Green Fuel Production: The Risks of Backyard Biodiesel

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ABSTRACT

For a variety of reasons, energy production will move from centralized facilities to distributed networks of community-scale or smaller, independent producers. If such on-site energy producers are guided by sound engineering principles and safe practices, there is nothing to fear about Distributed Generation (DG) of power, energy or fuel. However, moving the production facilities closer to residences—whenever such facilities are operated with substandard equipment by poorly trained people- could be quite dangerous. The worst case is an improvised facility operated by non-professional staff that uses toxic chemicals. Home-based biodiesel production fits this model. Thus this article documents the biodiesel production process. The chemicals of concern are described. A "what if" exercise follows to understand the various risk exposures. A Preliminary Hazard List is developed. Finally, the risks of each potential challenge are quantified and assessed to determine severity and policy implications. Recommendations include procedures for safe operation as well as facility and equipment design and installation guidelines.

Keywords: Backyard Biodiesel, home-made biodiesel, biodiesel process, hazard analysis, fault tree analysis, FMEA, Failure Mode and Effect Analysis

STUDY OVERVIEW

Credible estimates are unavailable for the number of home brewers (individuals making biodiesel for their personal use) operating nationally. It appears unlikely that more than 1 percent of America's light-duty diesel vehicle owners will become biodiesel producers. That unscientifically suggests a potential population of 80,000 persons (Endnote 1). Policies and procedures to manage the risks inherent to biodiesel production are needed to safeguard communities across the country. The goal of this article is to identify the most potentially harmful risks, prioritizing them by severity and ability to avoid. Assumptions about current processes are noted in the narrative. They form the basis for the risk evaluation. What if scenarios define perceived threats, with fault tree analyses used to clarify the causes for the worst concerns. Finally, procedures to address the risks are offered as a guide to safer, more sustainable production.

PRODUCTION PROCESS

What is Biodiesel?

In policy terms, biodiesel is a renewable fuel made from biomass capable of supplementing or replacing petroleum diesel fuel and heating oil in today's diesel engines and furnaces without modification. In personal terms, it can be an inexpensive way to power a car, heat a home, or generate electricity. It is an attractive alternative to fossil fuel. The National Biodiesel Board, the national advocacy group for the biodiesel industry, recommends the following definition for use in all state statues and regulations, "A fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, meeting ASTM D 6751" (2008). Although in a fact sheet describing its taxing policy, the state of Maryland equates unprocessed vegetable oil and biodiesel (Maryland 2009), this article focuses on a fuel created by the conversion of vegetable oil through a chemical process called transesterification.

TRANSESTERIFICATION PROCESS OVERVIEW USING WASTE VEGETABLE OIL

Biodiesel is manufactured in a variety of ways with different raw materials. Often the decision of what raw materials to use depends on local conditions such as the type of crops grown in that region or nearby industries with sympathetic waste streams. According to Tickell (2000), the main ingredient is a vegetable oil (palm, soybean, rapeseed, canola, or sunflower among others) converted into a fuel with many of the properties of petroleum diesel fuel oil. The conversion process is called transesterification. The goal is a chemical reaction to reduce the fat content of the feedstock oil by mixing it with an alcohol in the presence of a catalyst. For this article, the feedstock oil will be waste vegetable oil collected from restaurants. This is a common source for amateur producers or "home brewers." The catalyst will be Potassium Hydroxide. This is also a common choice for home brewers since it is available in many supermarkets as drain cleaner. The alcohol of choice is Methanol (or methyl alcohol). Methanol is relatively inexpensive and generally available since it has a variety of uses from windshield de-icer to racing fuel.

After determining the proportions of additives needed to react with the specific fat content of the oil collected, the catalyst is combined with the methanol. They do not readily mix. The ingredients are placed in a container and mechanically mixed for 20-30 minutes. Then the solution is added to heated waste vegetable oil in what most sources call a "processor." For the home brewer, this is typically a repurposed water heater. Again the solution must be mixed. Kemp suggests using a pump to circulate the ingredients in order to thoroughly mix the components. Transesterification occurs when a triglyceride molecule is removed from the oil to create a Fatty Acid Methyl Ester (Button). This result is raw biodiesel and a byproduct: glycerol. They are allowed to settle and then separated by a visual inspection when draining the heavier glycerol from the bottom of the processor. The final step is removal of the glycerol and unreacted catalyst from the biodiesel. This is usually done with a water wash. The hydrophilic glycerol and alcohol combine with the water and precipitate to the bottom of the wash tank. Again, a visual inspection while draining the tank is used to separate the two. Up to three washings are necessary to completely remove the byproducts (Kemp).
Additional processing of byproduct is necessary to remove and recycle methanol from the glycerol. The process is graphically depicted in the flowchart below (Fig. 1).

The process depicted in Fig. 1 has been evaluated by at least one team of investigators and found to be valid. Narayanan, et al. developed a risk assessment quantification process for biodiesel production to assess sustainability (2007). The researchers evaluated the major methods and materials currently in use for making biodiesel. They evaluated the activity on environmental, economic, and safety factors and concluded that the optimal process for small-scale biodiesel production was a

