



Evaluation of USF Bio-Diesel Fueled Bull-Runner Service

November 2004

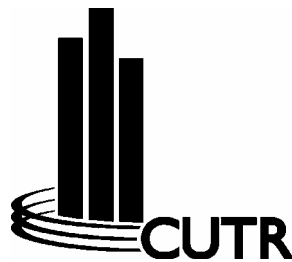
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16. Abstract Biodiesel is the name given to an alternative fuel used in place of and along with conventional petroleum diesel fuels. Biodiesel fuels are derived from sources including oils such as those found in rapeseed, corn, mustard, soybean, sunflower, macadamia, coconut, and peanut seeds. They are also derived from animal fats through a procedure that removes the glycerin from the oil, leaving a clean burning fuel product that can be used in conventional compression ignition engines. These fuels hold advantages surpassed by most other unconventional fuel sources. The greatest of these, besides the ample emissions reductions, is the near 100% compatibility of biodiesel fuels in standard combustion ignition petroleum diesel engines. Biodiesel fuels can be blended with petroleum diesel at any proportion to achieve varying degrees of unwanted emission reductions. This paper summarizes and compares the performance of the University of South Florida (USF) Bull-Runner Shuttle (BRS) fleet during two six-month periods. The purpose of this examination is to determine the cost difference in terms of fuel efficiency for the transition from conventional biodiesel to petroleum diesel. The first six months (August 1, 2001 to January 31, 2002) observes the fleet operations six months prior to operating with biodiesel fuel, and the second six months (August 8, 2002 to January 31, 2003) observes the fleet of operations with biodiesel six months after transitioning to biodiesel.			
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Evaluation of USF Bio-Diesel Fueled Bull-Runner Service

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1.0 Overview

1.1 Benefits

Biodiesel fuels have inherent advantages over other alternative fuels. Although compressed natural gas, liquid natural gas, methanol, and ethanol prove to be viable alternatives to diesel fuels, the properties of biodiesel make it very promising.

The most prominent of the benefits offered by biodiesel is the ease with which fleet operators can transition their fleets from petroleum diesel to biodiesel fuel. Biodiesel can be blended in any proportion with petroleum diesel. It can be used as a pure fuel in almost all combustion ignition petroleum diesel engines with minimal, if any, modifications to the engine itself. The most common blend is the B20, a mix with a 1:5 ratio of biodiesel to fuels. With today's market and fuel prices, the B20 mix marks a point chosen by the Environmental Protection Agency (EPA) of maximizing benefits while keeping cost to a minimum. It is true that the greatest fuel emission benefits are achieved when B100 (pure biodiesel fuel) is used, but mixes containing as much as 80% petroleum diesel still show significant improvements in reducing fuel emissions.

Studies have shown that biodiesel holds significant environmental benefits over conventional petroleum diesel fuel. Burning biodiesel reduces the amount of unburned hydrocarbons, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter with relation to petroleum.

Biodiesel's evident potential for wide spread use in petroleum diesel engines with little vehicle alterations makes biodiesel fuel the most researched and tested alternate fuel available in the alternative fuel market. As a result, biodiesel fuels have advanced over its competitor fuel products with regards to being recognized as a viable alternate renewable fuel source. Biodiesel fuel is the only alternate fuel to date to pass the standards of the 1990 Clean Air Act and to be recognized as a viable fuel by the EPA¹.

1.0 Overview

1.2 Technical Definition

Although several variations of general definitions exist for biodiesel, ultimately the final qualification is found in the definition prepared by the American Society of Testing Materials (ASTM). That definition reads as follows:

Biodiesel, n – a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751.

Biodiesel blend, n – a blend of biodiesel fuel meeting ASTM D 6751 with petroleum-based diesel fuel, designated BXX, where XX represents the volume percentage of biodiesel fuel in the blend.ⁱⁱ

This technical ASTM definition translates to biodiesel being a “renewable fuel for diesel engines derived from natural oils like soybean oil, and it meets the specification of ASTM D 6751.”ⁱⁱⁱ In addition to this, biodiesel can be blended to any proportion with petroleum diesel based diesel fuel. It should be noted, “biodiesel is not the same thing as raw vegetable oil. It is produced by a chemical process which removes the glycerin from the oil.”^{iv}

1.3 EPA Registration

In the United States, all fuels must be registered with the EPA prior to becoming legal in the economic market. All fuels must also pass all the health effects regulations in 40 CFR Part 49. The National Biodiesel Board has completed the testing and registration process on behalf of the rest of the biodiesel industry. That makes biodiesel “the only alternative fuel to have fully completed the health effect testing requirements of the 1990 Clean Air Act Amendments...[and be] registered as a fuel and fuel additive with the EPA and meets the clean diesel standards established by California Air Resources Board (CARB). Neat biodiesel (B100) has been designated as an alternative fuel by the Department of Energy (DOE) and the US Department of Transportation (DOT).” (National Biodiesel Board, FAQ)

1.0 Overview

1.4 Emissions

Biodiesel demonstrates a substantial reduction to nearly all regulated and non-regulated pollution emission components according to research conducted and gathered by the National Biodiesel Board. An overview of the emissions data for B100 is as follows:

- a. The overall ozone (smog) forming potential of biodiesel is less than diesel fuel. The ozone forming potential of the speciated hydrocarbon emissions was nearly 50% less than that measured for diesel fuel.
- b. Sulfur emissions are essentially eliminated with pure biodiesel. The exhaust emissions of sulfur oxides and sulfates (major components of acid rain), from biodiesel were essentially eliminated compared to sulfur oxides and sulfates from diesel.
- c. Criteria pollutants are reduced with biodiesel use. Tests show the use of biodiesel in diesel engines result in substantial reductions of unburned hydrocarbons, carbon monoxide, and particulate matter. Emissions of nitrogen oxides stay the same or are slightly increased.
- d. Carbon Monoxide -- The exhaust emissions of carbon monoxide (a poisonous gas) from biodiesel are on average 47% lower than carbon monoxide emissions from diesel.
- e. Particulate Matter -- Breathing particulate has been shown to be a human health hazard. The exhaust emissions of particulate matter from biodiesel are about 47% lower than overall particulate matter emissions from diesel.
- f. Hydrocarbons -- The exhaust emissions of total hydrocarbons (a contributing factor in the localized formation of smog and ozone) are on average 67% lower for biodiesel than diesel fuel.
- g. Nitrogen Oxides -- NO_x emissions from biodiesel increase or decrease depending on the engine family and testing procedures. NO_x emissions (a contributing factor in the localized formation of smog and ozone) from pure (100%) biodiesel increase on average by 10%. However, the lack of sulfur in biodiesel allows the use of NO_x control technologies that cannot be used with conventional diesel. So, biodiesel NO_x emissions can be effectively managed and efficiently eliminated.

1.0 Overview

Biodiesel reduces the health risks associated with petroleum diesel. Biodiesel emissions show decreased levels of polycyclic aromatic hydrocarbons (PAH) and nitrated PAH compounds which have been identified as potential cancer causing compounds. In the recent testing, PAH compounds were reduced by 75% to 85%, with the exception of benzo(a)anthracene, which was reduced by roughly 50%. Targeted nitrated PAH compounds were also reduced dramatically with biodiesel fuel, with 2-nitrofluorene and 1-nitropyrene reduced by 90%, and the rest of the nPAH compounds reduced to only trace levels.^v

Table 1.1, shows a summary of the above described emission reductions numbers for biodiesel fuel compared to petroleum diesel fuel. The table is divided into two sections showing the reduction in percentage from petroleum diesel emission of first regulated then unregulated emission control criteria. Each section compares pure biodiesel to B20 with relation to petroleum diesel.

Table 1.1 Emissions Overview

Average Biodiesel Emissions Compared to Conventional Diesel		
Emission Type	B100 Fuel	B20 Fuel
(Regulated)		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NOx	+10%	+2%
(Unregulated)		
Sulfates	-100%	-20%
PAH (polycyclic aromatic hydrocarbons)	-80%	-13%
nPAH (nitrated PAH's)	-90%	-50%
Ozone potential of speciated Hydrocarbons	- 50%	-10%

Source: National Biodiesel Board^{vi}

2.0 Third Party Lifecycle Study

The Department of Energy (DOE) and the US Department of Agriculture (USDA) conducted a three and half year lifecycle analysis of the entire production and consumption process for both biodiesel and petroleum diesel fuels. Their aim was to study not only the promising emissions benefits from burning biodiesel fuel, but also to examine all other aspects including “inventory of materials used, energy resources consumed, and air, water and solid waste emissions generated” (National Biodiesel Board, Lifecycle Summary). The major findings of their study of B100 are as follows:

- a. The total energy efficiency ratio (ie. total fuel energy/total energy used in production, manufacture, transportation, and distribution) for diesel fuel and biodiesel are 83.28% for diesel vs. 80.55% for biodiesel. The report notes, "Biodiesel and petroleum diesel have very similar energy efficiencies."
- b. The total fossil energy efficiency ratio (ie. total fuel energy/total fossil energy used in production, manufacture, transportation, and distribution) for diesel fuel and biodiesel shows that biodiesel is four times as efficient as diesel fuel in utilizing fossil energy; 3.215% for biodiesel vs. 0.8337% for diesel. The study notes, "In terms of effective use of fossil energy resources, biodiesel yields around 3.2 units of fuel product for every unit of fossil energy consumed in the lifecycle. By contrast, petroleum diesel's life cycle yields only 0.83 units of fuel product per unit of fossil energy consumed. Such measures confirm the 'renewable' nature of biodiesel." The report also notes, "On the basis of fossil energy inputs, biodiesel enhances the effective utilization of this finite energy source."
- c. In urban bus engines, biodiesel and B20 exhibit similar fuel economy to diesel fuel, based on a comparison of the volumetric energy density of the two fuels. The study explains, "Generally fuel consumption is proportional to the volumetric energy density of the fuel based on lower or net heating value... diesel contains about 131,295 Btu/gal while biodiesel contains approximately 117,093 Btu/gal. The ratio is 0.892. If biodiesel has no impact on engine efficiency, volumetric fuel economy would be approximately 10% lower for biodiesel compared to petroleum diesel. However, fuel efficiency and fuel economy of biodiesel tend to be only 2% to 3% less than number 2 diesel."
- d. The overall lifecycle emissions of carbon dioxide (a major greenhouse gas) from biodiesel are 78% lower than the overall carbon dioxide emissions from petroleum diesel. "The reduction is a direct result of carbon recycling in soybean plants," notes the study.

- e. The overall lifecycle emissions of carbon monoxide (a poisonous gas and a contributing factor in the localized formation of smog and ozone) from biodiesel are 35% lower than overall carbon monoxide emissions from diesel. Biodiesel also reduces bus tailpipe emissions of carbon monoxide by 46%. The study observes, "Biodiesel could, therefore, be an effective tool for mitigating CO in EPA's designated CO non-attainment areas."
- f. The overall lifecycle emissions of particulate matter (PM), recognized as a contributing factor in respiratory disease, from biodiesel are 32% lower than overall particulate matter emissions from diesel. Bus tailpipe emissions of PM10 are 68% lower for biodiesel compared to petroleum diesel. The study notes, "PM10 emitted from mobile sources is a major EPA target because of its role in respiratory disease. Urban areas represent the greatest risk in terms of numbers of people exposed and level of PM10 present. Use of biodiesel in urban buses is potentially a viable option for controlling both life cycle emissions of total particulate matter and tailpipe emission of PM10."
- g. The study also finds that biodiesel reduces the total amount of particulate matter soot in bus tailpipe exhaust by 83.6%. Soot is the heavy black smoke portion of the exhaust that is essentially 100% carbon that forms as a result of pyrolysis reactions during fuel combustion. The study notes there is on-going research to discover the relationship between exposure to diesel soot and cancerous growths in mice. Beyond the potential public health benefit from substantially reduced soot emissions, the study also notes, "there is an aesthetic benefit associated with significantly less visible smoke observed from the tailpipe. For urban bus operators, this translates into improved public relations."
- h. The overall lifecycle emissions of sulfur oxides (major components of acid rain) from biodiesel are 8% lower than overall sulfur oxides emissions from diesel. Biodiesel completely eliminates emissions of sulfur oxides from bus tailpipe emissions. The study notes, "Biodiesel can eliminate sulfur oxides emissions because it is sulfur-free."
- i. The overall lifecycle emissions of methane (one of the most potent greenhouse gases) from biodiesel are almost 3.0% lower than overall methane emissions from diesel. The study notes, "Though the reductions achieved with biodiesel are small, they could be significant when estimated on the basis of its 'CO2 equivalent'-warming potential."

- j. The overall lifecycle emissions of nitrogen oxides (a contributing factor in the localized formation of smog and ozone) from biodiesel are 13% greater than overall nitrogen oxide emissions from diesel. An urban bus that runs on biodiesel has tailpipe emissions that are 8.89% higher than a bus operated on petroleum diesel. The study also notes, "Smaller changes in NOx emissions for B100 and B20 have been observed in current research programs on new model engines but it is still too early to predict whether all or just a few future engines will display this characteristic." and "... solutions are potentially achievable that meet tougher future (vehicle) standards for NOx without sacrificing the other benefits of this fuel."
- k. The bus tailpipe emissions of hydrocarbons (a contributing factor in the localized formation of smog and ozone) are 37% lower for biodiesel than diesel fuel. However, the overall lifecycle emissions of hydrocarbons from biodiesel are 35% greater than overall hydrocarbon emissions from diesel. That is to say although the tailpipe emissions are less for biodiesel, the production of biodiesel produces more hydrocarbons than petroleum diesel. The study notes, "In understanding the implications of higher lifecycle emissions, it is important to remember that emissions of hydrocarbons, as with all of the air pollutants discussed, have localized effects. In other words it makes a difference where these emissions occur. The fact that biodiesel's hydrocarbon emissions at the tailpipe are lower may mean that the biodiesel life cycle has beneficial effects on urban area pollution."
- l. The study also cautions about drawing hard conclusions related to the total life cycle emissions of hydrocarbons from sources other than the engine tailpipe, "We have less confidence in the hydrocarbon air emissions results from this study. Our data set includes numbers reported as "unspecified hydrocarbons" and as "non-methane hydrocarbons" (NMHC). Given these kinds of ambiguities in the data, results on hydrocarbon emissions need to be viewed with caution."
- m. The overall lifecycle production of wastewater from biodiesel is 79.0% lower than overall production of wastewater from diesel. The study notes, "Petroleum diesel generates roughly five times as much wastewater flow as biodiesel."
- n. The overall lifecycle production of hazardous solid wastes from biodiesel is 96% lower than overall production of hazardous solid wastes from diesel. However, the overall life cycle production of non-hazardous solid wastes from biodiesel is twice as great as the production of non-hazardous solid wastes from diesel. The study

notes: "Given the more severe impact of hazardous versus non-hazardous waste disposal, this is a reasonable trade-off."^{vii}

Aside from the tremendous decrease in emissions, compared to conventional petroleum diesel fuels, biodiesel has additional environmental advantages. Biodiesel is nontoxic; it has been tested to have a lethal dose greater than 17.4g/Kg body weight (that equates to roughly 50 ounces for a 160 pound man). Comparatively "table salt (NaCl) is nearly 10 times more toxic" than pure biodiesel. Biodiesel also exhibits four times the biodegradability rate of petroleum diesel fuel. On account of this relationship, even a B20 blend will degrade up to two times faster than number 2 diesel would alone.

2.1 Expected Biodiesel Performance

The USF BRS performance with biodiesel is expected to be similar to the petroleum diesel performance. This hypothesis is drawn knowing that the energy efficiency ratio of both fuels is very similar. This being true, fleet operational costs with biodiesel fuel usage should be similar to petroleum diesel as well (neglecting market price differences in the fuel types).

As previously stated, the overall production, manufacturing, transportation, and distribution of biodiesel has a 2.73% less energy efficiency ratio than petroleum diesel. There are many more beneficial factors involved in using biodiesel fuel that far outweigh petroleum diesel's slightly more time-tested and energy efficient infrastructure. The over all energy efficiency reduction is not significant when compared to the fossil energy ratio. The significance of the fossil energy ratio lies in the fact that there is a limited supply of fossil fuels. Biodiesel fuel is superior to petroleum if for no other reason than the fact that it takes about one quarter the amount of fossil fuel to generate one unit of biodiesel fuel than it does to generate one unit of petroleum diesel fuel (provided that both fuel types have similar fuel consumption measures).

