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PRODUCING HYSEE BIODIESEL FROM USED FRENCH FRY OIL AND ETHANOL FOR AN OVER-THE-ROAD TRUCK

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Summary:

Hydrogenated Soy Ethyl Ester (HySEE) biodiesel has been produced from used french fry oil and ethanol. The fuel was used in EPA 211(b) emissions tests and to fuel an over-the-road truck. Fuel production and quality verification plans, truck performance, summary of non-regulated emissions, and fuel cost data are included.

Keywords:

Biodiesel, alternative fuels, emissions, processing

Producing HySEE Biodiesel from Used French Fry Oil and Ethanol for an Over-The-Road Truck

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Abstract

U of I personnel are producing fuel from used french fry oil and ethanol, both of which are available at the J. R. Simplot plant in Caldwell, Idaho. The fuel is part of an Over-the-road project sponsored by the Department of Energy, Office of Transportation Technologies. The project involves IDWR Energy Division, Caterpillar, Western States Caterpillar, Kenworth, Trebar Kenworth, J. R. Simplot Company, University of California-Davis and the University of Idaho.

Hydrogenated soy ethyl ester (HySEE) biodiesel is being tested in two 3406E (324 kW (435 hp)) engines donated by Caterpillar Inc. and a truck donated by Kenworth Truck Co. The truck is operated by J. R. Simplot Co. in their daily operations from their Caldwell, Idaho plant and is fueled with a 50/50 blend of HySEE and petroleum diesel. One of the Caterpillar engines is used to power the Kenworth truck, the other was used at the Caterpillar technical center in Peoria, Illinois for engine break-in and emissions testing including performance, regulated emissions, PAH and NPAH compounds, and toxicology as required by U.S. EPA under 211(b) provisions to provide environmental data for a new fuel.

The University of Idaho process, used at the Simplot ethanol plant, is made in 1893 L (500 gal) batches and requires about 0.3486 L of ethanol/L of used french fry oil (gal of ethanol/gal of oil) and 0.012 kg of potassium hydroxide per L of used french fry oil (0.109 lb per gal) processed. About 0.84 L of biodiesel/L of used fat (gal/gal) results from the reaction. The excess alcohol is recovered by using the distillation column of the ethanol plant. About 0.1 L/L (0.1 gal/gal) of glycerol is produced during the production of the ester.

Over the course of this 321,870 km (200,000 mile) over-the-road truck demonstration and emissions testing, 79,494 - 90,850 L (21,000 - 24,000 gal) of biodiesel will be produced from used french fry oil. First, 11,356 L (3000 gal) were produced at the University of Idaho in Moscow and sent to the Caterpillar plant in Peoria, Illinois for engine startup and emissions tests. Following the production of this first fuel, the biodiesel reactor built at the University in Moscow was transported to the J. R. Simplot plant in Caldwell and set-up to make HySEE on-site, which was then mixed in a 50-50 blend with diesel to provide the fuel for the Kenworth Truck. The truck averages about 2.18 km/L (5.25 mpg) and thus was expected to require 151,416 L (40,000 gal) of fuel 75,708 L (20,000 gal) of HySEE) over the course of the 321,870 km (200,000 miles.)

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the vegetable oil causing a chemical reaction which separates the vegetable oil into two components: ester and glycerol. The ester is lighter than the glycerol and rises to the top after the reaction is complete. After carefully washing to remove all remaining catalyst, alcohol and glycerol, the ester is used as a fuel in diesel engines. Glycerol has many food and industrial uses such as cosmetics, toothpaste, pharmaceuticals, foodstuffs, plastics, explosives, and cellulose processing to name a few. However, the material obtained from biodiesel production requires purification before it can be used for these purposes.

$$\begin{array}{lcllcl} CH_2OCOR & & & CH_2OH & & RCOOC_2H_5 \\ | & & KOH & | & & \\ CHOCOR' & + \; 3C_2H_5OH & \rightarrow & CHOH & + & R'COOC_2H_5 \\ | & & & | & & \\ CH_20C0R'' & & & CH_2OH & & R''COOC_2H_5 \end{array}$$

Vegetable Oil	Ethyl Alcohol + catalyst	Glycerol	Ethyl Ester

Figure 1. Vegetable Oil Transesterification

French fry processing plants use hydrogenated oils because of their stability at higher temperatures and ease of handling the frozen product. Typically, the hydrogenated oils used in such processes are derived from soybeans because of their relative abundance in the United States. It is estimated that there are several million kilograms of waste vegetable oil available from these operations each year. Additional waste frying oil is available from smaller processors, off-grade seeds, and restaurant deep fryers.

The J. R. Simplot's Caldwell, Idaho, facility offers a unique combination of resources in a single location. In addition to processing potatoes into french fries, Simplot also produces fuel grade ethanol from its potato wastes. From a single facility comes the two main ingredients to make Biodiesel -- vegetable oil and alcohol.