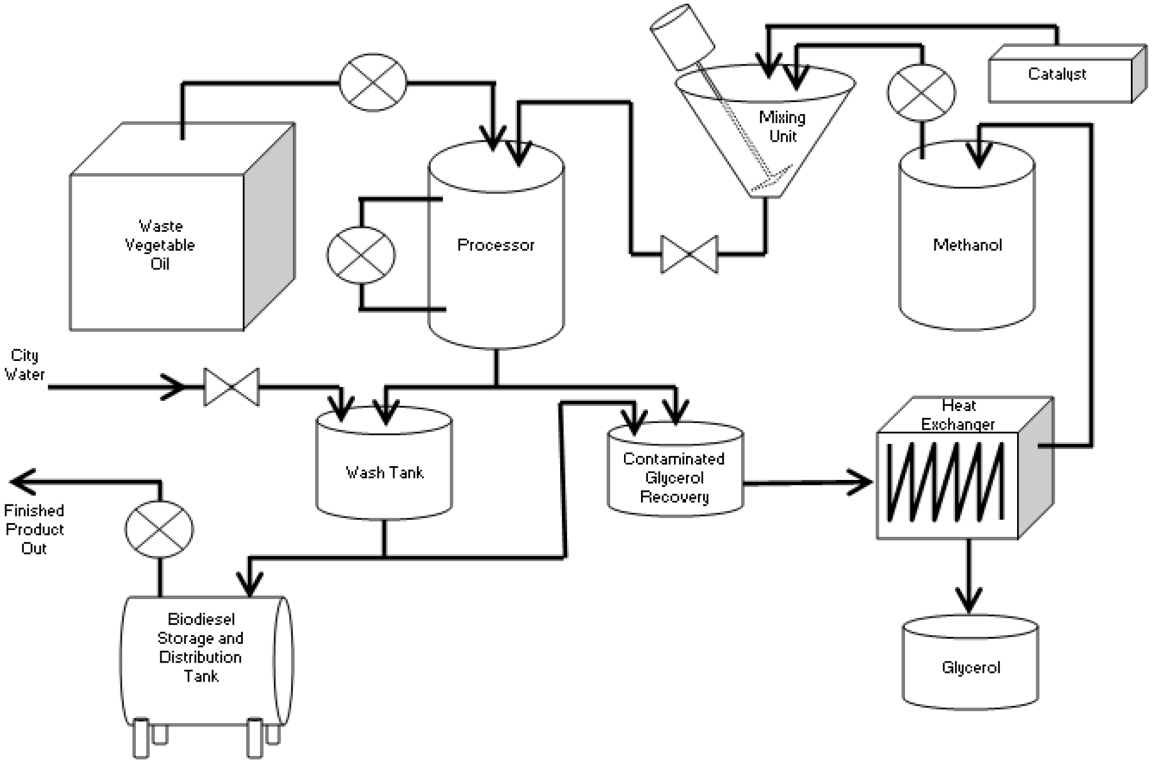


Figure 1. Biodiesel Process Flowchart

transesterification process using soybean oil with a basic catalyst like potassium hydroxide and purifying the raw product with a water wash. Waste vegetable oil was not an alternative considered.

DESCRIPTION OF TYPICAL OPERATING ENVIRONMENT

The environment this article is studying is small-scale, home producers. Home brewers, as stated above, usually manufacture biodiesel for personal use in rudimentary laboratories. Kemp does a very good job of profiling home brewers at various stages of sophistication and proficiency in his book *Biodiesel: Basics and Beyond* (2006). Button used Kemp's depiction of "amateur producers" for his own paper on biodiesel production (2009).

Home brewers use portions of garages and garden sheds as "refineries." They are motivated by saving money as much as saving the environment. Discussions of "living off the grid" are common on the biodiesel websites. For these reasons, home brewers are likely to power the refinery with a biodiesel-powered generator and heat it with a similarly-fueled furnace. They process biodiesel in batches rather than in a continuous flow like their large-scale commercial counterparts. Most importantly, home brewers usually rely on waste vegetable oil discarded by restaurants as their feedstock oil. Another characteristic of these small-scale producers is that they do not produce biodiesel fulltime. It is a hobby, maybe a sideline business, but it is not a profession. Many, if not most home brewers, are self-taught. Structured training in chemistry or industrial processes is rare. They usually get their training from the variety books and instructional websites where how-to information is freely shared. Some regions have academic programs in biodiesel production, and cooperatives that offer classes have begun in others (Estill, Burton), but this is also rare nationally.

TYPICAL EQUIPMENT

The heart of the process is the processor. Many vendors offer pre-assembled processor units for this home and small-business market (Evolution), but home brewers often create their own equipment by adapting household appliances like water heaters into biodiesel processors (Tickell). Kemp recommends standard domestic hot waters but describes modifications such as adding sight glasses and external thermometers. Tickell provides instructions for adding a water heater heating element to a steel storage drum to create a homemade processor (2000). The literature reviewed always refers to electrically-heated units, but in the spirit of independence and cost savings that usually accompanies biodiesel processing instruction, it is likely that a small portion of home brewers are using gas-fired tanks. The processor for this study was assumed to be an electrically-heated, former, domestic hot water heater.

A variety of pumps may be used to move the product between its development stages. Care must be taken to use pumps appropriate for the material being moved; pumps designed for water will be overworked moving more viscous oil. The pump used to move methanol and the methanol and catalyst solution must be specifically designed for alcohol use. The seals must be corrosion-resistant, and the motor must be enclosed in an explosion-proof housing. This is essentially a motor housing that encloses the armature and brushes since the interface of these two components involves arcing and sparks.

A number of tanks are used to contain the ingredients during reactions and storage. Polyethylene is the preferred material due to its cost and corrosion resistance, but as Kemp demonstrates, home brewers make use of anything from plastic, five-gallon buckets to steel, 55-gallon drums. Polyethylene has a maximum working temperature of 140° F (WMRC). For the purposes of this study, some of the tanks are connected by schedule 40 PVC piping (the pipe most readily available and least expensive to retail consumers), while moving product between some portions of the process was via buckets. This allows analysis of the widest variety of possible hazardous conditions.

