

# Field Evaluation of Biodiesel (B20) Use by Transit Buses

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## ABSTRACT

The objective of this research project was to compare B20 (20% biodiesel fuel) and ultra-low-sulfur (ULSD) diesel-fueled buses in terms of fuel economy, vehicle maintenance, engine performance, component wear, and lube oil performance. We examined 15 model year (MY) 2002 Gillig 40-foot transit buses equipped with MY 2002 Cummins ISM engines. The engines met 2004 U.S. emission standards and employed exhaust gas recirculation (EGR). For 18 months, eight of these buses operated exclusively on B20 and seven operated exclusively on ULSD. The B20 and ULSD study groups operated from different depots of the St. Louis (Missouri) Metro, with bus routes matched for duty cycle parity.

The B20- and ULSD-fueled buses exhibited comparable fuel economy, reliability (as measured by miles between road calls), and total maintenance costs. Engine and fuel system maintenance costs were also the same for the two groups after correcting for the higher average mileage of the B20 group. Fuel filter plugging during unseasonably cold temperatures was more prevalent for the B20 group. Lube oil samples were collected over a wide range of mileage within the drain interval, and analyses indicate reductions in soot loading and wear metals in the B20 buses. Viscosity loss and lead corrosion were greater in the B20 group, while the total base number (TBN) loss was not significantly changed.

## INTRODUCTION

Biodiesel is an important petroleum displacement fuel that is produced from various fats, oils, and greases. It consists of fatty acid methyl esters produced from the various feedstocks by transesterification with methanol. Biodiesel used in the United States must meet the

quality requirements of the ASTM D6751 specification. The National Biodiesel Board estimates that 700 million gallons of biodiesel were produced in the United States in 2008 [1]. Typically, biodiesel is used as a blend with petroleum diesel at levels ranging from 2% to 20% by volume. Energy content per gallon is slightly lower for B20, resulting in a small reduction in peak torque and fuel economy, but no change in thermal efficiency [2].

Because biodiesel is still a relatively new fuel, the impact of biodiesel blends on engine maintenance costs and durability is of great interest to engine manufacturers and diesel vehicle users. These potential impacts have been evaluated in several prior studies [3-7] that found no significant differences in fuel economy, maintenance costs, or engine wear. The higher incidence of fuel filter plugging for B20 reported in some studies can be traced to low-temperature operability issues or out-of-specification biodiesel. A recent study has shown that out-of-specification biodiesel is far less prevalent in the marketplace today than it was just a few years ago [8].

The objective of this project was to evaluate the extended in-use performance of transit buses employing engines equipped with EGR, a newer engine technology than those assessed in prior studies. Specific objectives were to compare fuel economy, vehicle maintenance costs, reliability, and lube oil performance in comparison to ULSD. The buses were operated by St. Louis Metro from October 2006 to April 2008. Thus, the initiation of this test coincided with the introduction of ULSD that occurred in most of the United States in October 2006.

## BACKGROUND AND METHODS

St. Louis Metro owns and operates the St. Louis Metropolitan region's public transportation system. The system includes MetroLink, the region's light rail system;

MetroBus, the region's bus system; and Metro Call-A-Ride, a paratransit van system. In FY 2005, Metro transported more than 46.5 million passengers on the MetroLink, MetroBus, and Metro Call-A-Ride systems. Metro maintains a fleet of 433 buses, 77 light rail vehicles, and 125 paratransit vans.

Metro maintains four garage facilities, two of which are the focus of this evaluation. The Brentwood Garage dispatched and maintained the B20-fueled buses and the Debaliveire Garage handled the diesel bus control group. Buses at each garage are fueled every few days at two indoor fueling dispensers. As part of service and cleaning operations, the buses are washed and fueled in the evening hours as they return to the garage.

Service and cleaning personnel fuel the buses, while hubodometer readings and fuel volume dispensed are automatically logged electronically. Maintenance is also performed on the buses at each facility in several bays dedicated to maintenance operations. Maintenance work is recorded electronically by mechanics by capturing data on repair codes, parts, and labor hours.

