Biodiesel Use in Fargo-Moorhead MAT Buses

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1. INTRODUCTION

Biodiesel is a naturally grown, alternative fuel source. It's a cleaner burning fuel than traditional fossil fuels and, therefore, substantially reduces emissions of pollutants, such as air toxics and hydrocarbons. It also provides significant reductions in greenhouse gases that cause global warming. The technical definition of biodiesel is a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats and meeting the requirements of American Society for Testing and Materials (ASTM) D 6751 (National Biodiesel Board 2007).

Biodiesel is most often blended with petroleum-based diesel fuel, at varying concentrations, for use in existing diesel engines, with little or no modifications required. Because it is homegrown, it reduces America's dependence on foreign oil, and it is renewable. Studies have also shown that it can reduce wear on the life of an automotive engine by up to half (National Biodiesel Board, 2007).

The Fargo-Moorhead Metropolitan Area Transit (MAT) has been using biodiesel mixed fuels in its buses since 2005. The Small Urban & Rural Transit Center (SURTC) examined the direct effect on the bus fleet of switching to biodiesel. Attributes such as fuel economy, ridership, and service records were analyzed. MAT and city officials were also interviewed to identify changes they have seen since the switch to biodiesel from both a bus fleet and public relations perspective.

The study begins by reviewing the current state of biodiesel and its usage in public transportation. This serves as a premise for MAT's experience as well as a means of comparison. Next, a synopsis of biodiesel in the United States is presented followed by an overview of MAT and its biodiesel experience. Data analysis follows with comparisons drawn from similar transit providers located in other regions of the country. Finally, conclusions highlight the major findings of the research. The objective of this research is to determine the overall effect biodiesel blended fuel has had on MAT's bus fleet as well as the auxiliary effect on the F-M community.

2. REVIEW OF PREVIOUS RESEARCH ON BIODIESEL USAGE

Previous studies have analyzed the effects of biodiesel use on emissions, fuel economy, cold weather performance, and maintenance. The studies tend to show similar results. Biodiesel has been found to significantly reduce emissions of three pollutants: carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). Carbon monoxide is a poison; hydrocarbons cause formation of ozone, a serious air pollutant; and particulate matter refers to aerosols or fine particles that can be detrimental to human health. The presence of oxygen in biodiesel causes the reduction of these pollutants (McCormick et al. 2006). Biodiesel has also been found to significantly reduce emissions of carbon dioxide (CO_2), a greenhouse gas, on a net lifecycle basis. Some studies, however, have found increases in emissions of nitrogen oxides (NO_x) from biodiesel usage, but these estimates vary. NO_x, along with CO and HC, leads to the formation of ground level ozone and smog in urban areas.

A few studies have found that fuel economy decreases slightly with biodiesel, while others have found no measurable change. The studies generally show that maintenance costs and general performance are not significantly affected by the use of biodiesel blends. A few studies have documented problems with fuel filters plugging, but it is generally not considered to be a major problem. Increased lubricity and cetane numbers are well documented benefits of biodiesel. Concern about the cold weather performance of biodiesel, on the other hand, is one of the main deterrents, along with cost, for the adoption of the fuel. Previous research has shown that biodiesel blends can be used successfully in colder climates of the northern United States and Canada.

A few of these studies have specifically researched the use of biodiesel in transit buses. Proc et al. (2006) studied the use of biodiesel in transit buses in Boulder, CO. In this study, nine identical transit buses were operated on the same route for two years, logging about 100,000 miles each. Five of these buses operated exclusively on B20 (a blend containing 20% biodiesel and 80% regular diesel) and four on regular diesel. Comparisons were made between the B20 and regular diesel buses for fuel economy, maintenance costs, road calls, and emissions. They found that emissions were reduced, including NO_x emissions, with B20, and that there were no significant differences in on-road average fuel economy, engine and fuel system maintenance costs, or miles between road calls.

The BIOBUS Project (2003) tested the use of B5 and B20 in buses for a year in Montreal from March 2002 to March 2003. A total of 155 buses were involved in the project, and they did not encounter any major maintenance or customer service problems.

One of the first mass transit providers to adopt biodiesel was the Bi-State Development Agency, a transit provider for the St. Louis, Missouri, area. The agency began using B20 in 2001. The results were found to be favorable. They reported a significant reduction in vehicle emissions with no impact on fuel economy or performance (Clean Cities 2002).

The National Renewable Energy Laboratory (NREL), part of the U.S. Department of Energy, conducted extensive research comparing life cycle emissions from using biodiesel with those from using petroleum diesel (Sheehan et al. 1998). This study estimated the life cycle emissions from the use of petroleum diesel, B20, and B100 in an urban bus. They found that biodiesel usage significantly reduces life cycle emissions of CO, total PM, and CO_2, but emissions of NO_x and total HC increase. McCormick et al. (2006) tested eight heavy duty diesel vehicles, including three transit buses, to measure the impact of B20 on regulated pollutant emissions. They found significant reductions in CO, total HC, and PM emissions, and even a small decrease in NO_x emissions. This differs from the NREL study, which measured just tailpipe emissions rather than total lifecycle emissions. The results from these studies will be discussed in more detail in the following section.

2.1 Emissions

One of the main benefits from biodiesel usage is a reduction in emissions. A number of previous studies have measured these changes. The U.S. Environmental Protection Agency (EPA) (2002) conducted a comprehensive analysis of the emission impacts of biodiesel using publicly available data, mostly for heavy-duty highway engines. They estimated that the use of soybean-based B20 in place of regular diesel results in a 10.1% reduction in PM, a 21.1% reduction in HC, an 11.0% reduction in CO, and a 2.0% increase in NO_x emissions. Their study also found that the impacts of biodiesel on emissions varied depending on the feedstock used to produce the biodiesel - whether it is soybean oil, rapeseed oil, or animal fat - and the type of conventional diesel to which the biodiesel is added. They found that NO_x emissions increase the most with soybean-based biodiesel and the least with animal-based biodiesel; the reductions in PM and CO emissions are the greatest with animal-based biodiesel; canola-based biodiesel reduces CO emissions at a greater rate and PM emissions at about the same rate as soybean-based biodiesel; and HC emissions decrease at about the same rate for all three sources.

McCormick et al. (2006) argued that the small apparent increase in NO_x emissions in the EPA study occurred because the dataset was not adequately representative of on-highway engines. In their study, McCormick et al. tested entire vehicles rather than just the engine as in other studies, to measure the impact of B20 on regulated pollutant emissions. They tested eight heavy-duty diesel vehicles, including three transit buses, two school buses, two Class 8 trucks, and one motor coach, with engine model years ranging from 2000 to 2006. On average, they found that soy-based B20 caused PM and CO emissions to decrease by 16% to 17% and HC emissions to decrease by 12% relative to petroleum diesel. They also found that NO_x emissions from use of B20 varied with engine/vehicle technology and test cycle, ranging from a 5.8% reduction to a 6.2% increase. In the three transit buses, PM emissions were reduced 15%-20%, CO emissions were reduced 12%-27%, and total HC emissions were reduced 20%-28% with the use of B20. These reductions were all statistically significant. NO_x emissions were reduced by 5.8% for the first bus and 3.9% for the second bus. These two buses used biodiesel containing a proprietary multifunctional diesel additive. A third bus was tested to determine if the additive was responsible for the NO_x reduction, but NO_x emissions also decreased on this bus by nearly as much without the additive. This suggested that the NO_x reduction occurs generally for biodiesel for this engine-transmission combination on this drive cycle. All changes in NO_x were significant at 95% confidence or better. NO_x emissions, on the other hand, for the Class 8 trucks, the motor coach, and the school buses were found to increase by a range of 2% to 6%.