Mechanical mixers similarly run a gamut from explosion-proof industrial units to electric drills with paint stirrers. Tickell and Kemp explain another form of agitation by “bubbling” air through the solution until fully combined. This is also used as an supplemental method to ensure mixture. Bubbling is accomplished by placing an aquarium aerator at the bottom of the mixing tank and feeding it from a small air compressor. A non-explosion-proof, mechanical stirring mixer was assumed for this study.

CHEMICALS OF CONCERN

The chemicals considered for this study are the basic ingredients of biodiesel and the product itself: waste vegetable oil, methanol, potassium hydroxide, glycerol, and biodiesel. None of the chemicals are carcinogenic. The characteristics of each, as documented in material safety data sheets and other fact sheets, were reviewed and the pertinent safety and environmental issues were gleaned.

Table 1. Vegetable Oil

Flammability Hazard Rating	1 (Slight)
Flash Point	255°C (491° F)
Ignition Temperature	445°C (833° F)
Typical Exposure Path	Inhalation
Toxicity	Avoid inhalation. No known effects from chronic exposure
Environmental Toxicity	• Non-toxic to aquatic and terrestrial organisms.
Special Handling Requirements	• Do not inhale. • Absorb spill with an inert, dry material and wash with soap and water. • The repeated heating of vegetable oil leads to the formation of aldehydes and acids (Button).

Source: ScholAR

Environmental, Health and Safety Note: Khan, Lakhal, and Islam offer that "The advantages of biodiesel are even higher if currently used chemicals and catalysts are substituted with non-toxic and natural catalysts…" (pg 531). Research to date has not found another source detailing such alternatives, but the possibility for operator safety is worth consideration.

Button adds, "biodiesel showed no major dermal toxicity in test animals. Also, oral toxicity was determined to have a lethal dose for half the population (LD_{50}) of at least 5000 mg/kg in laboratory rats" (2009, page 1317). Furthermore, dermal exposure to biodiesel is reported to not cause "diesel dermatitis" (Kingwell and Plunkett, pg 10).

Table 2. Methanol

Flammability Hazard Rating	3 (High)
Flash Point	12°C (53.6° F)
Ignition Temperature	445°C (833° F)
Typical Exposure Path	Inhalation, Dermal, Oral
Toxicity	• Ingestion of 80 to 150 mL usually fatal. • 4000 ppm is roughly equivalent to 1140 mg/kg over the 12 hour period • No epidemiological data available on toxic dermal absorption level.
Environmental Toxicity	• Low acute toxicity to aquatic organisms • Unlikely toxic to terrestrial animals.
Special Handling Requirements	Absorb spill with an inert, dry material.

Sources: Tickell, EPA

Table 3. Potassium Hydroxide

Flammability Hazard Rating	Non-combustible
Flash Point	N/A
Ignition Temperature	N/A
Toxicity	Avoid inhalation.
Typical Exposure Path	Inhalation
Environmental Toxicity	• High acute toxicity to aquatic organisms • Unlikely toxic to terrestrial animals.
Special Handling Requirements	• Avoid contact skin or eyes. Severe burns can occur. • Absorb spill with an inert, dry material. • Avoid contact with water in containers. Exothermic reaction may ignite surrounding combustibles. • Reacts violently with strong acids. • Corrosive to metals in moist air. • Forms flammable and explosive hydrogen gas in moist air and poisonous potassium oxide gas in fire.

Sources: New Jersey, Oxford (2007)

HAZARD ANALYSIS

Potential Hazard Scenarios—What If? Being the only flammable and poisonous component, activities involving methanol were the most hazardous. Fire was deemed the next greatest concern. The effect of a spill on the environment was the third hazard category. Events were

Table 4. Glycerol

Flammability Hazard Rating	1 (Slight)
Flash Point	160˚C (320˚ F)
Ignition Temperature	370˚C (698˚ F)
Toxicity	No known effects from exposure
Typical Exposure Path	Avoid long term exposure to skin or inhalation.
Special Handling Requirements	• No special Personal Protective Equipment requirements. • Absorb spill with an inert, dry material and wash with soap and water. • Potential slipping hazard if spilled. • Acrolein, a toxic substance, is produced when burned (Button).

Sources: Oxford (2005), Science Stuff

Table 5. Biodiesel

Flammability Hazard Rating5	1 (Slight)
Flash Point	130˚C (266˚ F)
Ignition Temperature	N/A
Toxicity	No known effects from exposure
Typical Exposure Path	Inhalation of heated vapors, dermal and ingestion may cause irritation.
Special Handling Requirements	• Absorb spill with an inert, dry material. • Wash with soap to remove slippery surface. • Biodegradable

Sources: National Biodiesel Board (ND), 3E

categorized both in terms of the physical process and by chemical to multi-parcel the system horizontally and vertically. Although some events occur in several categories, duplication has been avoided.

(Note regarding material flow: Most portions of the system are assumed to be piped and pumped between stages. Buckets are used to transfer both the raw biodiesel exiting the processor and the wash water to the next stage due to the need to visually inspect the effluent.)

Following the Potential: Activities Involving Methanol

What If Circulation Piping Burst?

The worst case condition would be a pipe downstream from an electric pump moving methanol from the storage drum to the mixing tank. Pure methanol would be pumped onto the floor until shutdown. See methanol storage drum spill discussion. Since this would never be an automated process, the entire drum would not be drained. The outfall would be under pressure, so the alcohol would be spread much farther than a simple leak and the liquid would be atomized—with the increased flammability of fumes rather than liquid.

