WASTE COOKING OIL TO FUEL PROGRAM

"HOW TO START YOUR OWN BIODIESEL FUEL PROGRAM"

R·I·T

Syllabus

Topic 1: Biodiesel Basics/Fuel Properties

Topic 2: Overview of Biodiesel Production Using Waste Oil

Topic 3: Feedstock Sources for Making Fuel

Topic 4: Operation of the BioPro 190 Equipment

Topic 5: Waste Disposal and Byproducts

Topic 6: Biodiesel Fuel Quality Assurance

Topic 7: Greenhouse Gas Reduction Calculations

Topic 8: Program Cost Estimates

Question and Answer

Visit to EcoPark and demo of equipment at RIT

Topic 1: Biodiesel Basics

- What is Biodiesel?
  - A biodegradable, combustible fuel made from vegetable oils and/or animal fats
- Usually done by base-catalyzed trans-esterification of fats/oils (i.e. make a big multi-chain molecule into 3 smaller molecules)
- Can be used in any compression ignition engine that will accept regular diesel fuel
  - Engine does NOT need to be modified to use biodiesel blended with regular diesel

Biodiesel Basics

- **Fats/oils** are reacted with **alcohol** (methanol), using a strong **alkaline catalyst** (sodium hydroxide NaOH or potassium hydroxide KOH)

- This yields **mono-alkyl methyl esters** (biodiesel) and **glycerin**

Example:

100 pounds + 10 pounds → 10 pounds + 100 pounds

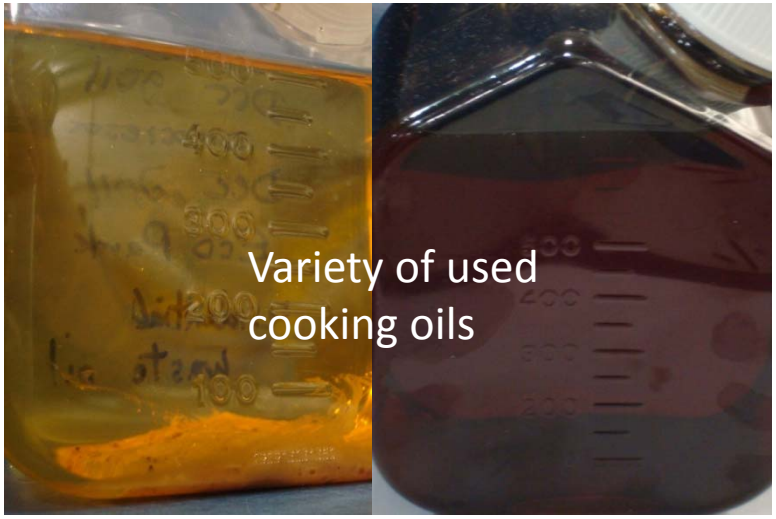
Triglyceride (Vegetable Oil) **Alcohol** (Methanol) **Glycerin** **Mono-Alkyl Methyl Esters** (Biodiesel)

Reaction 2: esterification to biodiesel

Methanol + KOH

Reaction 1: free fatty acid conversion

Sulfuric Acid + Methanol



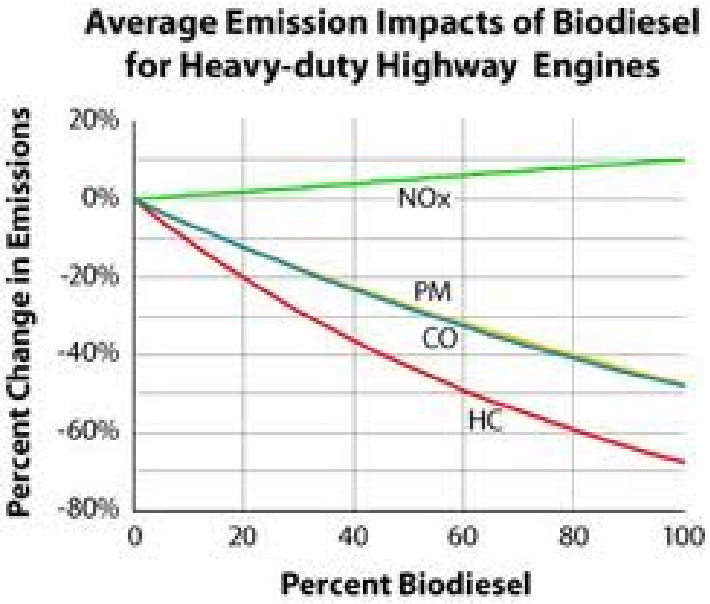
Biodiesel Basics

- Commercial biodiesel is sold as a "blend" with regular ultra low sulfur diesel (ULSD)
  - Example: **B10**
  - 10% biodiesel
  - 90% petroleum diesel
- Pure biodiesel is known as **B100 (100%)** or neat biodiesel
  - Normally B100 is **not used** in vehicle engines due to engine warranty concerns
  - Operation with biodiesel blends may result in very slightly **lower mpg** due to lower energy content
- Most vehicles are now warranted up to **B20** (20% biodiesel)

Biodiesel Fuel Properties

- Performance and handling of biodiesel:
  - Can be stored and handled exactly like regular diesel fuel
  - It has a higher flashpoint (minimum 130° C) and is therefore safer than petroleum diesel fuel (minimum 52° C)
  - It is biodegradable
  - Aids in keeping the fuel system clean
  - Improved engine lubricity
- Engine Emissions:
  - lower carbon monoxide (CO)
  - lower particulate (PM)
  - lower unburned hydrocarbons (HC)
  - increase or reduce NOx emissions*