**VEHICLE SELECTION** - Fifteen identical buses were included in this evaluation project. Basic vehicle attributes are presented in Table 1, and detailed vehicle specifications can be found in a preliminary report [9]. Eight of the buses operated on B20 fuel and seven operated on ULSD as a control group.

While all 15 buses were acquired in February 2004, the two study groups had not accumulated exactly the same mileage at the start of the evaluation, as shown in Table 2. On average, the B20 buses had driven about 20,000 additional miles per bus prior to the start of the evaluation.

Table 1. Metro B20 Transit Bus Basic Description

| Vehicle Information  | Evaluation Buses                                        |
|----------------------|---------------------------------------------------------|
| Number of Buses      | 7 Diesel (Bus #s 3401-3407)<br>8 B20 (Bus #s 3408-3415) |
| Chassis Manufacturer | Gillig                                                  |
| Chassis Model Year   | 2002                                                    |
| Engine               | Cummins ISM                                             |
| Engine Model Year    | 2002 (2004 emissions certification)                     |
| Max. Horsepower      | 280 hp @ 2100 rpm                                       |
| Max. Torque          | 900 lb-ft @ 1200 rpm                                    |
| Fuel Capacity        | 125 gallons                                             |
| Transmission         | Voith DIWA 863                                          |
| Curb Weight          | 29,000 lb.                                              |
| Gross Vehicle Weight | 40,600 lb.                                              |

Table 2. Study Bus Information

| Bus Unit Number             | Date of Acquisition | Fuel | Evaluation Start Mileage |
|-----------------------------|---------------------|------|--------------------------|
| 3401                        | 2/3/2004            | ULSD | 110,990                  |
| 3402                        | 2/4/2004            | ULSD | 98,042                   |
| 3403                        | 2/5/2004            | ULSD | 113,496                  |
| 3404                        | 2/9/2004            | ULSD | 87,056                   |
| 3405                        | 2/3/2004            | ULSD | 110,583                  |
| 3406                        | 2/3/2004            | ULSD | 103,929                  |
| 3407                        | 2/3/2004            | ULSD | 129,510                  |
| <i>ULSD Vehicle Average</i> |                     |      | <i>107,658</i>           |
| 3408                        | 2/3/2004            | B20  | 127,467                  |
| 3409                        | 2/3/2004            | B20  | 125,630                  |
| 3410                        | 2/3/2004            | B20  | 127,825                  |
| 3411                        | 2/3/2004            | B20  | 123,374                  |
| 3412                        | 2/16/2004           | B20  | 133,231                  |
| 3413                        | 2/23/2004           | B20  | 129,086                  |
| 3414                        | 2/18/2004           | B20  | 125,081                  |
| 3415                        | 2/3/2004            | B20  | 129,530                  |
| <i>B20 Vehicle Average</i>  |                     |      | <i>127,653</i>           |

**ROUTE/DUTY-CYCLE SELECTION** - The B20-fueled study buses are driven on the 11 Chippewa route out of the Brentwood garage, while the ULSD-fueled study buses are operated on the 32 Wellston route from the Debaliveire garage. Route duty-cycle characteristics are summarized in Table 3. Average speed is a more accurate representation of real-world driving and was therefore the defining metric in selecting these two routes for comparison.

Table 3. Evaluation Duty-Cycle Descriptions

| Route               | 11 Chippewa     | 32 Wellston        |
|---------------------|-----------------|--------------------|
| Garage (Fuel)       | Brentwood (B20) | Debaliveire (ULSD) |
| Average Speed (mph) | 13.75           | 14.57              |
| Revenue Speed (mph) | 12.32           | 14.18              |
| Passengers/Mile     | 3.03            | 2.9                |
| Passengers/Trip     | 47              | 56                 |
| Total Boardings/Day | 5100            | 4932               |

**VEHICLE FUELING AND DATA COLLECTION** - Rack-blended (in-line proportional blending) B20 was delivered to Brentwood by Hartford Wood River Terminal. ULSD was delivered to Debaliveire by Energy Petroleum. Brentwood has four 20,000-gallon underground storage tanks (USTs), which have been converted to B20 storage. Debaliveire has tanks in equal number and relative location. All USTs are connected to three interior fuel dispensers by about 1,000 feet of underground supply line. There is a 30-µm filter downstream of the supply pump, and a 10-µm filter at the fuel dispenser. Two dispensers are actively used and one is kept as a spare.

