expense prior to submitting samples for the full set of ASTM tests.

Here are some examples of international standards:

- **Europe**—EN 14214 and Biodiesel Heating Oil Standard EN 14213
- **Brazil**—ANP 225 (2003)
- **South Africa**—provisional standard
- **United States**—ASTM Biodiesel Standard D6751

The following paragraphs discuss the ASTM test parameters (listed in italic type), reasons for the various testing and some small-scale bench methods (listed in bold type) that may be used to evaluate the quality in an acceptable manner. It must be emphasized that there is no substitute for producing a quality fuel than knowing your feedstock and insuring the process used is the best for that feedstock. Small producers are encouraged to keep detailed production records, including notes on oil sources, catalyst and methanol amounts, mixing time and temperature, and other relevant variables. The small-scale tests are not necessarily quantitative, but they do provide an indication as to whether the samples are approaching ASTM quality.

**Free Glycerol.** The presence of excess glycerol is of concern because it will lead to injector deposits. Free glycerol in fuel will be prevented by water washing and adequate settling of fuel before pumping into storage tanks. A goal of all biodiesel producers should be full conversion of triglycerides to biodiesel in the container. (Many small producers use 27 ml of methanol with 5 ml of biodiesel, thus this test is a measure of conversion in a two-stage test). The container is then inverted a few times to mix the fluids together, after which a visual inspection is performed to check the level of dissolution. This test should be carried out with methanol and biodiesel at roughly 70 degrees Fahrenheit. A “pass” of this test will result in clear, lightly colored methanol with no residue settling to the bottom. Samples that result in cloudy methanol but no settling of residue may also be considered a “pass.” A “fail” will result in some level of cloudiness, which on closer inspection reveals fine droplets of undissolved oil floating in the methanol that gradually settle out into the bottom of the container. The residue that settles out is unreacted glycerides. “Fail” is a qualitative term, and the level of conversion can be roughly assessed by the relative amount of material that settles out between various samples of fuel. Depending on the level of failure, failed batches of fuel may still be run in equipment if blended with diesel fuel at low concentrations. Very poorly converted batches should be returned to the biodiesel processor for further reacting with additional methanol and catalyst (see Reprocess Test below).

It is important that high purity (dry) methanol be used for this test, as the presence of small amounts of water in the methanol will result in inconsistent results. Methanol purity can be checked by weighing a sample of methanol, as described in Methanol Recovery. Accurate measurements are also essential for obtaining consistent results. As always, wear goggles and gloves and work in a well-ventilated, spark-free space when handling any quantity of methanol. While fuel samples that pass the methanol solubility test will be assumed to have achieved a high level of conversion, this is not a guarantee that fuel will meet the ASTM specifications for glycerol content. Complete analysis requires gas chromatography or other testing by a qualified lab. For a complete discussion of this test, see the References section.

**Methanol Solubility Test.** Conversion is most easily assessed using the Methanol Solubility Test, first attributed to a small producer named Jan Warnqvist. Pure biodiesel will completely dissolve in methanol, while compounds containing glycerol will not. Thus, the ability of a sample of supposed biodiesel to dissolve in methanol is a moderately reliable indicator of the level of conversion. This test is most easily performed in a tall, narrow container such as a test tube, olive jar, or centrifuge vial. Nine parts methanol are combined with one part biodiesel in the container. (Many small producers use 27 ml of methanol with 5 ml of biodiesel, thus this test is a measure of conversion in a two-stage test). The container is then inverted a few times to mix the fluids together, after which a visual inspection is performed to check the level of dissolution. This test should be carried out with methanol and biodiesel at roughly 70 degrees Fahrenheit. A “pass” of this test will result in clear, lightly colored methanol with no residue settling to the bottom. Samples that result in cloudy methanol but no settling of residue may also be considered a “pass.” A “fail” will result in some level of cloudiness, which on closer inspection reveals fine droplets of undissolved oil floating in the methanol that gradually settle out into the bottom of the container. The residue that settles out is unreacted glycerides. “Fail” is a qualitative term, and the level of conversion can be roughly assessed by the relative amount of material that settles out between various samples of fuel. Depending on the level of failure, failed batches of fuel may still be run in equipment if blended with diesel fuel at low concentrations. Very poorly converted batches should be returned to the biodiesel processor for further reacting with additional methanol and catalyst (see Reprocess Test below).