The fuel economy based on the volumetric energy density of the two fuels is very similar for both fuel types. Theoretically, a system operator is expected to experience about a 10% increase in fuel usage when switching from petroleum diesel to biodiesel fuel. In spite of this, previous studies have shown the fuel economy to differ only by two to three percent.

3.0 USF Study

3.1 USF Bull-Runner Shuttle

The USF Parking and Transportation Services (PTS) converted the USF BRS fleet from burning conventional petroleum diesel fuel to 100% biodiesel fuel in the beginning of August 2002. The transition to biodiesel fuel occurred without pressure from any legislation forcing lesser fuel emissions on the BRS fleet. The large number of electric vehicles used on the USF campus holds the system wide emissions averages well below the minimum standards set by the EPA.

The USF PTS made the transition because of a desire to do its part ecologically by providing a more environmentally friendly transit system for USF. This desire is the reason that USF PTS choose 100% biodiesel fuel (B100) as opposed to the EPA proposed 20% biodiesel and 80% petroleum diesel (B20) fuel mix that most system operators choose. Although, the B20 mix provides a great deal of emissions reductions, the greatest reductions are achieved when there is no petroleum diesel used.

The USF BRS fleet did not experience any problems with the sudden transition from 100% petroleum diesel fuel to 100% biodiesel fuel with respect to engine parts and other mechanical components. No engine manufacturers warranty were voided by the change in fuel. The engine manufacturers warrantee does not regulate the type of fuel under which they warrant their product. All engines are guaranteed to be mechanically sound and problem free; it is the fuel manufacturer that will warrant their fuel to meet industry standards and not damage engine parts under normal use.

The only challenge that the BRS fleet encountered was the need to replace its vehicle's fuel filters more frequently than before. This was however an expected initial outcome of the transition to biodiesel fuel. Biodiesel fuel has the inherent property of being a natural solvent. As such, its effects are broken into two categories. Outside the engine, the fuel will effectively eat through painted surfaces if allowed to sit. Inside the engine, the fuel dissolves settlement left over from burning petrol. The downside of the cleansing effect is a highly increased amount of residue collected in the fuel filters. It was necessary to change each vehicle's fuel filter at a minimum of once per week or every 500 miles for a period of two months. The USF PTS plans on replacing the fuel filters twice as frequently than the regular maintenance schedule as a preventive measure for a period of one year after the two months of weekly servicing.

As the fuel filters became overburdened each vehicle reacted differently. The Cummings engine vehicles would begin to produce a great deal of white smoke instead of the normal exhaust. The Chevy engines would express a significant loss of power as an indication of a clogging filter. Whereas the Ford engines would not show any signs of problems until exceeding a threshold at which point the Fords would simply stop functioning.

A possible solution to help reduce the vehicle maintenance when transitioning to B100 would be to operate at gradually increasing ratios of biodiesel fuel over a prolonged time. Such frequent maintenance was manageable for the USF fleet because of its relative small size. Nevertheless, the transition would have been smoother for the BRS if a gradual step program would have been implemented instead of a sudden transition to B100 fuel.

Another common issue, which was not experienced by the USF BRS fleet, is the degradation of fuel hoses and gaskets in different engine parts due to biodiesel being a solvent. The BRS fleet did not experience these problems because all of their vehicles are post 1990; the early 90's marks the date after which most engine manufactures began producing parts resistant to solvents like biodiesel fuel. Ironically, the only pre 1990 vehicle in the fleet is the fuel tanker that is used for transportation, storage, and refueling of vehicles. The tanker was purchased with the appropriate modifications in place that would allow for it to be used with biodiesel fuel.

The decision to purchase a fuel truck for transportation and storage came out of necessity. Biodiesel does not have the same distribution infrastructure that petroleum diesel does despite it being much safer and easier for transportation than petroleum diesel. Biodiesel is safer for transportation in part because it is environmentally friendly. However, certain tank materials, like polyethylene, cannot be used because of biodiesel's solvent properties, thereby limiting the tanks it can be stored in.

Biodiesel seems to be not only the most cost effective way to reduce emissions, but biodiesel fuels are the most beneficial alternative fuel types. Although the typical price of biodiesel fuel (\$1.50 per gallon as of September 2003) is slightly higher than petrol, there were times during 2004, with uncertainties in the Middle East and fuel supply, that petrol was actually more expensive than biodiesel. The beauty of the biodiesel fuel product is that it is not only ecologically sound, but a fleet can easily be converted by simply putting a different fuel in its tank. A fleet that converts to another alternative fuel, like compressed natural gas, is limited to using that fuel source. Biodiesel has the unique property of being compatible with petroleum diesel which is by far the most widely used fuel source of commercial vehicles. This means that the contingency plan of using petroleum diesel (should biodiesel become scarce) is always implementable at no additional cost.

3.2 Data Collection

The USF PTS provided two different data sets for analysis. The first and oldest of the data sets was an excel spread sheet comprised of fuel performance data and maintenance records for each vehicle in the fleet for the time range of July 1998 to August 2002. The maintenance records consisted of the entry date, problem with the vehicle, date the vehicle went out of service and returned, the file and work order number, and other descriptive notes. The maintenance records included only descriptive records; there were not scheduled maintenance records or costs associated with any field. The performance fuel data consisted of service date, total vehicle mileage, volume of fuel added, miles since service, fuel type used, volume of oil added, and calculated miles per gallon.

The second set of data was a comprehensive collection of system information from August 2002 to June 2003 contained in a Microsoft Access Database. The information utilized from this set of data was vehicle identification number, date of service, total vehicle mileage, fuel type added, quantity of fuel and oil added, total mileage and average mileage since last service. The table containing fuel performance information also contained transmission, brake and power steering fluid figures. These figures were not utilized because this data was not collected prior to August 2002 for comparison.

The data was provided in an electronic format and could easily be manipulated and resorted. The common fuel data key elements contained within the two sets of data were compared to each other in several ways. The USF BRS service schedule revolves around the school semesters, therefore six-month time periods were chose to be measured two years in a row and compared to each other. The two periods are two consecutive fall semesters.

The two time sets were analyzed in two separate categories. The first set of figures encompasses all the vehicles within the given time frame¹ and the second set of figures analyzes only those vehicles that were used during both the petroleum diesel time period as well as the biodiesel time period². This division was done in accordance with the USF PTS request to focus the study on the same type of vehicle to reduce the number of variables potentially affecting the fuel efficiency performance of the vehicle. In addition to this, the records were divided into two additional categories; one showing the overall system performance per fuel time for the given time frame and the other breaking down the performance on an individual vehicle basis.

¹ Data Analysis report sections 5.2 and 5.3

² Data Analysis report section 5.4

3.3 Data Measures and Calculations

The entire dataset covering the dates of June 29, 1998, through June 13, 2003, contained 6,099 records of which 5,887 (96.5%) were usable for the purposes of calculations. The 127 records omitted from the data set were omitted for reasons including missing data as well as data extremes outside the normal range. For example there were twenty-three records with missing mileage data and there were three entries reporting incorrect dates.

Five separate fuel types were reported by the data: “biodiesel”, “B-100”, “B-20”, “diesel”, and “gas”. Of the 6,016 (98.6%) records reporting fuel type data, biodiesel was reported two times (0.03%) with out specifying what blend of fuel was used; 1,532 (25.5%) reported B-100 fuel; 152 (2.5%) reported B-20 fuel; 207 (3.4%) reported gas fuel; and 4123 (68.5%) reported petroleum diesel. Since the USF BRS systems does not have any vehicles equipped to run on compressed or liquid natural gas, the records noted “gas” are assumed to be petroleum diesel gasoline. All biodiesel entries are recorded either generally as “biodiesel” or specifically as “B-100” or “B-20.” The USF BRS only uses biodiesel in B20 and B100 proportions, the records noted as “biodiesel” must be B20 or B100. The appearances of “gas” and “biodiesel” entries serve only to illustrate a small inconsistency in the data reporting process; all of those values were not included in the study’s system analysis.

Calculated values include all averages, modes, medians, standard deviations, minimums and maximums. These values were obtained using suitable Microsoft Excel formulas. Distance traveled between fuel services was calculated by subtracting reported mileage data of successive records sorted by date. This calculation was necessary because only 3,255 (53.4%) records contained miles traveled data where as 6,016 (98.6%) records contained total vehicle odometer readings. The fuel economy was calculated using both reported and calculated odometer and gallons of fuel figures.

Errors in calculations and extreme outlier data points were omitted, and noted in a Microsoft Excel sheet, from data sets used for final calculations. Points that were three standard deviations from the mean were examined to check if they are extreme data outliers. Outliers were defined as any point greater than three times the value of the previous greatest value beyond the tested range. For example, in the data range August 1, 2002, through January 31, 2003, the five highest value distance traveled prior to a service are 310,543 miles, 78,570 miles, 44,737 miles, 10,547 miles, and 6,222 miles. The three highest values were omitted when calculating averages on account of 44,737 miles being greater than 31,641, three times 10,547 miles.

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4.0 Data Analysis Report

4.1 Data Overview

The first six-month block studied encompasses data for all the vehicles during both August 1, 2001, through January 31, 2002, and August 1, 2002, through January 31, 2003. These time ranges cover the first instances of biodiesel being used and the same time period one year earlier when petroleum diesel was being used. This time period contains seven hundred and sixty four records; 13.0% of the total usable collected data falls in this time range. This data set includes all the vehicles.

4.2 Petrol Gas Time Range

The petroleum diesel fuel usage time period is August 1, 2001 to January 31, 2002.

4.2.1 MPG Reported Findings

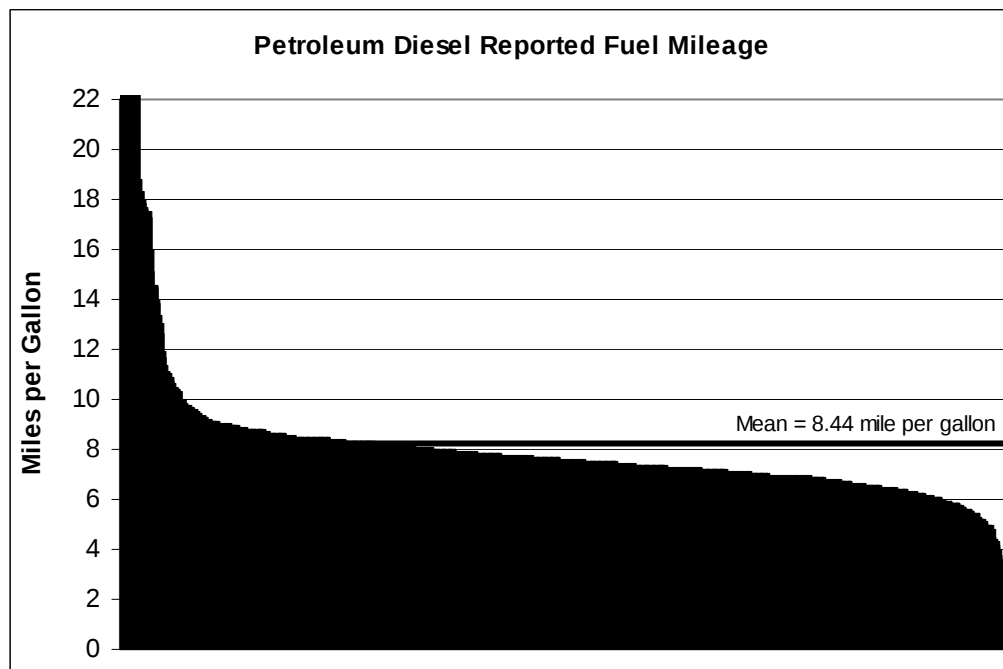
The data set for the petroleum diesel time range contains a complete record of the fuel economy. This reported figure is compared to a calculated value of the fuel economy using mileage and fuel consumption data.

4.2.1.1 Petroleum Diesel Fuel Vehicles

In the first six-month record of petroleum diesel fuel there are seven hundred and sixty two (100.00%) records for which fuel economy data was reported. The average miles per gallon reported value was 8.44 miles per gallon of petroleum diesel fuel. Of these, 68.31 miles per gallon is the maximum calculated fuel mileage and 0.39 miles per gallon the least. The data set has a median value of 7.67 miles per gallon and a most occurring value of 8.00 miles per gallon. This data set exhibits a positive 6.36 skew. Using a standard deviation of 4.63 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 4.2a, illustrates the trends in reported fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage. The horizontal axis represents each of the seven hundred and sixty two records arranged in decreasing order of fuel economy. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial curve and location of the average value near the bottom quarter of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean with outlier values on the high end.

Figure 4.2a Reported Petroleum Fuel Economy



The seventeen (2.23%) highest value records in this data set lie beyond three deviations from the mean. Seven hundred and thirty nine records (96.98%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Seven hundred and seventeen (94.09%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 22.32 miles per gallon, three deviations above; 17.70 miles per gallon, two deviations above; 13.07 miles per gallon, one deviation above; 8.44 miles per gallon, the mean; 3.81 miles per gallon, one deviation below; -0.82 miles per gallon, two deviations below; and -5.44 miles per gallon, three deviations below.

4.2.2 MPG Calculated Findings

The reporting of calculated fuel mileage values comes solely from the reported mileage values and reported fuel consumption values. The fuel economy measure was calculated by dividing the distance traveled between vehicle services (calculated by subtracting total vehicle odometer readings from subsequent services) by the reported fuel consumption measures. The generation of this figure was necessary for comparison purposes because during the second study block, when biodiesel is being used, a calculated value for the fuel economy of biodiesel is the only account possible since fuel mileage was not recorded for instances of biodiesel usage³.

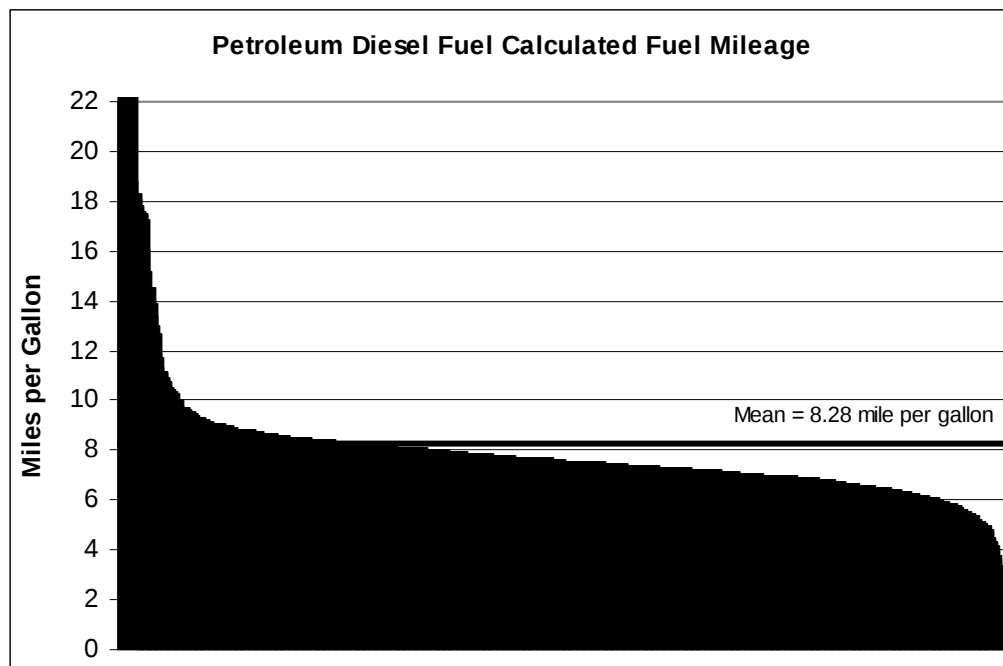
³ See the appendix for a complete record reporting all the calculated distance traveled data as well as the fuel consumption figures used for obtaining the calculated miles per gallon figures.