Each bus is scheduled to fuel every other day. As the bus enters the fueling island area, a radio frequency connection is established between the bus, the fueling

dispenser, and Metro's M5 electronic database. The bus is recognized, and the odometer reading, fueling volume, and lube oil requirements are uploaded to M5. These fueling records were transferred to NREL for evaluation and analysis.

**VEHICLE RELIABILITY** - A road call (RC) is defined as a call-in to a dispatcher to report a mechanical problem. Depending on the nature of the problem, the dispatcher may instruct operators to continue driving their routes. Alternatively, a RC may stem from an issue that requires the bus to stop driving and allow for roadside mechanical repair or a tow back to the maintenance facility. These RCs and average miles (driven) between road calls (MBRC) are important reliability indicators for the transit industry. For the purposes of this analysis, data received from Metro indicating that an RC occurred was recorded as such, regardless of its relative severity.

**VEHICLE MAINTENANCE AND DATA COLLECTION** - Scheduled maintenance is performed as required, and preventive maintenance (PM) events are conducted every 6,000 miles of driving. Maintenance events in the form of labor hours and parts costs are captured electronically by M5. These events are separated by work order and further by job line. Each job line is specific to the vehicle subsystem under repair. Metro submitted maintenance records electronically to NREL, where they were reviewed for accuracy and analyzed for a maintenance cost per mile comparison of the B20 and diesel groups. Maintenance cost per mile figures were calculated for specific vehicle subsystems that could be impacted by B20 fuel use.

For the B20-fueled buses in this evaluation, routine maintenance was identical to the diesel buses, with one exception. During the first two months of the study, fuel filters on the B20 buses were replaced every 2,000 miles rather than at the 6,000-mile PM interval. This is a common practice for fleets starting to use B20 because biodiesel, which is thought to be a stronger solvent than petroleum diesel, can loosen deposits in the storage system or vehicle, and this can result in fuel filter plugging. We are not aware of quantitative data to support this practice, but many biodiesel producers and fleet operators believe it to be a conservative approach.

The buses evaluated in this study had a 2-year/100,000-mile general warranty, with emissions control systems warranted to 200,000 miles. Thus, all buses operated in this study were outside their warranty or went out of warranty shortly after the start of the evaluation. Data on warranty repairs were collected in a manner similar to that for data on normal maintenance actions. However, the cost data are not included in the operating cost calculation. Labor costs may be included, depending on whether or not those hours were reimbursed under the warranty agreement. Warranty maintenance information is collected primarily as an indication of reliability and durability.

**FUEL AND LUBRICANT ANALYSIS** – B20 samples were obtained from the fuel supplier delivery trucks

approximately weekly from February 2007 through July 2007. The samples were tested for biodiesel content by FTIR method EN14078 and for cloud point by ASTM D2500. Results of this fuel analysis can be found in a previous NREL technical report [9].

**LUBE OIL ANALYSIS** - Metro uses Chevron RPM 15W-40 lube oil in the evaluation buses. Oil is changed every 6,000 miles as part of Metro's PM schedule. Metro maintenance staff sampled lube oil from the Cummins ISM sampling port every 2,000 miles, and sometimes more frequently. Lube oil samples were collected in sampling containers and mailed in pre-labeled packing provided by Cummins. Cummins conducted analyses to compare the performance of lube oil samples of vehicles fueled with B20 and ULSD. Analyses included these:

- TBN decay
- Soot content
- Wear metals (Fe, Cu, Cr)
- Evaporative metals (Ca, Zn, P)
- Other (Ba, Mg, Mo, Sn, Pb, Al, Si, Na)