Other studies have also specifically analyzed changes in emissions in transit buses. In the Proc et al. (2006) study, chassis emissions were tested for two transit buses both for #2 petroleum diesel and B20. In the first bus, total HC decreased 28.2%, CO decreased 26.8%, and PM decreased 17.3% when B20 was used. When B20 was used in the second bus, total HC, CO, and PM decreased 28.0%, 20.3%, and 19.9%, respectively. The two buses also showed reductions of NO_x emissions of 5.8% and 3.9% when B20 was used, similar to the McCormick et al. (2006) study. The authors of this study remarked that the oxygen content of the biodiesel is responsible for the reductions of total HC, CO, and PM, but that the situation for NO_x emissions is less clear.

In the BIOBUS Project (2003), they found that the use of B20 in transit buses led to a 25%-30% reduction in PM; a 20%-30% reduction in CO emissions; a 10%-30% reduction in total HC emissions, depending on the engine and type of feedstock used to produce the biodiesel; a 15% reduction in SO_4 emissions in an engine with electronic fuel injection; and a 10%-30% reduction in polycyclic aromatic hydrocarbons (PAHs) in an engine with electronic fuel injection. They found that the effect of B20 on NO_x emissions was generally neutral.

These studies have all measured tailpipe emissions, as opposed to life cycle emissions. Life cycle emissions include the emissions from the entire process of producing and burning the fuel. Sheehan et al. (1998) argued that understanding the benefits of biodiesel means understanding how its life cycle emissions compare to those of petroleum diesel. Their life cycle analysis for biodiesel included producing the soybeans through using the fuel in a diesel bus engine, and that for petroleum diesel included extracting the crude oil from the ground through its use in a diesel bus engine.

When life cycle emissions are analyzed, the reduction in emissions of CO_2 becomes apparent. Biodiesel is generally found to have a negligible effect on tailpipe emissions of CO_2 (BIOBUS 2003, EPA 2002) or to even have a small increase on such emissions (Sheehan et al. 1998), but life cycle emissions decrease due to carbon recycling in soybean plants. The soybean or canola plants used to produce biodiesel absorb carbon dioxide from the atmosphere while they are growing, thereby recycling previously emitted carbon dioxide and reducing life cycle emissions. Use of petroleum diesel, on the other hand, simply results in an increase in carbon dioxide emitted into the atmosphere, all of it coming from carbon which had been sequestered beneath the earth's surface and none of it being recycled. Sheehan et al. (1998) estimated that pure biodiesel reduces net life cycle emissions of CO_2 from urban buses by 78.5%, and that such emissions drop by 15.7% when using B20.

Sheehan et al. (1998) also estimated that when using B20, life cycle emissions decreased 6.9% and 6.5% for CO and total PM, respectively, but that emissions increased 2.7% and 7.2% for NO_x and total HC, respectively. They also found small reductions in SO_x and methane emissions. As other studies have shown, they found that tailpipe emissions of hydrocarbons decrease, but they estimated that lifecycle HC emissions would increase due to the release of hexane in the processing of soybeans and the volatilization of agrochemicals applied at the farm. Reductions in tailpipe HC emissions still can be beneficial by reducing urban area pollution.

These studies all show that the use of biodiesel significantly reduces both tailpipe and life cycle emissions of CO and PM as well as tailpipe emissions of HC, three important pollutants, while the effects on NO_x emissions are mixed. Other studies which have analyzed different types of diesel engines have reached similar conclusions (Clark and Lyons 1999, Schumacher et al. 2001, Peterson et al. 2000). Turrio-Baldassarri et al. (2003), on the other hand, found that the decrease in emissions was not statistically significant, and that the use of biodiesel blends caused a statistically significant increase in emissions of formaldehyde. Most studies contradict these findings, however, including the EPA study which found a statistically significant reduction in formaldehyde emissions with the use of biodiesel. A number of studies have shown a small increase in NO_x emissions from biodiesel, and this is an important concern. A few states have cited this as a deterrent for adoption where air quality is a primary consideration for the selection of fuels (Humburg et al. 2006). NO_x emissions have been shown to vary depending on the vehicle and drive cycle, and some studies which have specifically analyzed transit buses have shown a reduction in NO_x emissions. McCormick et al. (2006) concluded that when considering all data available, B20 has no net impact on NO_x. Finally, the reduction in net life cycle emissions of CO_2, a major greenhouse gas, is a significant benefit from the adoption of biodiesel.

2.2 Fuel Economy

One concern about the use of biodiesel is a potential decrease in fuel economy. The EPA (2002) estimated that the energy content of conventional diesel is 129,500 BTUs per gallon, and that for 100% canola- or soybean-based biodiesel it is about 119,200 BTUs per gallon. Plant-based pure biodiesel, therefore, has 7.9% less energy content per gallon than does conventional diesel. Based on this reduced energy content, B20 would be expected to produce a 1.6% reduction in fuel economy. Some studies have shown reductions in fuel economy in this range, while others have found no measurable difference. Proc et al. (2006) reported that laboratory testing revealed a 2% reduction in fuel economy for the B20 transit buses, but they found no difference in on-road miles per gallon between the B20 and regular diesel groups. The BIOBUS Project (2003) found that the energy efficiency of biodiesel is comparable to that of petroleum diesel. There was also no impact on fuel economy found for transit buses operating on B20 in St. Louis (Clean Cities 2002).

Bickel and Strebig (2000) studied the use of B20 in four road maintenance trucks and found that the average miles per gallon for these trucks was no different than that for the two trucks running on regular diesel. Humburg et al. (2006) surveyed state transportation agencies regarding their experience with biodiesel. They reported that of the 12 states that measured changes in fuel efficiency, half of them indicated there was no change in fuel economy when using biodiesel blends, and the other half reported some declines.

2.3 Cold Weather Performance

According to the Humburg et al. (2006) survey of state departments of transportation (DOTs), the most common deterrent for biodiesel adoption among these agencies, besides cost, was concern about cold weather performance. The cold flow properties of biodiesel are a significant limiting factor for use of the fuel, but blending it with regular diesel minimizes the disadvantage. Many studies have shown that biodiesel blends can be used successfully even in colder climates, although a few problems have been reported. Cold weather behavior was not found to be a widespread problem for those state transportation agencies that had adopted the fuel (Humburg et al. 2006).