**Reprocess Test.** A somewhat more cumbersome conversion test involves taking a sample of biodiesel and reprocessing it in a small container as if it were vegetable oil. In the reprocessing test, only 50 ml of methanol and 1 gram of NaOH or KOH are used per liter of biodiesel to be tested. The reaction is carried out at 120 to 130 degrees Fahrenheit. If residual glycerol is present in the fuel, it will
Washed biodiesel has a very high flashpoint (greater than 150 degrees Celsius) compared to gasoline (40 degrees Celsius), kerosene, No. 1, and No. 2 diesel fuel (52 to 60 degrees Celsius). It is an important parameter when preparing biodiesel because it gives an indication of alcohol (methanol or ethanol) left in the biodiesel product; the more alcohol remaining, the lower the flash point. With even 1 percent methanol remaining in the biodiesel the flash point would be lowered to a level requiring caution. Most producers increase the biodiesel flashpoint by water washing above the methanol. Methanol and systems will also sufficiently increase the flash point of the finished product. Unwashed fuel will have a low flash point due to methanol content and should be considered flammable and toxic.

Water. Water is present in fuels as dissolved water or free water. In No. 2 diesel fuel, the amount of absorbed water is about 50 parts per million (ppm) at ambient temperatures. Biodiesel on the other hand, because of its more polar nature, can absorb in the neighborhood of 1,500 ppm. This absorbed water can be corrosive to components of the fuel system. Water can also affect the stability of the fuel and be the media for bacterial growth in storage. Filter plugging can also occur at low temperatures.

Testing for Water. Washed fuel should be properly dried. Dry fuel will be clear enough to see through—this can be casually assessed by holding a jar of fuel in front of a printed sheet of white paper. However, wet fuel may appear clear when warmed, so it is best to assess the clarity of the fuel at or below room temperature (but not very cold, even dry biodiesel will cloud at low temperatures).

Fuel (and waste vegetable oil feedstock) can be tested for water by carefully heating it past the boiling point of water (100 degrees Celsius/212 degrees Fahrenheit). In this test, a small sample of fuel or oil is heated over a hot plate while stirring. If no bubbles arise in the fuel at the boiling temperature of water, the fuel is dry.

Caution: This test is best done over a hot plate in a safe, fire-proof, well ventilated area. Wet oil or fuel may "spit" if not stirred, or if heated too quickly. Hot fuel may produce smoke. It only takes a few minutes to heat oil to 212 degrees Fahrenheit (100 degrees Celsius), so never walk away while heating a sample of fuel or oil. Never throw water on an oil fire (water will spread an oil fire). Have a fire extinguisher handy.

Cloud Point. Biodiesel fuels have poorer low-temperature properties than petroleum diesel fuels. The cloud point and pour point of fluids are indicators of their low-temperature properties. The cloud point limitation in the biodiesel specification is to "report" the clouding temperature of the fuel according to ASTM Method D2500. This gives an indication of the temperature at which fuel-filter plugging is likely to occur. A new ASTM cold-flow filter plugging test is also published, and may soon be implemented by the biodiesel industry.

When blending biodiesel into winterized diesel fuel, the cloud point should not be a problem at low blend levels (concentrations). The compounds in biodiesel responsible for the formation of crystals at low temperatures will still form, but not as much methanol. Methanol, in low levels, dilution by winterized diesel fuel will minimize the problem. (See Cold Temperature Issues, for further discussion.)

Sediment. Inorganic materials in fuel are undesirable since they can contribute to wear of engine components. Extraneous contamination, oxidation, storage stability, and residual catalysts can contribute to sediment in biodiesel fuels. Filters used in engines take out larger particles according to their nominal size. ASTM D482 and ASTM D874 are used to characterize and measure inorganic materials. ASTM D874 is included in the biodiesel specification ASTM D6751. It converts inorganic materials, including the sodium and potassium catalysts from the transesterification reaction, to sulfated ash. The catalyst residues are the most likely source of ash in the newly processed biodiesel.