4.2.2.1 Petroleum Diesel Fuel Vehicles

In the first six-month period of petroleum diesel fuel there are seven hundred and sixty two (99.74%) records for which fuel economy data could be calculated using calculated distance measures. The average miles per gallon reported value was 8.28 miles per petroleum diesel fuel gallon; this method yields an average fuel economy value with a 1.91% error for this category. Of these, 41.53 miles per gallon is the maximum calculated fuel mileage and 0.39 miles per gallon the least. The data set has a median value of 7.59 miles per gallon and a most occurring value of 8.00 miles per gallon. This data set exhibits a positive 5.31 skew. Using a standard deviation of 4.26 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 4.2b, illustrates the trends in calculated fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage. The horizontal axis represents each of the seven hundred and sixty two records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial curve and location of the average value near the bottom quarter of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean with outlier values on the high end.

Figure 4.2b Calculated Petroleum Fuel Economy



4.0 Data Analysis Report

The sixteen (2.09%) highest value records in this data set lie beyond three deviations from the mean. Seven hundred and thirty six records (96.08%) fall within two deviations; a range where 95 of data will theoretically fall if normally distributed. Seven hundred and thirteen (93.08%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 21.04 miles per gallon, three deviations above; 16.79 miles per gallon, two deviations above; 12.53 miles per gallon, one deviation above; 8.28 miles per gallon, the mean; 4.02 miles per gallon, one deviation below; -0.23 miles per gallon, two deviations below; and -4.49 miles per gallon, three deviations below.⁴

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⁴ There was one reported value for B100 fuel for this time range (6.70 miles per gallon).

4.3 Biodiesel Fuel Time Range

The biodiesel fuel usage time period is August 8, 2002 to January 31, 2003.

4.3.1 MPG Reported Findings

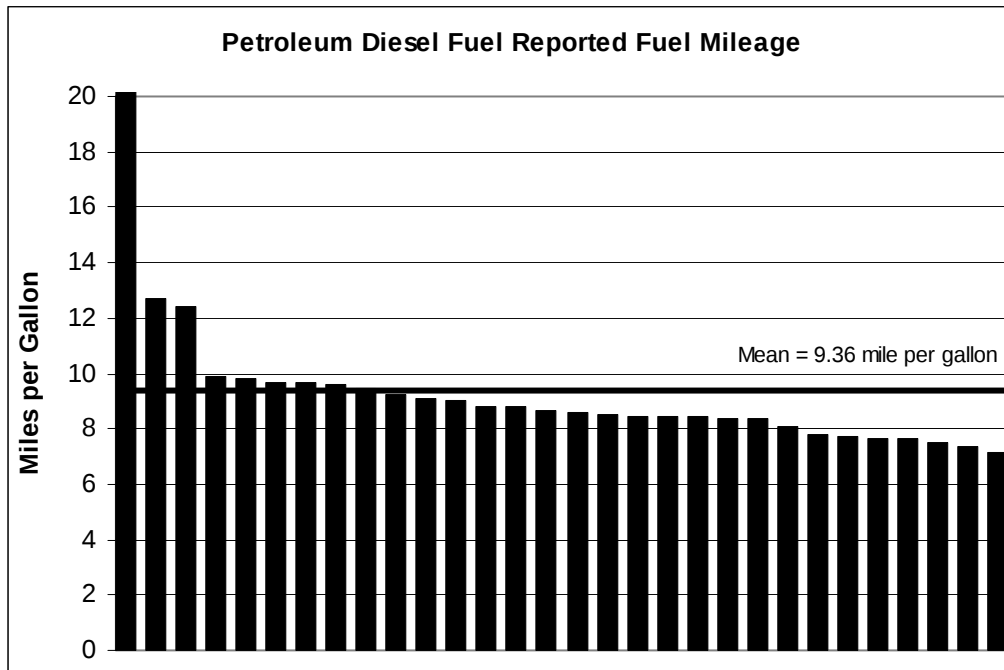
The following sections summarize the fuel economy findings for each of the fuel types. These “reported” figures are the values collected directly from the USF Parking Transportation Services database.

4.3.1.1 Petroleum Diesel Fuel Vehicles

In the first six-month period of biodiesel fuel there are thirty (100.00%) records for which fuel economy data was reported. No records were eliminated as outliers. The average miles per gallon reported value was 9.36 miles per petroleum diesel fuel gallon. Of these, 23.63 miles per gallon is the maximum calculated fuel mileage and 7.12 miles per gallon the least. The data set has a median value of 8.62 miles per gallon and a most occurring value of 8.46 miles per gallon. This data exhibits a 4.10 positive skew. Using a standard deviation of 2.97 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 4.3a, illustrates the trends in calculated fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage when using petroleum diesel fuel. The horizontal axis represents each of the thirty records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph’s steep initial slope, later constant curve and location of the average value near the bottom third of the data range supports the numerical calculations, placing the data set outside an acceptable range from the mean.

Figure 4.3a Reported Petroleum Fuel Economy



The highest value (3.33%) records in this data set lie beyond three deviations from the mean. Twenty-nine records (96.67%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Twenty-seven (90.00%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 18.28 miles per gallon, three deviations above; 15.30 miles per gallon, two deviations above; 12.33 miles per gallon, one deviation above; 9.36 miles per gallon, the mean; 6.38 miles per gallon, one deviation below; 3.41 miles per gallon, two deviations below; and 0.43 miles per gallon, three deviations below.⁵

⁵ There are no reported mileage data for B100 or B20 for this time range.

4.3.2 MPG Calculated Findings

The following sections summarize the fuel economy findings for each of the fuel types. These “calculated” values are computed using mileage and fuel consumption data in USF Parking Transportation Services database.

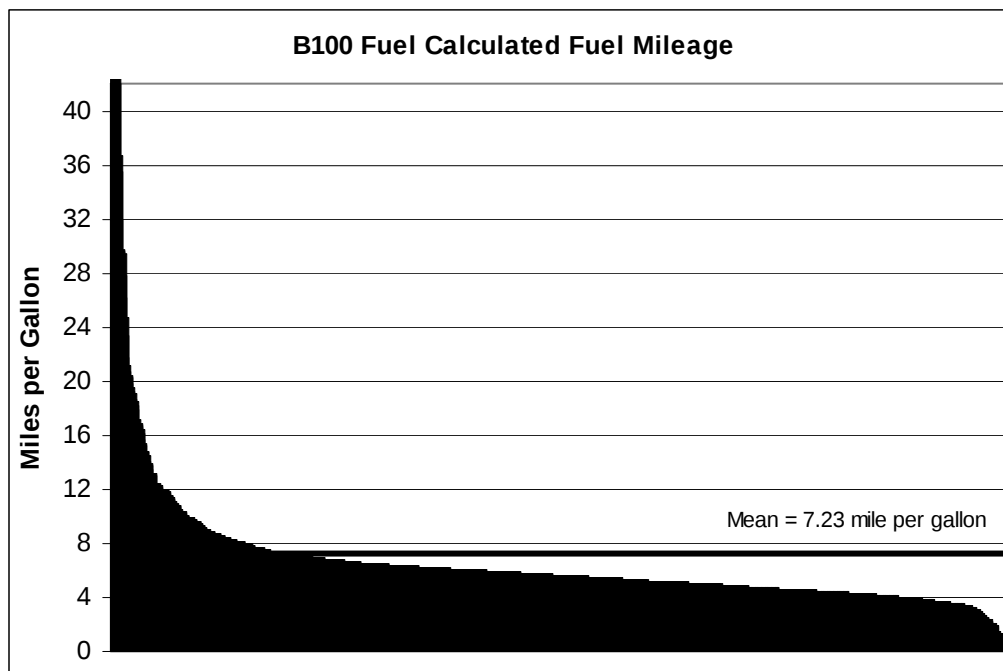
4.3.2.1B100 Fuel Vehicles

In the first six-month period of biodiesel fuel there are one thousand one hundred and eighty (72.04%) records for which fuel economy data could be calculated using calculated distance measures. Four outlier data records were not included for gallons of fuel calculations. The average miles per gallon reported value was 7.23 miles per petroleum diesel fuel gallon. Of these, 180.00 miles per gallon is the maximum calculated fuel mileage and 0.01 miles per gallon the least. The data set has a median value of 5.67 miles per gallon and a most occurring value of 6.00 miles per gallon. This data exhibits an 11.33 positive skew. Using a standard deviation of 11.24 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 4.3b, illustrates the trends in calculated fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage when using B100 fuel. The horizontal axis represents each of the one thousand one hundred and eighty records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph’s sharp initial slope and location of the average value near the bottom twenty-fifth of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean.⁶

⁶ See the appendix for a complete record reporting all the calculated distance traveled data as well as the fuel consumption figures used for obtaining the calculated miles per gallon figures.

Figure 4.3b Calculated B100 Fuel Economy



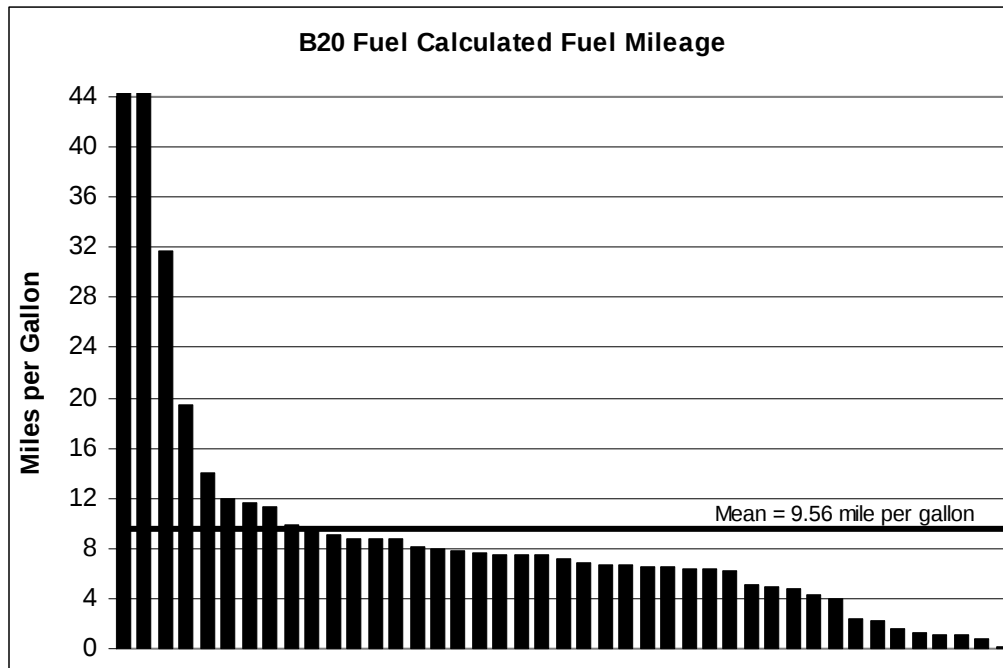
The twelve (1.02%) highest value records in this data set lie beyond three deviations from the mean. One thousand one hundred and sixty four records (98.64%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. One thousand one hundred and forty six (97.11%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 40.96 miles per gallon, three deviations above; 29.71 miles per gallon, two deviations above; 18.47 miles per gallon, one deviation above; 7.23 miles per gallon, the mean; -4.02 miles per gallon, one deviation below; -15.26 miles per gallon, two deviations below; and -26.50 miles per gallon, three deviations below.

4.3.2.2 B20 Fuel Vehicles

In the first six-month period of biodiesel fuel there are forty-three (2.63%) records for which fuel economy data could be calculated using calculated distance measures. The average miles per gallon reported value was 9.56 miles per petroleum diesel fuel gallon. Of these, 60.97 miles per gallon is the maximum calculated fuel mileage and 0.17 miles per gallon the least. The data set has a median value of 7.14 miles per gallon. This data exhibits a 3.30 positive skew. Using a standard deviation of 11.45 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 4.3c, illustrates the trends in calculated fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage when using B20 fuel. The horizontal axis represents each of the forty three records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial slope and location of the average value near the bottom sixth of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean.

Figure 4.3c Calculated B20 Fuel Economy



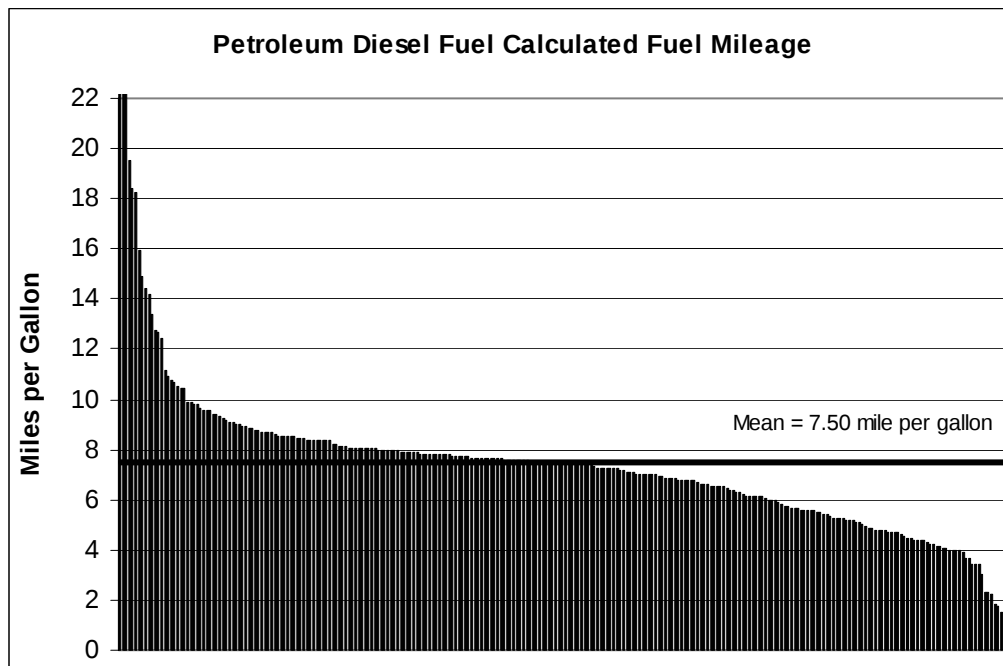
The two (4.65%) highest value records in this data set lie beyond three deviations from the mean. Forty one records (95.35%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Forty (93.02%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 43.91 miles per gallon, three deviations above; 32.46 miles per gallon, two deviations above; 21.01 miles per gallon, one deviation above; 9.56 miles per gallon, the mean; -1.89 miles per gallon, one deviation below; -13.34 miles per gallon, two deviations below; and -24.79 miles per gallon, three deviations below.

4.3.2.3 Petroleum Diesel Fuel Vehicles

In the first six-month period of biodiesel fuel there are two hundred and seventy eight (16.97%) records for which fuel economy data could be calculated using calculated distance measures. One outlier data record was not included for gallons of fuel calculations. The average miles per gallon reported value was 7.50 miles per petroleum diesel fuel gallon. Of these, 62.60 miles per gallon is the maximum calculated fuel mileage and 0.09 miles per gallon the least. The data set has a median value of 7.44 miles per gallon and a most occurring value of 8.05 miles per gallon. This data exhibits a 7.49 positive skew. Using a standard deviation of 4.45 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 4.3d, illustrates the trends in calculated fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage when using petroleum diesel fuel. The horizontal axis represents each of the two hundred and seventy eight records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's sharp initial slope and location of the average value near the bottom eighth of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean.

Figure 4.3d Calculated Petroleum Fuel Economy



The three (1.08%) highest value records in this data set lie beyond three deviations from the mean. Two hundred and seventy two (97.84%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Two hundred and fifty three (91.01%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 20.84 miles per gallon, three deviations above; 16.39 miles per gallon, two deviations above; 11.94 miles per gallon, one deviation above; 7.50 miles per gallon, the mean; 3.05 miles per gallon, one deviation below; -1.40 miles per gallon, two deviations below; and -5.84 miles per gallon, three deviations below.

4.0 Data Analysis Report

4.4 Case Study

The case study group encompasses figures for only the ten vehicles BRS utilized during both August 1, 2001, through January 31, 2002 (the petroleum diesel time range), and August 1, 2002, through January 31, 2003 (biodiesel time range).

4.4.1 MPG Reported Findings

The following table, table 4.4a, shows the average reported fuel consumption values for each of the ten vehicles for both time ranges. The average value on the right is of gallons per fuel type used by each vehicle. Nine vehicles reported values during the biodiesel time range.