Cold flow properties of biodiesel can be measured by its cloud point, pour point, and cold filter plugging point. Cloud point is the temperature at which a clear distillate fuel becomes hazy or cloudy because of the appearance of wax crystals; pour point is the lowest temperature at which a fuel will pour or flow when tested under standard conditions; and cold filter plugging point is the temperature at which fuel crystals cause a fuel filter to plug.

Table 2.1 Cold flow properties of biodiesel as a function of feedstock and comparison to petroleum diesel

Feedstock	Cloud point (ºF)	Pour point (ºF)	Cold Filter Plugging Point (ºF)
Soybean oil	31.1	25.2	24.1
Canola oil	24.8	12.6	38.5
Tallow	57.0	48.2	51.8
Sunflower oil		19.4	
Cottonseed oil		37.4	
Palm oil		60.8	
<u>Petroleum Diesel</u>			
Diesel #1	-40	-40	
Diesel #2	5	-27	-4 to 14

Source: Graboski and McCormick 1998

Graboski and McCormick (1998) reviewed a number of studies which estimated the cold flow properties of biodiesel with different feedstocks used. The average values which they reported are shown in Table 1 and are compared to the cold flow properties of #1 and #2 diesel. Feedstocks that have a higher percentage of unsaturated fat, such as canola oil and soybean oil, produce biodiesel with superior cold weather performance, while those high in saturated fat such as animal fats or palm oil produce biodiesel with poor cold flow properties. Canola oil has the lowest level of saturated fat and has been shown to be the best feedstock for cold weather performance, as shown by the lower cloud points and pour points in Table 1. Graboski and McCormick reported a higher cold filter plugging point for canola biodiesel, but the value reported for canola biodiesel was highly unreliable. They reported just two studies which estimated the cold filter plugging point for canola biodiesel, and the results of the two studies varied widely, ranging from 9ºF to 68ºF. In a later study, Kinast (2003) estimated the cold filter plugging point at 25°F.

Regardless of the feedstock used, the cold flow properties of biodiesel are markedly worse than those for either #1 or #2 diesel. The cold flow properties shown in Table 1 are for neat, or 100%, biodiesel. However, biodiesel is normally blended with petroleum diesel, reducing the negative impacts on cold weather performance. Biodiesel can be blended at lower percentages in colder weather to prevent gelling or wax formation, and additives can also be used to improve the cold flow properties. Kinast (2003) estimated the cloud point, pour point, and cold filter plugging point of biodiesel from various feedstocks at different blends. The results for B5, B20, and B100 soy, canola biodiesel and 100% diesel are shown in Table 2. The biodiesel blends perform much better than neat biodiesel, although it is still not as good as pure biodiesel.

Table 2.1 Cold flow properties for diesel and biodiesel blends estimated by Kinast (ºF)

	Pour Point		Cloud Point		Cold Filter Plugging Point	
	Soy	Canola	Soy	Canola	Soy	Canola
B5	-6	-6	3	1	-2	0
B10	0	-6	5	1	0	0
B20	0	0	7	5	1	0
B100	30	25	36	27	28	25
Diesel		-17		0		-4

Source: Kinast 2003

The Agricultural Utilization Research Institute and the University of Minnesota (2002) estimated cold flow properties for soy biodiesel blends with the use of cold flow improving additives. They found that B2 with additives had cloud, pour, and cold filter plugging points that were actually better than those for regular diesel, and B20 with additives had pour and cold filter plugging points that were as good as those for regular diesel but a cloud point that was higher. By blending 20% biodiesel with a winter blend diesel (50% #1 and 50% #2) and including an additive, they reduced cloud, pour, and cold filter plugging points to -3ºF, -50ºF, and -34ºF, respectively.

The BIOBUS Project (2003) concluded that, under actual operating conditions, biodiesel blends of B5 and B20 can be viable in a region like Montreal where winter temperatures can drop to -30ºC (-22ºF). During their demonstration, cold weather caused no problems for buses on the road despite three cold spells (three to five days long) when daytime temperatures remained below -20ºC (-4ºF). The blended biodiesel was stored underground, and when necessary, the pure biodiesel was heated prior to delivery to a temperature high enough for the final blend to be above 0ºC (32ºF). Their buses were parked in garages heated to 15ºC (59ºF) when not running, and they recommended that transit authorities with vehicles that are not parked in heated garages should use a lower concentration of biodiesel such as B5 or B2. Proc et al. (2006) mentioned no cold weather problems with the use of B20 in Boulder, Colorado.

Bickel and Strebig (2000) studied the performance of biodiesel in road maintenance trucks in the cold weather of Minnesota. Their 17-month study (December 1998-April 2000) spanned two winters in Hennepin County, Minnesota, and they concluded that B20 with a fuel additive had cold flow properties comparable to those of a winter blend diesel fuel. With the additive, the pour point and cold filter plugging point for B20 were comparable to those for the baseline diesel fuel, and they remarked that these measures are more accurate than the cloud point in determining how a fuel will perform in cold weather. During this test period, the trucks were always parked inside in a heated area, and they were equipped with fuel line heaters. The pure biodiesel was stored in a heated, insulated, above-ground fuel tank before being mixed with petroleum diesel.

Humburg et al. (2006) reported that there were few cold weather problems for state DOTs that adopted the fuel. Ohio and Iowa, however, reported filters plugging exclusively under cold conditions, and the North Dakota DOT decided not to use biodiesel during the winter months. The city of Fargo experimented with the use of B20 in city-owned landfill equipment in 2001 (Grubb and Pedersen 2007), and they experienced problems in the cold weather. Fuel filters were frequently plugged due to the gelling of the fuel. After the experiment, they decided to continue the use of B20 on a seasonal basis (April-October) and to investigate alternatives for cold weather use.

2.4 Lubricity and Cetane Number

There are other benefits from using biodiesel besides reduced emissions. One benefit is that biodiesel has greater lubricity than conventional diesel (Strong et al. 2004). Lubricity is a measure of the extent to which liquid diminishes friction. One test of lubricity is the Ball on Cylinder Lubricity Evaluator (BOCLE). Fuels with a good lubricity give BOCLE results in the 4500-5000 g range (Graboski and McCormick 1998). The BOCLE results reported by Graboski and McCormick are 4200-4250 for conventional diesel, 6100 for soybean biodiesel, and 7000 for canola biodiesel. Kinast (2003) performed scuffing load BOCLE tests on different blends of biodiesel, and their results show that blending even a small percentage of biodiesel can significantly improve the lubricity. Kinast's SLBOCLE results were 3600 for diesel, 5400 for soy B5, 5950 for canola B5, 6150 for soy B20, and over 7000 for canola B20. Knothe and Steidley (2005) reached the same conclusion.