200,000 Mile Heavy Duty Over-The-Road Truck Demonstration Project

The Department of Energy, Office of Transportation Technologies is sponsoring this Over-the-road project which involves a number of entities including IDWR Energy Division, Caterpillar, Western States Caterpillar, Kenworth, Trebar Kenworth, J. R. Simplot Company, University of California-Davis, and the University of Idaho. U of I personnel are producing fuel from used french fry oil and ethanol, both of which are available at the J. R. Simplot plant in Caldwell, Idaho.

Caterpillar plant in Peoria, Illinois for engine startup and emissions tests. Following the production of this first fuel, the biodiesel reactor built at the University of Idaho in Moscow was transported to Caldwell and set-up to make fuel which is being mixed in a 50-50 blend with diesel.

The University of Idaho process, used at the Simplot plant, is made in 1,893 L (500 gal) batches and requires about 0.3486 L of ethanol/L of used french fry oil (gal of ethanol/gal of oil) and 0.012 kg of potassium hydroxide per L of used french fry oil (0.109 lb per gal) processed. About 0.84 L of biodiesel/L of used fat (gal/gal) results from the reaction. The excess alcohol is recoverable by using the distillation column of the ethanol plant. About 0.1 L/L (0.1 gal/gal) of glycerol is produced during the production of the ester.

Ethyl Ester from Used Hydrogenated Soybean Oil (HySEE)

Ethyl ester production utilizes absolute or 100 percent ethanol (EtOH) in a 6:1 molar ratio of alcohol to oil, which is 100 percent molar excess alcohol. Potassium hydroxide varies slightly with each batch due to the differences encountered in free fatty acid (FFA) content of the used oil. Reactants in Table 1 are based on a laboratory-scale batch of 100 g or 3.785 L (1 gal).

Table 1

Relative Component Quantities used for Production of HySEE Biodiesel using the University of Idaho Process Developed by the Biological and Agricultural Engineering Department

	Lab Scale	One Gallon Scale
Oil (Used Hydrosoy, d=0.914)	100g	3.785 L or 1.00 gal
KOH (Main Treatment)	1.43 g	49.48 g or 0.1091 lb
*KOH (for each 1% FFA as stearic acid)	0.197 g	8.82 g or 0.015 lb
KOH (total) = Main treatment plus variable for FFA treatment		
EtOH (d=0.789)	30.0 g	1038 g or 2.288 lb = 1.3196 L or 0.3486 gal

*Must be multiplied by free fatty acid content (in percent.)

Example: (For a batch using 500 gal of oil with 2.1% FFA)

Oil	= 1,893 L (500 gal)
KOH (Main Treatment) = 500 gal *0.1091 lb	= 24.8 kg (54.6 lb)
KOH (for FFA) = 500 gal *0.015 lb *2.1	= 7.17 kg (15.8 lb)
KOH (Total)	= 31.9 kg (70.4 lb)
EtOH = 500 gal *0.3486	= 960 L (174.3 gal)

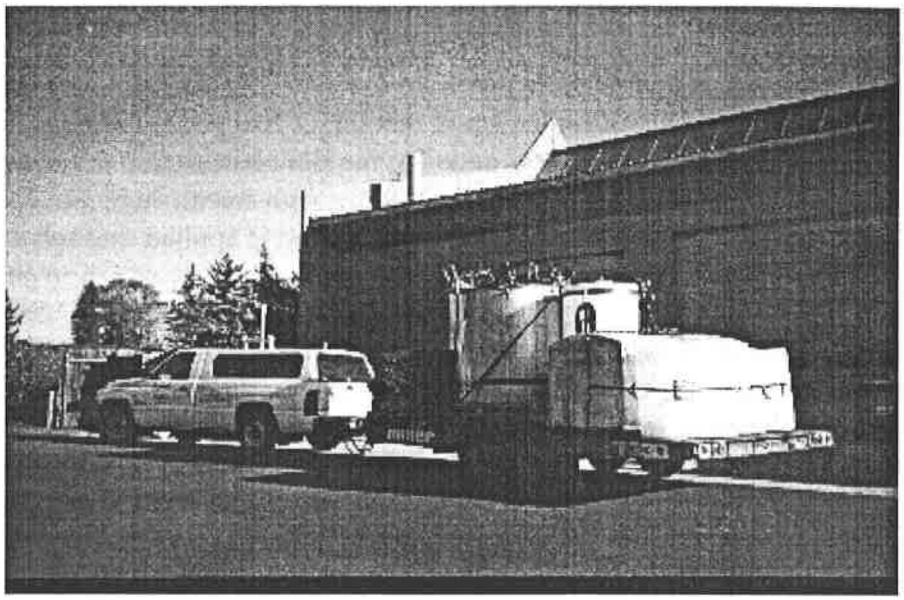

Figure 3. Moving the 1,893 L (500 gal) reactor and waste vegetable oil tank to Caldwell for producing HySEE biodiesel fuel from used french fry oil and ethanol at the J. R. Simplot potato processing plant.