*engine design dependent



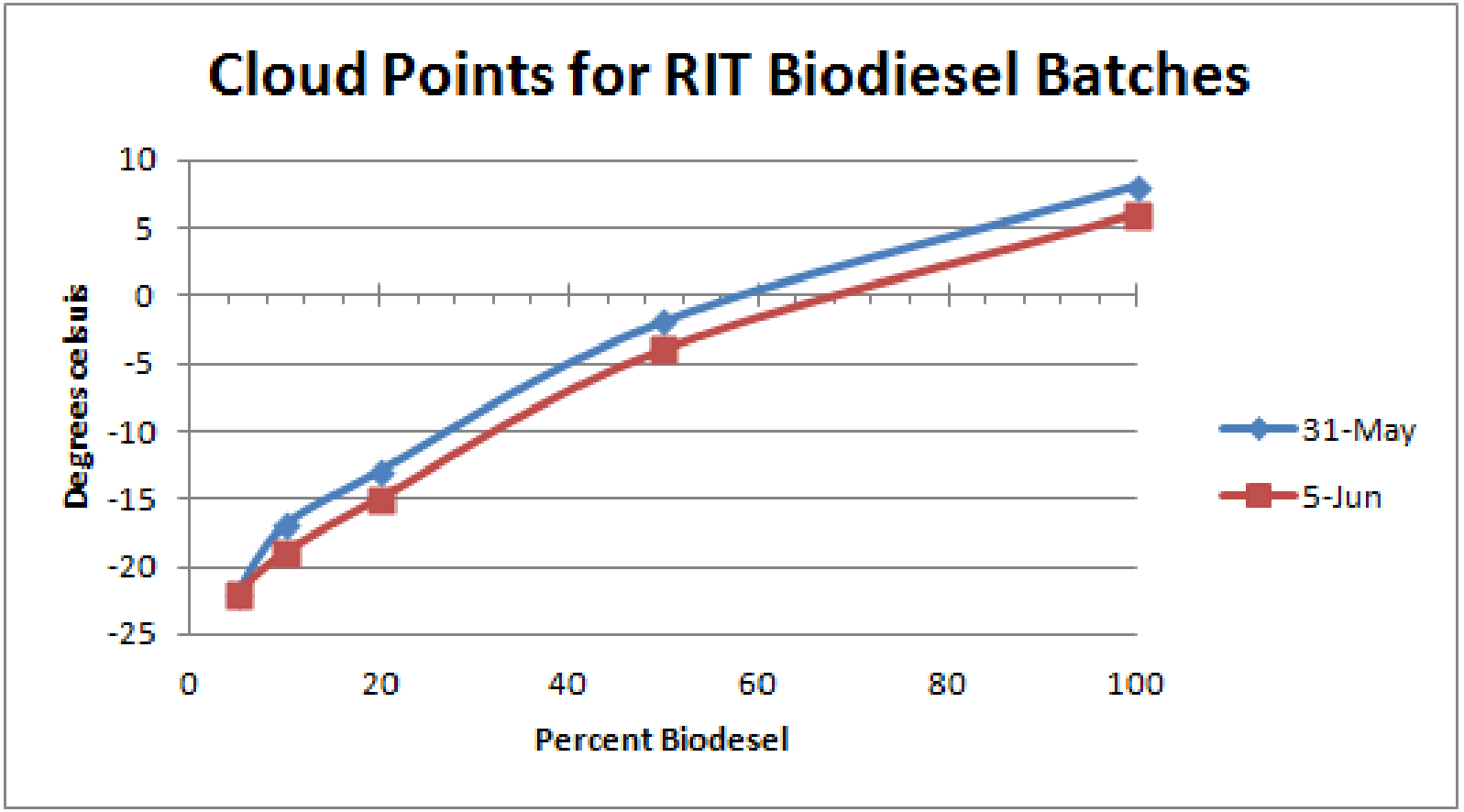
Biodiesel Fuel Properties

- Cloud Point
  - Most conservative temperature at which components begin to precipitate from the pure biodiesel fuel
  - May cause operability issues
  - Will vary significantly depending upon the feedstock

- Cloud point for B100 from various oils:
  - Soy biodiesel 32° F
  - Tallow (animal fat) biodiesel 50-55° F
  - Canola biodiesel 27°F
  - Palm (coconut) biodiesel 55-60° F

Diesel fuel ~ -4 to 13° F

RIT Cloud Point Data



Two ASTM-quality B100 batches had cloud points of 6 and 8°C (43 and 46°F)

Biodiesel Fuel Properties

- Storage:
  - Winter concerns (fuel gelling in storage tank)
  - Water concerns (fuel stability reduced by bacterial growth if water is present)
- Biodiesel blends will “gel” sooner than diesel blends at low temperatures
  - Outdoor, above ground storage tanks are potentially vulnerable to low temperature problems
  - Splash blending of biodiesel with petroleum diesel will not work well at temperatures below the biodiesel gel point (typically 16-32° F), but this can be handled by blending in kerosene as done with ULSD

RIT Study of Biodiesel Use

- RIT has an above ground tank to fuel 2 study vehicles on the campus
  - 3 year study
  - Monitored vehicle performance and emissions
- Various blends
  - B20 used for all winter driving
- Results:
  - No adverse effects were seen either in the vehicles or in the storage tank from the low winter temperatures.

Topic 2: Overview of Biodiesel Production Using Waste Oil

- The high viscosity vegetable oil must be chemically converted for it to operate properly in a diesel engine
  - Biodiesel conversion process does this
- Caution: DO NOT use raw vegetable oil in an engine no matter what you read on the internet!
- Raw vegetable oil cannot meet biodiesel fuel specifications
  - It is not registered with the EPA
  - It is not a legal motor fuel
  - It is high viscosity so burns poorly (poor atomization and varnish formation)
- It is important that the fuel produced meets the biodiesel ASTM standards, otherwise there could be engine damage.

Topic 3: Feedstock Sources For Making Fuel

- Any refined vegetable oils
- Obtained from
  - restaurants,
  - food courts,
  - snack bars,
  - cafeterias,
  - lunch trucks….
- Food production facilities may also have waste oil in **bulk storage**.