The benefit from increased lubricity is even more important as EPA regulations are requiring changes in diesel fuel. The EPA is mandating a substantial reduction in the sulfur content of diesel from 500 ppm (parts per million) to 15 ppm. New regulations for sulfur content began in 2006, and by June 1, 2010, all highway diesel in the United States must be ultra-low sulfur diesel (ULSD) fuel. ULSD is being mandated because it will significantly reduce emissions of particulate matter and nitrogen oxides. ULSD, however, has a lower level of lubricity (Knothe and Steidley 2005), so biodiesel blends could become an attractive alternative to improve lubricity.

Biodiesel also has a higher cetane number than conventional diesel. The cetane number is a measure of the self-ignition quality of fuel. Higher cetane numbers indicate that vehicles are easier to start and quieter to operate when fueled with biodiesel compared to conventional diesel. No. 2 diesel fuel in the United States usually has a cetane number between 40 and 45, while the values for biodiesel have been shown to be from 45 to 67 (Van Gerpen 1996). Graboski and McCormick (1998) found that the average reported cetane number is 50.9 for soy biodiesel and 52.9 for canola biodiesel, while Kinast (2003) estimated cetane numbers of 59 and 54 for 100% soy and canola biodiesel, respectively. Kinast found that B20 has a cetane number of about 49 and 47 for regular diesel, and Proc et al. (2006) estimated a cetane number of 47 for B20 and 40 for diesel.

2.5 Maintenance Costs

An objective of many of the studies that have analyzed biodiesel use is to determine if there are any significant maintenance issues with the adoption of the fuel. Proc et al. (2006) estimated that total maintenance costs per mile were 5.2% lower for transit buses operating on B20 (54 cents per mile for diesel and 51 cents per mile for B20), but the difference was not statistically significant. The lower cost for the B20 buses was due to transmission repairs in the diesel group, which was unrelated to fuel use. The engine and fuel system maintenance costs per mile were actually 39% higher for the B20 group, but, again, this was not statistically significant. Engine and fuel system costs for the two groups were very similar for most of the test period, but average B20 maintenance costs increased during the last three months of the study due to component replacements in one of the buses. Maintenance costs can vary significantly among vehicles, so it can be difficult when using a small sample size to determine the impacts of biodiesel use on these costs. Proc et al. (2006) wrote that future studies will need to be conducted on a larger fleet or over a longer period of time to mitigate the impact of high variability in maintenance costs among vehicles.

The plugging of filters may be expected during the introduction of a biodiesel blend due to the cleansing properties of the fuel. Of the 19 state DOTs that reported use of biodiesel in the Humburg et al. (2006) survey, eight reported fuel filtering problems in excess of what they experienced during petroleum diesel use, but all eight reported that the problems ultimately resolved themselves.

Proc et al. (2006) noted that B20 buses had a few fuel filter plugging events, necessitating extra fuel filters. This did not add significantly to the operating cost, but it created disruptions in service. The BIOBUS Project (2003), on the other hand, found that using biodiesel did not result in any incidents causing a disruption in service. Further, they concluded that mechanical maintenance was unproblematic during and after the transition to biodiesel for most buses, including both older and newer models.

Brooklyn Park, Minnesota, began using B5 and B20 in its equipment in 1999, and they have experienced very few problems. According to Lawrence (2007), the only problem they had was replacing a small number of fuel filters on older equipment. The Humburg et al. (2006) survey of state DOTs reported that no state had any fuel pump problems or fuel system/fuel line leaks; no state reported any change in viscosity, oil acidity, engine wear, or other oil-related activities; and no state attributed any other vehicle maintenance issue specifically to the usage of biodiesel blended fuel. Bickel and Strebig (2000) reported that no unusual engine wear occurred in any of the trucks running on B20. They experienced no instances of filter clogging, and all fuel system components on the trucks were in good condition at the conclusion of the testing period. The consensus of the drivers was that there was no observable difference between B20 and regular diesel fuel.

Fraer et al. (2005) studied the wear characteristics of eight engines from U.S. Postal Service trucks, four of which had been operating on B20 for four years, accumulating more than 600,000 miles on the fuel. The results indicated that there was little difference in operational and maintenance costs between the B20 and diesel groups that could be attributed to the fuel. They found no difference in wear. They noted, however, that two Mack tractors operating on B20 experienced a greater frequency of fuel filter and injector nozzle replacement, but that they essentially had the same maintenance costs as the petroleum diesel tractors. The vans operating on B20 did not have any of these problems.

The BIOBUS Project (2003) recommended that a consistent multi-step filtering process be followed to ensure consistent blend quality, and they stated that it is essential that suppliers use filters whose performance has been proven by documented test procedures. They also recommended that adequate training be provided for technical workers to make them aware of the importance of identifying the source of a problem in order to achieve the correct diagnosis. Lawrence (2007), on the other hand, indicated that in his experience, no training was needed to prepare mechanics for the use of biodiesel blends.

3. U.S. BIODIESEL OVERVIEW

The use of biodiesel as an alternative fuel for diesel engines has grown significantly in recent years. Its popularity stems from the fact that it is a domestically produced, renewable fuel with certain environmental benefits. The federal government, along with many local and state governments, are providing subsidies, incentives, and, in some cases, mandates for the production and use of biodiesel (Mattson et al. 2007). The following chapter is divided into five sections discussing the U.S. biodiesel industry. These include biodiesel advantages, disadvantages, U.S. production, cost information, and incentives to provide a better understanding of biodiesel production and its usability in the United States.

3.1 Biodiesel Advantages

The motivation for supporting biodiesel is its perceived environmental, economic, and energy security benefits. In the United States, biodiesel is mostly produced from domestically grown soybeans, or in some cases, canola or other vegetable oils, recycled vegetable oils, or animal fats. Since it is domestically produced, it could lessen dependence on foreign oil imports. According to the Energy Information Association, the United States currently spends almost $250 billion annually on foreign oil, which is equal to more than $475,000 every minute (EIA 2007). The United States consumes approximately 20 million barrels of oil each day. By 2025, the demand is forecasted at 26 million barrels per day, of which 60% is projected to be imported.

Use of biodiesel benefits U.S. soybean producers, and it has positive environmental attributes. It reduces emissions of pollutants and greenhouse gases. According to the EPA, B20 reduces carbon monoxide (CO) and particulate matter (PM) by 12% each and unburned hydrocarbons (HC) by 20% (EPA 2002). A study by the U.S. Department of Energy found that biodiesel production and use, when compared to petroleum diesel, produces 78% less carbon dioxide (CO_2) emissions because soybeans actually consume CO_2 during the growing process (U.S. DOE 2008).

Biodiesel also exhibits a positive energy balance, whereas many alternative fuels do not. Based on the national average, for every BTU (British Thermal Unit) of energy used in the production of soybean-based biodiesel, an average of 3.4 BTUs of energy output is realized – a 240% energy gain (USDA 2008). According to the National Biodiesel Board (NBB), this represents the highest energy balance of any fuel. The calculations take into account all of the energy consumed during the production of biodiesel, including energy used for transportation, production of fertilizers and pesticides to grow the crop, fuels used to produce the final product, and the methanol used in the manufacturing process. The comparable efficiency factor for ethanol is about 1.6 BTUs of output for every BTU of input, while the production of petroleum yields an efficiency factor of less than one. Advocates of biodiesel highlight its positive energy balance as a major factor in ensuring its viability as an alternative fuel option.