What If The Methanol Delivery Pump Seizes And Ignites?

Liquid methanol would drain back into the storage tank, but the supply pipe would be filled with fumes. The fire at the pump would ignite the fumes and the vented methanol storage drum would ignite. If the vent was not sufficient to relieve the pressure, the drum would explode.

What If The Heat Exchanger In The Methanol Recovery Process Overheated?

The pressure would increase until the tank exploded (Potter). A pressure relief valve on the tank is the safety mechanism intended to avoid this.

Following the Potential: Fire

What If The Methanol Fumes Contacted The Mixer Motor Arcing?

The mixer motor would be outside the tank, so the uncontained fumes will flame but not explode. Any roof sheathing, trusses, or combustibles stored in the rafters above the mixer tank may ignite if the fire is not extinguished quickly.

What If The Heating Element In The Processor Overheated?

The pressure would increase until the tank exploded. A pressure relief valve on the processor tank is the safety mechanism intended to avoid this. If the ignition temperature is reached, the oxygen in the tank could ignite, but without an external source of oxygen, the fire would quickly extinguish (Potter).

What If Methanol Fumes Contacted The Laboratory's Oil-Burning Furnace?

The uncontained fumes would burn very quickly. If combustibles are in the vicinity of the flames, they may be ignited. Without a spill, it is unlikely that a significant amount of fumes would escape at sufficient concentration to be an explosion hazard.

What If Non-Explosion-Proof Switches
Or Faulty Wiring Ignites The Methanol Fumes?

Given sufficient volume of fumes, arcing wires could cause a fire. This is particularly true if, for example, a tank leaked overnight and a light was turned on first thing in the morning. A spark from the light switch could ignite the fumes contained in the laboratory.

What If An Unrelated Machine In The Room Ignites The Fumes?

See wiring and furnace assessments above.

Following the Potential: Chemical Spill

What If A Full Methanol Storage Drum Tipped Over?

Assume doors are blocked to contain the liquid within the shop walls. Any spark will ignite the fumes. Any wood that absorbs the alcohol will retain the flammability of the methanol perhaps for several days and become a fuel source if the residual fumes are ignited (Potter). Mechanical ventilation may ignite the fumes.

What If The Mixing Tank Tipped Or Split Suddenly?

This is a similar scenario as above with a smaller volume of alcohol. Caustic catalyst complicates cleanup.

What If The Processor Ruptured Immediately After The Reactant Is Added?

The reaction has not yet occurred, so the alcohol's flammability is a hazard, but it is diluted by the non-flammable vegetable oil. The vegetable oil is biodegradable.

What If A Bucket Of Raw Biodiesel Is Spilled While The Drain Valve Is Open?

Residual alcohol and its associated fumes could ignite if an ignition source is present; however, the methanol will be a minor portion of a solution with a non-combustible. With the drain valve open, the entire batch would eventually spill.

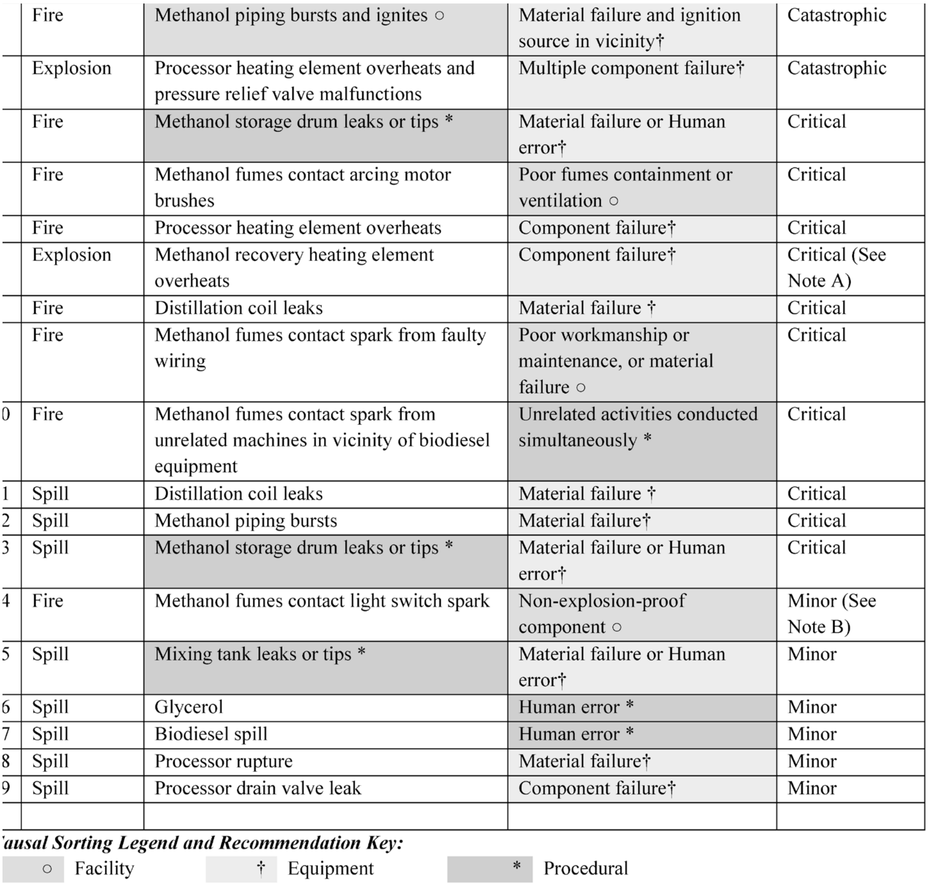
What If The Distillation Coil Leaked?

