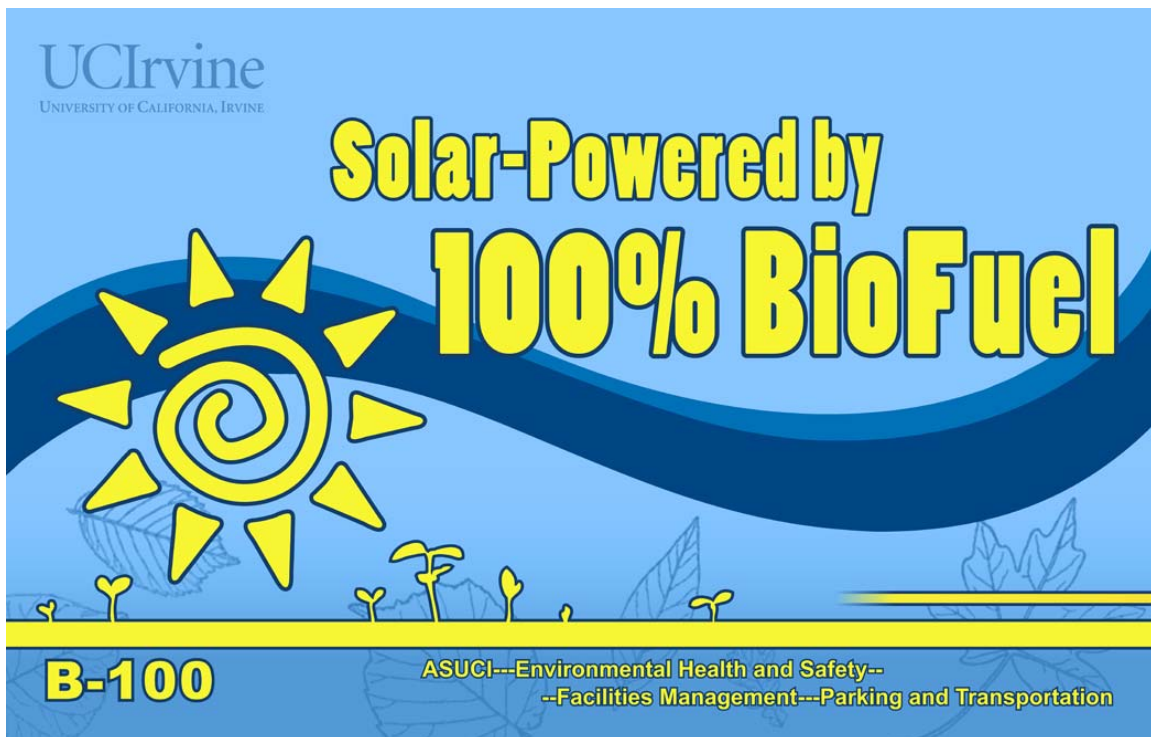


The B100 Retrofit Process



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I. BACKGROUND

In a time of growing concerns about greenhouse gas emissions and dependence on imported oil, ecological issues are of increasing social, political, and economic importance. The University of California, Irvine is addressing these challenges by incorporating sustainable practices in all aspects of campus life, including campus-owned transportation.

In 2006, Associated Students at UC Irvine (ASUCI) passed Measure S, an initiative to provide monies for new vehicles purchases, equipment, and route upgrades for the ASUCI Express Shuttle service, which carries more than 1,000,000 passengers a year. This legislation also provided funding for the equipment needed to retrofit the entire campus shuttle fleet to run on 100 percent biodiesel fuel (B100). Through the combined efforts of Fleet Services, Transportation Services, Environmental Health and Safety, and ASUCI, the first B100 shuttle bus became operational in March 2007. By converting the campus shuttle bus fleet to run on B100 versus petroleum diesel fuel, UC Irvine will reduce CO₂ emissions by 480 tons per year¹.



Debut celebration of UC Irvine's first B100 Shuttle Bus

¹Assumes that 100% of fuel consumed is carbon-neutral. Data is based on a national study of effects of biodiesel usage in buses. Life cycle emissions reductions for CO₂ from the use of B100 are 78% and 15.7% for B20.