Table 4.4a Reported Fuel Economy Per Vehicle

Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Average Reported MPG	Petroleum Before	9.69	9.49	9.49	8.30	8.04	8.28	8.74	8.46	8.47	8.48	8.74
	Petroleum After	8.84	8.43	8.43	8.51	13.27	9.05	8.81	9.41	--	10.41	9.46
	B20 After	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B100 After	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

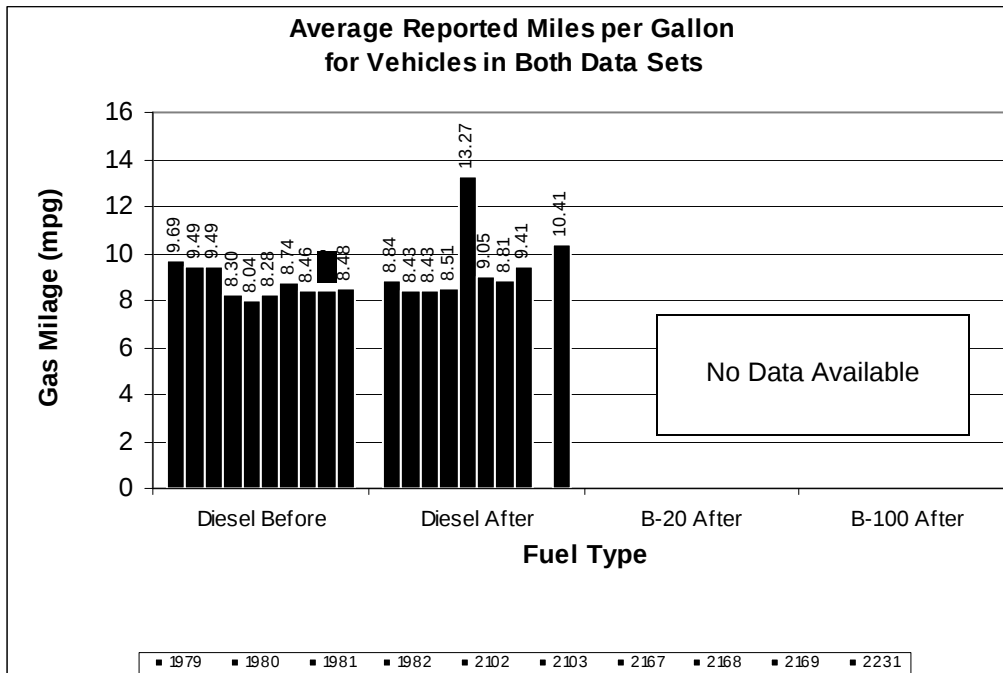
All the values for the above table are obtained directly from a database; large deviations in the values between time ranges (as with vehicle number 2102) are assumed to be caused by a data collection or reporting error.

4.4.1.1 Petroleum Diesel Fuel

Six of the ten vehicles reported a greater fuel economy. Bus 2102, exhibited a 65.15% increase in fuel mileage. The least increase in fuel mileage was bus 2167, which exhibited a 0.79% increase. The greatest decrease in reported fuel economy came from buses 1980 and 1981 which both reported an 11.11% decrease. Bus 1979 exhibited the least (8.78%) decrease in calculated fuel mileage. There was one vehicle during the petroleum diesel time range for which no fuel mileages were reported. Weighed against the petroleum diesel time range, the average of each of the vehicles in the case study exhibited an 8.26% increase in their fuel economy.

The following graph, figure 4.4a, illustrates the trends in the fuel economy values for each of the vehicles for both the petroleum diesel and the biodiesel time ranges of the study. The graph is divided into four sections, each showing the value for the ten vehicles in the order listed at the bottom of the graph. Blank columns in the graph indicate that there is no data available for this set.

Figure 4.4a Reported Fuel Economy per Vehicle



The graph and tables illustrate that reported values for petroleum diesel did not change much between the petroleum diesel and biodiesel time range. The values indicate a system wide increase of 8.26% in the fuel economy between the petroleum diesel fuel and the biodiesel fuel time range. The petroleum diesel time range has a range of 1.7 miles per gallon and the biodiesel time range has a range of 4.8 miles per gallon.⁷

⁷ There are no reported figures for B100 or B20 for this time range.

4.0 Data Analysis Report

4.4.2 MPG Calculated Findings

The following table, table, 4.4b, shows the average fuel efficiency values for each of the ten vehicles for both time ranges. The average value on the right is of gallons per mile per fuel type used by each vehicle.

Table4.4b Calculated Fuel Economy per Vehicle

Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Average Calculated MPG	Petroleum Before	9.35	9.49	7.62	8.30	8.04	8.28	8.74	8.46	8.28	8.48	8.50
	Petroleum After	9.31	8.07	5.51	7.65	9.42	7.52	8.18	8.68	10.28	7.82	8.24
	B20 After	7.91	8.36	7.17	8.67	8.06	8.49	9.24	17.87	10.39	7.30	9.34
	B100 After	8.17	8.11	3.76	6.89	7.35	6.83	8.36	7.22	9.61	6.01	7.23

4.4.2.1 Petroleum Diesel Fuel

Three of the ten vehicles exhibited an increase in calculated fuel mileage figures. Bus 2169 exhibited 24.11% increase in calculated fuel mileage when using petroleum diesel. The least increase in miles per gallon was bus 2168 which exhibited a 2.68% increase. The greatest decrease in reported mileage used was bus 1981 which exhibited a 27.62% decrease in fuel mileage. Bus 1979 exhibited the least (0.48%) fuel mileage decrease. Weighed against the petroleum diesel time range, the average of each of the vehicles in the case study exhibited a 3.04% fuel mileage decrease when running on petroleum diesel fuel during the biodiesel time range. Although there is a fairly large range of values compared to the petroleum diesel time range, as expected, the miles per gallon are fairly close during both time periods.

4.4.2.2 B20 Diesel Fuel

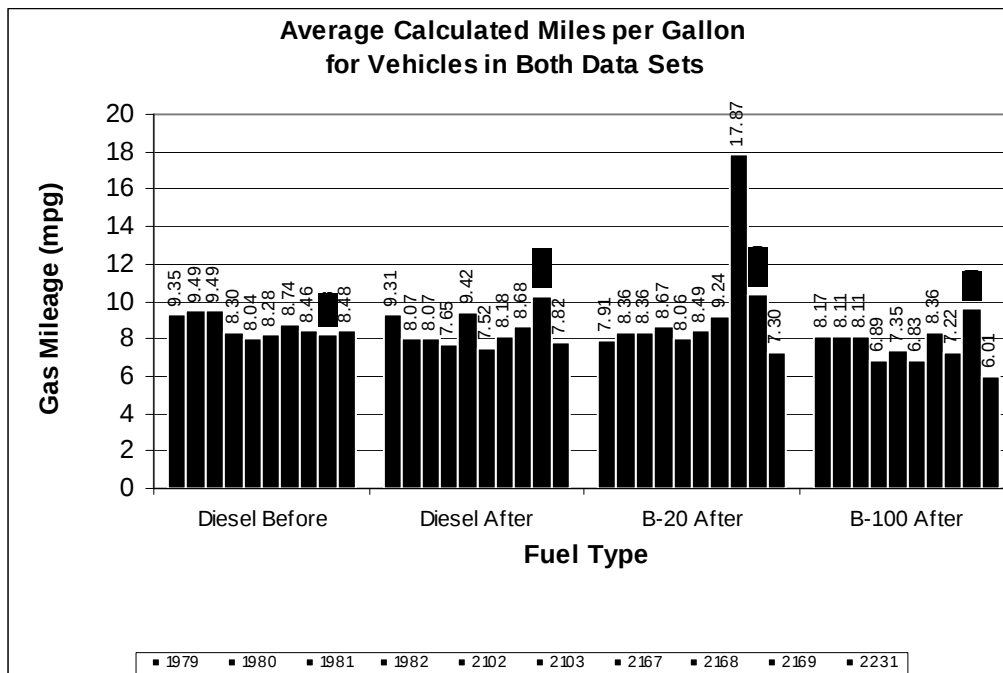
Six of the ten vehicles exhibited a larger calculated fuel mileage value. Bus 2168 exhibited the greatest (111.26%) increase in fuel economy. The least increase was a 0.27% increase calculated in bus 2102. The greatest decrease in calculated fuel mileage when reported on B20 fuel was 15.40% in bus 1979. Bus 1981 exhibited the least (5.92%) performance decrease. Weighed against the petroleum diesel time range, the bus exhibited an average fuel mileage increase of 9.91% for B20 fuel in the biodiesel fuel time range.

4.4.2.3 B100 Diesel Fuel

One of the ten vehicles, bus 2169, exhibited a 16.06% increase in fuel mileage; all other vehicles had worse fuel economy performance during the biodiesel time range. The greatest calculated performance decrease was bus 1981, which exhibited a 50.66% decrease. Bus 2167 exhibited the least (4.40%) decrease in miles per gallon values. Weighed against the petroleum diesel time range, the average calculated fuel mileage value for B100 fuel usage was 14.95% less than that calculated during the petroleum diesel time range for petroleum diesel fuel.

The following graph, figure 4.4b, illustrates the trends in the fuel economy values for each of the vehicles for both the petroleum diesel and the biodiesel time ranges of the study. The graph is divided into four sections, each showing the value for the ten vehicles in the order listed at the bottom of the graph.

Figure 4.4b Calculated Fuel Economy per Vehicle



The graph and tables of combined fuel consumption and distance traveled illustrate a very small variation (2.69% decrease from petroleum diesel time range) in the system wide fuel economy measures. This figure also shows the relative trend that, fuel consumption was fairly similar between fuel types during the biodiesel fuel range. The petroleum diesel values tend to be the most consistent values of the set, they have a range of 4.8 gallons per mile; the B100 values are second most consistent with a 5.8 gallons per mile range; and B20 is the most inconsistent with a 10.7 gallons per mile range. Comparing the average values of B20 and B100 to the petroleum diesel values during the biodiesel time range yields the following results: the average fuel economy for B20 was 13.36% more than petroleum diesel fuel and B100 fuel economy was 12.27% less than petroleum diesel fuel during the biodiesel fuel consumption period.

5.0 Conclusion

The transition between the fuel types clearly affected the BRS fuel economy performance measures. A general trend of decreased system wide average fuel economy existed for both study groups analyzed. It is important to note that the volumetric energy ration of petroleum diesel fuel and biodiesel fuel is different. Theoretically a system will use 10% more biodiesel fuel than petroleum diesel based on the energy in each fuel type⁸.

The first study group analyzed encompassed all the vehicles for the both August 1, 2001, through January 31, 2002, and August 1, 2002, through January 31, 2003. The study reported a 10.85% system wide increase in average fuel mileage. The calculated value for the same data set was a system wide decrease of 2.23% in fuel mileage. This significant difference between the values is assumed to be accounted for by the deficiency of reported data for the time period of biodiesel usage. The petroleum diesel time range contains 762 reported fuel records compared to 30 reported fuel records for the biodiesel time range.

The second study group analyzed encompassed only ten vehicles in operation during both August 1, 2001, through January 31, 2002, and August 1, 2002, through January 31, 2003. The study reported an 11.31% system wide increase in average fuel mileage. The calculated value for the same data set was a system wide decrease of 5.36% in fuel mileage. This significant difference between the values is assumed to be accounted for by the fact that the data reported for the time period of biodiesel usage is incomplete as well. The petroleum diesel time range contains 461 reported fuel records compared to 20 reported fuel records for the biodiesel time range.

The assessment of calculated values in contrast to reported values arrives at the same conclusion upon analyzing the percent error between calculated and reported values of petroleum diesel fuel in the petroleum diesel period and biodiesel periods separately. From the reference point of the reported values, the percent error between reported and calculated values for petroleum diesel fuel in the petroleum diesel time period is -1.91; comparatively, the percent error between reported and calculated petroleum diesel fuel for the biodiesel fuel usage time period is -19.86. The difference between these two values again appears to be a function of the incomplete values reported. The reported values for the data measures cannot be used because they represent a partial dataset; the calculated values are a more accurate representation of the true performance during the biodiesel time range.

⁸ See Section "3.1 Expected Biodiesel Performance" for a complete explanation.

5.0 Conclusion

From a pure cost analysis, based on the system performance and comparable price between the fuel types, the transition from petroleum diesel fuel to biodiesel does not seem worth the trouble. That is especially so when the additional system maintenance costs are included during the additional vehicle adjustment period. In addition, the less than perfect biodiesel distribution infrastructure at the time of the study makes biodiesel seems more and more like a bad idea.

Fortunately for biodiesel fuels, and the environment alike, the economics surrounding a cost analysis of the fuels is much more complex than assuming the fuel costs will be the same overtime. As noted before, biodiesel has inherent advantages over other alternative fuel types in so far as having the ability to transition back and forth between it and conventional fuel at a moments notice; for example during a time where petroleum diesel fuel prices increase or biodiesel fuel prices decrease. In addition to this, biodiesel is a renewable fuel source as opposed to the finite amount of petroleum diesel fuel that can be extracted. Ultimately, as the supply of petroleum diminishes, the price will increase forcing vehicle operators to seek alternatives. Biodiesel fuels are a viable alternative now with competitive prices.

Although the system experienced a system wide decrease in fuel economy, it was not the case that all the fuel types demonstrated less mileage per gallon. With relation to the petroleum diesel fuel figures during the first time range, the percent change in average fuel economy for instances in the second time range are a 9.44% decrease for petroleum diesel fuel usage, 15.48% increase for B20 fuel usage and 12.72% decrease for B100 fuel diesel usage. This radical increase in calculated average system wide fuel economy for instances of B20 usage can be accounted for by the fact that there were far fewer instances of B20 usage than either petroleum diesel or B100 usage for both the system and the case study totals.

All systems whose nearby biodiesel distribution infrastructure will support their transition from petroleum diesel fuel to biodiesel fuel should do so. The operational cost difference of a fleet using petroleum diesel fuel and biodiesel fuel will be governed by the fuel costs since the fuel economy of the vehicles is not substantially reduced, and in some cases increased when using biodiesel. The fuel emissions reduction far outweighs the slight costs increase, which will remain comparable to conventional petroleum diesel costs. From experience, the USF BRS suggests that the transition be done in a step process of incrementally increased biodiesel to petroleum diesel ratios. The gradual implementation will allow system operators to be able to better handle the initial required increased maintenance schedule.

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6.0 Overview

The appendix reports all the calculations and figures used to attain the fuel economy figures for both the system totals and for the ten vehicle case study in the report section. Those values include mileage data and fuel consumption data for both the petroleum and the biodiesel time ranges. The appendix also reports all the figures calculated for the “gas” fuel type; these figures were omitted in all other sections of the report.

6.1 Fuel Economy Calculations

The Fuel Economy Calculation section reports all the fuel consumption and mileage values and calculations used to derive the fuel economy reported in section 5.0 Data Analysis Report.

6.1.1 Petroleum Gasoline Time Range

The petroleum diesel time range studied is August 1, 2001 to January 31, 2002.