- Some municipalities have collection sites for **residential cooking oils**
  - Make sure cooking oil drop-off is not confused with used motor oil drop-off
- Some sources may already have contracted with **commercial companies** to dispose of the oil
  - they pay ~ $1 per gallon for waste oil.

Feedstock Sources For Making Fuel

- Important:
  - Line up your oil supplier(s) early and confirm their participation if using cafeteria or restaurant fryer oil
  - The higher the quality of the oil, the easier it is to produce high quality fuel

Fresh Oil:

- all of one type
- no free fatty acids
- no water
- highest cost

Restaurant Fryer Oil:

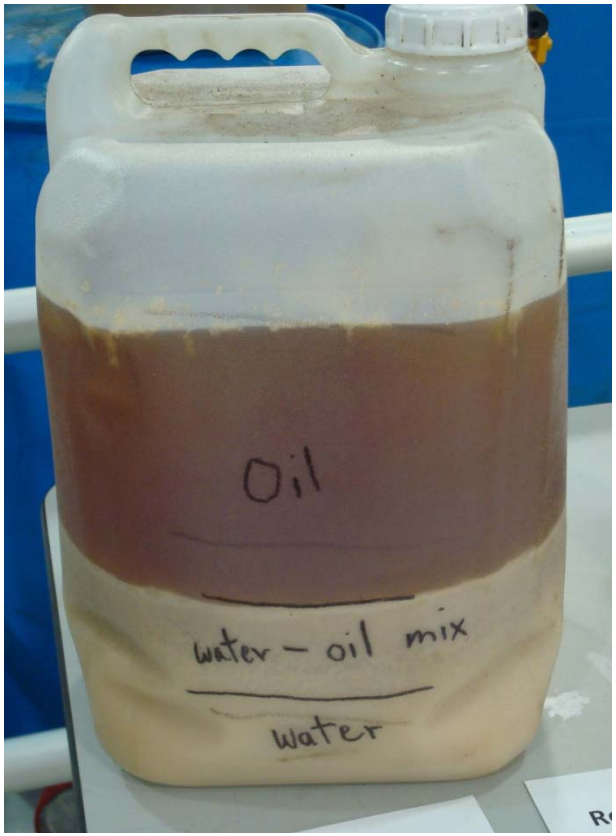
- typically all one oil type
- may contain water and food particles
- contains animal fats
- high free fatty acids
- lower cost
- compete with rendering companies for supply (They pay restaurants for their waste oil.)

Residential Cooking Oil:

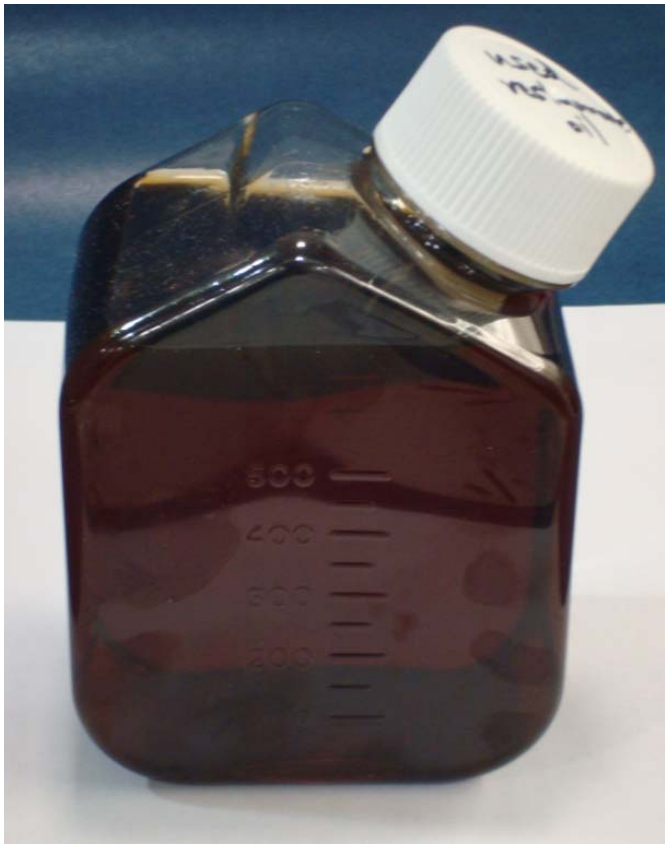
- mixed oils
- contains food particles
- contains water
- contains animal fats
- low in free fatty acids
- highly variable volume and quality
- only cost is collecting it

Production of Biodiesel Using Waste Cooking Oil

Residential Cooking Oil



Commercial Used Fryer Oil



Oil Collection Considerations

- Visually sort incoming oil
- Screening oil to remove large particles
- Settling tank to remove oil and oil-water emulsion
- 24-hour drying cycle to drive off remaining oil-water emulsion