II. INTRODUCTION TO SELECTIVE CATALYTIC REDUCTION TECHNOLOGY

Since the early 1970s, biodiesel fueled engines have been monitored by researchers in studies under both real-world operating conditions and under controlled conditions in the laboratory. In the course of searching for a cleaner alternative fuel, UC Irvine conducted studies on retrofitting a diesel engine to run on B100 using selective catalytic reduction (SCR) technology without increasing NO_x emissions.

Urea SCR has been proven to be a valuable diesel emissions reduction technology and has been in use for more than thirty years, predominately for stationary power generation. The United States Environmental Protection Agency (EPA) recently reconsidered its stance against SCR as a viable technology for on-highway diesel engines to meet stringent 2010 emissions standards and sent a letter to manufacturers outlining its intent to certify SCR engines (Nguyen, T., 2007). As a result, SCR technology is now even more a viable option than previously considered.

Retrofitting older vehicles to run on B-100 using SCR technology was a cost-effective way for the campus to reduce greenhouse gas emissions. Buying new “clean emissions” buses would have been costly, and the fuels and emissions would still have been carbon-based. A new “clean emissions” bus would cost around \$30,000. The cost of retrofitting an old bus is about \$1,500. Although UC Irvine purchased and retrofit some used buses that cost around \$12,000 each, the campus still saved around \$16,500 per bus. The campus saved even more retrofitting vehicles in the campus-owned fleet.

In addition to being economical, UC Irvine’s approach was extremely green and actually extends the life of diesel buses. These buses may end up running a million miles. The environmental benefits of retrofitting the ASUCI shuttles will be discussed in the testing and conclusion sections of this document.

III. THE RETROFIT PROCESS

The following steps were taken to retrofit the first UC Irvine B100 shuttle (see picture below):

1. Scrubbed the fuel tanks prior to filling them with B100 (B100 fuel has a solvency effect on metal parts).
2. Replaced fuel hoses and rings with Viton to avoid any fuel pump/engine problems associated with the B100 solvency effect.
3. Installed a test port upstream and downstream of the catalyst to collect representative air sample concentrations of NO_x, CO, O₂ and CO₂ using a portable emissions analyzer.
4. Installed a urea selective catalytic reduction (SCR) system, manufactured by Kleenair Systems, downstream of the catalytic converter to control NO_x emissions.
 - a. Installed the modular aluminum plate to the bus ribs with 3/8" bolts.
 - b. The air tank, urea tank, air compressor, and urea pump were upside down.
 - c. Ran 12v power from the ignition to the power strip positive side and a ground to the negative side of the power strip. This powers the compressor.
 - d. Installed the diesel oxidation catalyst in the exhaust pipe as close to the engine as possible.
 - e. Installed thermister bung in exhaust pipe in front of the diesel oxidation catalyst.
 - f. Installed thermister into bung.
 - g. Installed the SCR catalyst 24" to 36" behind the diesel oxidation catalyst.
 - h. Installed Swagelok fitting in exhaust pipe 24" in front of the SCR catalyst.
 - i. Installed urea nozzle into Swagelok fitting so that the nozzle is in the center of the exhaust stream pointed at the SCR. This required bending the nozzle at a 90 degree angle about 2" from the tip.
 - j. Installed the supply hose from the urea pump to the nozzle. Filled urea tank.
 - k. Turned on power to the system and allowed the compressor to build up pressure. The compressor shuts off at 30 psi and restarts at 18 psi. When the compressor shut off, adjusted the regulator to the urea tank to 15 psi. Then adjusted the regulator to the urea pump to 14.5 psi.
 - l. Installed the Sobris controller in a safe place. Connected 12v ignition power to the controller.
 - m. Connected the two thermisters to the controller.
 - n. Connected the urea pump to the controller.
5. Performed testing.