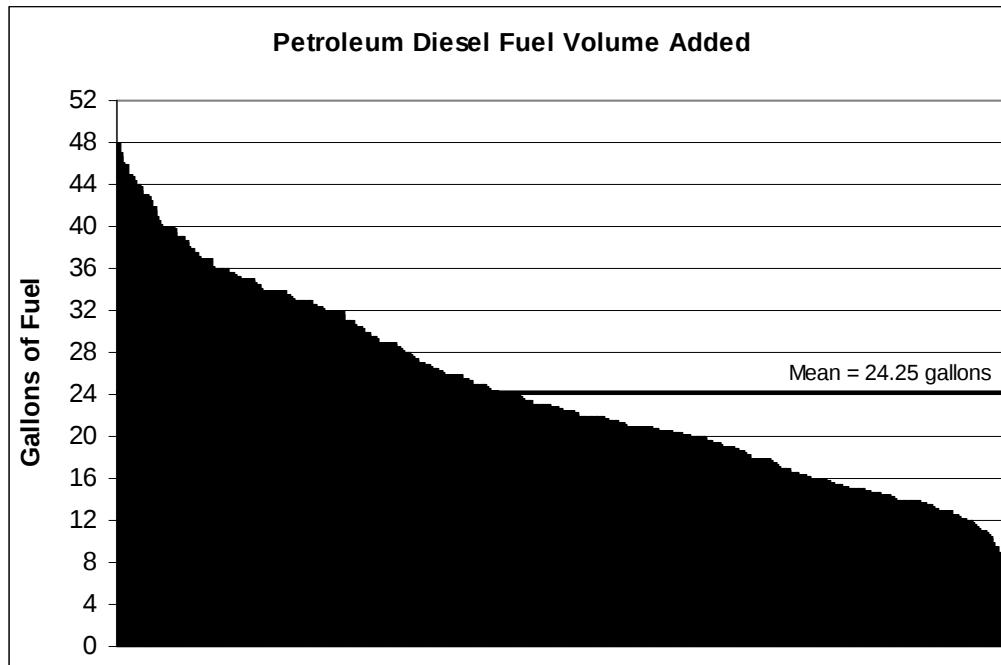
6.1.1.1 Fuel Consumption Reported Findings

6.1.1.1 Diesel Fuel Vehicles

There are seven hundred and sixty two (99.74% of the seven hundred and sixty four records in this category) records showing data for petroleum diesel fuel in the first six-month period. This high figure was expected since biodiesel fuel was not used extensively until August 2003. The average number of gallons of fuel added to each vehicle when serviced up with petroleum diesel was 24.25 gallons. Of these, 48.00 gallons is the maximum volume reported and 3.50 gallons was the least reported. The data set has a median value of 22.50 gallons and a most occurring value of 34.00 gallons. This data set exhibits a positive 0.45 skew. Using a standard deviation of 9.07 gallons and the mean value, all the values in the data set fall within an acceptable three standard deviations above or below the mean.

The following graph, figure 6.1a, illustrates the trends in amount of fuel added during each occurrence of a vehicle service. The vertical axis represents the volume in gallons of petroleum diesel fuel added. The horizontal axis represents each of the seven hundred and sixty two records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's smooth curve and location of the average value near the center of the data range supports the numerical calculations placing the dataset within an acceptable range from the mean.

Figure 6.1a Reported Petroleum Fuel Consumption



Seven hundred and twenty nine records (95.67%) fall two deviations within the mean; a range where 95% of data will theoretically fall if normally distributed. Four hundred and seventy three (62.07%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 51.46 gallons, three deviations above; 42.39 gallons, two deviations above; 33.32 gallons, one deviation above; 24.25 gallons, the mean; 15.17 gallons, one deviation below; 6.10 gallons, two deviations below; and -2.97 gallons, three deviations below.

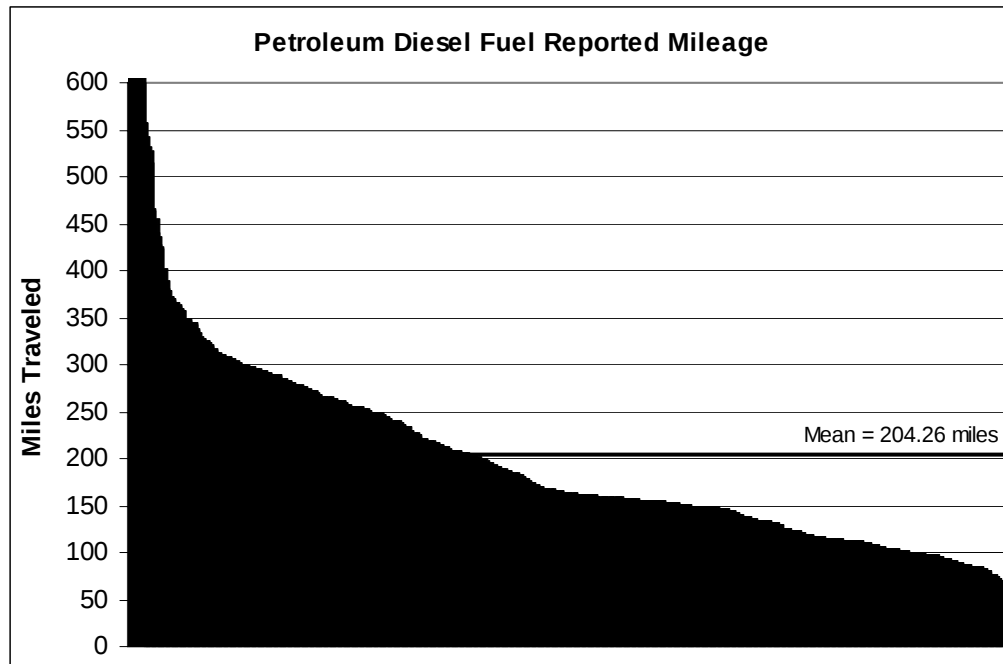
6.1.1.2 Miles Reported Findings

6.1.1.2 Petroleum Diesel Fuel Vehicles

In the first six-month period of petroleum diesel fuel there are seven hundred and sixty six (100.00%) fuel records containing odometer data. The average reported distance value was 204.26 miles for petroleum diesel fuel. Of these, 1,619.00 miles is the maximum distance reported and 6.00 miles was the least reported. The data set has a median value of 163.50 miles and a most occurring value of 160.00 miles. This data set exhibits a positive 4.12 skew. Using a standard deviation of 133.03 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.1b, illustrates the trends in reported distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled. The horizontal axis represents each of the seven hundred and sixty two records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial curve and location of the average value near the bottom quarter of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean.

Figure 6.1b Reported Petroleum Mileage



The fourteen (1.83%) highest value records in this data set lie beyond three deviations from the mean. Seven hundred forty four records (97.64%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Six hundred and ninety (90.55%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 603.34 miles, three deviations above; 470.31 miles, two deviations above; 337.28 miles, one deviation above; 204.26 miles, the mean; 71.23 miles, one deviation below; -61.80 miles, two deviations below; and -194.83 miles, three deviations below.

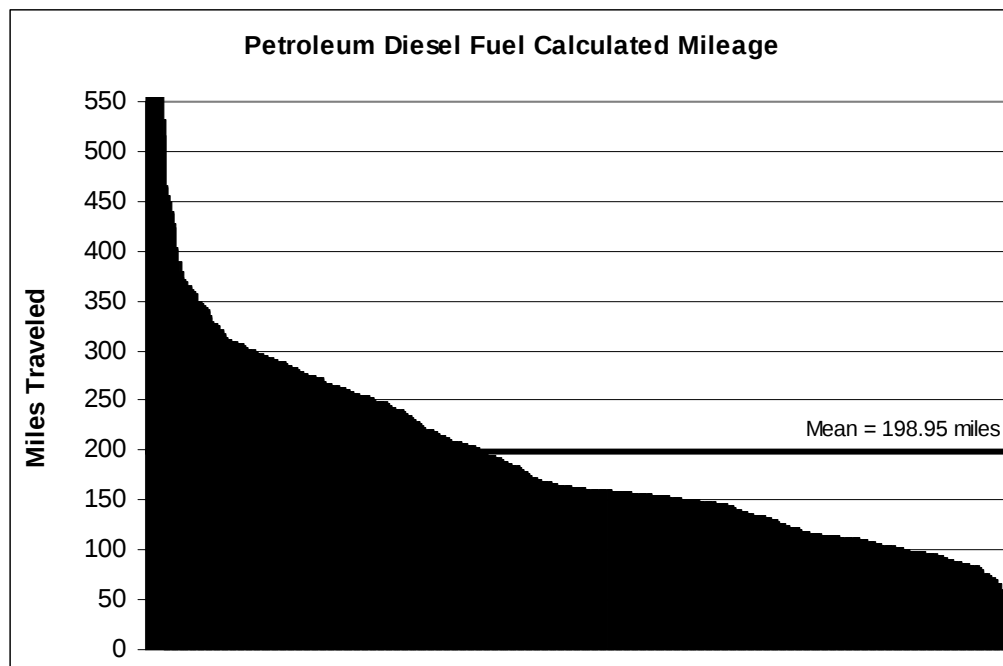
6.1.1.3 Miles Calculated Findings

6.1.1.3 Petroleum Diesel Fuel Vehicles

There are seven hundred and sixty two (99.74%) records for which mileage data could be calculated for petroleum diesel fuel in the first six-month period of petroleum diesel fuel usage. The average calculated distance traveled before refueling for petroleum diesel vehicles was 198.95 miles. Of these, 1,047.00 miles is the maximum distance reported and 6.00 miles was the least reported. The data set has a median value of 162.00 miles and a most occurring value of 160.00 miles. This data set exhibits a positive 2.78 skew. Using a standard deviation of 117.51 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.1c, illustrates the trends in calculated distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled. The horizontal axis represents each of the seven hundred and sixty two records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial curve and location of the average value near the bottom quarter of the data range supports the numerical calculations placing the dataset outside an acceptable range from the mean with outlier values on the high end.

Figure 6.1c Calculated Petroleum Mileage



The fifteen (1.97%) highest value records in this data set lie beyond three deviations from the mean. Seven hundred and thirty eight (96.60%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Six hundred and sixty four records (86.91%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 551.49 miles, three deviations above; 433.98 miles, two deviations above; 316.47 miles, one deviation above; 198.95 miles, the mean; 81.44 miles, one deviation below; -36.07 miles, two deviations below; and -153.59 miles, three deviations below.

6.1.2 Biodiesel Fuel Time Range

The biodiesel time range studied is August 1, 2002 to January 31, 2003.

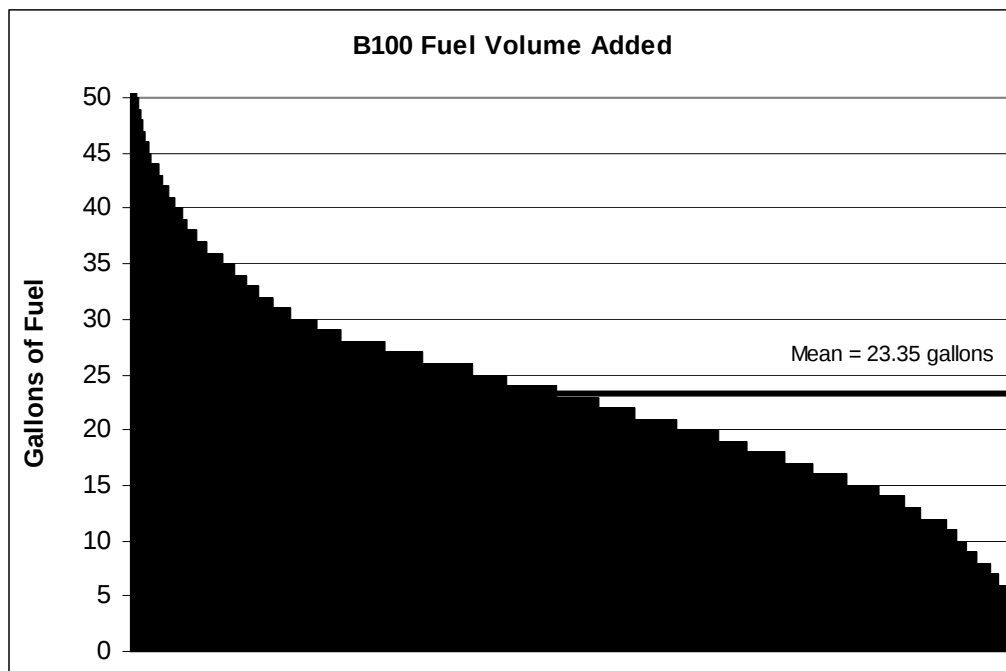
6.1.2.1 Fuel Consumption Reported Findings

6.1.2.1 B100 Fuel Vehicles

There are one thousand one hundred and eighty two (71.90% of records in this category) records showing data for B100 fuel were used for calculation in the first six-month period. Two outlier data records were not included for gallons of fuel calculations. The average number of gallons of fuel added to each vehicle when filled up with petroleum diesel was 23.35 gallons. Of these, 60.00 gallons is the maximum volume reported and 1.00 gallons was the least reported. The data set has a median value of 23.00 gallons and a most occurring value of 26.00 gallons. This data exhibits a 0.47 positive skew. Using a standard deviation of 9.15 gallons and the mean value, all the values in the data set do not fall within an acceptable three standard deviations above or below the mean with outlier values on the high end.

The following graph, figure 6.1.2a, illustrates the trends in amount of fuel added during each occurrence of a vehicle service. The vertical axis represents the volume in gallons of B100 biodiesel fuel added. The horizontal axis represents each of the one thousand one hundred and eighty two records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's smooth curve and location of the average near the center appears to support that all the values are within an acceptable range from the mean; however the initial slope is very steep, indicating that there are some outlier values.

Figure 6.1.2a Reported B100 Fuel Consumption



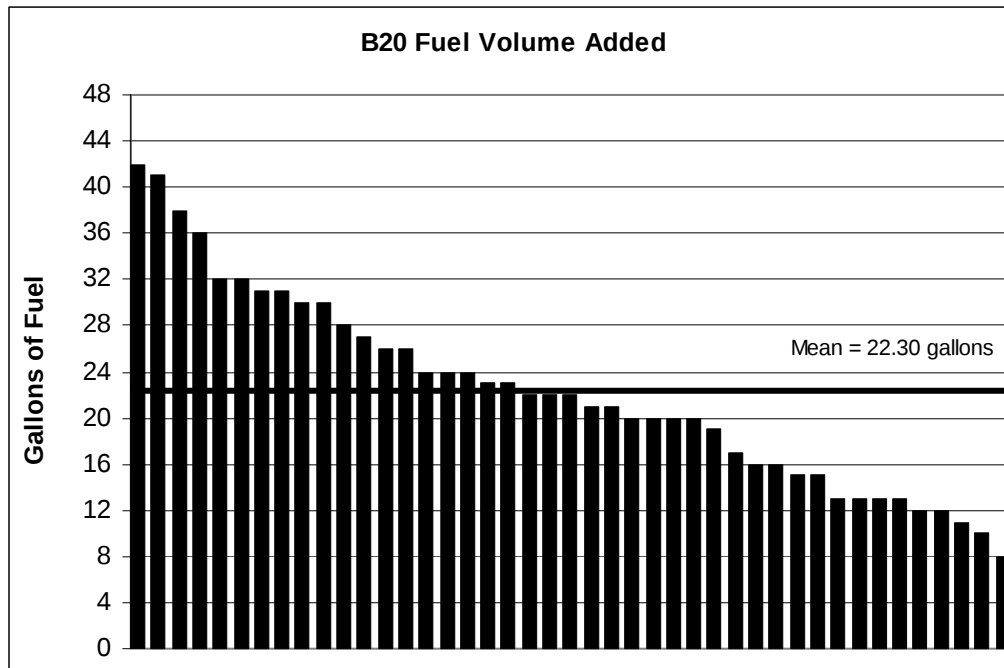
The six (0.51%) highest value records in this data set lie beyond three deviations from the mean. One thousand one hundred and twenty one (94.84%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Eight hundred and sixty two (72.93%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 50.80 gallons, three deviations above; 41.65 gallons, two deviations above; 32.50 gallons, one deviation above; 23.35 gallons, the mean; 14.21 gallons, one deviation below; 5.06 gallons, two deviations below; and -4.09 gallons, three deviations below.

6.1.2.1 B20 Fuel Vehicles

Forty three (2.62% of records in this category) records showing data for B20 fuel were used for calculation in the first six-month period. The average number of gallons of fuel added to each vehicle when filled up with petroleum diesel was 22.30 gallons. Of these, 60.00 gallons is the maximum volume reported and 8.00 gallons was the least reported. The data set has a median value of 22.00 gallons and a most occurring value of 20.00 gallons. This data exhibits a 0.49 positive skew. Using a standard deviation of 8.47 gallons and the mean value, all the values in the data set lie within an acceptable three standard deviations above or below the mean.

The following graph, figure 6.1.2b, illustrates the trends in amount of fuel added during each occurrence of a vehicle service. The vertical axis represents the volume in gallons of B20 biodiesel fuel added. The horizontal axis represents each of the forty three records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's smooth constant curve and location of the average value near the center of the data range supports the numerical calculations placing the dataset within an acceptable range from the mean.