3.2 Biodiesel Disadvantages

A main drawback of biodiesel use is the cost. Biodiesel traditionally costs more than petroleum diesel. This cost disadvantage decreases, however, as petroleum prices rise, and subsidies from the government also make biodiesel more affordable. Biodiesel also has a lower energy content when compared to conventional diesel fuel. Although the difference is more pronounced with B100 (100% biodiesel), a typical B20 blend (20% biodiesel and 80% conventional diesel) will reduce power, torque, and fuel economy by approximately 2%, which may be difficult to detect within day-to-day operations (Schiavone 2007).

Biodiesel can also act as a solvent in storage tanks and fuel lines. As a result, sediments may dislodge and plug lines, which may require biodiesel storage tanks to be cleaned in advance of biodiesel delivery. Failure to clean tanks in advance has led to time consuming fuel line cleaning processes that could have been avoided if tanks were cleaned prior to biodiesel use.

Cold weather operations with biodiesel are also a concern. Biodiesel begins to gel at higher temperatures than conventional diesel. TCRP Synthesis 72, (Schiavone 2007) questioned 18 transit agencies regarding cold weather-related problems with respect to biodiesel use. Ten of the 18 agencies reported having some type of problem. Seven agencies reported cold weather delivery problems; six agencies reported cold weather storage problems; and ten agencies reported cold weather vehicle problems. Problems were separated into three temperature categories: below 0ºF, 0ºF to 19ºF, and above 19ºF. The majority of the delivery problems occurred when temperatures were below 0ºF, while storage problems and vehicle issues were evenly distributed among the three temperature categories.

3.3 Production

As a result of the increased demand and government support, U.S. biodiesel production tripled from 25 million gallons in 2004 to 75 million gallons in 2005, and then more than tripled again to 250 million gallons in 2006. In 2007, an estimated 450 million gallons of biodiesel was produced (Figure 1). Currently, there are 171 biodiesel plants in the United States (See Appendix for biodiesel plant maps). The potential for further expansion is significant as 57 new plants are being built along with the expansion of three existing plants, and many plants are currently operating below full capacity (National Biodiesel Board 2008).

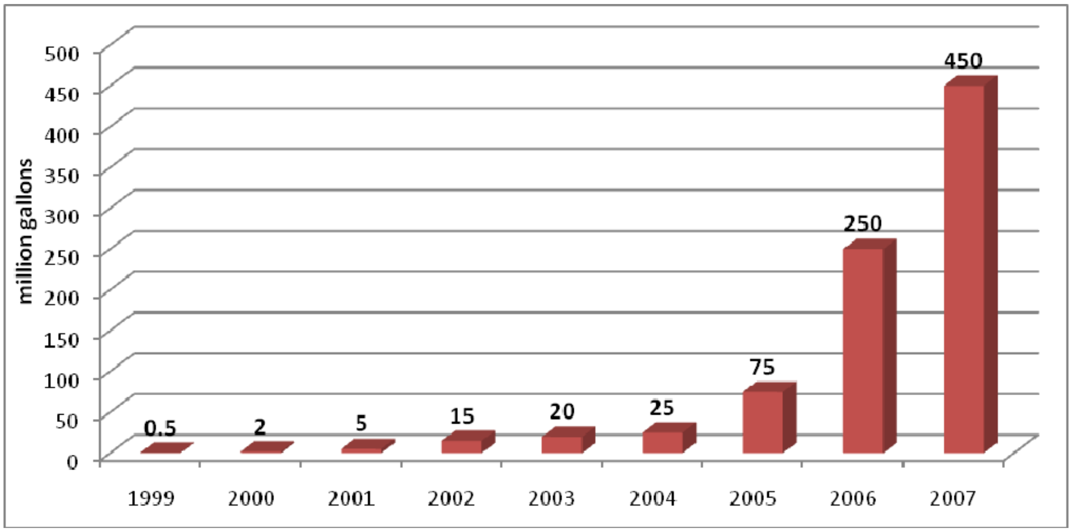

Figure 3.1 U.S. biodiesel production

Three plants, two of which are located in North Dakota and one in central Minnesota, are each unique and of interest to current and potential Fargo-Moorhead biodiesel users. Ironton, Minnesota, is home to Green Range Renewable Energy. Recycled cooking oil is used at this facility to produce biodiesel. They have an annual production capacity of 150,000 gallons and have been in operation since July 2006. Green Range Renewable Energy currently has 70 regular customers and is 10 cents cheaper than their nearest competitor. Their retail pump is powered by two small wind turbines (Central Region 2006). The two other potential plants are located in Velva, North Dakota, and York, North Dakota. The Velva plant is projected to produce 85 million gallons of biodiesel annually from canola, and the York plant is scheduled to produce 2 million gallons annually from soybeans, (National Biodiesel Board 2008).

3.4 Cost Information

Table 3.1 shows the cost of biodiesel (B20) compared to conventional diesel throughout the United States along with the number of stations surveyed by the U.S. Department of Energy (U.S. DOE 2008) in January 2008. The cost of B20 is very comparable to that of conventional diesel. B20 ranges from an average of $3.31/gallon in the Midwest to $3.49/gallon in the New England states with a standard deviation of $0.25/gallon. Conventional diesel ranges from $3.30/gallon in the Gulf Coast region to $3.60/gallon in the New England states with a standard deviation of $0.24 cents per gallon. The average cost of both B20 and conventional biodiesel in the Midwest is slightly below the national average.

Table 3.1 Biodiesel (B20) average prices by region

	Biodiesel (B20) Information		Diesel Information	
Region	Average Price/Stan.Dev. of Price	Stations	Average Price/Stan.Dev. of Price	Stations
New England	$3.49 / 0.30	20	$3.60 / 0.12	30
Central Atlantic	$3.31 / 0.24	13	$3.53 / 0.15	38
Lower Atlantic	$3.36 / 0.14	20	$3.36 / 0.12	60
Midwest	**$3.31 / 0.28**	**24**	**$3.37 / 0.32**	**109**
Gulf Coast	$3.37 / 0.12	5	$3.30 / 0.07	38
Rocky Mountain	$3.32 / 0.23	30	$3.26 / 0.23	43
West Coast	$3.45 / 0.24	22	$3.47 / 0.18	67
National Average	**$3.37 / 0.25**	**134**	**$3.40 / 0.24**	**385**

Figure 3.2 illustrates the cost difference between B20 and conventional diesel by state. The unshaded states had no data available for the month of January 2008 (U.S. DOE 2008). The light gray shaded states reported higher B20 prices compared to conventional diesel, while the dark shaded states reported B20 prices between 0 and 25 cents cheaper per gallon than conventional diesel. Both Pennsylvania and New York reported B20 prices 25 to 75 cents cheaper than conventional diesel prices, respectively. Viewing prices from a state perspective rather than a regional perspective (Table 3.1) gives a more precise indicator as to which states offer B20 at a discount (Pennsylvania, New York, Minnesota, Ohio, Texas, etc.) versus the states that charge a premium (Washington, Maine, Alaska, Illinois, etc.) compared to conventional diesel.