A relatively minor amount of methanol would spill becoming a fire hazard. See methanol storage drum spill discussion.

What If The Finished Biodiesel Storage Tank Leaks?

The finished product, like all of the components, biodegrades in time. That time is roughly one quarter the time of petroleum diesel or three weeks (Button). The slipping hazard noted for glycerol should also apply to the biodiesel.

Table 6. Preliminary Hazard List and Safety Analysis



	Fire	Methanol piping bursts and ignites ○	Material failure and ignition source in vicinity†	Catastrophic
	Explosion	Processor heating element overheats and pressure relief valve malfunctions	Multiple component failure†	Catastrophic
	Fire	Methanol storage drum leaks or tips *	Material failure or Human error†	Critical
	Fire	Methanol fumes contact arcing motor brushes	Poor fumes containment or ventilation ○	Critical
	Fire	Processor heating element overheats	Component failure†	Critical
	Explosion	Methanol recovery heating element overheats	Component failure†	Critical (See Note A)
	Fire	Distillation coil leaks	Material failure †	Critical
	Fire	Methanol fumes contact spark from faulty wiring	Poor workmanship or maintenance, or material failure ○	Critical
0	Fire	Methanol fumes contact spark from unrelated machines in vicinity of biodiesel equipment	Unrelated activities conducted simultaneously *	Critical
1	Spill	Distillation coil leaks	Material failure †	Critical
2	Spill	Methanol piping bursts	Material failure†	Critical
3	Spill	Methanol storage drum leaks or tips *	Material failure or Human error†	Critical
4	Fire	Methanol fumes contact light switch spark	Non-explosion-proof component ○	Minor (See Note B)
5	Spill	Mixing tank leaks or tips *	Material failure or Human error†	Minor
6	Spill	Glycerol	Human error *	Minor
7	Spill	Biodiesel spill	Human error *	Minor
8	Spill	Processor rupture	Material failure†	Minor
9	Spill	Processor drain valve leak	Component failure†	Minor

ausal Sorting Legend and Recommendation Key:

○ Facility † Equipment * Procedural

Note A: Explosion of the methanol recovery system is rated "Critical" because the methanol is in solution with a relatively large quantity of wash water thereby reducing the probability of an accompanying fire.

Note B: Light switch locations will be below the concentration of fumes at ceiling level. The probability of fire is unlikely.

RISK ASSESSMENT PROCESS

Broad severity categories were assigned to each hazard. These categories are:

- "Catastrophic," an event considered likely to cause death or severe injury,
- "Critical," an event that may cause severe injury,
- "Minor," an event potentially resulting in minor injury, and
- "Negligible," an event that does not result in injury.

Bahr includes affects on the mission of the operation as well as physical harm to persons in the vicinity in these ratings, but in the context of home-based biodiesel production mission is a nominal concern.

The "What-if" brainstorming identified three high-severity potential hazards. Those rated as "catastrophic" were selected for more detailed study. A Fault Tree Analysis (FTA) was performed on these three events.

A. Methanol storage tank explosion
B. Methanol circulation piping fire
C. Processor explosion

The FTA diagrams are in Appendices A, B and C, respectively. Very conservative probability estimates were assigned to all basic and intermediate events. The fault tree calculations were then assessed using Crystal Ball software in over ten thousand trials in a Monte Carlo simulation.

Fault Tree Analysis Findings

While challenges were expected, the findings of the Fault Tree Analysis were surprisingly negative. In risk management terms, there were strong possibilities for catastrophic failure and severe injury. There was approximately a 1 percent chance of a methanol storage drum explosion. An explosion of the biodiesel processor was less likely at 0.3 percent. Even the scenario of a fire in the methanol circulation piping (from the storage drum to the catalyst mixing tank) was unacceptably high at slightly more than one in ten thousand. From this collection of assumptions, backyard biodiesel production is a very dangerous hobby. Referring back to the estimate of home brewers in the overview, there should be mass media reports of over 60 methanol drums exploding per month nationally. Since there are not, the assumptions must be revisited.

First, all the probability estimates should be researched and refined with empirical data. Some may be over-estimating the risk by an order of magnitude.

A major element of two scenarios is an electric pump to move the methanol from the storage drum to the mixing tank. Kemp and others use manual pumps for this activity. What was perceived as a cost consideration may have a safety justification that is not explained in the literature.

Ventilation was not considered in any of the scenarios, yet two of the most serious outcomes were the result of a concentration of fumes coming into contact with an ignition source. The chance of ventilation failure would be a high-level intermediate event in the fault tree, and it would have to occur in conjunction with other events. That means the ventilator's failure would be depicted with an "AND" gate. Its effect would be to reduce overall risk by multiplying other factors by a very small number just as the pressure relief valve's failure affects the processor explosion scenario.

Some of the events in the FTA represent procedural errors. Operating unrelated equipment while processing biodiesel can easily be managed with operational protocols or changes in the facility that physically separate the biodiesel processing space from any other activities. Similarly, the heating plant for the space could be located outside the area. Since both of these scenarios are assessed through an "OR" gate, they are added to the facility's risk exposure.

Finally, some perceived threats may be unwarranted. For example, "faulty wiring" was included as a potential risk because the nature of home brewing and the do-it-yourself tenor of instructional sources suggested that untrained homeowners may attempt to do their own electrical work in building their refineries. Undersized wires, overloaded circuits, or poorly-located components are all potential ignition sources. An assumption that all wiring would be done by qualified professionals would remove this risk, but that may not survive surveys, observations, or other empirical checks. More data on actual home refinery conditions are needed to assess whether some of the risks included are real concerns.