In practice, filtration and gravity settling over time provide adequate sediment control for small scale biodiesel production. Particulates settle into the glycerol layer in initial processing, and into the wash water layer in washing stages. It is a good practice to filter fuel as it is passed from tank to tank during processing stages (especially if using open-topped wash tanks, which may accumulate debris or insects). Fuel should be filtered when pumping from the final storage tank to the equipment fuel tank with a water block filter of 10 micron (or smaller) capacity. Standard diesel fuel filters available at farm or auto parts stores are normally sufficient. Washable cloth "sock" or "bag" filters, in a variety of dimensions, are also commercially available for between tank filtering. A helpful practice is to raise pump intake tubes to avoid pumping from the very bottom of the storage tank, and to remove any residual sediment by periodic cleaning.

Note: Operators running fuel in new diesels with high-pressure injection systems may desire to filter fuel to 1 micron, as particulates smaller than 10 microns in size have been shown to cause premature failure of high pressure injection equipment. Consult the engine manufacturer for specifications.

Soap Test. Residual sodium or potassium catalyst dissolved in biodiesel will be present in the form of soap, which is formed when free fatty acids and water in the feedstock oil react with the catalyst at the terminal addition of methoxide. Soap is commonly removed from fuel by water washing, or by settling and filtration after methanol recovery from the fuel. Testing for soap can help producers determine the effectiveness of soap removal methods, and at what point to stop washing or filtering.

The soap test used by small producers is similar to titrating the acid, or washing fat, remaining in the oil, but it uses bromophenol blue as an indicator solution, and hydrochloric acid (HCl) as a titration solution.

1. Put a 250 mL flask on an accurate scale.
2. Add 100 mL of Isopropyl Alcohol (e.g., red bottle of HEET) and 12 drops of 0.04 percent Bromophenol Blue.
3. Carefully weigh the flask, alcohol, and Bromophenol Blue, and record the weight.
4. Add 10 grams biodiesel (approximately 11.5 mL) to the flask, using the scale to determine exactly how much biodiesel to add.
5. Place the flask on a stable surface.
6. Slowly add 0.01N HCL, keeping track of how much is added. Swirl the flask between additions.
7. When the color just changes to yellow and stays there, the test is done.

Use the amount of HCL added to calculate the soap content of fuel in parts per million (ppm):

\[
\text{ppm soap} = \frac{\text{mL of 0.01N HCL}}{\text{mL of biodiesel}} \times 304.4
\]

Soap factor = 304.4 for sodium catalyst, 320.6 for potassium catalyst.

Producers seeking high-quality fuel will wash or filter soap until the levels are found to be below 20 ppm for ASTM spec. Further information on this test can be found in References.

There are currently no commonly used bench tests for the following ASTM specifications:

Sulfur. ASTM D874 is the test method in the biodiesel specification for determining sulfated ash. Sulfated ash was discussed above under sediment. High ash can result in increased rates of wear.

Sulfur (ASTM D5453). The limitation on sulfur in the biodiesel specification is tied directly to the EPA regulations controlling sulfur levels in the oil. The 15-ppm level coincides with the regulation for the sulfur levels of Ultra

Cold Temperature Issues. Flash Point.

This is an indication of the flammability of the liquid and is temperature at which the fluid gives off enough vapor to produce a flammable mixture.
Low Diesel Fuel for on-highway diesel fuel that went into effect in 2007. The 500 ppm level regulations are for fuels that after 2007 are used for off-highway vehicles. The main concern with high levels of sulfur is that they contribute to engine particulate emission levels. The sulfur oxides produced can also contribute to acidic corrosion of the engine cylinders if the water jacket temperatures are too low (less than 180 degrees Celsius). Biodiesel fuel typically has a very low sulfur content.

Copper Strip Corrosion (ASTM D130). This is a test used to measure copper corrosion. It is an indication of level of acidic components in the biodiesel product.

Cetane No. Cetane Number (CN) is analogous to Octane Number (ON) in gasoline and is an indicator of the performance level of the fuel. Fuels with high CN have better energy content and combustion characteristics in the engine. CN can be determined using ASTM Method D613. Recent studies have shown that higher CN can also result in lower NOx emissions.