IV. TESTING

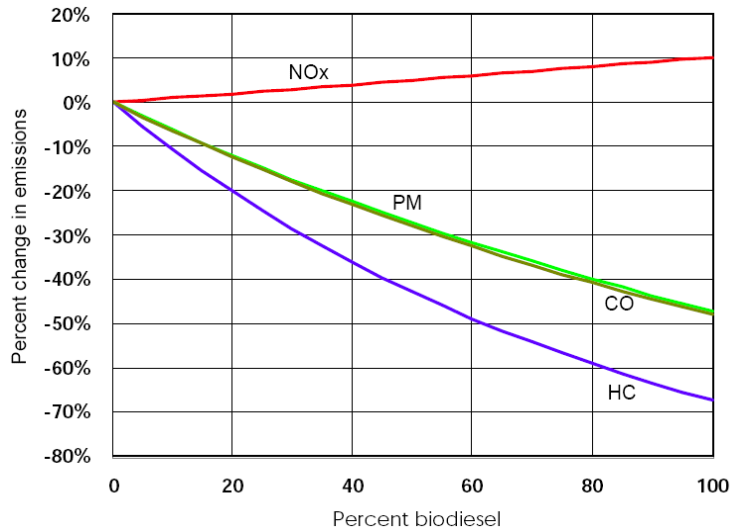
The tests at UC Irvine were preformed using diesel #2, 20 percent biodiesel (B20), and B100. The campus used soybean based oil, although other vegetable oils such as rapeseed or canola are also commonly used to make biodiesel. Testing results were used to calibrate the NO_x reduction system, as the system does not use a NO_x sensor. Instead, the system utilizes a solenoid that is set to a temperature setting to engage the urea system. Basically, when the engine reaches a certain operating temperature, urea is injected onto the SCR system, thus reducing NO_x emissions. Each test cycle (for each fuel) was comprised of three 15-minute runs, and consisted of driving on a pre-determined path around the City of Irvine. Also, testing generally occurred around the mid-morning to early afternoon (i.e. 9 a.m. to 1 p.m.) time frame, so that the ambient temperature would not become a independent variable.

Once the SCR was installed, another set of test readings was collected, and a percent control value was calculated (emissions in – emissions out/emissions in x 100). Since this type of control device is specifically used to control NO_x emissions, a percent control value was only calculated for NO_x and not on the other pollutants (e.g., CO, PM, VOCs, etc.).

V. ANALYSIS AND FINDINGS

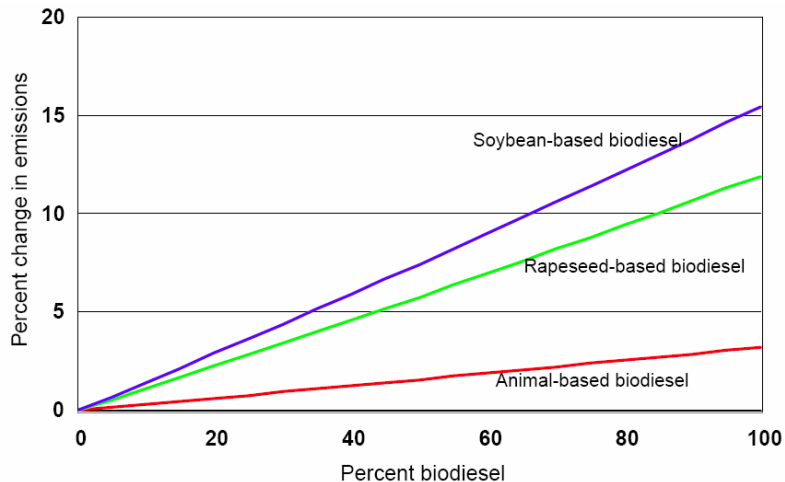
The following graph was created using statistical regression analysis to correlate the concentration of biodiesel in conventional diesel fuel with changes in regulated and unregulated pollutants. Since the majority of available data were collected on heavy-duty highway engines, this data formed the basis of the analysis. The average emission impacts are shown in the following figure (EPA, 2002).