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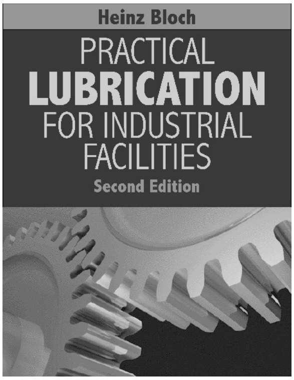

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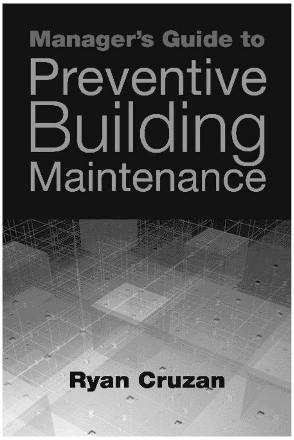

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Failure Modes and Effects Analysis

The findings of the Fault Tree Analysis suggested validation with another method. Failure Modes and Effects Analysis (FMEA) calculates a Risk Priority Number (RPN) based on the severity of the event, frequency of occurrence, and the ability to detect it. The definitions have been customized match the activity. These characteristics are defined in Table 7.

High RPNs indicate a condition that requires corrective action. The threshold for corrective action is up to the operator. The maximum RPN is 1000, so a threshold factor of 100 would yield 90 percent confidence in safe, productive operation for the failure mode in question. The comfort level for risk aversion will be different for every home brewer; however, the 90 percent confidence level is probably a good goal for all. A reasonable corrective action plan would be to improve the highest RPNs and continue improvements and revisiting the FMEA until no RPNs are above 100.

FMEA is intended to rate every component of a process for a very detailed view of what could go wrong and what it means to the operation, product, customer satisfaction, and persons nearby. It can be laboriously comprehensive, but that may not be meaningful given the level of sophistication of home brewing generally. This is particularly true of testing regimes for quality assurance and process control systems. For purposes of comparison here, the FMEA will use the events of the FTA.

The Risk Priority Numbers resulting from the Failure Modes and Effects Analysis show that electrical wiring is the highest risk component of the biodiesel production process/facility. This is followed by use of a pump not designed to transfer alcohol and thermocouple failure.

RECOMMENDATIONS

Facility Design Issues

All electrical wiring should be installed by a qualified electrician to the applicable building code. Light switches and fixtures should be explosion-proof units. The use of extension cords should be prohibited or extremely limited.

No open flames or spark-producing equipment should be employed in the refinery space. The biodiesel processing area should be

Rating	Severity		Occurrence		Detection	
	Description	Definition	Description	Definition	Description	Definition
10	Dangerously High	Death or severe injury	Failure almost inevitable	> 3/10 batches	Absolute Uncertainty	Not inspected or not detectable
9	Extremely High	Injury to bystanders	Failure as likely as not	3/10 batches	Very Remote	Inspected but difficult to detect
8	Very High	Equipment inoperable	Repeated failures	5/100 batches	Remote	Samples inspected but not tested
7	High	Unacceptable quality	Often fails	1/100 batches	Very Low	Inspected during process
6	Moderate	Unacceptable process delay	Frequent failures	$3/10^3$ batches	Low	Process inspected
5	Low	Tolerable process delay	Occasional failures	$5/10^4$ batches	Moderate	Samples inspected offline
4	Very Low	Requires minor adjustment	Infrequent failures	$6/10^5$ batches	Moderately High	Product 100% inspected
3	Minor	Nuisance	Few failures	$6/10^7$ batches	High	Samples laboratory tested
2	Very Minor	Adjustment more costly than problem	Virtually no failures	$2/10^9$ batches	Very High	Product 100% laboratory tested
1	None	Failure unnoticeable	Failure unlikely	$< 2/10^9$ batches	Almost Certain	Defect obvious

Source: Resource Engineering, Inc. (2004)

Table 7. Failure Modes and Effects Analysis Ratings

Table 8. Failure Modes and Effects Analysis Workchart

	Specific Hazard Description	Severity	Occurrence	Detection	RPN
	Methanol Storage Drum Explosion				
1	Fuse Malfunctions	8	1	10	80
2	Power Surge	9	3	1	27
3	Static	5	2	1	10
4	Faulty Wiring	9	4	10	360
5	Bad Ground	9	4	10	360
6	Pump not Designed for Alcohol	9	5	7	315
7	Electric Pump Ignites	10	3	5	150
8	Methanol Supply Line Ignites	10	4	5	200
9	Drum Vent too Small for Gas Expansion	10	2	5	100
	Methanol Circulation Piping Fire				
1	Fuse Malfunctions	8	1	10	80
2	Power Surge	9	3	1	27
3	Static	5	2	1	10
4	Faulty Wiring	9	4	10	360
5	Bad Ground	9	4	10	360
6	Unrelated Machinery Operating in Refinery Space	10	4	1	40
7	Open Flame Heating Source	10	4	2	80
8	Atomized Alcohol Reaches an Ignition Source	10	1	1	10
9	Methanol Supply Line Bursts Downstream of Pump	10	3	1	30
	Processor Explosion				
1	Sacrificial Anode Failure	1	5	4	20
2	Electrolytic Corrosion	2	3	5	30
3	Thermocouple Failure	4	5	3	60
4	Fuse Malfunctions	8	1	10	80
5	Power Surge	9	3	1	27
6	Thermocouple Fails to Control Temperature	10	5	6	300
7	Rust or Corrosion	2	3	7	42
8	Clogged Pipe/Inlet	4	3	2	24
9	Poor Calibration	4	4	9	144
10	Pressure Relief Valve Malfunctions	10	2	9	180
11	Heating Element Overheats	9	2	8	144

dedicated to biodiesel production. No other activities using motors should be conducted in the space. No heating equipment employing open flames should be collocated in the space. Forced hot air or circulated hot water (via baseboards or radiators) should be fed by furnaces outside the refinery space. Similarly, diesel generators for off-grid electricity should be external.