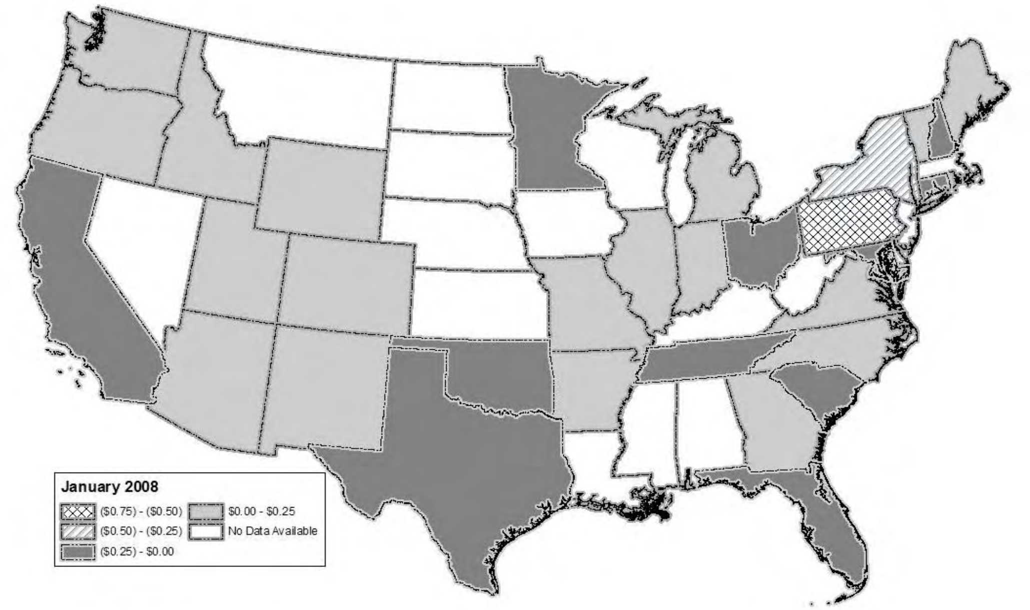

Figure 3.2 Cost differentials between B20 and conventional diesel

3.5 Incentives

Many states and cities are now requiring or encouraging use of biodiesel blends in state- or city-owned, diesel-powered vehicles. For example, Illinois requires all government, school, university, and mass transit diesel vehicles to use a biodiesel blend that contains at least 2% biodiesel (B2). Indiana, Kansas, and New York have similar requirements for state-owned vehicles. Missouri requires at least 75% of the DOT vehicles be fueled with a blend of 20% biodiesel (B20). Many other states have also enacted or considered some form of policy requiring or encouraging use of the alternative fuel. Minnesota was the first state to enact a statewide biodiesel requirement, mandating that all diesel fuel sold in the state contains at least 2% biodiesel. Some cities such as Portland, Oregon, San Francisco, California, and Albuquerque, New Mexico, have enacted policies requiring use of B20 in city-owned vehicles.

With or without a mandate, many publicly-owned vehicles, including transit buses, are now using, or being considered for the use of, biodiesel. Some organizations may be hesitant to adopt the fuel due to concerns about cost or performance. Due to the growing use of this fuel and concerns that may exist, it is important to study the effects of biodiesel use on vehicle performance. The advantages and disadvantages need to be measured and documented. A number of previous studies have researched the effects of biodiesel usage. These studies were reviewed in the previous section.

4. FARGO-MOORHEAD METRO AREA TRANSIT OVERVIEW AND BIODIESEL USAGE

The Fargo-Moorhead Metro Area Transit (MAT) is the public bus system serving the communities of Fargo, Moorhead and West Fargo. The system is operated jointly by the cities of Fargo, North Dakota, and Moorhead, Minnesota, to ensure comprehensive service within the communities. Approximately 150,000 residents are served by MAT, which includes 19 fixed routes in Fargo, Moorhead, and West Fargo. In 2007 alone, MAT provided more than 1.3 million rides on its fixed-route service (Figure 4.1), and the paratransit service in Fargo gave 300,000 rides. In 2007, MAT fixed-route drove 603,419 miles in Fargo and 319,997 in Moorhead, while the Fargo paratransit drove 311,160 miles, respectively.

Figure 4.1 illustrates the fixed-route ridership on MAT between 2000 and 2007. Total ridership for the entire system is shown along with segmented ridership in both Fargo and Moorhead. Fargo ridership has steadily increased throughout the past seven years with a large single year increase occurring from 2003 to 2004 (Figure 4.2) This was in large part due to the implementation of two circulator routes at the North Dakota State University campus. The circulators operate during fall and spring semesters providing transportation from near-campus apartments and student parking lots to the heart of campus. They have been heavily utilized throughout the past four school years. A downtown NDSU circulator was also added a couple of years ago and has contributed to Fargo's fixed-route ridership growth.

Moorhead fixed-route ridership declined from 2000 to 2004, but has grown during each of the past three years (Figure 4.3). An increase in fuel prices is believed to have played a role in the recent ridership growth in both Fargo and Moorhead. Overall, the entire MAT fixed-route system has seen ridership growth compared to the previous year in every year since 2000. A one-year exception occurred from 2000 to 2001 when ridership remained relatively constant.