Daphne Utilities, Alabama

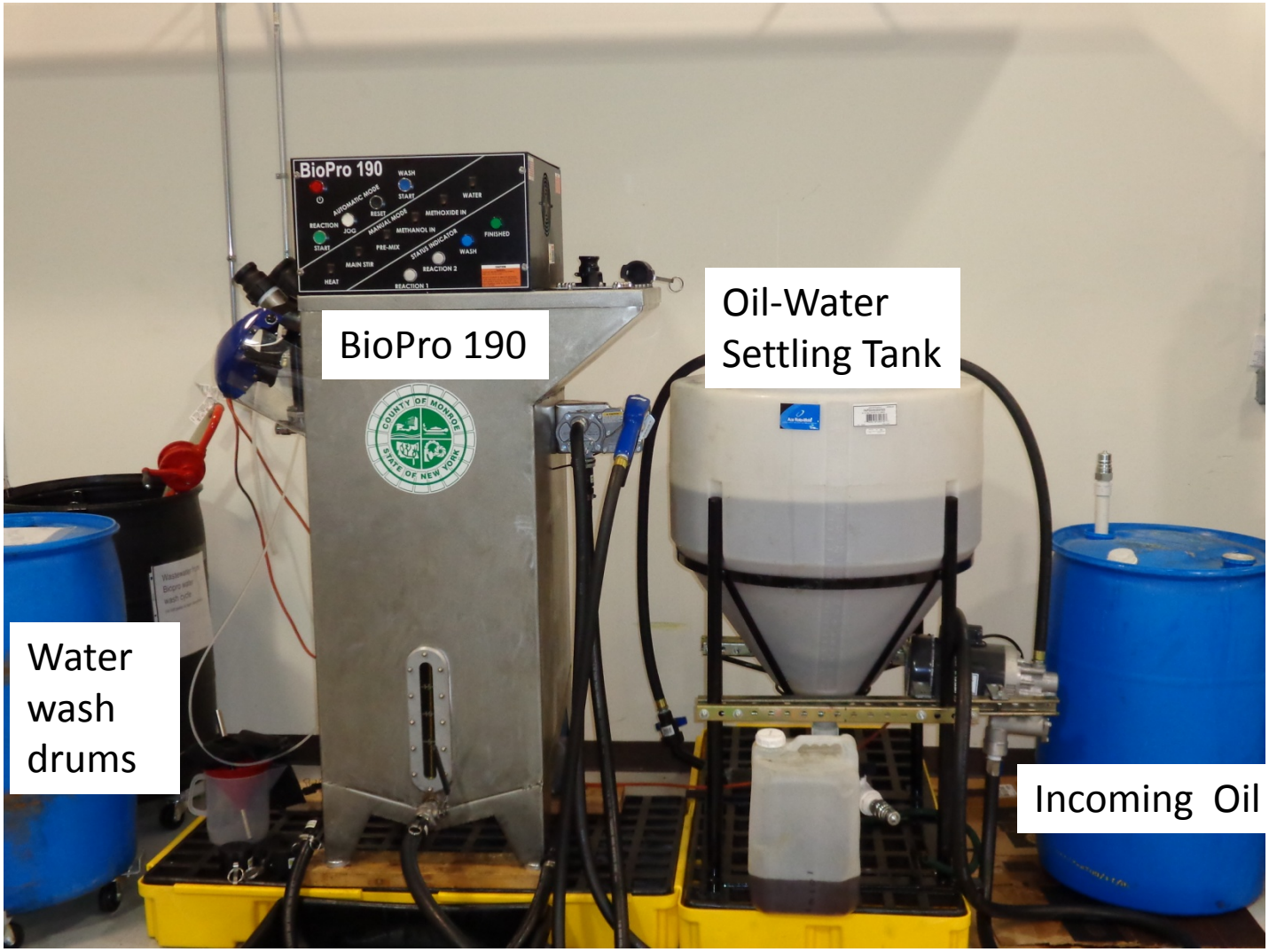
- Cooking oil collection program
  - Decreased the amount of oils going to the POTW
  - Collected in consumer friendly areas
- Oil used to make biodiesel
  - Started in 2006
  - Collect 300-500 gallons/month (population 22,000)

Daphne Utilities, Alabama

http://daphneutilities.com/daphne/recycle_bio.htm

- Started their whole program for ~$3,000
  - Recycling program
  - Homemade biodiesel equipment
- B20 blended and used in their fleet of vehicles
- $10,000 annual fuel cost savings
- Reduction of greases in the municipal waste water

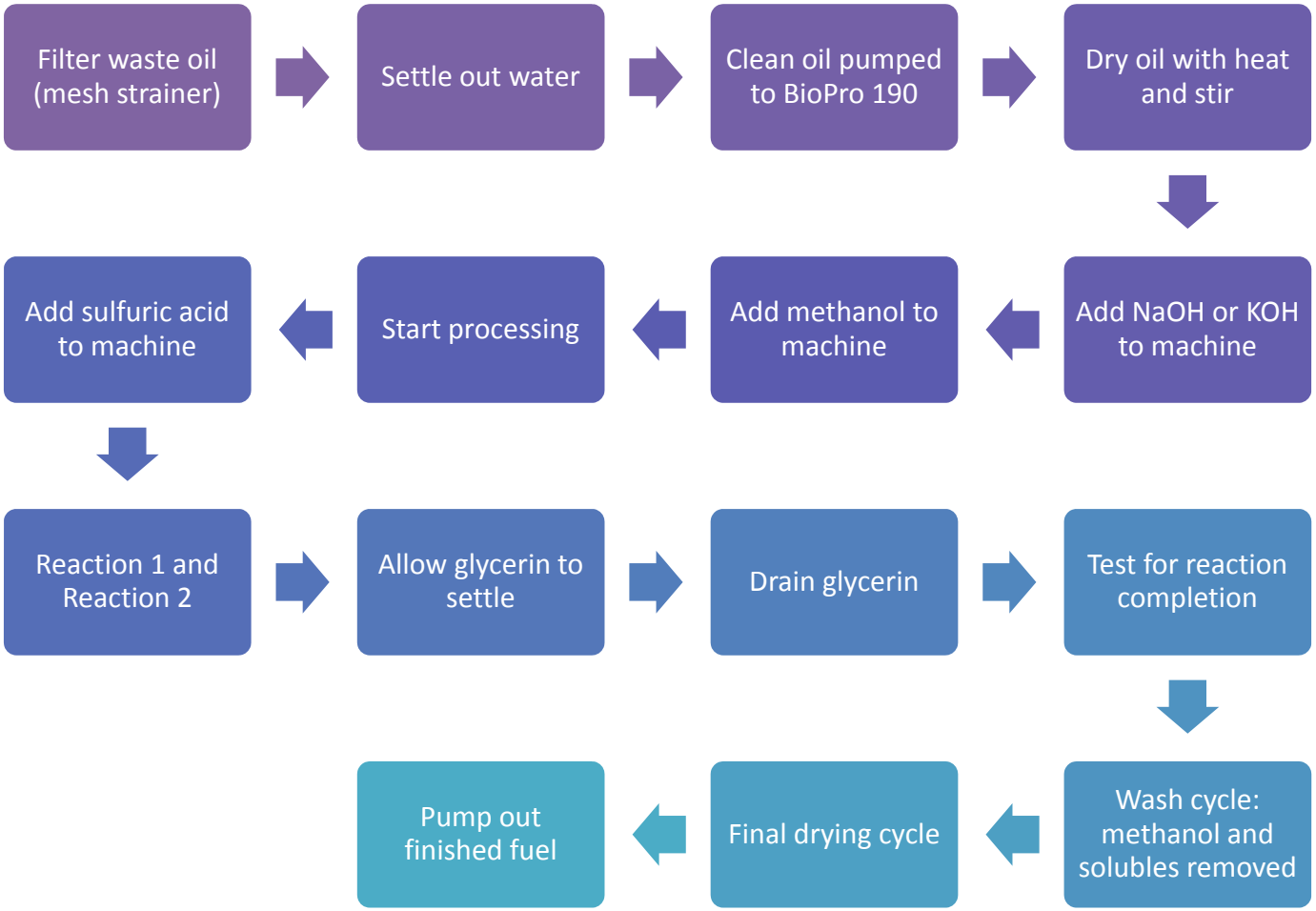
Topic 4: Operation of the BioPro 190 Equipment