Carbon Residue. Carbon residue is an indicator of the tendency of the fuel to form deposits. ASTM Method D4530 is used for this test. Normally, if the fuel meets ASTM Specification D6751, carbon residue should not be an issue. ASTM Method D4951 is used to determine via a simple chemical analysis called titration.

Titrated Test for Used-Fryer Oil Feedstock: Vegetable oil will develop an acidic condition as it is heated for frying in the presence of water. Extra lye catalyst must be added to account for the catalyst that is neutralized by any acid in the starting oil. A precise amount of extra lye to be added is determined via a simple chemical analysis called titration. This step is essential to making quality fuel as the correct amount of catalyst is necessary to achieve full conversion of vegetable oil into biodiesel.

Materials needed: Isopropyl alcohol (91 percent or better), oil to be tested, pH indicator solution, lye-water solution, small beakers or plastic cups, 5c (3mL) and 5c (5mL) plastic veterinary syringes without needles.

A lye-water solution is made by adding exactly 1 gram of the NaOH (or KOH) that will be used for processing to exactly 1 liter of distilled water. It is helpful to use a high-accuracy digital scale for this step. An effective pH indicator solution can be made by mixing 5 grams of turmeric powder (an Indian spice) to 100mL of isopropyl alcohol, then allowing the powder to settle and decanting the liquid. These stock solutions can be stored for months if they are not contaminated.

Reagents should be at room temperature if possible for successful testing. Cold oil may not dissolve well in cold alcohol.

1. Measure 10 mL of isopropyl alcohol into a small beaker or plastic cup.
2. Add 5 drops pH indicator.
3. Using a 5mL syringe, add lye-water solution one drop at a time until a clear, colorless lye-water solution mix just begins to turn red. This is a “blank titration” and accounts for any acidity in the alcohol.
4. Using a 5mL syringe, add exactly 1 mL of the oil to be tested to the alcohol-indicator mix, and swirl to dissolve.
5. Note the amount of lye-water solution in the 5mL syringe and write it down.
6. Carefully add lye-water solution to the beaker, a few drops at a time, and swirl to mix after each addition.
7. When the oil-alcohol-indicator mix turns red or red-orange and stays that way for 15 seconds or more, the titration point has been reached. (Note, the mixture may return to yellow over time if left in the beaker. The initial 15-second color change is all that matters for this test).
8. Note the amount of lye-water solution remaining in the syringe, and subtract that from the amount in step 3, to determine the total lye-water solution added (in mL).
9. The amount of lye-water solution added (in mL) equals the amount of extra lye that should be used for this oil (in grams).

Example: 5 grams of NaOH per liter of oil is commonly used as the necessary base amount for oil with negligible free fatty acids. If 2 mL of lye water was added to a used oil sample, then the total lye amount to be used for this oil would be 5 grams + 2 grams = 7 grams NaOH per liter of oil.

Small producers must become comfortable with accurately performing this simple test, as proper catalyst amounts will impact the quality of the finished product. It is recommended to perform several titrations on oil used in large batch processing in order to obtain an accurate representation.

Some producers will also test restaurant feedstock oils collected from restaurants to determine if they are of sufficient quality. In general, oils that titrate below 4 or 5 mL of NaOH lye water are recommended for the simple single stage base catalyzed transesterification practiced by most small-scale producers. At high titration numbers, more soap will be formed during processing as free fatty acids react with extra catalyst added for neutralization. Excessive soap complicates washing, and will result in reduced yield of biodiesel. High titration number oils should be blended with low titration number oils to reach an acceptable average. Very high titration number oils (over 10 mL NaOH titration) are not worth collecting for those using basic processing techniques, though they may be very useful (or neutralization number: Acid number is of concern for two reasons, the first is that it can lead to acid corrosion and the second is that over time, it can catalyze the formation of additional acid. ASTM Method D694 is recommended to measure acid number.

Those desiring a more thorough discussion of biodiesel quality testing are encouraged to review the National Renewable Energy Laboratory document (see References).