## RESULTS

**BUS USE** - Table 4 presents information on bus utilization during the study period for the two groups. The overall 18-month average monthly miles per bus for the B20 buses was about 3.7% higher than for the ULSD buses at Debaliveire. Based on a two-tailed, paired t-test, the difference between the two groups is not statistically significant with a high degree of confidence ( $P = 0.13$ ). The average mileage accumulated per bus during the study is also very similar for the two groups. The approximately 20,000-mile difference in average total miles per bus noted at the start of the study is also seen at the end of the study. Figure 1 shows cumulative average monthly miles per bus for each study group. The average usage of the buses declined slightly during the evaluation period, in which the B20 and ULSD study bus groups accumulated 590,042 and 497,654 miles, respectively.

Table 4. Average Miles Driven per Month per Bus by Study Group

| Bus Group | Average Miles per Month | Average Study Miles | Average Total Miles |
|-----------|-------------------------|---------------------|---------------------|
| B20       | 4,097                   | 73,755              | 201,420             |
| ULSD      | 3,950                   | 71,093              | 178,251             |

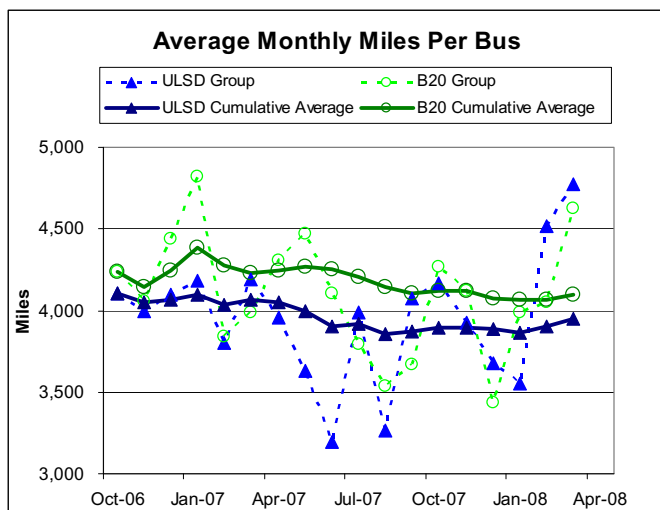


Figure 1. Cumulative Average Monthly Mileage per Bus

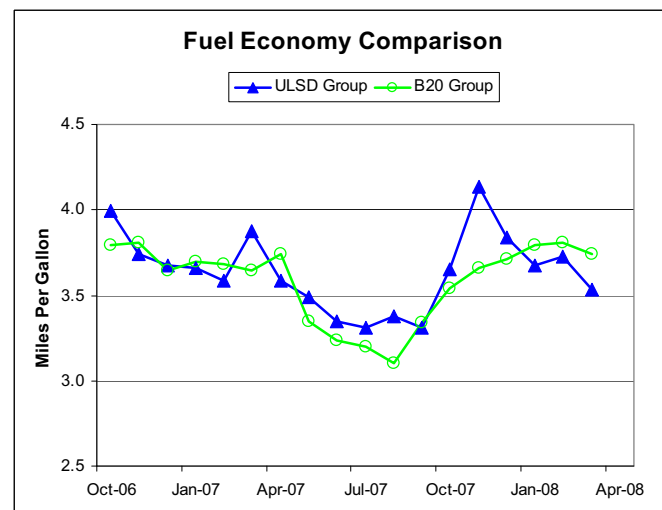


Figure 2. Average Fuel Economy

**FUEL ECONOMY** - Fuel consumption and economy data are presented in Table 5. The calculated 18-month average fuel economy for the B20 buses is 1.5% lower than that of the ULSD buses. This difference is expected because of the approximately 2% lower energy content in a gallon of B20; however, based on a two-tailed, paired t-test, the difference between the two groups is not statistically significant with a high degree of confidence ( $P = 0.2$ ).

Figure 2 shows the average monthly fuel economy for the two study groups for the 18-month evaluation period.