Figure 1 Average emission impacts of biodiesel for heavy-duty highway engines



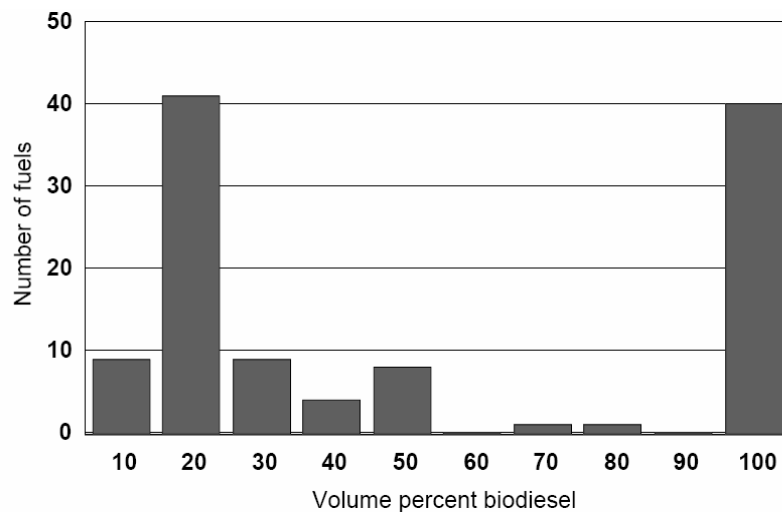
In Figure 2, the available data shows that biodiesel impacts on emissions varied depending on the type of biodiesel (soybean, rapeseed, or animal fats) and on the type of conventional diesel to which the biodiesel was added. With one minor exception, emissions impacts of biodiesel did not appear to differ by engine model year (EPA, 2002).

Figure 2 Biodiesel source effects for NO_x



Biodiesel can be blended into conventional diesel fuel at any concentration. This fact is reflected in the distribution of biodiesel concentrations in the EPA's database, shown in Figure 3. Although 20 percent volume biodiesel is the most common blend among in-use biodiesel programs, the fact that biodiesel can be blended at any level suggests that the most useful analysis of biodiesel impacts on emissions would be to use biodiesel concentration as the independent variable in a traditional curve-fitting process. This approach permits us to use all the available data in the analysis, and provides a means for estimating the impact of biodiesel on emissions for any biodiesel concentration.