CONCLUSIONS

As we have attempted to show, small-scale biodiesel production can be conducted in a safe and environmentally responsible manner which generates a quality product. It is however, important to ensure that best management practices are followed in order to protect the health and safety of the producer and the environment, and to minimize the risk of vehicle/machinery problems. While we have tried to cover all aspects of small-scale production, each individual’s facility will be different, with its own set of risks. Each biodiesel producer must take personal responsibility for his or her own safety and fuel quality. Producers are encouraged to keep up to date with new technologies and to stay informed. There are many different sources of information on biodiesel production, some of which are presented in the next section.

If you are a small-scale biodiesel producer, we congratulate you on your initiative to help mitigate air pollution, climate change, and our nation’s energy crisis by using a renewable, alternative fuel. We hope that the small-scale biodiesel community will continue to work with regulatory agencies and academic institutions to cooperate towards the goals of a clean environment, safe workplaces, and a sustainable energy future.

REFERENCES

Regulatory Agencies And Applicable Laws

Environmental Protection Agency (EPA)

US EPA Region 3
1600 Arch Street (3PM52)
Philadelphia, PA 19103-2029
Phone: 800-438-2474

Internal Revenue Service Forms and Publications

http://www.irs.gov/formspubs/

This link provides access to all of the Internal Revenue Service’s forms and publications that are needed for registration, payment of excise tax, and any biodiesel producer or blender credits.

Code of Federal Regulations (U.S. Regulations)

www.gpoaccess.gov/cfr/index.html

This link provides access to all of the federal regulations. For those referenced in this publication, browse to the appropriate title (40—Protection of the Environment) and find the appropriate part.
PDAE’s Preparedness, Prevention, and Contingency Plan
Guidance
www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1
457&p=1875&k=watershedmgmtNev-1
Click on “Technical Information” and then “Guidelines for the Development and Implementation of Environmental Emergency Response Plans.”

Request for Determination (PDAE Air-Quality Issues)
www.dep.state.pa.us/dep/deputate/airwaste/aq/permissions/rfd.htm

Pennsylvania Code (Pennsylvania’s Regulations)
www.pacode.com
This link provides access to all of the Pennsylvania regulations. For those referenced in this publication, browse to the appropriate title (25 for Environmental Protection or 37 for Flammable and Combustible Liquids) and find the appropriate chapter.

Pennsylvania Department of Revenue (PAREV)
www.revenue.state.pa.us
Bureau of Motor Fuel Taxes
717-783-1563
Pennsylvania Department of Labor and Industry, Flammable and Combustible Liquids Section (PADL&I)
Room 1614, L&I Building
7th and Forster Streets
Harrisburg, PA 17121
Phone: 717-705-2787

GENERAL BIODIESEL INFORMATION

Biodiesel Production References and Biodiesel Reactor Designs
• The Collaborative Biodiesel Tutorial: www.biodieselcommunity.org
• The University of Idaho: www.uidaho.edu/bioenergy/
• General Discussion Forum: biodiesel.infopop.cc/6/ubb.x?a=cfrm&s=447609751
• Biodiesel Smarter Magazine: www.biodieselsmarter.com
• Biodiesel Quality Testing—National Renewable Energy Laboratory Document
www.nrel.gov/docs/fy04osti/36240.pdf
• Biogas (Anaerobic) Digesters: Small-Scale Plans and Discussion
www.biorealis.com

<table>
<thead>
<tr>
<th>Cost Assumptions</th>
<th>Biodiesel Purchase Price ($/gal)</th>
<th>Electricity ($/kwh)</th>
<th>Gasoline ($/gal)</th>
<th>Labor ($/hr)</th>
<th>Feedstock Oil Cost (used cooking oil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of feedstock</td>
<td>$1.38</td>
<td>$0.08</td>
<td>$0.70</td>
<td>$10.00</td>
<td>$0.00</td>
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Biodiesel Production and Value

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<th>Biodiesel Value</th>
<th>Capital Investment Depreciated</th>
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<tr>
<td>54</td>
<td>$183.98</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Capital Cost of Equipment</th>
<th>Number of Batches per Year</th>
<th>Payback period (yr)</th>
<th>Cost</th>
</tr>
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<tr>
<td>$1,550.00</td>
<td>10</td>
<td>7</td>
<td>$90.00</td>
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Feedstock Acquisition