Biodiesel Processing Equipment Requirements

- Biodiesel processing equipment (heating, mixing)
- Water supply
- Waste oil supply
- Clean drums
  - for strained oil
  - finished fuel
  - glycerin
- Containers, beakers, buckets of various sizes for chemical pouring, waste glycerin, and waste oil emulsion

- Safety Equipment
  - Face shield,
  - gloves,
  - apron
- Storage area for finished fuel
- Chemicals
  - KOH or NaOH
  - Methanol
  - Sulfuric Acid


Filter waste oil (mesh strainer)
Settle out water
Clean oil pumped to BioPro 190
Dry oil with heat and stir
Add NaOH or KOH to machine
Add methanol to machine
Start processing
Add sulfuric acid to machine
Reaction 1 and Reaction 2
Allow glycerin to settle
Drain glycerin
Test for reaction completion
Wash cycle: methanol and solubles removed
Final drying cycle
Pump out finished fuel

Factors Affecting the Biodiesel Reaction

Waste oil type: Bacon grease and other solid greases are not acceptable for biodiesel production since they raise the cloud point and could cause cold weather problems.

Restaurant fryer oils: Tend to be high in free fatty acids which results in lower yields of biodiesel due to soap production during the reaction.

High water content in the oil: Water impedes the biodiesel reaction resulting in only partial conversion of the oil to biodiesel.

The biodiesel process used at RIT was tailored for the residential cooking oil which tends to be high in water content.

Initial Oil Collection and Processing to Deal with Water

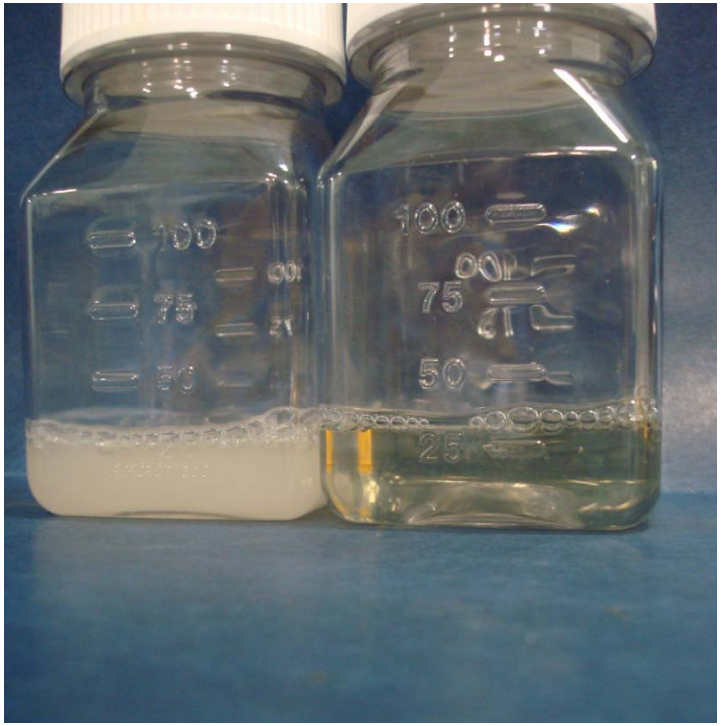
Visual sorting: Milky liquid is likely to be either high in water, animal fats, or both. This liquid is rejected.

Mechanical screening: To remove large food particles that could plug pumps

Settling Tank: To allow oil and oil emulsion to settle out (~24 hours) for removal before going to the processing tank

Pre-drying step: Once the oil is in the processing tank, it is heated and stirred for at least 12 hours to drive off any remaining water

Robust Process Considerations



- Use additional alkali to drive the reaction to completion
  - Approx 10% additional KOH
  - eliminates residual oil or glycerides at the end of the biodiesel reaction
- Test for completion with 27-3 test
  - Re-run batch If reaction not complete using 190 grams of KOH and 2 gal of methanol

Robust Process Considerations

- Use water wash to remove reaction by-products
  - Salts
  - Residual Glycerin
  - Residual Methanol

Topic 5: Waste Disposal and Byproducts

The biodiesel production process results in two primary waste products:

- Waste water from the fuel washing process (approximately 1 gallon of water for every gallon of biodiesel)
- Glycerin is drained off at the end of the fuel production process (approximately 1 gallon for every 3 gallons of biodiesel)

*Both the waste water and glycerin have small amounts of methanol in them.