Figure 3 Distribution of biodiesel concentrations in database

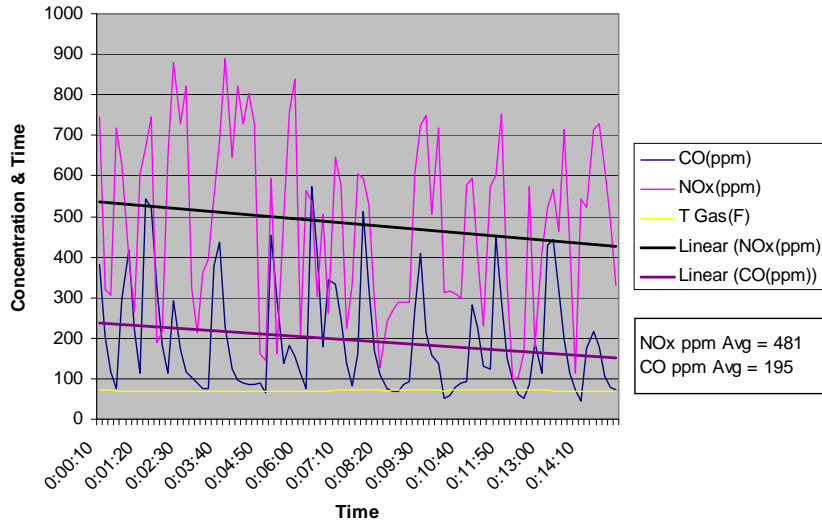


A review of available engine dynamometer test data for a variety of diesel engines indicates that there is a reduction in the emission rate of PM, CO, and HC and an increase in the emission rate of NO_x. These results are based upon analysis of a database compiled by the U.S. EPA (EPA, 2002). The EPA has analyzed the data by general categories of engine types. An overall average among all engine types is that emissions decreased on B20 versus petroleum diesel by 10 percent for PM, 11 percent for CO, and 21 percent for HC, but increased by 2 percent for NO_x. For B100 versus petroleum diesel, emissions decreased 47 percent for PM, 48 percent for CO, and 67 percent for HC, but increased by 10 percent for NO_x. The qualitative difference in comparisons between the fuels depends on what engine categories and test procedures are considered. A general finding is a consistent decrease in emissions of PM, CO, and HC and a consistent small increase in NO_x emissions.

The following data were obtained from testing the UC Irvine shuttle mentioned in *The Retrofit Process* section of this document. Figures 4 through 6 show the baseline emissions for diesel #2, B20, and B100 fuels, respectively.

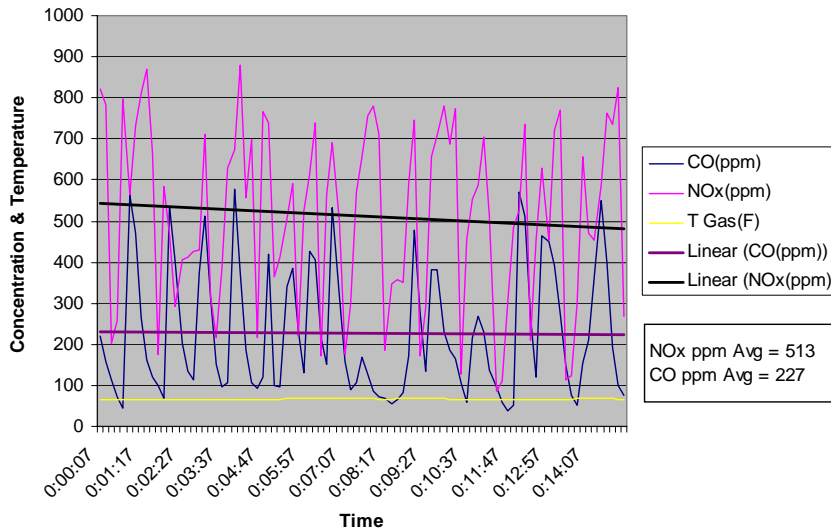
In Figure 4, the NO_x concentrations averaged 481 ppm, while the CO concentrations averaged 195 ppm. Based on literature published by the EPA for off-road heavy-duty engines, this is within the average when using diesel #2.

Figure 4 Diesel #2 Baseline Results



In Figure 5, the NO_x concentration averages 513 ppm, while the CO concentrations average 227 ppm. When compared with diesel #2, there was an increase of 6.7 percent for NO_x and a decrease of 4.1 percent for CO. The 6.7 percent increase in NO_x and 4.1 percent decrease in CO for B20 were within the range of the EPA results of 2 percent and 11 percent, respectively.

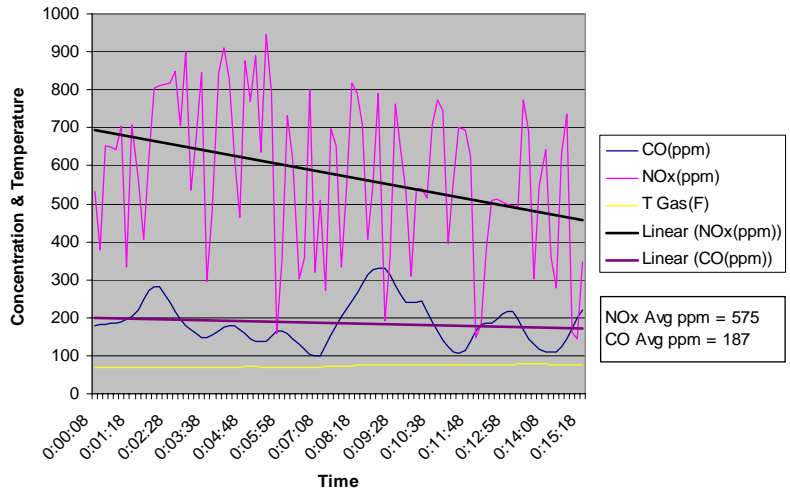
Figure 5 B20 Baseline Results



In Figure 6, the B100 NO_x concentrations averaged 575 ppm, while the CO concentrations average 187 ppm. When compared with diesel #2, there was an increase of 19.5 percent for NO_x and 16.4 percent for CO. The NO_x for B100 was 6.7 percent higher than the EPA results of 10 percent. The tested CO emissions should have