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<th>Process Step</th>
<th>Input</th>
<th>Units</th>
<th>Quantity</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Oil</td>
<td>Gallon</td>
<td></td>
<td></td>
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Chemical Cost

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<tr>
<th>Chemical Step</th>
<th>Quantity Purchased</th>
<th>Purchase Price</th>
<th>Quantity Input</th>
<th>Quantity Recovered</th>
<th>Not Quantified</th>
<th>Cost</th>
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<tr>
<td>Methanol (gal)</td>
<td>96</td>
<td>$71.39</td>
<td>11</td>
<td>1.25</td>
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<td>0.79</td>
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<tr>
<td>Soy (gram)</td>
<td>5000</td>
<td>$0.94</td>
<td>1000</td>
<td>4.50</td>
<td></td>
<td>4.10</td>
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Electricity

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<th>Process Step</th>
<th>Device</th>
<th>Instantaneous power draw (watts)</th>
<th>Time (hours)</th>
<th>Kilowatt hours</th>
<th>Electricity Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lye (gram)</td>
<td></td>
<td>2200</td>
<td>$5.94</td>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td>Methanol (gal)</td>
<td>55</td>
<td>$179.30</td>
<td>12</td>
<td>1.25</td>
<td>10.75</td>
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Process Step

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<tr>
<th>Input</th>
<th>Units</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock Acquisition</td>
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</tbody>
</table>

Total Cost

<table>
<thead>
<tr>
<th>Volume (gal)</th>
<th>Cost/gal</th>
<th>Cost/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,500</td>
<td>$2.12</td>
<td>$7.10</td>
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Cost Summary

<table>
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<th>Total Cost</th>
<th>Volume (gal)</th>
<th>Cost/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10,500</td>
<td>3,500</td>
<td>$7,100</td>
</tr>
</tbody>
</table>

Cost to buy biodiesel

| Cost to buy biodiesel | $183.98 |

Cost of oil

| Feedstock Oil Cost (used cooking oil) | $183.98 |

Assumptions

| Assumptions | $41.22 |
|-------------| $0.76 |

<table>
<thead>
<tr>
<th>Difference</th>
<th>Extra</th>
</tr>
</thead>
</table>
CROSSWINDS

Biodiesel

Glossary

Agricultural Waste—Waste that is generated in the production and marketing of poultry, livestock, fur bearing animals, and their products. Agricultural waste also includes agronomic, silvicultural, and horticultural commodities grown on farms or other agricultural lands. Waste generated during normal farming operations, including manure and food-processing waste, may be disposed on lands where the materials will improve the condition of the soil or improve the growth of crops. Biodiesel and waste generated during the production of biodiesel, would not be considered agricultural waste because biodiesel production is not a normal farming operation (see also “normal farming operation”).

General Permit—A regional or statewide permit issued by PADEP for the beneficial use or processing of solid waste.

Hazardous Waste—Waste that, because of its quantity, concentration, or physical or chemical characteristics may pose a substantial hazard to human health or the environment when improperly stored, transported, or disposed. Characteristic hazardous waste exhibits one of the following characteristics: ignitability, corrosivity, toxicity, or reactivity, or is listed as a hazardous waste under 40 CFR, Chapter 261. Hazardous wastes from biodiesel production may meet the ignitable characteristic for hazardous waste.

Municipal Waste—Waste including solid, liquid, semisolid, or contained gaseous material resulting from the operation of residential, municipal, commercial, or institutional establishments. Municipal waste may include waste or off-spec vegetable oils, yellow grease, and tank bottoms, or on-site rendering waste from farms, used for biodiesel production from residual waste sources as named in this definition. As a by-product of biodiesel production, glycerol and tank bottoms may fall under this definition (see also “hazardous waste”).

Soap Test—A by-product of biodiesel production, glycerol and tank bottoms may fall under this definition. As a by-product of biodiesel production, glycerol and tank bottoms may fall under this definition.