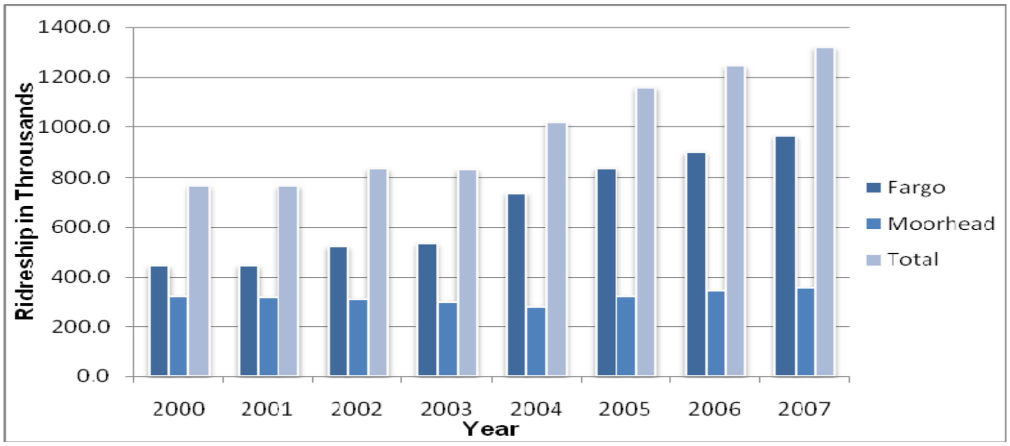

Figure 4.1 2000-2007 MAT fixed-route ridership

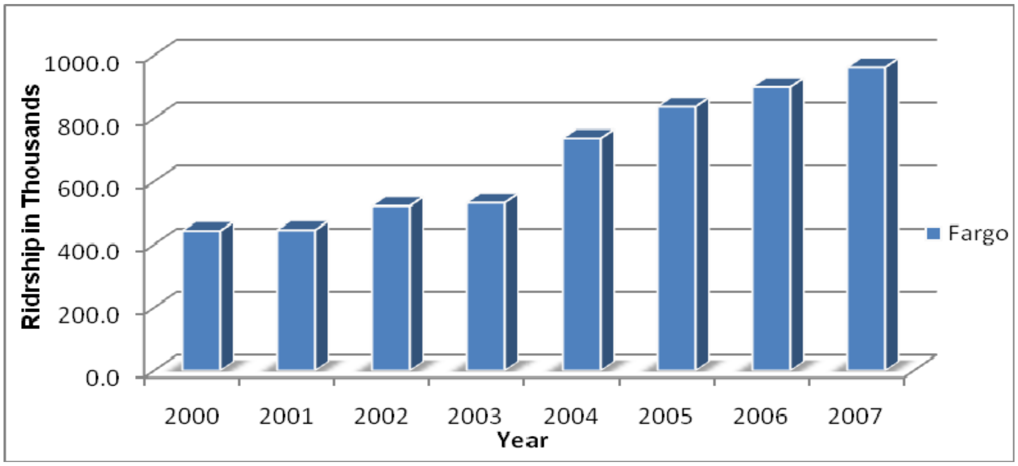

Figure 4.2 2000-2007 Fargo fixed-route ridership

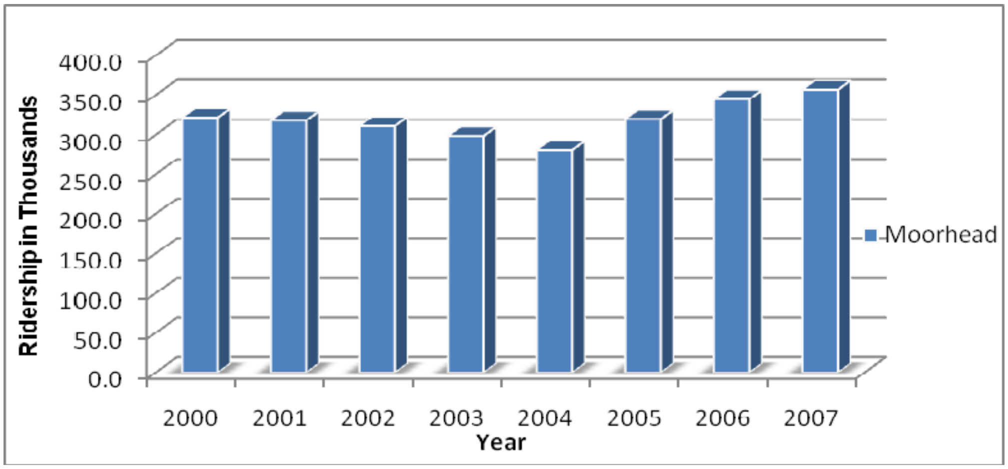

Figure 4.3 2000-2007 Moorhead fixed-route ridership

4.1 Biodiesel Experience

Fargo-Moorhead MAT began using biodiesel in its buses in 2005 largely because the city of Fargo's Renewable Energy Committee felt it needed to be proactive in utilizing and promoting renewable energy resources. The first step was to use biodiesel in all city fleet vehicles. The switch at MAT has been a success, and the bus fleet has had very few mechanical problems that can be attributed to biodiesel use.

The city of Fargo also has the ability to blend biodiesel with conventional diesel at varying levels throughout the year in its fueling tanks. This is especially important in North Dakota and Minnesota where temperatures range from 90ºF during the summer to -30ºF during winter months. Common blends that have been used include B5 during the months of April and October, B2 during November and December, and B20 in May through September. Conventional diesel is used, without blending biodiesel, throughout much of the coldest weather months of January, February, and March.

The ability to market the use of alternative fuels in transit vehicles is worth mentioning as well. Transit service in a small urban community such as Fargo-Moorhead is often thought to be of secondary importance compared to transit in a large metropolitan area. However, advertising the use of biodiesel allows the public to identify transit in a different way. Potential riders, who do not currently ride transit may consider utilizing the service because they feel they are contributing to a “greener” community and are supporting local farmers. MAT has marketed its use of biodiesel very effectively throughout the Fargo-Moorhead community. Their advertising has focused on biodiesel, and they also involved local citizens by sponsoring a bus naming competition for a transit vehicle with a soybean bus wrap. While difficult to quantify, the relationship between alternative fuel use and ridership should be considered when analyzing ridership trends and developing transit marketing campaigns in small urban and rural areas.

5. METRO AREA TRANSIT BIODIESEL FINDINGS

All MAT biodiesel results are based on data collected from 2004 and 2007. These two years were chosen to provide a before and after analysis with respect to the use of biodiesel. In 2004, MAT did not use biodiesel in its bus fleet. Therefore, 2004 served as the before analysis and 2007 as the after. In using both biodiesel and non-biodiesel data, analysis was performed to compare the effect biodiesel has had on the fleet as a whole as well as its effect on each individual vehicle. There were 13 of the same standard transit buses and 10 of the same cutaway buses in use during both 2004 and 2007. These vehicles were analyzed throughout the study to gain an understanding of the effect biodiesel has on vehicle performance. Comparing biodiesel's effect using different vehicles from 2004 and 2007 would not provide as accurate of a comparison because the nuances of the different vehicles would also need to be considered in the analysis. Any change in performance could be attributed to the fact that different vehicles were compared, rendering the biodiesel effect insignificant.

Monthly data was analyzed from both 2004 and 2007. Miles per gallon (MPG) was a performance characteristic given particular attention since various research findings have found that biodiesel use decreases fuel efficiency (EPA 2002, University of Houston 2006, Proc et al. 2006). With the recent large increase in fuel prices, decreased fuel efficiency is of particular interest. Cents per mile (CPM) fuel data as well as maintenance and repair (M&R) costs were also collected in 2004 and 2007.

5.1 Total Fleet

Table 5.1 shows the averages of all data from 2004 and 2007, including standard deviations. Fuel cost, M&R cost, and total costs were all measured in CPM. Total costs are the sum of fuel and M&R costs. This total cost does not take into account other miscellaneous expenses, such as accidents, traffic tickets, etc. MPG decreased 4% in 2007 compared to 2004. This is quite insignificant compared to fuel costs and M&R costs, which rose by 88% and 47%, respectively, over the same period. Diesel fuel prices rose more than 80% per gallon over this same period, which accounts for nearly all of the CPM increase in fuel cost. The M&R cost increase is attributable to both a rise in the price of parts and labor, along with an aging bus fleet in 2007 that required more repair work compared to the same, newer fleet in 2004. The increase in both fuel and M&R costs contributed to the 64% increase in total cost. The Standard Deviations (SD) show the variability of the data over each one year period. Variability increased slightly for fuel mileage (MPG) in 2007 compared to 2004, while the variability of M&R actually decreased over the same period. The SD for fuel cost more than doubled in 2007 compared to 2004, showing a major volatility increase with respect to fuel prices over this period. Total cost variability increased slightly, also due to the increase in fuel volatility, which outweighed the decreased variability of M&R costs.