Glycerin Disposal

- Crude glycerin is not a high value commodity.
  - At 2¢ per lb., 15 gallons of glycerin = $3 (excluding shipping)
- Crude glycerin from the biodiesel conversion process has three possible uses:
  - Compost accelerator
  - Methane booster in anaerobic digesters
  - Soap production
- Low end disposal
  - send to the local wastewater treatment facility (with permission)

Daphne Utilities, Alabama

- The glycerin byproduct was used to make soap
- Little soaps are their main marketing tool in schools

Topic 6: Biodiesel Fuel Quality Assurance

- ASTM D6751 Testing Requirements:

ACID NUMBER - ASTM D664
ASH, SULFATED RESIDUE - ASTM D874
CARBON RESIDUE, RMS, % WT - ASTM D524
CETANE NUMBER - ASTM D613
CLOUD POINT - ASTM D2500
COPPER CORROSION, STRIP - ASTM D130
DISTILLATION, (REDUCED PRESS.) - ASTM D1160
FLASH POINT (PMCC) - ASTM D93
GLYCERIN, FREE & TOTAL - ASTM D6584
OXIDATION STABILITY (ACCEL.) - ASTM D2274
POUR POINT - ASTM D97
SEDIMENT & WATER (BS&W) - ASTM D1796 / D2709
SULFUR CONTENT - ASTM D4294
SPECTROCHEMICAL, ppm - ASTM D6728
VISCOSITY @ 40 DEG - C ASTM D445

- Testing costs can be $325 or more per sample

Screening Tests

- Raw waste oil
  - Free fatty acids, > 5% will have problems (depends on oil source)
  - Water content, Karl Fischer test
- Finished biodiesel
  - 27-3 test to screen for completion of the biodiesel reaction
    - 3 ml. of biodiesel
    - 27 ml. of methanol
  - If the biodiesel fails the 27-3 test, it will not pass the ASTM test

Topic 7: Greenhouse Gas Reduction Calculations

Using published equations, the level of greenhouse gas (GHG) emissions reduction from production of biodiesel fuel can be calculated based on the known amount of waste grease converted

CO_2 produced by combustion of 1 gallon of petroleum-based diesel[1]= 22.2lbs.

GHG emissions reduction from replacing petroleum-based diesel with biodiesel[2] = 86%

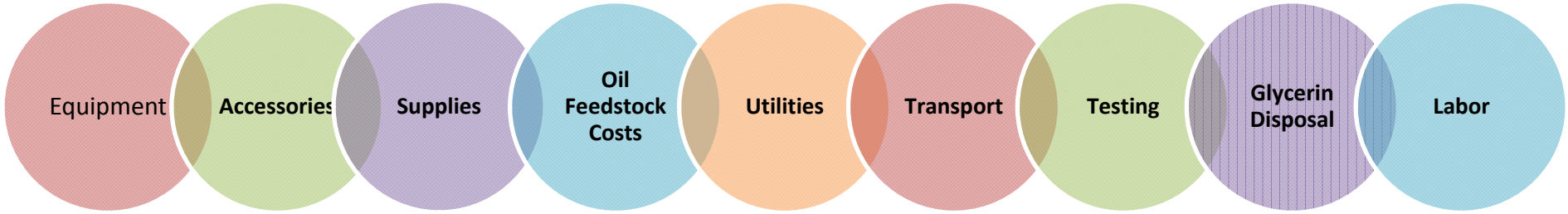
GHG emissions reduction (in tons) = {[Waste oil in gallons]*22.2*0.86} / 2000

For Monroe County, there is a potential GHG emissions reduction of 21,800 tons/year

[1] Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel, US Environmental Protection Agency, EPA420-F-05-001, Feb 2005.
[2] Environmental Protection Agency, Renewable Fuel Standards Program Regulatory Impact Analysis, released in February 2010 (http://www.extension.org/pages/Used_and_Waste_Oil_and_Grease_for_Biodiesel).