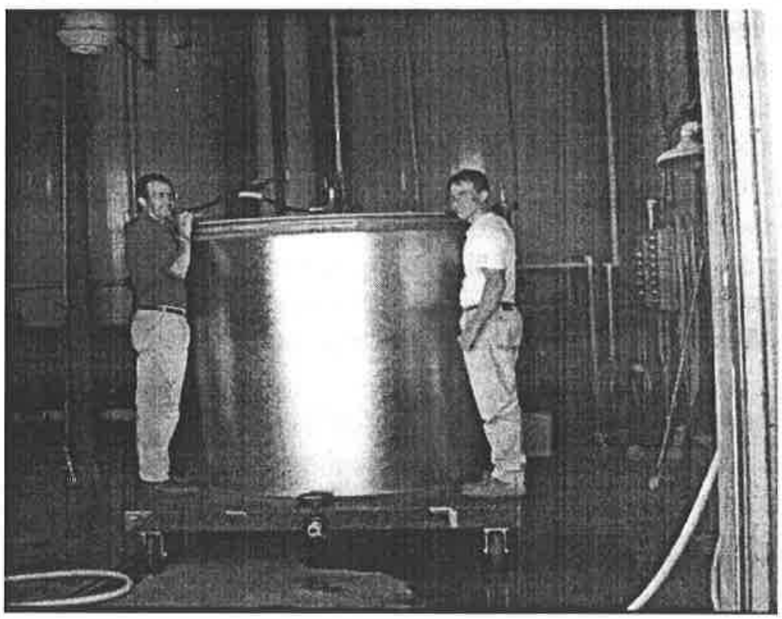

Figure 4. The reactor in place at Simplot. Paul Mann of Simplot on the left and Gary Lowe, University of Idaho graduate assistant, on the right.

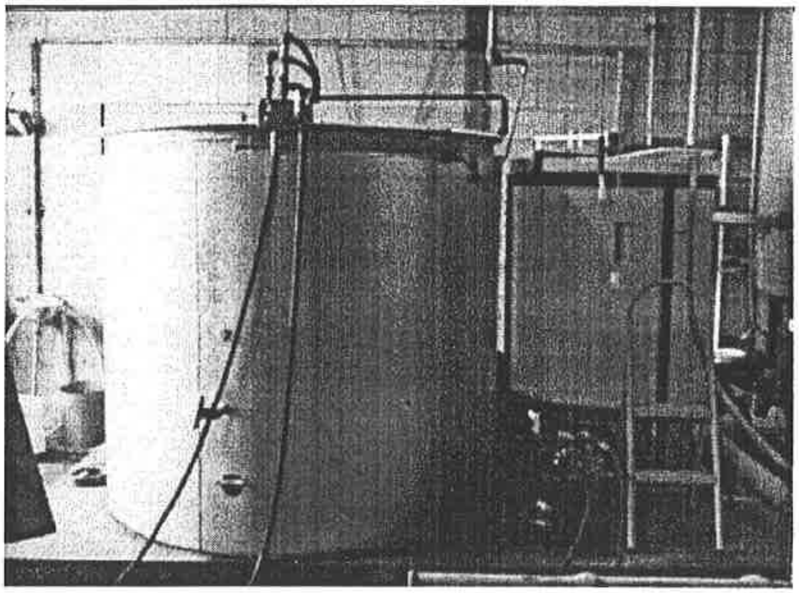

Figure 5. The 1,893 L (500 gal) reactor used for producing HySEE. The reactor, alcohol mixing tank, and transfer pump are all mounted on a steel frame with wheels and fork lift eyes.

Fuel Production and Quality Verification Plan

As part of the project outline, a procedure was established whereby the fuel produced for the 321,870 km (200,000 mile) over-the-road test and related startup and emissions activities would be of consistent quality and within a defined specification. This plan included an agreed upon fuel specification, a production plan, and a fuel analysis plan.

Fuel for the Caterpillar engine startup, the emissions tests and the 321,870 km (200,000 mile) over-the-road test will be produced and characterized using the above described procedure according to the following plan:

Materials:

1. Used french fry oil will be collected at the Caldwell, ID Simplot Plant and either processed into HySEE on-site or transported to Moscow, Idaho via bulk tank for processing.
2. Anhydrous ethyl alcohol (200 proof) will be either purchased from a chemical supply house or obtained from the Simplot alcohol plant without denaturing.
3. KOH will be purchased from Rogers Supply Company as flakes in 226.8 kg (500 lb) lots.
4. Water will be obtained from the University of Idaho domestic water supply or from the Simplot Plant potable water supply without further treatment.
5. Tannic acid and octanol will be obtained from Sigma Chemical Co.