Viscimeter—A permit issued by the department to operate a waste disposal or processing facility, or beneficially use municipal or residual waste.
“Straight Vegetable Oil”—Converting the Diesel Equipment

This second viable option for using vegetable oil as fuel requires altering the fuel system of the diesel engine to heat the vegetable oil, thereby reducing its viscosity. There are many commercially available kits, as well as homemade conversions, most of which function on the same basic principles.

A second fuel tank, made from aluminum, plastic, or stainless steel, is added to the equipment; this tank will be filled with filtered, dewatered vegetable oil or used cooking oil. This tank is equipped with a heat exchanger of some kind (aluminum or stainless steel coils, or a small radiator inserted into the spare tank; copper heat exchangers are not compatible with vegetable oil fuel systems). This heat exchanger is plumbed into the motor’s cooling system, such that when the motor is hot, high-temperature coolant can be routed through the heat exchanger in the spare fuel tank. A fuel line from the vegetable oil fuel tank is routed to a mechanical tank selector valve upstream of the injector pump. Typically this vegetable oil fuel line is equipped with its own separate fuel filter, and both filter and fuel line are heated by bundling them with the hot coolant line from the engine. Some designs also use electrically heated components throughout the fuel system.

Fuel return lines may be looped back into the injector pump, so that unburned diesel or vegetable oil will not be pumped into the wrong tank. Alternately, the valves can be staggered in their switching to prevent cross-contamination of different fuel tanks, which also allows for shortened purge times and eliminates air entrainment issues sometimes caused by looped return lines.

The engine is started on diesel fuel from its original fuel tank. Once the engine is up to normal operating temperature, the operator throws a switch that controls the mechanical valve, switching the input to the injector pump from diesel fuel over to hot vegetable oil. The engine continues to run on hot (160 degrees Fahrenheit) filtered vegetable oil from the engine's original fuel tank. The mechanical valve, switching the input to the inlet of the injector pump from diesel fuel over to hot vegetable oil. The engine continues to run on hot (160 degrees Fahrenheit) filtered vegetable oil from the engine's original fuel tank. The engine continues to run on hot (160 degrees Fahrenheit) filtered vegetable oil from the engine's original fuel tank.

Because the engine must be started and stopped on diesel fuel, SVO systems make sense for equipment that will be operated for long periods at a time, such as field tractors, irrigation pumps, and vehicles that regularly travel more than 20 miles per trip. Other comparative advantages and disadvantages between straight vegetable oil conversions and biodiesel can be summarized as follows:

SVO Advantages

- SVO systems do not use chemicals to convert the fuel (as in biodiesel). This minimizes the user's input of nonrenewable energy, off-farm inputs, and money. Biodiesel requires an input of purchased chemicals for each gallon produced. Handling of hazardous chemicals and by-products is not an issue with SVO systems.

- If farmers extract oil from their own crops, SVO conversions would potentially allow them to produce their own fuel in complete independence.

- After the initial expense of converting the fuel system, there is minimal additional cost to SVO users except for the periodic purchase of filters. SVO systems can be very cost effective.

- The heated spare tank allows SVO systems to be operated in cold weather, whereas biodiesel must be cut substantially with petroleum fuel or additives in winter to prevent gelling and clogged fuel filters.

SVO Disadvantages

- The fuel system modifications in SVO systems are significant, and will certainly void engine warranties. Service technicians may be unfamiliar with the operation of SVO systems should fuel system troubles arise.

- The custom-fit nature of SVO systems typically requires occasional tinkering under the hood by the user.

- Running equipment on SVO requires the conversion of the fuel system on each engine, and may require a greater initial investment if a farm has several diesels in the fleet. Biodiesel users can build one machine to convert vegetable oil to fuel for any diesel on the farm.

- The user must find room for the on-board spare fuel tank for mobile diesel equipment.

- The effects on the engine of long-term use of SVO are unknown.

For more detailed information on straight vegetable oil conversions, see the References section in this booklet.