Table 5. Bus Fuel Use and Economy

| Fuel Economy Comparison October 2006 - March 2008 |             |                |                     |                    |
|---------------------------------------------------|-------------|----------------|---------------------|--------------------|
| Bus                                               | Fuel        | Mileage Total  | Fuel Used (gallons) | Fuel Economy (mpg) |
| 3401                                              | ULSD        | 75,795         | 21,519              | 3.52               |
| 3402                                              | ULSD        | 65,026         | 18,044              | 3.60               |
| 3403                                              | ULSD        | 71,679         | 19,664              | 3.65               |
| 3404                                              | ULSD        | 74,478         | 20,941              | 3.56               |
| 3405                                              | ULSD        | 67,241         | 18,289              | 3.68               |
| 3406                                              | ULSD        | 70,401         | 19,463              | 3.62               |
| 3407                                              | ULSD        | 73,034         | 19,080              | 3.83               |
| <b>Total</b>                                      | <b>ULSD</b> | <b>497,654</b> | <b>137,000</b>      | <b>3.63</b>        |
| 3408                                              | B20         | 80,241         | 22,250              | 3.61               |
| 3409                                              | B20         | 78,561         | 21,384              | 3.67               |
| 3410                                              | B20         | 71,113         | 20,429              | 3.48               |
| 3411                                              | B20         | 77,461         | 22,191              | 3.49               |
| 3412                                              | B20         | 72,667         | 19,957              | 3.64               |
| 3413                                              | B20         | 68,320         | 19,734              | 3.46               |
| 3414                                              | B20         | 73,202         | 19,695              | 3.72               |
| 3415                                              | B20         | 68,477         | 19,327              | 3.54               |
| <b>Total</b>                                      | <b>B20</b>  | <b>590,042</b> | <b>164,967</b>      | <b>3.58</b>        |

**VEHICLE RELIABILITY ANALYSIS** - Figure 3 shows the cumulative MBRC for all RCs for the ULSD and B20 groups. Average MBRC values over the evaluation period were 2,690 and 2,694 for ULSD and B20 groups, respectively, a difference that is not statistically significant based on a two-tailed, paired t-test ( $P = 0.95$ ).

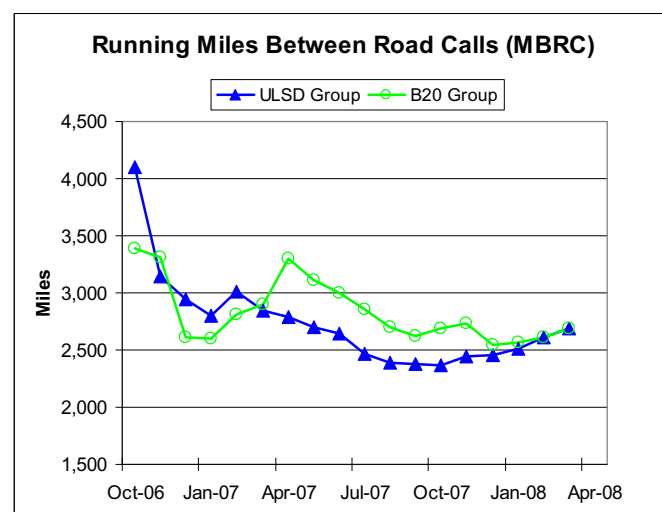


Figure 3. Cumulative MBRCs

In addition, reliability as measured in MBRCs is assessed for the engine and fuel systems. Figure 4 shows the cumulative MBRC for all engine and fuel system RCs for the ULSD and B20 groups. The ULSD group had a three-month run of exceptionally high MBRC numbers, creating a spike, but that was followed by a few months of a high number of road calls that dragged the cumulative average below that of the B20 group for seven months. For the last four months of the 18-month evaluation, the B20 buses and ULSD buses were comparable, with cumulative engine and fuel system MBRC values of 8,435 and 8,310 for the ULSD and B20 groups, respectively, at the end of the evaluation period. Based on a two-tailed, paired t-test, this difference is not significant ( $P = 0.8$ ).