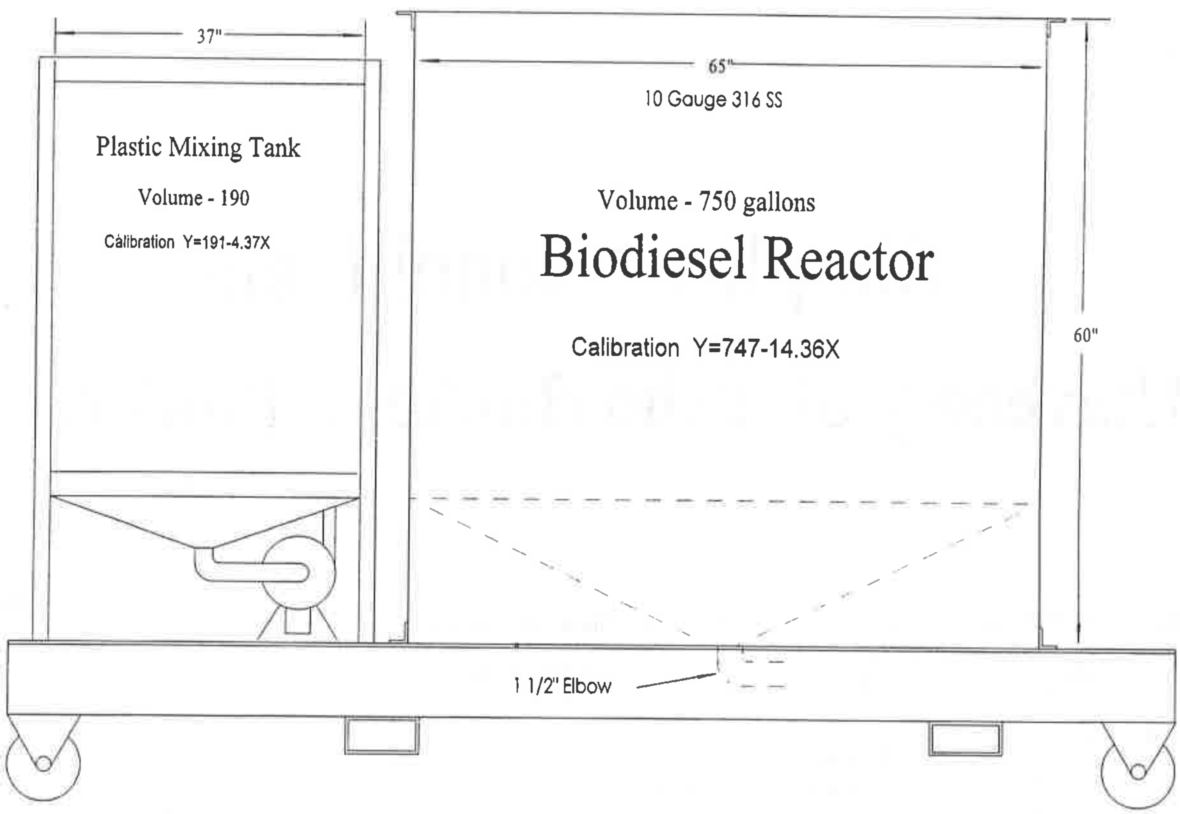

Figure 7. Side view of the 1,893 L (500 gal) reactor showing the tanks and castor mounted skid.

Process Control

The following process is being used to produce the Biodiesel:

Fuel Production Timing and Measurements

Timing - All reaction and washing times allowed are at least 100 percent in excess of that deemed necessary in order to obtain complete reaction and settling; exact timing for these processes is not critical.

Measurements - Measurements are made from calibration marks on the tank and a metal rule (calibrated to an eighth of an inch). Each batch is produced by manually measuring the quantities used. During each batch computed measurements and actual measurements are recorded as the process progresses.

Measurements made include:

1. Volume of used french fry oil as a function of depth of oil in the tank.
2. Volume of ethanol as a function of depth of alcohol in the auxiliary tank.
3. Mass of KOH as measured by a laboratory scale. The scale will be calibrated each day with a 1000 gram laboratory weight prior to each day's use. (The amount of KOH for each batch is dependent on the amount of free fatty acids in the oil, the computation will be part of the check sheet.)
4. Free fatty acids will be measured on each batch using AOCS standard method
5. The amount of water, tannic acid and octanol used are less critical and proprietary but will be measured using standard laboratory scales and pipettes. The amounts used will be listed in the check sheet.