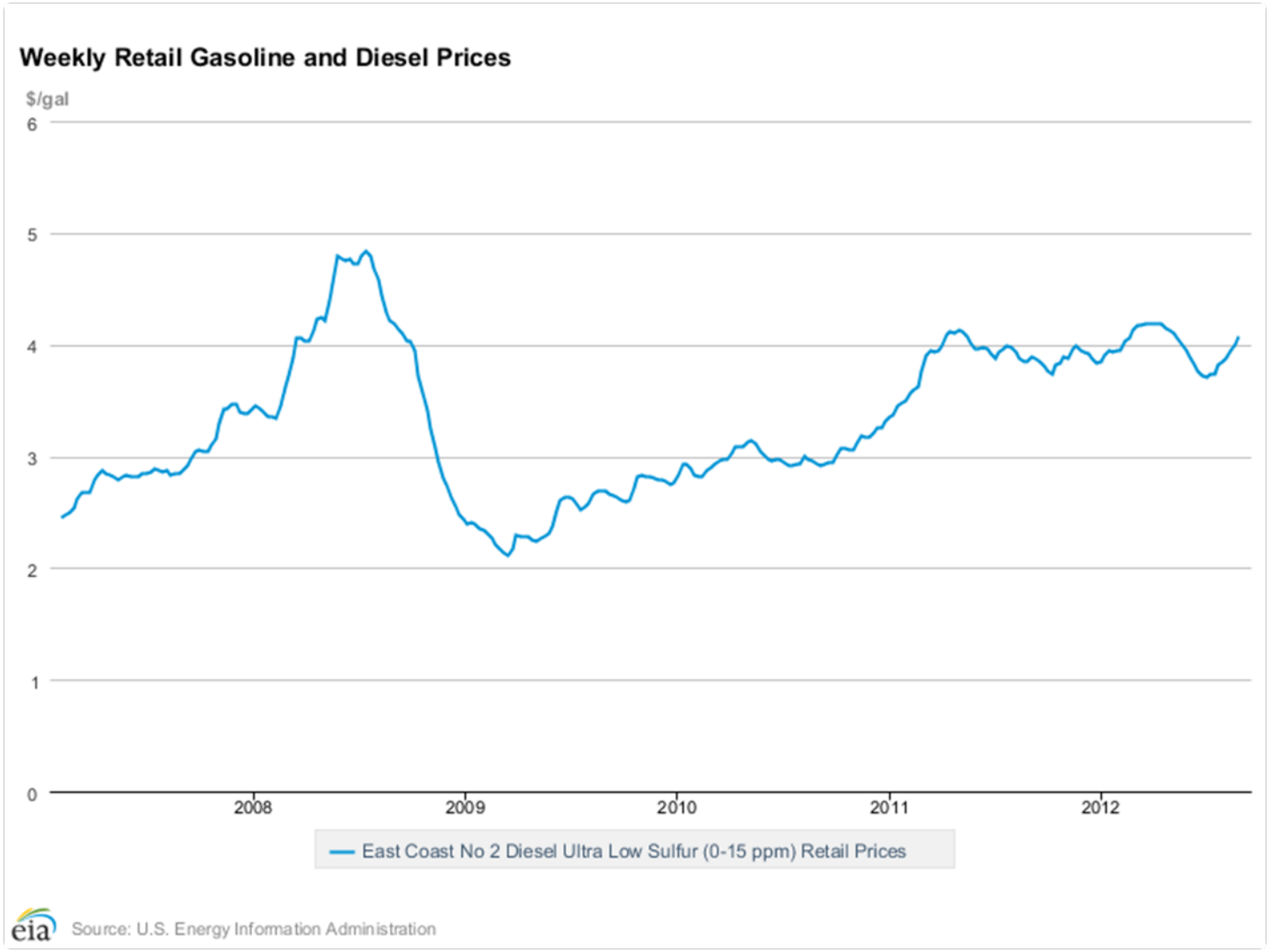
Topic 8: Program Cost Estimates

- A **make-or-buy trade study** on the costs and benefits of a do-it-yourself program
  - Components of program cost:



- What volume of biodiesel can you consume in a year? (B5, B10, B20?)
- All balanced against selling the waste oil outright, if possible, and buying your own regular diesel fuel @ ~ $4 per gallon