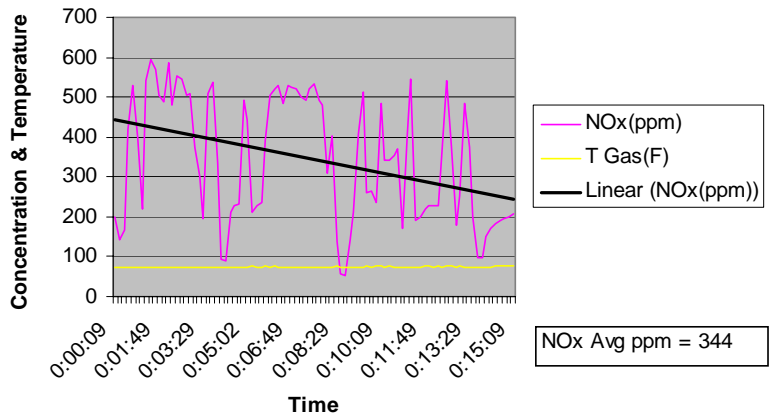
decreased approximately 48 percent, according to EPA results. The variability in results will be explained at the end of this section.

Figure 6 B100 Baseline Results



In Figure 7, the B100 (with the SCR) NO_x concentrations averaged 344 ppm. When compared with diesel #2, the NO_x decreased by 28.4%. The NO_x emissions for B100 with the SCR exceeded the diesel #2 baseline results, confirming that the SCR successfully reduced NO_x emissions.

Figure 7 B100 NO_x Reduction System Test Results



In Figure 8, the graph shows the comparison between diesel #2 and B100 (with the SCR).

Figure 8 B100 NO_x Controlled Versus Diesel #2 NO_x

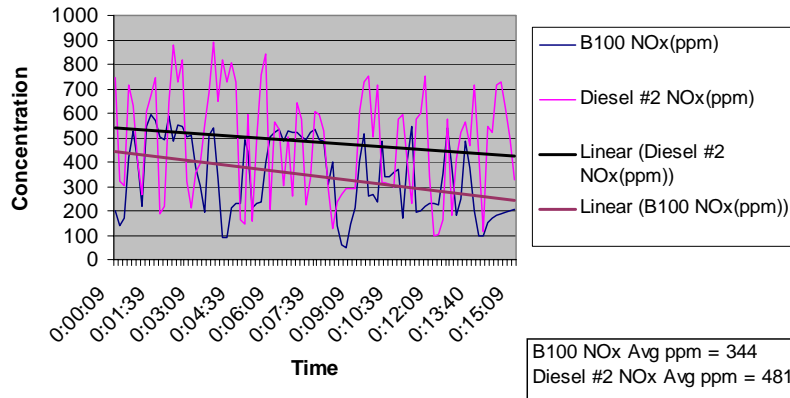


Table 1 summarizes the testing results for diesel #2, B20, B100, and B100 (with the SCR), which also shows whether the fuels either increased or decreased in emissions versus diesel #2.

Table 1 Summary of Test Results

	Diesel #2	B20	B100	B100 Controlled w/SCR	NO _x Reduction/Increase %		
					B20	B100	B100C
NO _x ppm	481	513	575	344	+6.7	+19.5	-28.4
CO ppm	195	187	227	2.5	-4.1	+16.4	-98.7

The variability of the CO emissions data for the B100 baseline test results could have been attributed to external factors or the equipment that was used to obtain the data. However, after the test, the equipment was calibrated using the internal program and it appeared that everything was fine. Therefore, some of the factors that could be responsible for the observed variability in emissions include: vehicle size, engine type, vehicle weight, and fuel. Vehicle size and weight could influence fuel use and emissions, based on previous EPA studies (EPA, 2002). The emissions of other pollutants (PM, HC, and SO₂) typically, but not always, increased by size and weight, which can cause the CO to fluctuate (EPA, 2002).