![Simplified Example of Straight Vegetable Oil Conversion Concept for Diesel Engine](image-url)
### BIODIESEL BATCH RECORD SHEET

**Batch #:**

<table>
<thead>
<tr>
<th>Date started</th>
<th>Name of brewers:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Quantity of oil used:**

<table>
<thead>
<tr>
<th>Quantity of methanol used:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Methanol purity:**

<table>
<thead>
<tr>
<th>Titration #1</th>
<th>G</th>
<th>CB</th>
<th>(Avg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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**Catalyst used:**

<table>
<thead>
<tr>
<th>Catalyst used:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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**Time heat on:**

<table>
<thead>
<tr>
<th>Time heat off:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Mixing temp:**

<table>
<thead>
<tr>
<th>Mixing time:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<table>
<thead>
<tr>
<th>5% prewash</th>
<th>Yes</th>
<th>No</th>
</tr>
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**Washing notes:**

<table>
<thead>
<tr>
<th>Washing notes:</th>
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<tbody>
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**Drying notes:**

<table>
<thead>
<tr>
<th>Drying notes:</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
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**Method of disposal of glycerol:**

<table>
<thead>
<tr>
<th>Method of disposal of glycerol:</th>
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<tbody>
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**Quality Testing Notes:**

<table>
<thead>
<tr>
<th>27/3:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water test:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soap test:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

---

### APPENDIX B: SAMPLE BIODIESEL BATCH STATUS CHECKLIST

**Batch #:**

<table>
<thead>
<tr>
<th>Date started:</th>
<th>Name of brewers:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Methanol purity:**

<table>
<thead>
<tr>
<th>Methanol purity:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Catalyst used:**

<table>
<thead>
<tr>
<th>Catalyst used:</th>
</tr>
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<tbody>
<tr>
<td></td>
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</tbody>
</table>

**Processing Step**

<table>
<thead>
<tr>
<th>Processing Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Day 1: Biodiesel Reaction**

<table>
<thead>
<tr>
<th>Load oil into reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note oil temp on thermometer</td>
</tr>
<tr>
<td>Heat oil: note start time</td>
</tr>
<tr>
<td>Note heat stop time</td>
</tr>
<tr>
<td>Note pump start time</td>
</tr>
<tr>
<td>Note reaction temp</td>
</tr>
<tr>
<td>Inject methoxide</td>
</tr>
<tr>
<td>Note total mix time</td>
</tr>
<tr>
<td>Note pump stop time</td>
</tr>
<tr>
<td>Note special processing comments</td>
</tr>
</tbody>
</table>

**Day 2: Methanol Recovery from Fuel**

<table>
<thead>
<tr>
<th>Connect vent hose to glycerol tank, open glycerol vent valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect glycerol hose to glycerol tank</td>
</tr>
<tr>
<td>Turn on power and pump glycerol to storage</td>
</tr>
<tr>
<td>Note approx. glycerol amount, add to glycerol tank record</td>
</tr>
<tr>
<td>Attach methanol jug and connect to vent</td>
</tr>
<tr>
<td>Note tank temp</td>
</tr>
<tr>
<td>Turn on heat, note heat start time</td>
</tr>
<tr>
<td>Turn on pump at or before 150°F; note pump start time</td>
</tr>
<tr>
<td>Turn on cooling water at or before 150°F</td>
</tr>
<tr>
<td>Be sure to watch monitor water level in wash tank</td>
</tr>
<tr>
<td>At 190°F tank temp, switch out methanol jug for “wet methanol”</td>
</tr>
<tr>
<td>Wash in 1-liter sample of recovered methanol, note weight</td>
</tr>
<tr>
<td>Note methanol sample temperature and purity (from chart)</td>
</tr>
<tr>
<td>Stop heat and pump at 200–212°F tank temp; note stop time</td>
</tr>
<tr>
<td>After 5 minutes, turn off cooling water</td>
</tr>
<tr>
<td>Label and store methanol jug in locked cabinet</td>
</tr>
<tr>
<td>Close all valves that should not be open</td>
</tr>
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**Washing Notes**

<table>
<thead>
<tr>
<th>Washing Notes:</th>
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**Drying Notes**

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**Quality Testing Notes**

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<table>
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<tr>
<th>Soap test:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

---

**Notes:**

- Add batch number to fuel tank log
- Add this sheet to record book
- Add 27/3 results
- Add batch number to fuel tank log
- Add this sheet to record book
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