Ventilation is necessary for safe operation. Ventilation fans using explosion-proof motors must be employed whenever methanol is uncontained. A ventilator hood over the methanol storage and mixing areas is preferred, but a wall-mounted unit capable of ventilating the entire refinery area is acceptable. Opening a window is too passive given the danger (flammable and poisonous) of methanol fumes. Consider storing the methanol outside the refinery space, particularly in an open air space adjacent to the processing area.

Floor and walls should be constructed of impervious materials. If a spill should occur, floors and walls made of wood will absorb the spill. Aside from the slipping hazard, the increased danger of fire is prolonged by the slow release of fumes, and the cleanup is hampered.

Use only schedule 80 PVC piping, valves, and fittings designed for corrosive chemical applications.

Precautionary Rules and Procedures

Appropriate personal protective equipment must be used when processing biodiesel. Examples include non-absorbent aprons and other exposed clothing, eye protection (preferably face shields), respirators to guard against methanol fume inhalation, and corrosive-resistant gloves.

Moving the methanol storage drum should be avoided. If necessary, it should only be moved with appropriately designed equipment such as drum dollies and forklifts. Electric pumps which are not designed or intended to transfer flammable liquids should not be used to transfer methanol.

No process liquids should be transferred in open containers. Buckets used to separate glycerol from the raw biodiesel or to move the product to the wash tank must be tightly covered prior to the transfer. Drain valves should be confirmed operational and closed prior to filling.

Check the status of valves prior to engaging an electric pump. Valves should be open from origin to destination and closed to isolate the destination from subsequent process stages.

Equipment

The processor should be checked periodically. An independent, external thermometer should be installed to check the accuracy of the control system. Consider installing a temperature and/or pressure sensor with an alarm. Inspect the pressure relief valve for corrosion and accurate operation. The drain valve should be confirmed to be working properly. The sacrificial anode should be removed, checked for corrosion, and replaced as necessary. The heating element should be removed, checked for corrosion and electrical contact, and fixed or replaced as necessary.

Use an explosion-proof mixer or bubble system on the catalyst mixing tank. Conical bottom tanks should have their frames fastened to the floor to avoid tipping.

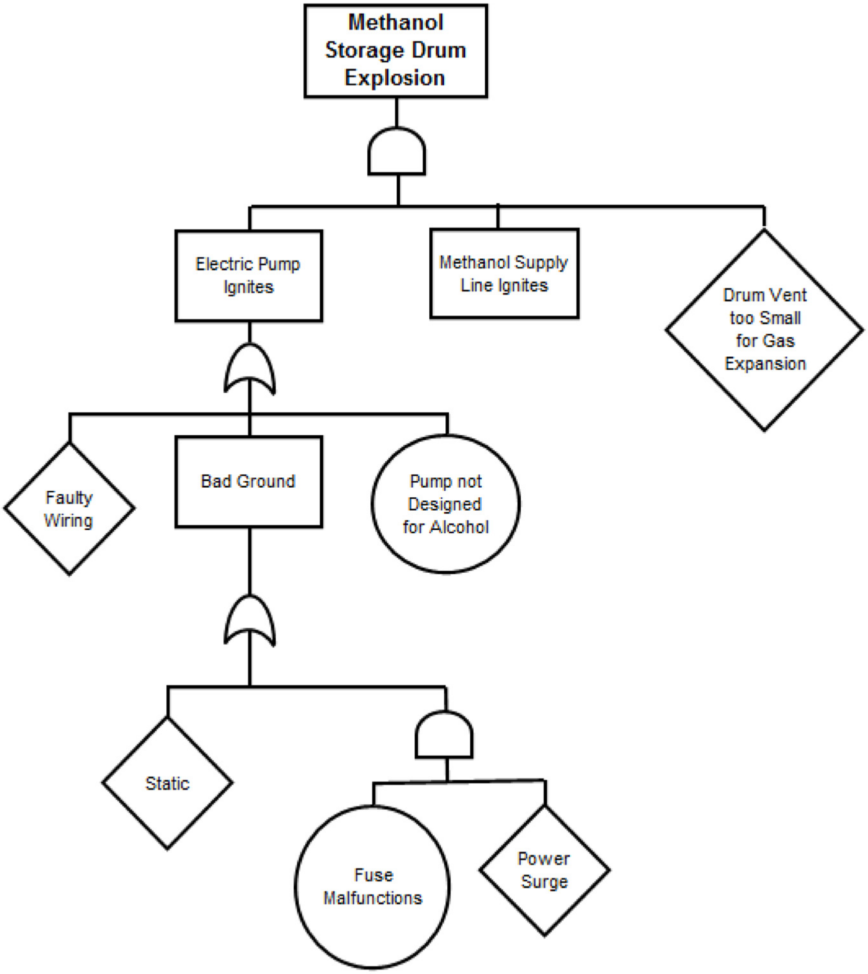
Inspect the distillation coil in the methanol recovery heat exchanger for signs of corrosion. Inspect the heating element and pressure relief valve as noted in the processor discussion above.