Since the increase of NO_x emissions from using biodiesel blends was the primary concern, it was not a big issue that the CO results did not coincide with the available data. Also, the other pollutants (PM, HC, and SO₂) were not tested because there is enough published data available that confirms the other pollutants decrease when using biodiesel fuels.

VI. CONCLUSIONS

The physical testing showed an increase in NO_x and a reduction in CO emissions, which was also confirmed by secondary data. However, when the biodiesel was used with a SCR, the NO_x emissions and other criteria pollutants (PM, HC, and SO₂ – are based on secondary data and the emission were not analyzed) were also reduced. With the SCR, the percent NO_x reductions were similar to or even greater than the published secondary data for diesel #2 fuel. The amount of reduction also depended on the quality of the biodiesel fuel that was obtained from the vendor. Since there are only a few large producers of biodiesel, there is very little oversight regulating the manufacturing of the fuel. Hence, the possible variability in the fuel quality and the direct effect it possesses on CO emissions. Also, quality will become less of an issue once there is a greater acceptance by society as a whole. Like oil refineries now, biodiesel will also have a place within the economic market with as many regulatory constraints as other industries today.

Biodiesel ...

- Reduces dependence on fossil fuels.
- Reduces emissions of CO by approximately 50 percent and CO₂ by 78.4 percent on a net lifecycle basis because the carbon in biodiesel emissions is recycled from carbon that was already in the atmosphere, rather than being new carbon from petroleum that was sequestered in the earth's crust (National Renewable Energy Lab, n.d.).
- Contains fewer aromatic hydrocarbons: benzofluoranthene- 56 percent reduction; Benzopyrenes- 71 percent reduction (EPA, 2002).
- Eliminates SO₂ because biodiesel does not include sulfur.
- Reduces the emission of particulates, small particles of solid combustion products, by as much as 65 percent (National Biodiesel Board, 2004).
- Produces more NO_x emissions than petrodiesel, but these emissions can be reduced through the use of catalytic converters. Properly designed and tuned engines may eliminate this increase (Frey, 2005).
- Has a higher cetane rating than petrodiesel, and therefore ignites more rapidly when injected into the engine (Schumacher, 1995).

Fleet service managers should locate and contract with a reputable vendor that can provide consistent biodiesel fuel quality that has the following constituents removed for better fuel quality and complete reaction:

- Glycerin
- Catalyst
- Alcohol
- Free fatty acids

Furthermore, the institution should continue to review new and updated studies that provide information on the efficiency and economic arguments that surround the use of biodiesel fuel (or alternative energy). According to a study that was conducted by Drs. Van Dyne and Raymer for the Tennessee Valley Authority, the average US farm

consumes fuel at the rate of 82 liters per hectare (8.75 US gallons per acre) of land to produce one crop. In general, crops of rapeseed produce oil at an average rate of 1,029 L/ha (110 US gal/acre), and high-yield rapeseed fields produce about 1,356 L/ha (145 US gal/acre). The ratio of input to output in these cases is roughly 1:12.5 and about 1:16.5 (Strandberg, 1993). Photosynthesis is known to have an efficiency rate of about 16 percent. If the entire mass of a crop is utilized for energy production, the overall efficiency of this chain is known to be about 1 percent. This does not compare favorably to solar cells combined with an electric drive train. Biodiesel out competes solar cells in cost and ease of deployment. However, these statistics by themselves are not enough to show whether such a change makes economic sense. For UC Irvine, these findings were encouraging and the campus will proceed with retrofitting the entire shuttle bus fleet to run on B100 fuel, utilizing the SCR system from Kleenair Systems.

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