Quality Verification

Process Sensitive Parameters

1. Each batch is evaluated for process sensitive characteristics as follows:
   A. Three replicates of viscosity
   B. Three replicates with HPLC for free and total glycerol
   C. One measurement for alcohol content (at present this requires an outside lab, if this can be measured in-house three replicates will be made)
   D. One replicate for Acid number
   E. One replicate for Density
   F. One replicate for Potassium

2. In addition to the above, the other characteristics (i.e, the remaining non-process characteristics) of the fuel on the Caterpillar Specification list are evaluated a minimum of twice during the fuel production for the start-up and emissions fuel production by blending a sample from each batch during the first and second halves of the production

Acid Number	mg. KOH/gm	0.5 max	ASTM D664
Alcohol Content (Ethanol)	wt. %	0.2 max	GC or LC method
Free Glycerin	wt. %	0.2 max	GC or LC method
Total Glycerin	wt.%	1.2 max.	GC or LC method
Iodine Number	cg I_2/gm	120 max	DIN 53941/IP 84/81
Phosphorous Content	mg/kg	10	DGF C-V14

[1]The Cloud point, pour point, and cold filter plugging temperatures are a function of the feedstock and can not be guaranteed to meet a particular limit.

Biodiesel Production Planning

A meeting was held at the Simplot Alcohol Plant to discuss the logistics of making HySEE in Caldwell. The first order of business was to outline the steps used for making fuel in Moscow to identify potential problems to avoid or overcome at Caldwell.

It was noted that the only place a 1.8 m x 3 m x 1.8 m (6 ft x10 ft x 6 ft) reactor would fit was in the Alcohol Plant distillation room. Everything in the room had to meet explosion-proof code. It was decided to use hydraulically driven pumps and motors for transferring liquids and stirring. A 3.7 kW (5 hp), 3 phase, totally enclosed, C-faced motor was procured from Simplot to power the hydraulic system. The hydraulic power system was subsequently built at the U of I.

The next concern was the wash water and the waste glycerol layer. It was estimated that for a 1,893 L (500 gal) batch, about 946 L (250 gal) each of wastewater and glycerol would be generated. Simplot personnel indicated that the amount of water would not be a problem, but glycerol storage and disposal would have to be worked out. It was hoped that the glycerol could be sold to a recycler to offset the cost of the raw products used for making fuel. To date, no buyer has been found, but the crude glycerol generated has been placed in storage.

Next, the logistics of getting the raw products needed for the reaction was worked out. The alcohol plant had a flat bed one-ton truck at their disposal at all times. It was decided to bring a 1,893 L (500 gal) tank from Moscow and use it on the flat bed to get oil from the holding tank at the potato processing plant across the street when needed. Potassium Hydroxide could be procured from Van Waters & Rogers in Nampa on short notice and picked up by the technician. The alcohol could be taken by hose directly from the molecular sieve to the plastic mixing tank. The operator could slow the flow through the molecular sieve to obtain an anhydrous alcohol.

Fuel Storage and Delivery

The fuel for Caterpillar startup and Emissions tests was placed in totes with new bottles. Figure 9 shows the fuel in the totes just before it was shipped. Because biodiesel has a high flash point, it can be stored inside as shown in the photo. If this were diesel fuel, this much fuel could not have been stored inside the building without special precautions.

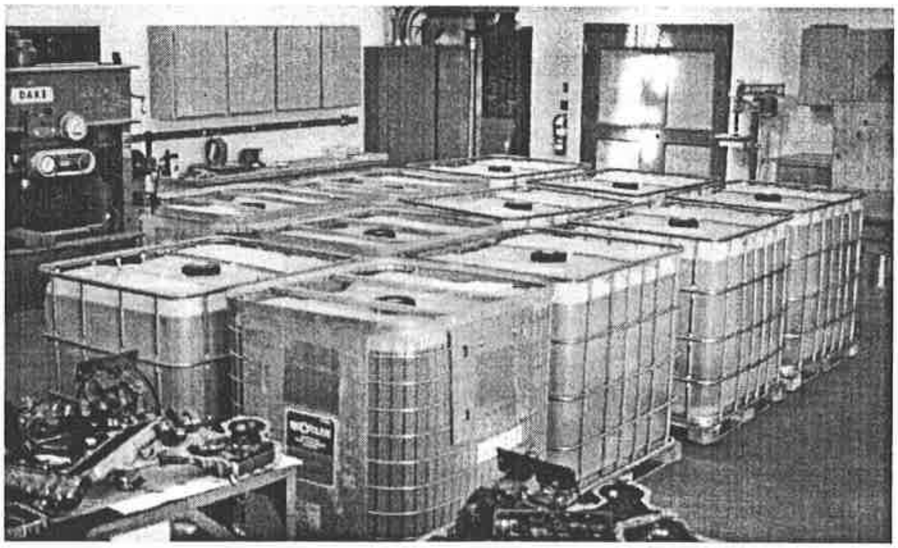

Figure 9. Ten totes of HySEE ready for shipment to Caterpillar.

The fuel for the over-the-road test at Simplot was to be stored using on-site facilities. Originally, the ester was stored in 1,041 L (275 gal) totes provided by Simplot. Simplot then made available a 37,854 L (10,000 gal), stainless steel, steam-jacketed tank located just outside the alcohol plant. The glycerol was stored in a 15,142 L (4,000-gal) tank and totes. Later, a pump was installed to transfer the glycerol into the alcohol plant beer well for alcohol recovery in the process.