Figure 6.1.2b Reported B20 Fuel Consumption



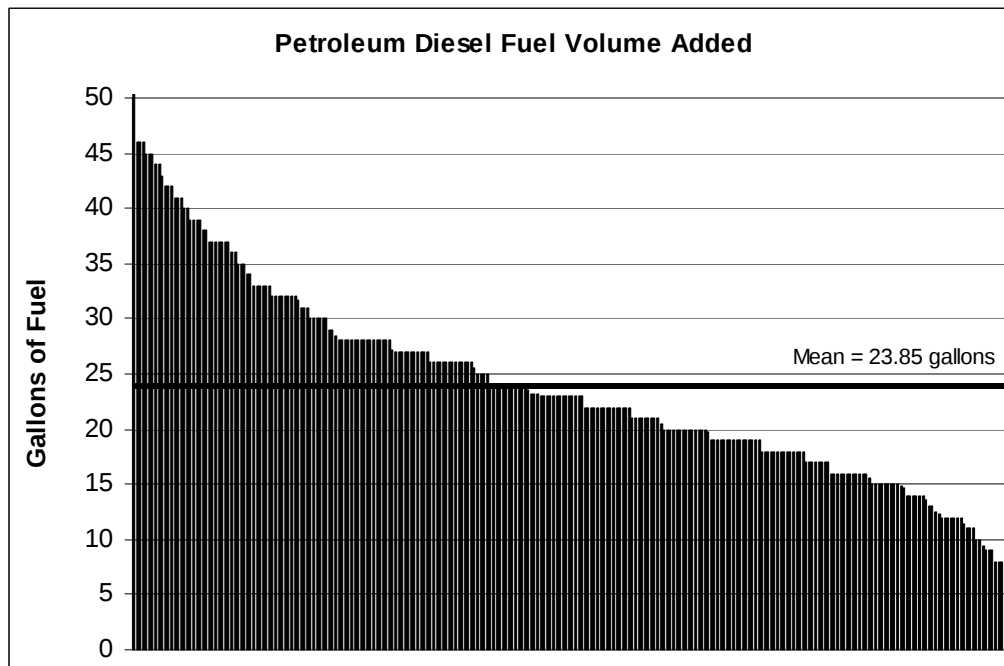
Forty one (95.35%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Twenty six (60.47%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 47.71 gallons, three deviations above; 39.24 gallons, two deviations above; 30.77 gallons, one deviation above; 22.30 gallons, the mean; 13.83 gallons, one deviation below; 5.36 gallons, two deviations below; and -3.11 gallons, three deviations below.

6.1.2.1 Petroleum Diesel Fuel Vehicles

Two hundred and seventy nine (16.97% of records in this category) records showing data for petroleum diesel fuel were used for calculation in the first six-month period. The average number of gallons of fuel added to each vehicle when filled up with petroleum diesel was 23.85 gallons. Of these, 66.00 gallons is the maximum volume reported and 5.00 gallons was the least reported. The data set has a median value of 23.00 gallons and a most occurring value of 28.00 gallons. This data exhibits a 0.79 positive skew. Using a standard deviation of 9.01 gallons and the mean value, all the values in the data set do not fall within an acceptable three standard deviations above or below the mean.

The following graph, figure 6.1.2c, illustrates the trends in amount of fuel added during each occurrence of a vehicle service. The vertical axis represents the volume in gallons of petroleum diesel fuel added. The horizontal axis represents each of the two hundred and seventy nine records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial slope yet smooth curve and location of the average value near the center of the data range supports the numerical calculations placing most of the dataset within an acceptable range from the mean with data outliers beyond the acceptable range.

Figure 6.1.2c Reported Petroleum Fuel Consumption



The highest value (0.36%) record in this data set lie beyond three deviations from the mean. Two hundred and sixty five (94.98%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Two hundred (71.68%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 50.89 gallons, three deviations above; 41.88 gallons, two deviations above; 32.86 gallons, one deviation above; 23.85 gallons, the mean; 14.83 gallons, one deviation below; 5.82 gallons, two deviations below; and -3.20 gallons, three deviations below.

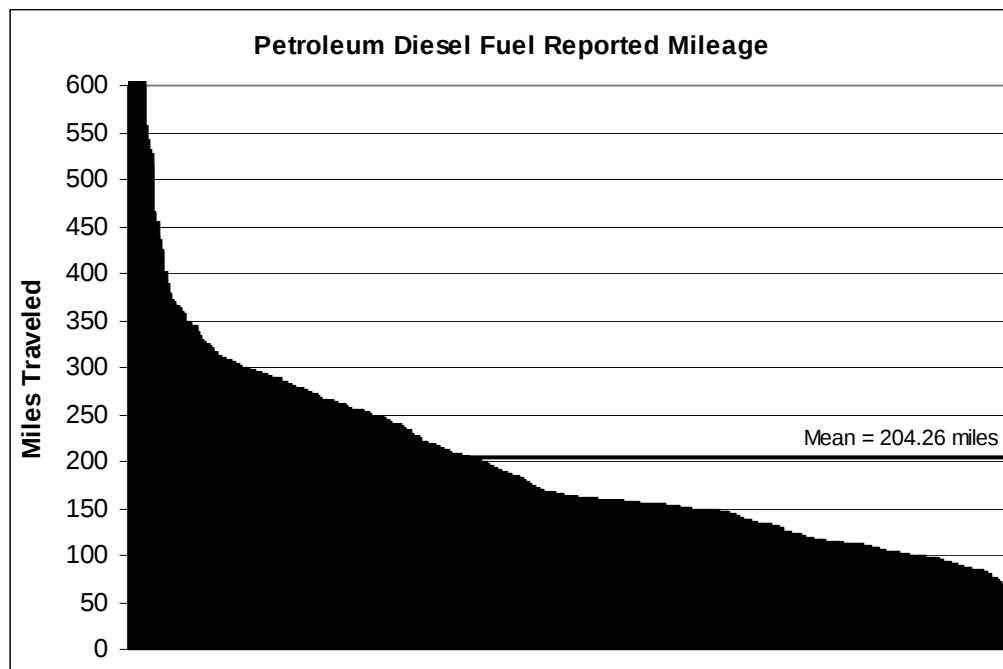
6.1.2.2 Miles Reported Findings

6.1.2.2 Petroleum Diesel Fuel Vehicles

In the first six-month period of biodiesel fuel there are thirty (100.00%) fuel records containing odometer data. The average reported distance value was 201.40 miles for petroleum diesel fuel. Of these, 671.00 miles is the maximum distance reported and 85.00 miles was the least reported. The data set has a median value of 192.50 miles and a most occurring value of 118.00 miles. This data exhibits a 2.64 positive skew. Using a standard deviation of 113.33 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.1.2d, illustrates the trends in reported distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled when using petroleum diesel fuel. The horizontal axis represents each of the thirty records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial slope then smooth curve and location of the average value near the bottom third of the data range supports the numerical calculations placing most of the data set with an acceptable range but with some outliers.

Figure 6.1.2d Reported Petroleum Mileage



The highest value (0.03%) record in this data set lie beyond three deviations from the mean. Seven hundred and forty four records (97.64%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Six hundred and ninety (90.55%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 603.34 miles, three deviations above; 470.31 miles, two deviations above; 337.28 miles, one deviation above; 204.26 miles, the mean; 71.23 miles, one deviation below; -61.80 miles, two deviations below; and -194.83 miles, three deviations below.⁹

⁹ There was no odometer data reported for B100 or B20 fuel for this data set.

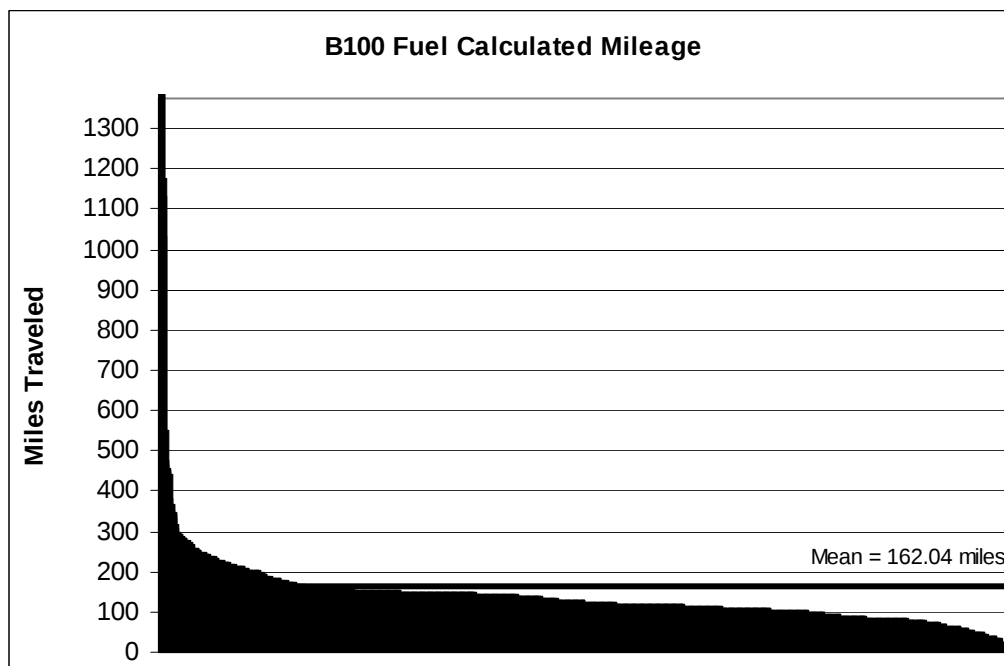
6.1.2.3 Miles Calculated Findings

6.1.2.3 B100 Fuel Vehicles

In the first six-month period of biodiesel fuel there are one thousand one hundred and eighty one (72.06%) records for which mileage data could be calculated for B100 fuel. Three outlier data records were not included for distance calculations. The average calculated distance traveled before refueling for petroleum diesel vehicles was a calculated value of 162.04 miles. Of these, 10,547.00 miles is the maximum distance reported and 2.00 miles was the least reported. The data set has a median value of 126.00 miles and a most occurring value of 119.00 miles. This data exhibits an 18.91 positive skew. Using a standard deviation of 405.16 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 7.1.2e, illustrates the trends in calculated distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled when using B100 fuel. The horizontal axis represents each of the one thousand one hundred and eighty one records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's sharp initial slope and location of the average value near the bottom twenty-fourth of the data range supports the numerical calculations placing the dataset outside an acceptable range from the mean with outlier values on the high end.

Figure 7.1.2e Calculated B100 Mileage



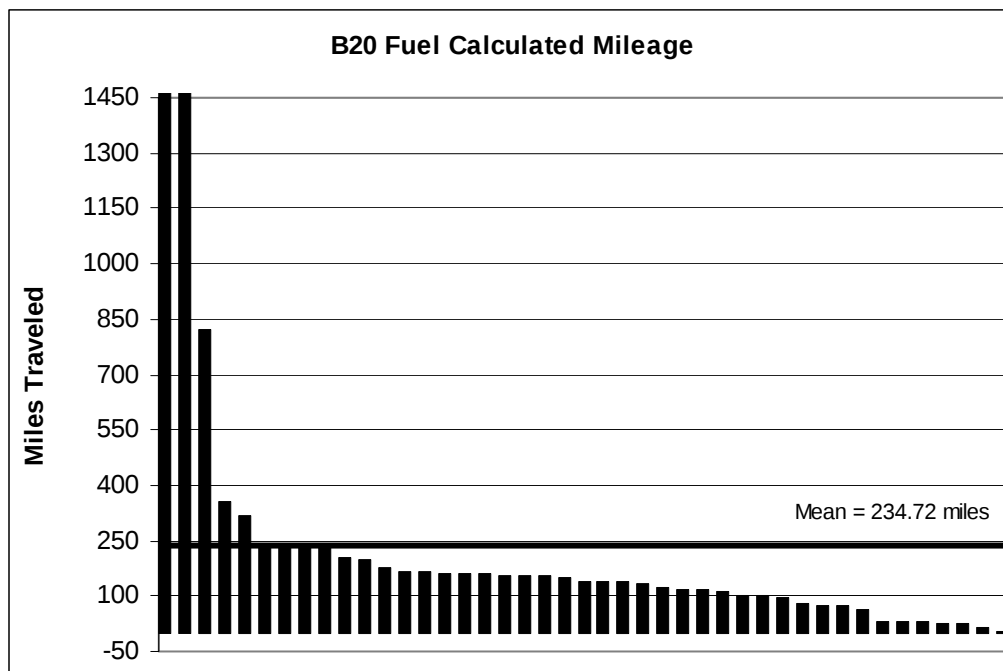
The eight (0.68%) highest value records in this data set lie beyond three deviations from the mean. One thousand one hundred and seventy one (99.15%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. One thousand one hundred and seventy records (99.07%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 1,377.52 miles, three deviations above; 972.36 miles, two deviations above; 567.20 miles, one deviation above; 162.04 miles, the mean; -243.12 miles, one deviation below; -648.28 miles, two deviations below; and -1,053.43 miles, three deviations below.

6.1.2.3 B20 Fuel Vehicles

In the first six-month period of biodiesel fuel there are forty three (2.62%) records for which mileage data could be calculated for B20 fuel. The average calculated distance traveled before refueling for petroleum diesel vehicles was a calculated value of 234.72 miles. Of these, 2,317.00 miles is the maximum distance reported and 4.00 miles was the least reported. The data set has a median value of 142.00 miles and a most occurring value of 160.00 miles. This data exhibits a 4.15 positive skew. Using a standard deviation of 408.25 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.1.2f, illustrates the trends in calculated distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled when using B20 fuel. The horizontal axis represents each of the forty three records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's sharp initial slope and location of the average value near the bottom tenth of the data range supports the numerical calculations placing the dataset outside an acceptable range from the mean with outlier values on the high end.

Figure 6.1.2f Calculated B20 Mileage



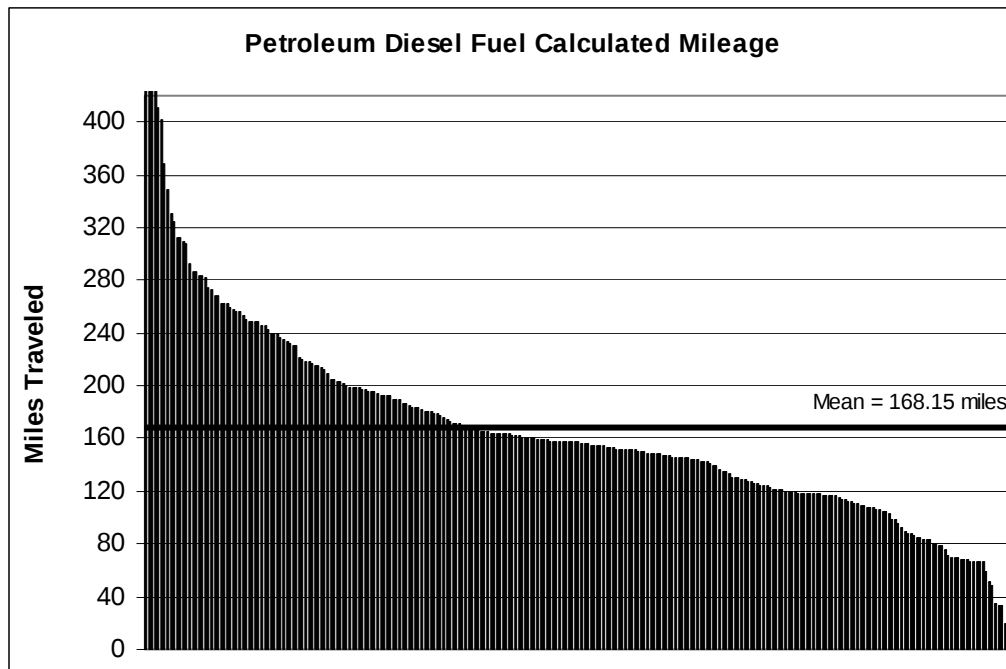
The two (4.65%) highest value records in this data set lie beyond three deviations from the mean. Forty one (95.35%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Forty (93.02%) records of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 1,459.48 miles, three deviations above; 1,051.22 miles, two deviations above; 642.97 miles, one deviation above; 234.72 miles, the mean; -173.53 miles, one deviation below; -581.78 miles, two deviations below; and -990.03 miles, three deviations below.