CONCLUSIONS

Small-scale, private biodiesel producers can safely create fuel. With forethought and care, these producers can be a solution to energy needs on a community scale. Without planning and respect for the ingredients and the biodiesel process, people can get seriously hurt and property can be damaged. More data is needed to refine a risk management strategy targeted at home brewers. Literature is generally lacking about the specific risks of hobby producers, although the study of industrial scale operations is growing. More educational opportunities by credible, academic providers would raise awareness and concerns for safe practices. There are relatively few high-risk portions of the transesterification process, but their understanding is vital to risk reduction for producers and their neighbors.

Endnote: The number of home brewers was estimated from the total number of passenger cars and light-duty trucks reported by the Energy Information Administration (203.4 million). The percentage of diesel vehicles in the United States from Evans (4%) was applied to quantify the population.

Appendix A: Fault Tree Diagram for Methanol Storage Drum Explosion



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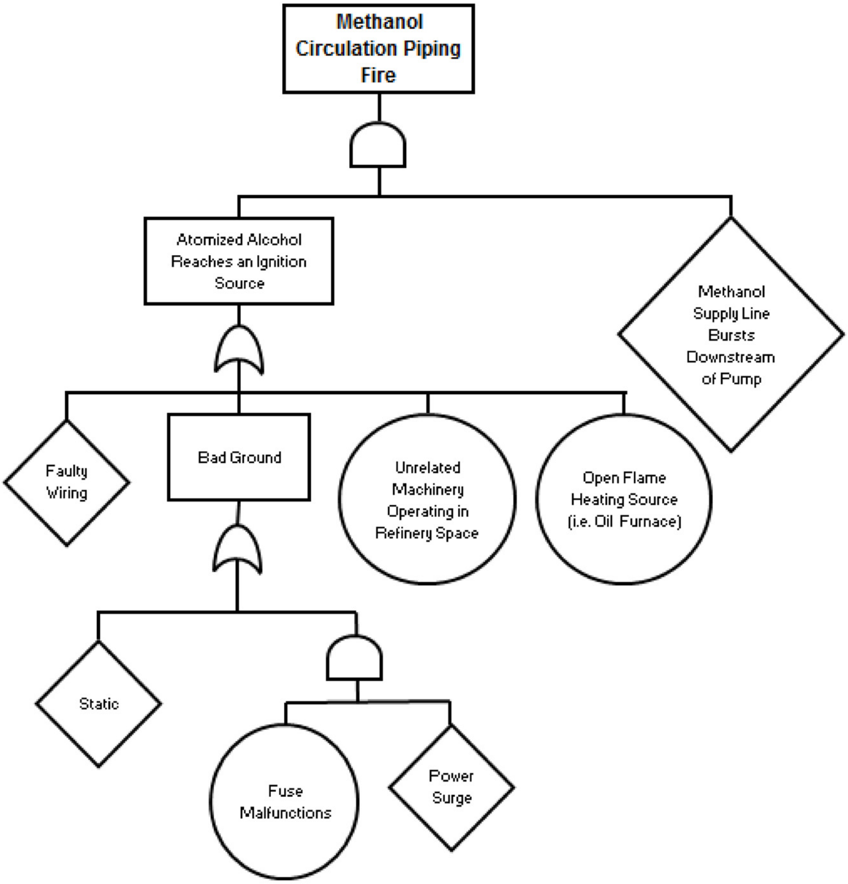
Appendix B: Fault Tree Diagram for Methanol Circulation Piping Fire



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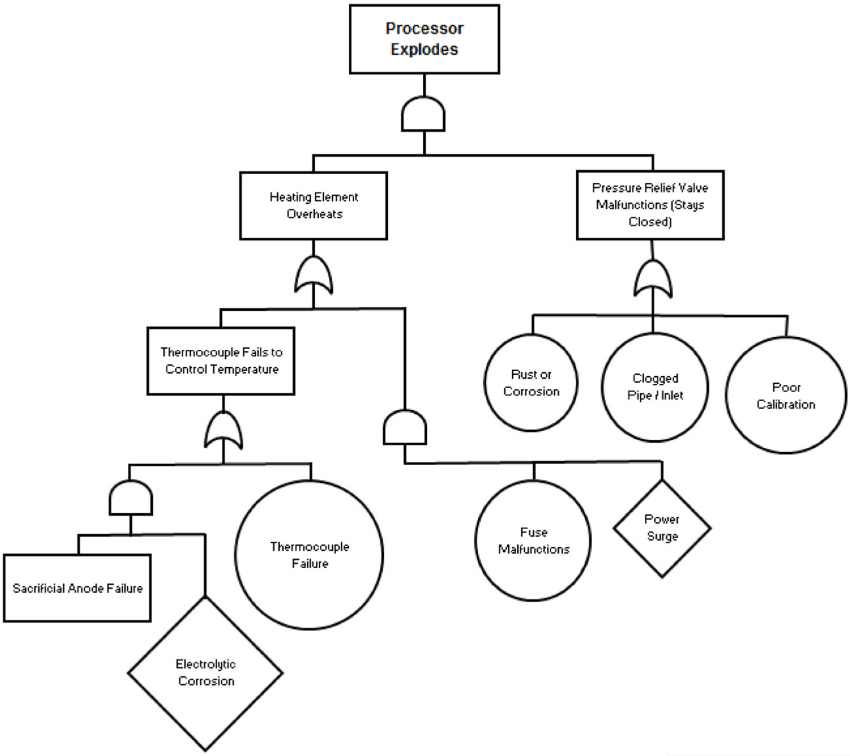
Appendix C: Fault Tree Diagram for Processor Explosion



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