To fuel the truck, a 1,893 L (500 gal) stainless steel, heated and insulated tank for storing the biodiesel was installed next to the diesel nurse tank at the Simplot refueling facility. At the suggestion of Simplot personnel and with advice from a supplier, the HySEE Biodiesel is blended with diesel as it is pumped into the truck. The valve is connected on one side to the biodiesel tank and on the other side to the Simplot diesel fuel nurse tank. A blending valve mixes 50% diesel and 50% HySEE as the truck is filled, pulling fuel out of each of the respective tanks. Calibration of the blending valve has shown it to be quite accurate. It delivered 51% biodiesel – 49% diesel when calibrated on September 20, 1997 and 52% biodiesel – 48% diesel when calibrated on January 12, 1998. Calibration was done using specific gravity determined by weight of fluid in 500 ml volumetric flasks.

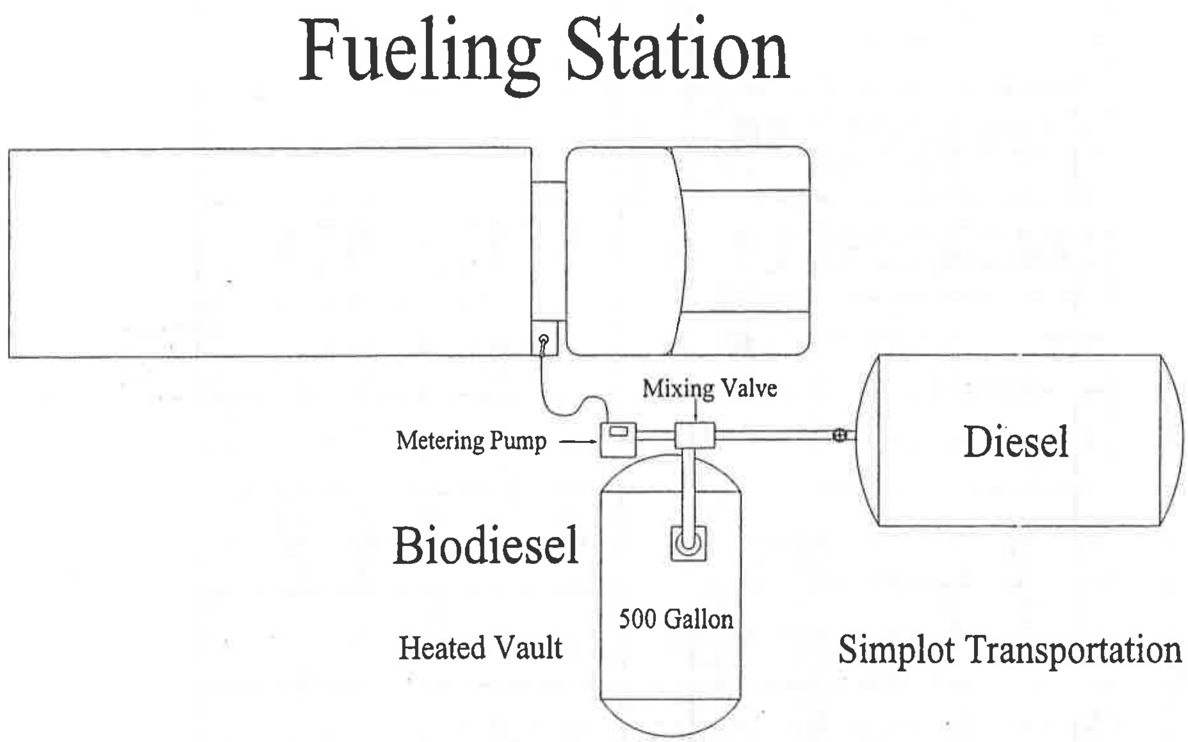

Figure 11. Schematic of the HySEE biodiesel Fueling Station at the J. R. Simplot Refueling Facility. The HySEE tank is heated and insulated.