6.1.2.3 Petroleum Diesel Fuel Vehicles

In the first six-month period of biodiesel fuel there are two hundred and seventy nine (16.96%) records for which mileage data could be calculated for petroleum diesel fuel. One outlier data record was not included for distance calculations. The average calculated distance traveled before refueling for petroleum diesel vehicles was a calculated value of 168.15 miles. Of these, 671.00 miles is the maximum distance reported and 2.12 miles was the least reported. The data set has a median value of 156.50 miles and a most occurring value of 157.00 miles. This data exhibits a 2.12 positive skew. Using a standard deviation of 83.86 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.1.2g, illustrates the trends in calculated distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled when using petroleum diesel fuel. The horizontal axis represents each of the two hundred and seventy nine records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's sharp initial slope and location of the average value near the bottom fourth of the data range supports the numerical calculations placing the dataset outside an acceptable range from the mean with outlier values on the high end.

Figure 6.1.2g Calculated Petroleum Mileage



The four (1.44%) highest value records in this data set lie beyond three deviations from the mean. Two hundred and seventy (97.12%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. Two hundred and sixteen records (77.70%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 419.72 miles, three deviations above; 335.87 miles, two deviations above; 252.01 miles, one deviation above; 168.15 miles, the mean; 84.29 miles, one deviation below; 0.44 miles, two deviations below; and -83.42 miles, three deviations below.

6.2 “Gas” Fuel Calculations

This sections reports all the “gas” fuel vehicle values and calculations from the data set. Although these are most likely petroleum diesel, they were not included in the findings in section 5.0 Data Analysis Report.

6.2.1 Biodiesel Fuel Time Range¹⁰

The biodiesel fuel usage time range is August 1, 2002 to January 31, 2003.

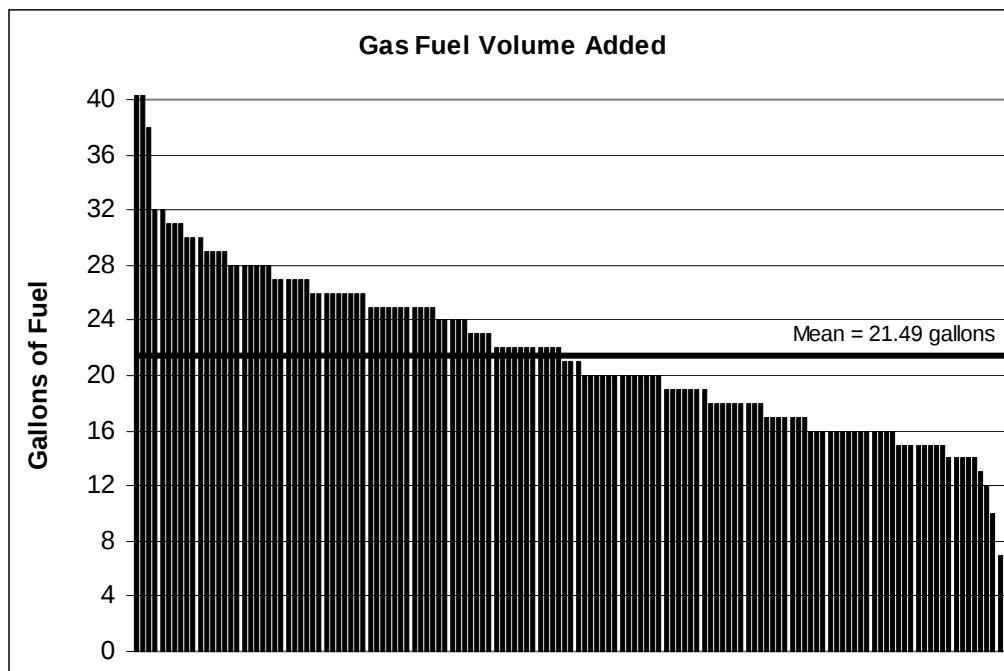
6.2.1.1 Gas Fuel Vehicles Fuel Consumption Findings

One hundred and forty (8.52% of records in this category) records showing data for gas fuel were used for calculation in the first six-month period. The average number of gallons of fuel added to each vehicle when filled up with gas was 21.49 gallons. Of these, 45.00 gallons is the maximum volume reported and 2.00 gallons was the least reported. The data set has a median value of 21.00 gallons and a most occurring value of 16.00 gallons. This data exhibits a 0.38 positive skew. Using a standard deviation of 6.27 gallons and the mean value, all the values in the data set do not fall within an acceptable three standard deviations above or below the mean.

The following graph, figure 6.2.1a, illustrates the trends in amount of fuel added during each occurrence of a vehicle service. The vertical axis represents the volume in gallons of gas fuel added. The horizontal axis represents each of the one hundred and forty records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph’s steep initial slope yet smooth curve and location of the average value near the center of the data range supports the numerical calculations placing most of the dataset within an acceptable range from the mean with data outliers beyond the acceptable range.

¹⁰ For the Petroleum Diesel time range, August 1, 2001 to January 31, 2002, there are: no reported mileage, or fuel economy figures, one reported fuel consumption figure (14 gallons), one calculated mileage figure (83 miles), and one calculated fuel economy (5.93 miles per gallon).

Figure 6.2.1a Reported Gas Fuel Consumption



Three (2.14%) values in this data set lie beyond three deviations from the mean, the two highest and one smallest value. One hundred and thirty four (95.71%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. One hundred and four (74.29%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 40.31 gallons, three deviations above; 34.04 gallons, two deviations above; 27.77 gallons, one deviation above; 21.49 gallons, the mean; 15.22 gallons, one deviation below; 8.95 gallons, two deviations below; and 2.68 gallons, three deviations below.

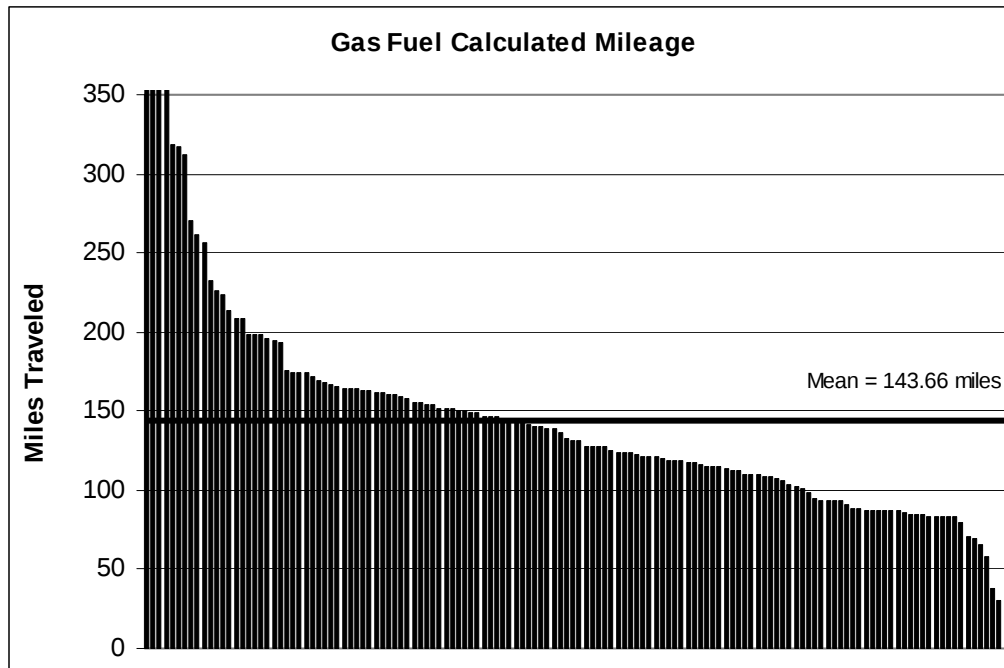
6.2.1.2 Gas Fuel Vehicles Miles Calculated Findings¹¹

In the first six-month period of biodiesel fuel there are one hundred and thirty seven (8.36%) records for which mileage data could be calculated for gas fuel. Three outlier data records were not included for distance calculations. The average calculated distance traveled before refueling for petroleum diesel vehicles was a calculated value of 143.66 miles. Of these, 433.00 miles is the maximum distance reported and 2.00 miles was the least reported. The data set has a median value of 131.00 miles and a most occurring value of 87.00 miles. This data exhibits a 1.77 positive skew. Using a standard deviation of 69.35 miles along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.2.1b, illustrates the trends in calculated distance traveled at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of miles traveled when using gas fuel. The horizontal axis represents each of the one hundred and thirty seven records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial slope and location of the average value near the bottom third of the data range supports the numerical calculations placing the dataset outside an acceptable range from the mean with outlier values on the high end.

¹¹ There was no odometer data reported for gas fuel vehicles for this data set.

Figure 6.2.1b Calculated Gas Vehicle Mileage



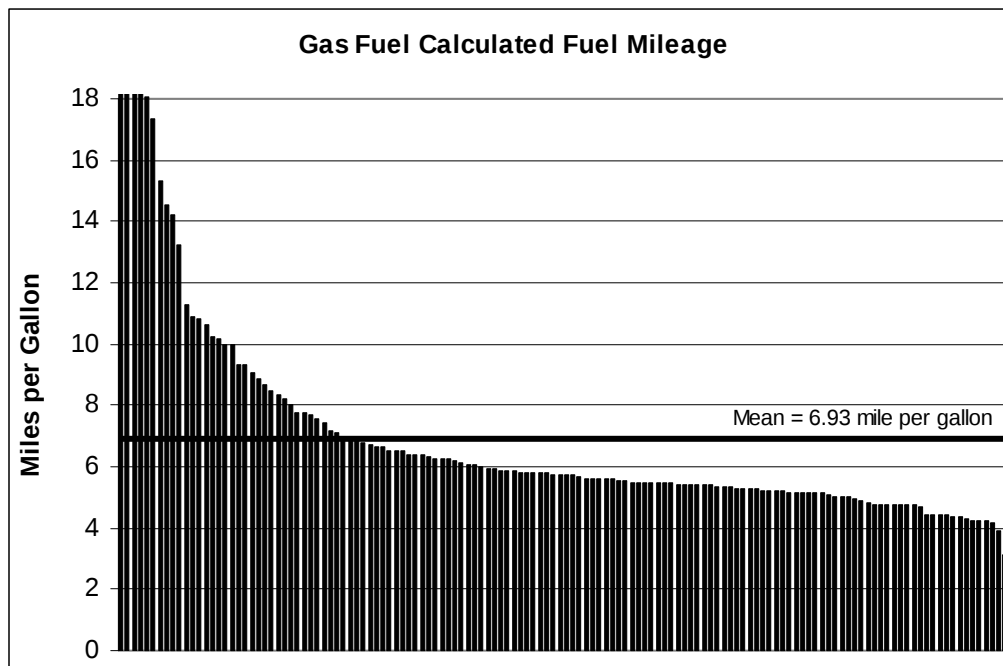
The four (2.92%) highest value records in this data set lie beyond three deviations from the mean. One hundred and twenty nine (94.16%) records fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. One hundred and sixteen records (84.67%) lay in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. The acceptable data range is: 351.69 miles, three deviations above; 282.35 miles, two deviations above; 213.00 miles, one deviation above; 143.66 miles, the mean; 74.31 miles, one deviation below; 4.97 miles, two deviations below; and -64.38 miles, three deviations below.

6.2.1.3 Gas Fuel Vehicles MPG Calculated Findings¹²

In the first six-month period of biodiesel fuel there are one hundred and thirty seven (8.36%) records for which fuel economy data could be calculated using calculated distance measures. Three outlier data records were not included for gallons of fuel calculations. The average miles per gallon reported value was 6.93 miles per petroleum diesel fuel gallon. Of these, 24.06 miles per gallon is the maximum calculated fuel mileage and 0.05 miles per gallon the least. The data set has a median value of 5.75 miles per gallon and a most occurring value of 5.50 miles per gallon. This data exhibits a 2.64 positive skew. Using a standard deviation of 3.62 miles per gallon along with the mean value, all the values in this data set do not fall within an acceptable three standard deviations from the mean.

The following graph, figure 6.2.1c, illustrates the trends in calculated fuel mileage at the time of each occurrence of a vehicle service since the last service. The vertical axis represents the numerical value of fuel mileage when using gas fuel. The horizontal axis represents each of the one hundred and thirty seven records arranged in decreasing order. The horizontal trend line illustrates the mean value of the data set. The graph's steep initial slope and location of the average value near the bottom third of the data range supports the numerical calculations placing the data set outside an acceptable range from the mean.

Figure 6.2.1c Calculated Gas Vehicle Fuel Economy



¹² There were no reported miles per gallon data reported for gas fuel runs.

The five (3.65%) highest value records in this data set lie beyond three deviations from the mean. One hundred and twenty eight records (93.43%) fall within two deviations; a range where 95% of data will theoretically fall if normally distributed. One hundred and twenty one (88.32%) of the records lie in the data range one standard deviation from the mean, where a theoretical 68% of normally distributed data should fall. The graph range shows only those records within the acceptable range. That data range is: 17.78 miles per gallon, three deviations above; 14.17 miles per gallon, two deviations above; 10.55 miles per gallon, one deviation above; 6.93 miles per gallon, the mean; 3.31 miles per gallon, one deviation below; -0.30 miles per gallon, two deviations below; and -3.92 miles per gallon, three deviations below.

6.3 Case Study Calculations

6.3.1 Data Overview Case Study

Of the twenty-nine vehicles for which information was collected in the first time data block, ten (34.42%) vehicles' data contained sufficient information in both the petroleum diesel and biodiesel usage periods to be analyzed and compared to one another for the case study. This ten-vehicle case study is done in an attempt to minimize the number of factors between the groups of data that can impact the system wide performance averages.

6.3.2 Records

The following tables show the number of records for each of the vehicles that were used for calculation purposes. The first table, table 6.3a, illustrates the number of calculated individual records for each fuel type in each vehicle. The table reports the number of records by the bus identification number for both before and after the biodiesel time range. Note that the time range of petroleum diesel fuel (08/01/01 through 01/31/02) usage is denoted as "before," whereas the time range where biodiesel fuel (08/01/02 through 01/31/03) is used is denoted as "after" for all subsequent tables.

Table 6.3a: Calculated Records by Vehicle

Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Number of Calculated Records	Petroleum Before	26.00	31.00	31.00	39.00	51.00	66.00	47.00	51.00	46.00	73.00	46.10
	Petroleum After	7.00	18.00	13.00	15.00	12.00	10.00	23.00	16.00	13.00	15.00	14.20
	B20 After	2.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00	2.00	5.00	2.70
	B100 After	43.00	30.00	22.00	46.00	60.00	53.00	64.00	71.00	61.00	61.00	51.10

The table is indicative of the fact that during the initial portion of the BRS's transition to biodiesel, each vehicle was brought in for service more frequently (a 47.5% increase).

The following table, table 6.3b, comparatively shows the number of individual records for each of the fuel types per vehicle that were reported in the collected data. Note that the records for the petroleum diesel numbers are the same for both calculated and reported records; all the values for biodiesel fuels for these vehicles are calculated measures; and the data shows a significant reduction in the number of values for petroleum diesel fuel during the biodiesel time range.

Table 6.3b Reported Records by Vehicle

Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Number of Reported Records	Petroleum Before	26.00	31.00	31.00	39.00	51.00	66.00	47.00	51.00	46.00	73.00	46.10
	Petroleum After	1.00	2.00	2.00	1.00	3.00	3.00	2.00	3.00	0.00	3.00	2.00
	B20 After	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B100 After	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

6.3.3 Fuel Consumption Reported Findings

The following table, table 6.3c, shows the average fuel consumption values in gallons for each of the ten vehicles for both time ranges. The average value on the right is of gallons per fuel type used by each vehicle.