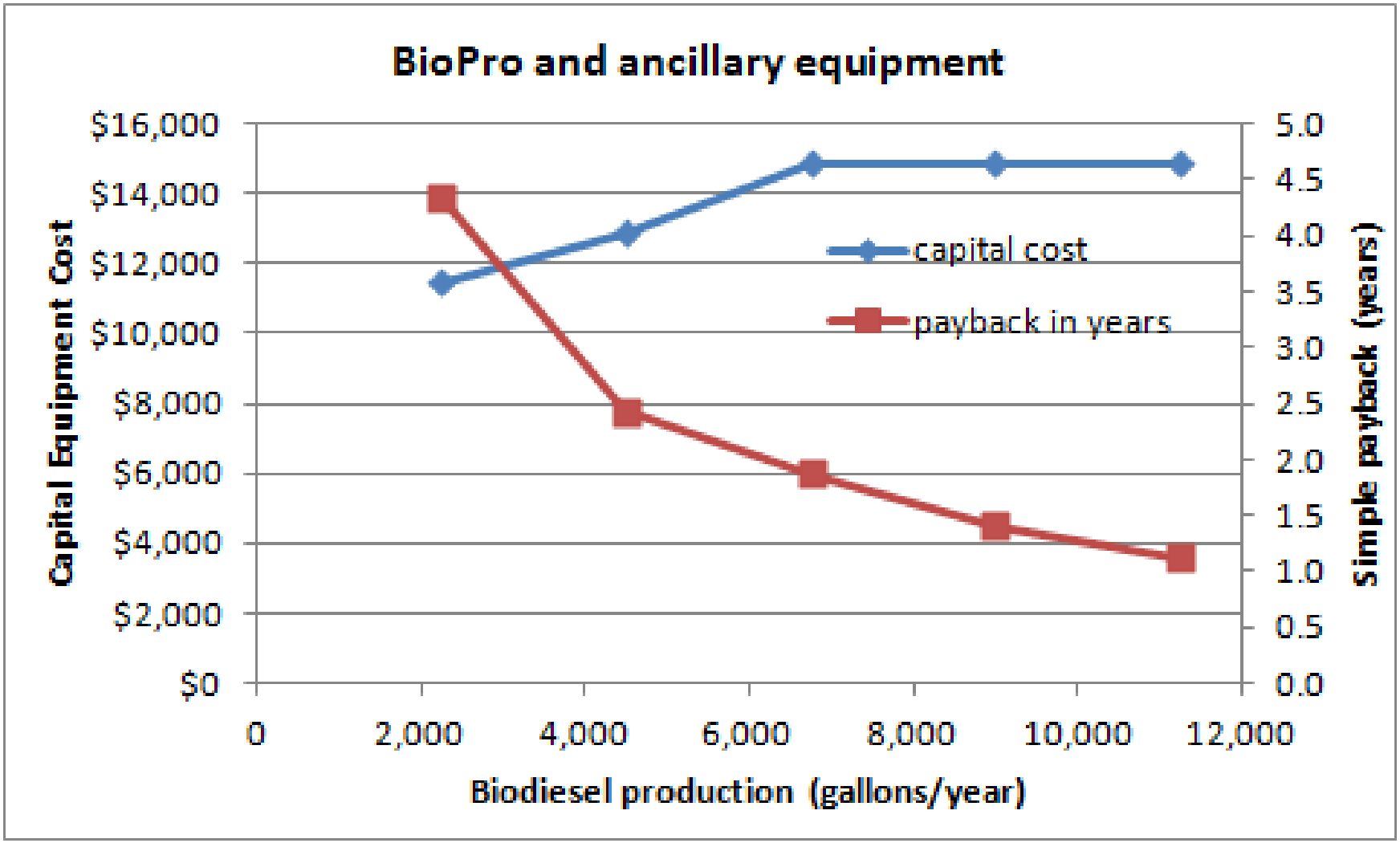
Diesel Prices East Coast



$4 per gallon

Cost item	Task	Time (hours) or quantity (lb, kWh, or gallons)	Units	Cost basis	Cost basis units	Cost per gallon produced (assume approx. 45 gallons per batch)
labor, oil collection	collect 55 gallons of waste cooking oil	1	hours	$30.00	fully burdened labor rate	$0.67
labor, oil conversion	run full biodiesel conversion process, including cleanup	1.25	hours	$30.00	fully burdened labor rate	$0.83
KOH	biodiesel reaction	2600	g.			$0.12
methanol	biodiesel reaction	10	gallons			$0.81
sulfuric acid	biodiesel reaction	190	ml.			$0.08
Bioextend 30	227 ml/45 gallons	227	ml.	$300/44 lb of Bioextend		$0.08
waste glycerin disposal	dispose of 45 gallons (3 batches)	0.5	hours	$30.00	fully burdened labor rate	$0.11
electricity	to run full cycle of the BioPro 190	54.4	kWh	$0.11	$/kWh	$0.13
					$/gallon of biodiesel	$2.83
					Total biodiesel cost per year	$6,361.13
gallons of biodiesel produced	NA	2250	gallons/ year	$4	gallons of diesel displaced by biodiesel	$9,000
						$2,639
BioPro and other equipment cost	$11,443				equipment payback in years	4.34

Payback period reduction through higher biodiesel production volumes



Summary

- Biodiesel
  - Safe and effective diesel replacement with some operational advantages over petro-diesel
  - Can be made from waste cooking oil
  - Reduces the amount of greenhouse gas emissions
- The equipment
  - Is commercially available
  - Can produce road-quality biodiesel
- The decision
  - “make-or-buy” calculations

References/Sources

- The Biodiesel Handbook (2nd Edition) by Gerhard Knothe, J. Krahl, J. Van Gerpen. Urbana IL: AOCS press, 2010.

- National Biodiesel Board: www.nbb.org

- Springboard Biodiesel: www.springboardbiodiesel.com

- U.S. Department of Energy Alternative Fuels Center: www.afdc.energy.gov/afdc/

- Coordinating Research Council: Biodiesel study reports, www.crcao.com/publications/index.html

Demo of BioPro Equipment

Biodiesel Fact Sheet

Rochester Institute of Technology — September 2012

Biodiesel fuel facts:

- Can be used in any vehicle or equipment that runs on petroleum diesel
- Typically biodiesel is used in blends up to 20% (B20) in summer and 5% (B5) in winter.

Biodiesel advantages over petroleum diesel fuel:

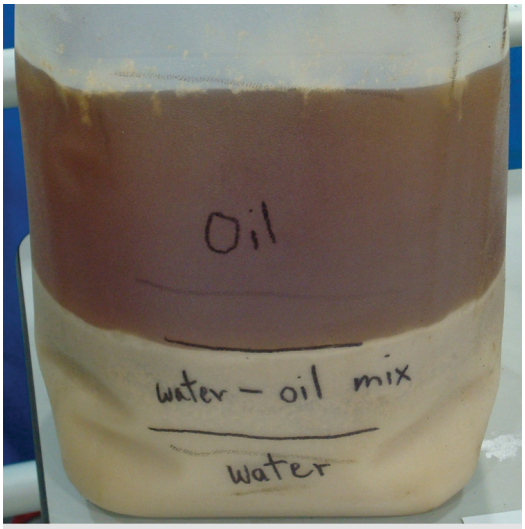
1. Up to 86% reduction in greenhouse gas emissions (primarily CO2) since it is a plant-based fuel (EPA-420-R-10-006, February 2010)
2. Reduction in vehicle exhaust emissions (reduced CO, unburned hydrocarbons, and particulate)
3. Helps keep the vehicle's fuel system clean (biodiesel solvency)
4. Biodiesel is more easily biodegraded compared to petroleum diesel. Therefore environmental risks due to spills are less problematic. However, biodiesel can degrade in the presence of moisture and bacteria during extended storage.
5. Biodiesel has a higher flashpoint (130° C minimum) compared to petroleum diesel (52° C minimum) so it is safer to transport and store.

Biodiesel from waste cooking oil facts:

- The chemical conversion process is relatively simple, requiring heating, mixing, and two sets of chemical additions.
- The main byproducts of the biodiesel process are glycerin and wastewater containing some salts, residual glycerin, and small amounts of methanol
- Any cooking oil can be converted to biodiesel. Canola and soybean oil are the most common but others such as cottonseed oil, peanut oil, and corn oil are also convertible to biodiesel with the same chemical process.
- The typical conversion rate is 50 gallons of oil to produce about 45 gallons of biodiesel
- The cost of producing biodiesel from waste cooking oil is estimated to be at least $1.00 per gallon less than the cost of diesel. If the source of waste cooking oil is free, then the cost of producing the biodiesel is relatively stable compared to the volatile cost of petroleum diesel.

Sources and properties of waste cooking oil:

- Fryer oil from restaurants and cafeterias has become a commodity due to the demand for biodiesel.
- Fryer oil tends to have high free fatty acids (FFA) which is a breakdown product of the oil due to extended time at high temperatures. The FFA content requires some pretreatment before the actual biodiesel reaction to prevent soap formation.
- Home cooking oils tend to be low in FFA but much higher in food particles and water. Both contaminants require some additional steps (screening for the food particles and water settling and drying steps) to ensure a quality biodiesel fuel.



Residential Cooking Oil with large amounts of water and fine food particles

Restaurant Fryer Oil, dark from heat degradation

Biodiesel production equipment:

- The equipment can be as simple as a steel drum with a heater and mixer, or off-the-shelf equipment such as the BioPro 190 (Springboard) which has sequential process controls for unsupervised biodiesel production.
- Depending on the cooking oil source, there may need to be some additional equipment such as a settling tank to help separate the oil from the water in the waste oil (residential cooking oil).

Automated BioPro equipment, RIT

Manual equipment, Daphne, Alabama

R·I·T

Maggie Brooks
County Executive

EPA United States Environmental Protection Agency

NYS P2I Pollution Prevention New York State Institute

ecopark

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