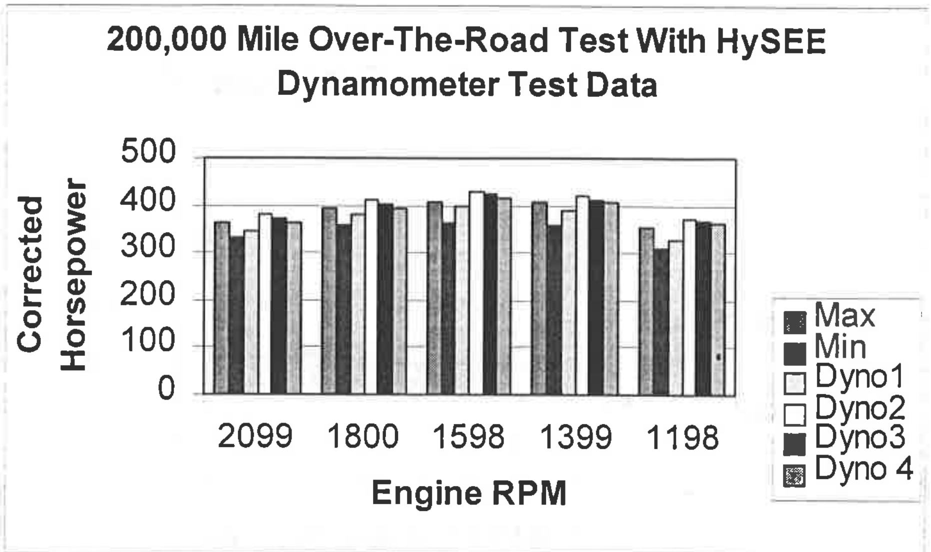

Figure 12. Corrected Horsepower chassis dynamometer test results for the 321,870 (200,000 mile) over-the-road, heavy duty truck demonstration.

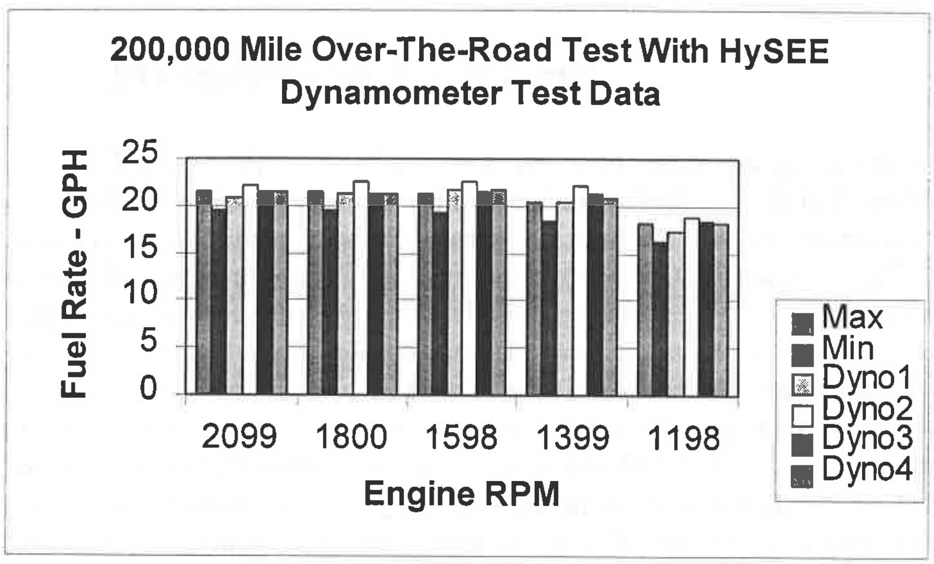

Figure 13. Fuel rate (gph) from the chassis dynamometer test results for the 321,870 (200,000 mile) over-the-road, heavy duty truck demonstration.

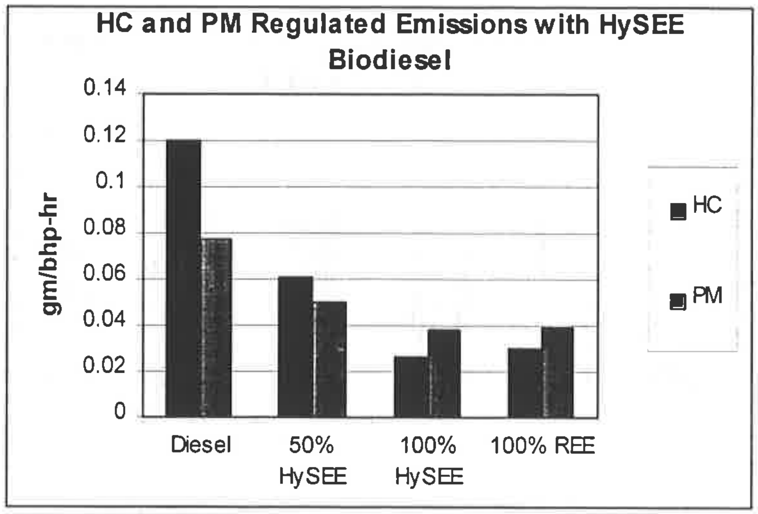

Figure 15. HC and PM from the regulated emissions tests with the Caterpillar 3406E engines at the Caterpillar Technical Center. Data represent the composite weighted average cold/hot emission averages.