Table 6.3c Fuel Consumption Figures by Vehicle

Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Average Gallons Consumed	Petroleum Before	30.74	30.75	30.75	35.81	29.23	26.97	27.86	28.80	28.98	17.05	28.69
	Petroleum After	24.14	19.12	29.17	23.63	27.88	29.23	20.30	25.44	23.85	16.98	23.97
	B20 After	25.00	26.00	20.67	19.33	21.00	18.50	12.33	20.50	14.00	21.20	19.85
	B100 After	18.00	18.87	29.86	23.59	20.28	22.38	21.47	20.94	21.05	18.92	21.54

6.3.3.1 Petroleum Diesel Fuel

One of the ten vehicles, bus 2103, exhibited an 8.38% increase in petroleum diesel usage, the rest required less fuel per fill up in the biodiesel time range. The greatest decrease in reported petroleum diesel gallons used was bus 1980 which exhibited a 37.82% decrease. Bus 2231 exhibited the least (0.43%) decrease. Weighed against the petroleum diesel time range, the average of each of the vehicles in the case study exhibited a 16.45% decrease in petroleum diesel gallons used in the biodiesel time range compared to petroleum diesel used in the petroleum diesel time range. This high range of values is somewhat unexpected, theoretically the only difference between the vehicles when looking at the times that petroleum diesel was used is the time; very similar values were expected for before and after values for petroleum diesel fuel. Perhaps the fact that each of the vehicles' fuel filters was cleaned more frequently (on account of biodiesel fuel cleaning out the system) made the fuel more efficient later.

6.3.3.2 B20 Diesel Fuel

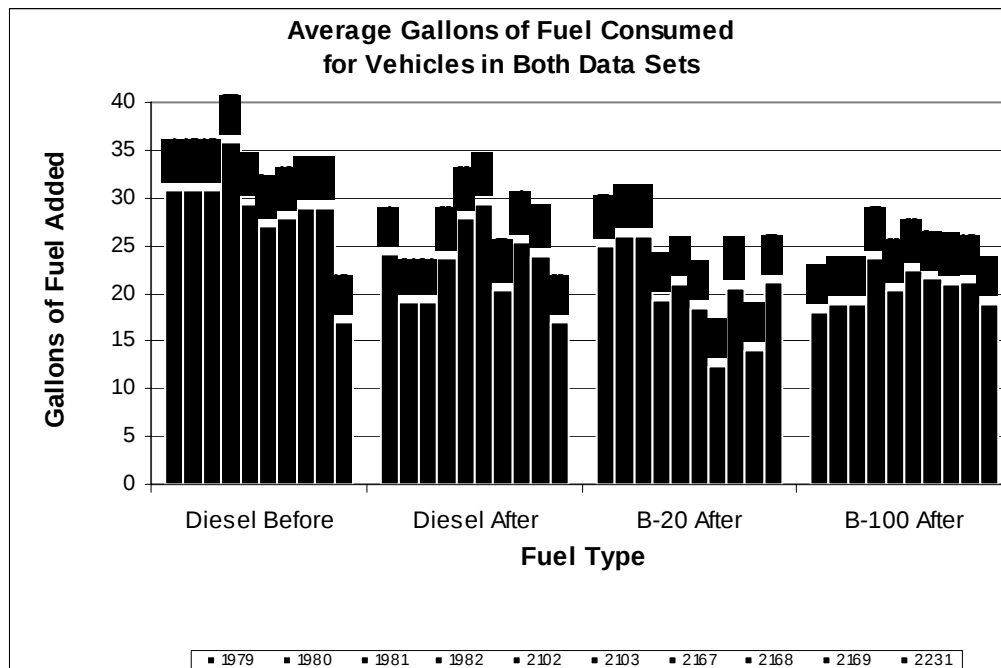
One of the ten vehicles, bus 2231, exhibited a 24.32% increase in gallons, all other vehicles required less fuel per fill up in the biodiesel time range. The greatest decrease in reported B20 fuel gallons used was bus 2167 which exhibited a 55.74% decrease. Bus 1980 exhibited the least (15.45%) decrease. Weighed against the petroleum diesel time range, the busses exhibited an average gallon of fuel usage decrease of 30.81% for B20 fuel in the biodiesel fuel time range.

6.3.3.3 B100 Diesel Fuel

One of the ten vehicles, bus 2231, exhibited a 10.93% increase in gallons, all other vehicles required less fuel per fill up in the biodiesel time range. The greatest decrease in reported B100 fuel gallons used was bus 1979 which exhibited a 41.44% decrease. Bus 1981 exhibited the least (2.89%) decrease in gallons used. Weighed against the petroleum diesel time range, the average usage of B100 gallons was 24.95% gallons less of petroleum diesel fuel.

The following graph, figure 6.3a, illustrates the trends in the fuel usage values for each of the vehicles for both the petroleum diesel and the biodiesel time ranges of the study. The graph is divided into four sections, each showing the individual value for each of the ten vehicles in the order listed at the bottom of the graph for the four fuel types.

Figure 6.3a Reported Fuel Consumption by Vehicle



The graph and tables clearly illustrate a system wide decrease (24.07%) in the average gallons consumed between the petroleum diesel fuel time range and the biodiesel fuel time range. This figure also shows the relative trend that, although the fuel types each have a different distribution of values, fuel consumption was fairly similar between fuel types during the biodiesel fuel range. The B100 values tend to be the most consistent values of the set, they have a range of 11.9 gallons; the petroleum diesel values are second most consistent with a 12.3 gallon range; and B20 is the most inconsistent with a 13.7 gallon range. Comparing the average values of B20 and B100 to the petroleum diesel values during the biodiesel time range yields the following results: the average consumption for B20 was 17.19% less than petroleum diesel fuel and B100 consumption was 10.17% less than petroleum diesel fuel during the biodiesel fuel consumption period.

6.3.4 Miles Reported Findings

The following table, table 6.3d, shows the average fuel consumption values for each of the ten vehicles for both time ranges. The average value on the right is of gallons per fuel type used by each vehicle. For this time set, there were no reported values for the biodiesel blends.

Table 6.3d Reported Mileage by Vehicle

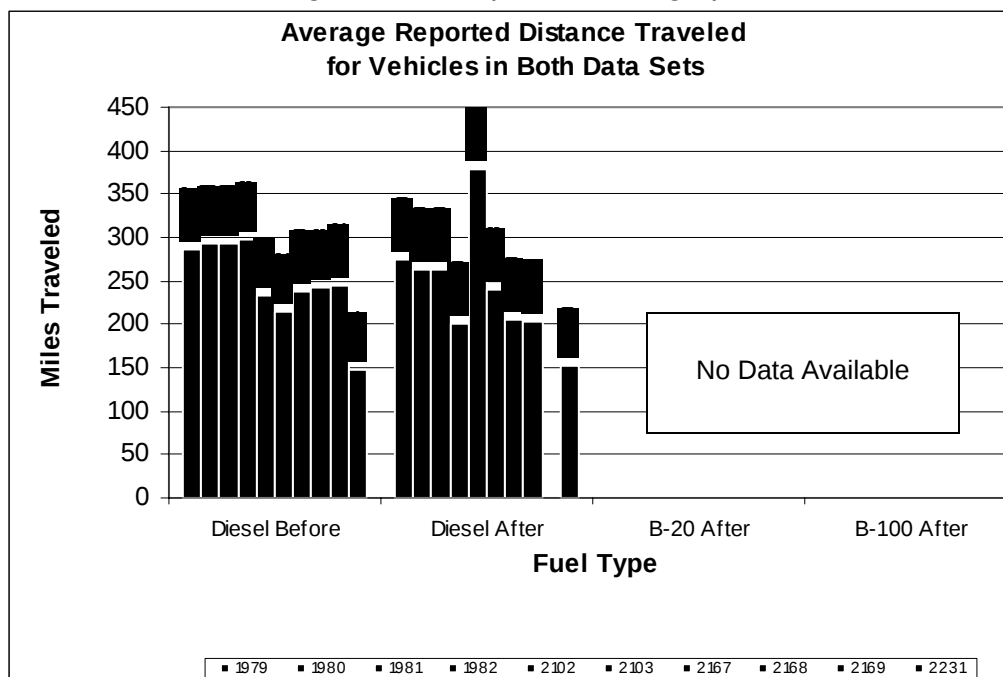
Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Average Reported Miles	Petroleum Before	286.77	292.71	292.71	297.18	234.10	213.82	237.89	241.88	245.22	147.74	249.00
	Petroleum After	274.00	262.50	262.50	200.00	377.33	239.33	205.50	203.67	--	153.00	241.98
	B20 After	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	B100 After	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

6.3.4.1 Petroleum Diesel Fuel

Three of the ten vehicles reportedly traveled a farther distance during the biodiesel time range while running on petroleum diesel fuel. Bus 2102, exhibited the largest mileage increase (61.19%). The least increase was in bus 2231, which traveled 3.56% more miles. The greatest decrease in reported mileage was in bus 1982, which reported a 32.70% decrease in distance. Bus 1979 exhibited the least (4.45%) distance decrease. Weighed against the petroleum diesel time range, the average of each of the vehicles in the case study exhibited a 2.82% decrease in reported distance traveled. Although these values are on the average very similar to the values reported during the initial time period, it is important to note that for each of the vehicles there was an average of only two records reported for petroleum diesel during the biodiesel time range compared to an average of 46.10 reported records for the petroleum diesel time period.¹³

The following graph, figure 6.3b, illustrates the trends in the calculated mileages values for each of the vehicles for both the petroleum diesel and the biodiesel time ranges of the study. The graph is divided into four sections, each showing the value for the ten vehicles in the order listed at the bottom of the graph. The missing columns in the graph represent the figures were there were not reported values.

Figure 6.3b Reported Mileage per Vehicle



¹³ There are no reported B100 or B20 data for the second time period with which to compare figures with.

The graph and tables illustrate that reported values for petroleum diesel did not change much between the petroleum diesel and biodiesel time range. The values indicate a system wide decrease of 2.82% in the average distance traveled between the petroleum diesel fuel time range and the biodiesel fuel time range. The petroleum diesel time range has a range of 149.4 miles and the biodiesel time range has a 224.3 miles.

6.3.5 Miles Calculated Findings

The following table, table 6.3e, shows the average calculated distances traveled by each of the ten vehicles for both time ranges. The “average” value is of distance traveled for the ten vehicles by fuel type used by each vehicle.

Table 6.3e Calculated Mileage per Vehicle

Measure	Fuel Type	Bus Identification Number										Average
		1979	1980	1981	1982	2102	2103	2167	2168	2169	2231	
Average Calculated Miles	Petroleum Before	279.73	292.71	235.42	297.18	234.10	213.82	237.89	241.88	240.00	147.74	242.05
	Petroleum After	221.57	149.22	147.38	176.67	267.58	217.90	163.09	214.06	241.92	131.27	193.07
	B20 After	196.00	225.00	154.00	163.00	170.50	152.00	110.67	221.00	153.00	154.00	169.92
	B100 After	117.37	129.07	104.27	156.33	135.92	142.98	138.44	140.54	140.62	112.23	131.78

6.3.5.1 Petroleum Diesel Fuel

Of the ten vehicles, three buses exhibited an increase in distance traveled in the biodiesel time range. The greatest increase occurred in vehicle 2102 which traveled 14.30% farther than before. The smallest increase in calculated miles traveled was a 0.80% increase in vehicle 2169. The greatest decrease in calculated distance traveled was bus 1980, which traveled 49.02% fewer miles. Bus 2231 exhibited the least (11.15%) mileage decrease. Weighed against the petroleum diesel time range, the average of each of the vehicles in the case study exhibited a 20.24% decrease in their range during the biodiesel time range when petroleum diesel was used compared to the petroleum diesel time range. This drop range of values is somewhat unexpected. A possible reason for these values is that on account of the new fuel being used, the vehicles were on the whole brought in for refueling and servicing more frequently than before.

6.3.5.2 B20 Diesel Fuel

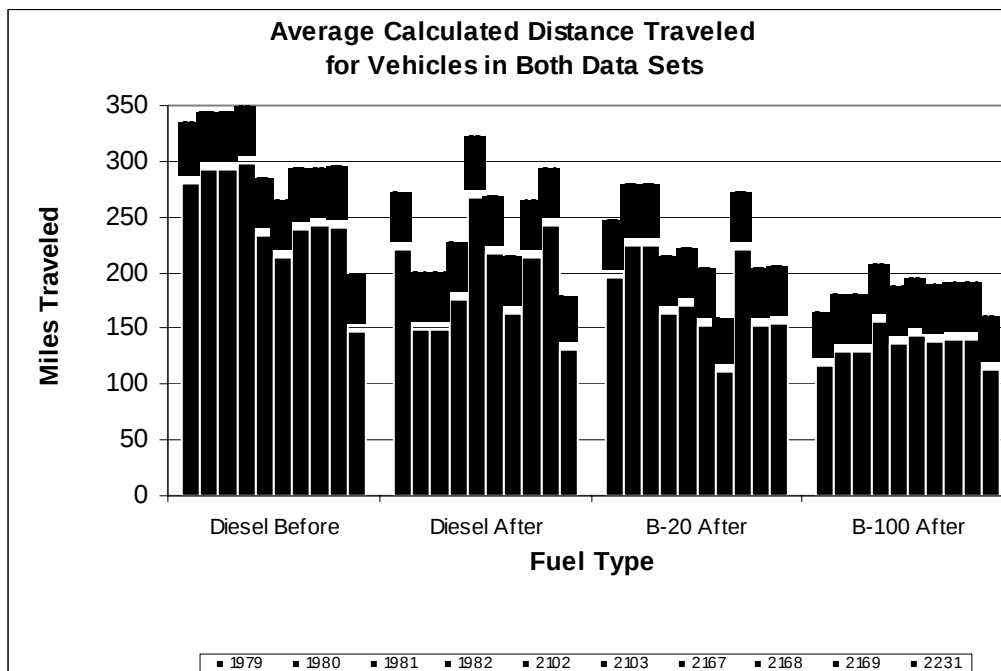
Only one of the ten vehicles traveled a longer distance when burning B20 than during the petroleum diesel time range. Bus 2231, exhibited a 4.24% increase, all other vehicles traveled a shorter distance when using B20 fuel. The greatest decrease in calculated mileage for B20 fuel was bus 2167 with a 53.48% decrease. Bus 2168 exhibited the least (8.63%) decrease. Weighed against the petroleum diesel time range, the bus exhibited an average calculated distance traveled decrease of 29.80% fewer miles with B20 fuel in the biodiesel fuel time range.

6.3.5.2 B100 Diesel Fuel

A lower distance value was calculated for all the vehicles when running on B100 fuel. The greatest decrease in calculated mileage for B100 fuel was bus 1979 which traveled 58.04% fewer miles. Bus 2231 exhibited the least (24.04%) decrease in calculated mileage. Weighed against the petroleum diesel time range, the average all ten vehicles traveled 45.56% fewer miles when using B100.

The following graph, figure 6.3c, illustrates the trends in the calculated mileages values for each of the vehicles for both the petroleum diesel and the biodiesel time ranges of the study. The graph is divided into four sections, each showing the value for the ten vehicles in the order listed at the bottom of the graph.

Figure 6.3c Calculated Mileage per Vehicle



The graph and tables clearly illustrate a system wide decrease (31.86%) in the average distance traveled between the petroleum diesel fuel time range and the biodiesel fuel time range. This figure also shows the relative trend that, although the fuel types each have a different distribution of values, fuel consumption was fairly similar between fuel types during the biodiesel fuel range. The B100 values tend to be the most consistent values of the set, they have a range of 52.1 miles; the B20 values are second most consistent with a 114.3 mile range; and petroleum diesel is the most inconsistent with a 136.3 mile range. Comparing the average values of B20 and B100 to the petroleum diesel values during the biodiesel time range yields the following results: the average distance traveled for B20 was 11.99% less than when petroleum diesel fuel was used. Mileage for B100 was 31.75% less than when petroleum diesel fuel was used during the biodiesel fuel consumption period.

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- i Source: "Biodiesel Emissions" report from the National Biodiesel Board.
 - ii Source: "Biodiesel 101" report from the National Biodiesel Board.
 - iii Source: "Biodiesel 101" report from the National Biodiesel Board.
 - iv Source: "FAQ" report from the National Biodiesel Board.
 - v Source: "Biodiesel Emissions" report from the National Biodiesel Board.
 - vi Source: "Biodiesel Emissions" report from the National Biodiesel Board.
 - vii Source: "Lifecycle Summary" report from the National Biodiesel Board.