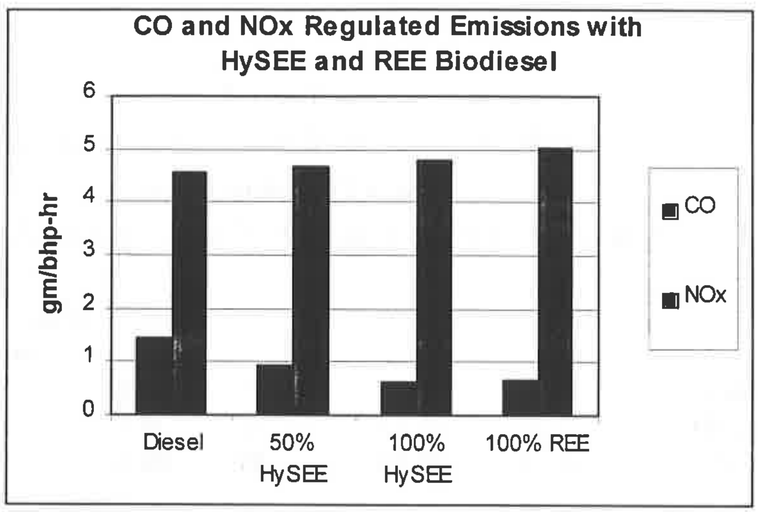

Figure 16. CO and NOx from the regulated emissions tests with the Caterpillar 3406E engines at the Caterpillar Technical Center. Data represent the composite weighted average cold/hot emission averages.

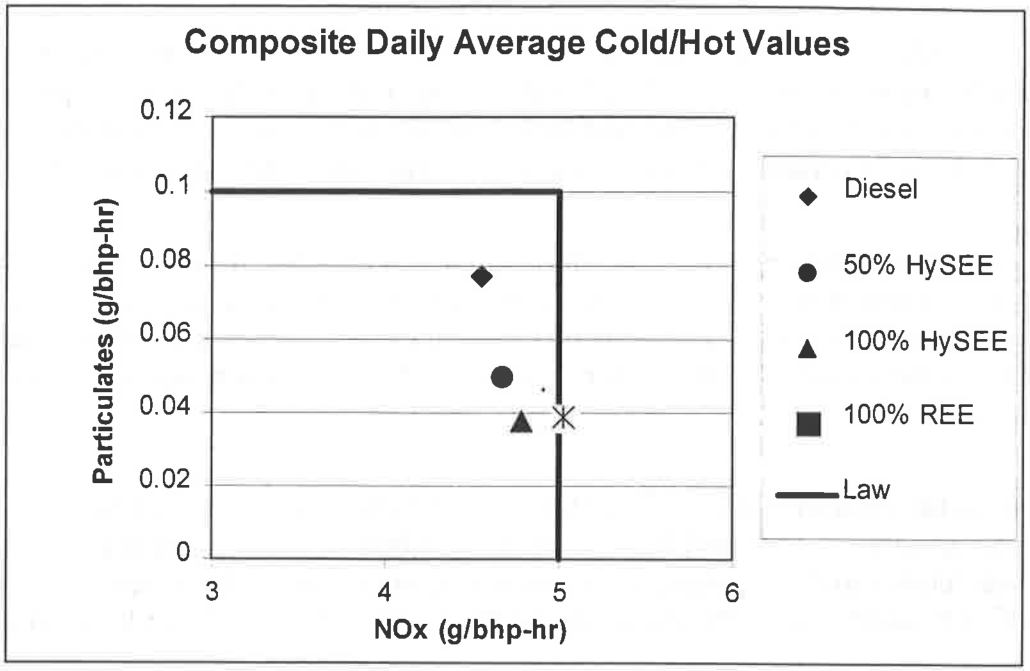

Figure 18. Data shown represent the composite weighted cold/hot emission averages for each test fuel and the 1994 law for PM and NOx from Smith et al. (1998). Note that 100REE exceeded the legal limit for NOx by 0.02 g/bhp-hr.

Fuel Cost

An estimate of the raw product cost for the HySEE produced from this project can be made from the J. R. Simplot project cost accounting. Ethanol cost \$0.38 per L (\$1.44 per gal), used oil cost an average of \$0.256 per kg (\$0.116 per lb) and KOH cost \$2.93 per kg (\$1.04 per lb). The cost per liter (gallon) estimate is based on the first 54,203 L (14,319 gal) of HySEE produced. Ethanol used was 23,200 L (6,129 gal), used oil used was 55,737 kg (122,880 lb), KOH and tannic acid used cost \$4,316.05 for a total of \$27,394.31 or \$0.505 per L (\$1.913 per gal). Using the quantities from Table 1, the cost would be \$0.452 per L (\$1.71 per gal) of fuel. The difference between these estimates may be that some of the material may have been charged out before it was used on a gross basis. The gross cost also includes material damaged and discarded and at least one batch that did not meet the specification (which was re-esterified). Crystals which form due to low temperatures are often re-esterified which adds additional cost on a gross basis. This estimate does not include processing costs of electricity, water and steam; taxes; labor; profit; or any capital recovery cost. A credit of \$0.20 per L (\$0.76 per gal) was given representing the cost of the diesel which was replaced. For the first 36 batches with an average oil-in of 1,831 L (483.8 gal), 1,539 L (406.6 gal) of HySEE was produced for a recovery percentage of 84%. Note that no credit was given for the alcohol recovered by distillation or for the glycerol which could be recovered in a large biodiesel plant.

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