Table 5.1 Yearly averages for buses and cutaways

		MPG	SD	Fuel	SD	M&R	SD	Total	SD
2004	Average	6.10	1.93	0.268	0.093	0.395	0.581	0.663	0.634
2007	Average	5.85	2.18	0.505	0.219	0.582	0.550	1.087	0.670
	% Change	-4.0%		88.3%		47.3%		63.9%	

Figure 5.1 illustrates the total CPM for all transit vehicles by month in 2007. Plotting each data point makes the the increased variability of the data easier to visualize. The largest outliers shown toward the top of the figure within the $2.00 to $4.50 CPM range include large item maintenance costs (new tires, major engine repairs, etc.), which increased the monthly CPM and added to the variability of the data.

Cutaway buses are represented by vehicle numbers 0-120 on the vehicles axis with the remaining points (121-300) representing standard transit buses. It is visually obvious that the larger transit buses account for much more variability in the CPM data than the cutaway buses. This variability will be discussed in greater detail throughout the following discussion.

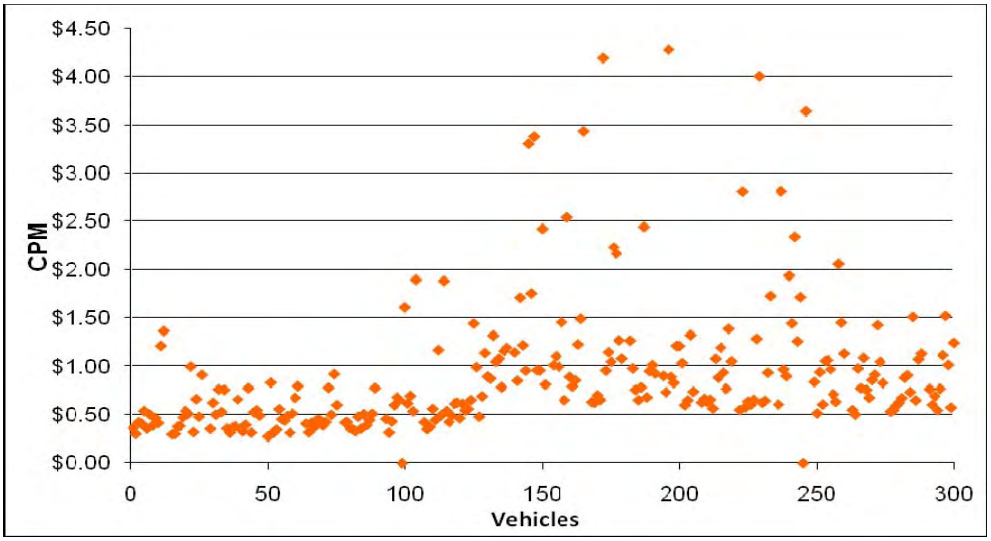

Figure 5.1 2007 Total Monthly CPM

5.2 Cutaway Buses

Table 5.2 shows the yearly averages for cutaway buses in 2004 and 2007. MPG decreased by less than 1% between the two years, while fuel CPM increased by 78%. The variability of fuel was also more than four times higher in 2007 compared to 2004. Both of these large increases are due to the inflated price and variability of fuel cost in 2007. The M&R CPM also increased by more than 78%. This shows that as cutaway buses age, maintenance costs increase at a faster rate than those of standard transit buses. The variability of M&R costs also more than doubled in 2007. The M&R monthly CPM costs are plotted in Figure 5.2, showing a large number of outliers signifying major maintenance costs (brake repacements, engine repairs, etc.). These outliers are largely responsible for the huge increase in overall M&R cost and the doubling of M&R cost variability in 2007 compared to 2004.

Table 5.2 Yearly averages for cutaway buses

		MPG	SD	Fuel	SD	M & R	SD	Total	SD
2004	Cutaways	7.94	0.62	0.185	0.020	0.125	0.126	0.309	0.129
2007	Cutaways	7.88	1.76	0.329	0.084	0.222	0.266	0.551	0.318
	% Change	-0.7%		78.0%		78.2%		78.1%	

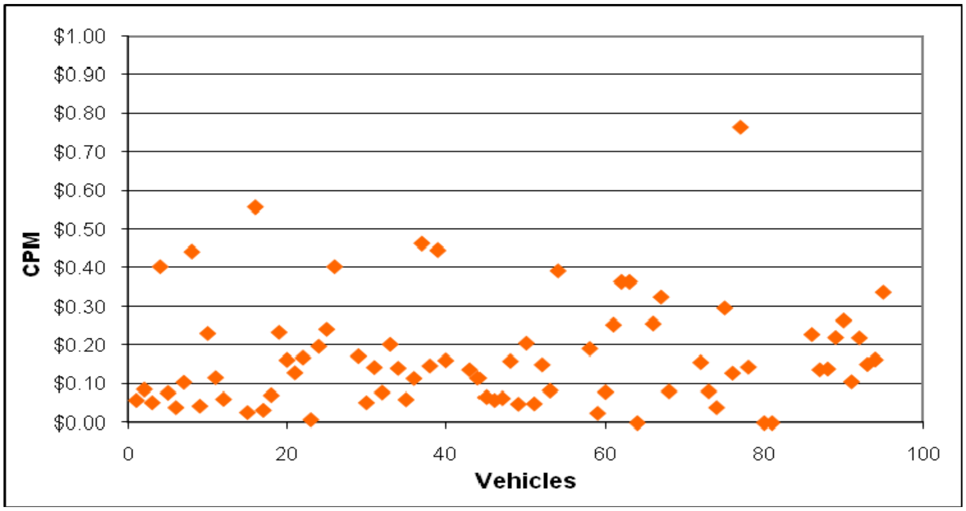

Figure 5.2 2007 cutaway M&R monthly CPM

5.3 Standard Transit Buses

Standard transit bus yearly averages are shown in Table 5.3. Gas mileage decreased by 1.9% in 2007 compared to 2004. The use of biodiesel in 2007, however, was insignificant in this mileage decrease. This small decrease in fuel efficiency is likely due to the aging bus fleet running less efficiently. Fuel costs accounted for nearly all of the increase in total cost for transit buses. The 84% increase in fuel costs for standard transit buses were 6% higher than those of cutaway buses. The variability in fuel costs were also nearly three times higher in 2007 than 2004. M&R costs increased by 10%, while their variability actually decreased from 0.762 to 0.661 over the same period. This decrease indicates that the maintenance crew at MAT is doing an excellent job of keeping M&R costs constant, even though the fleet has aged three years and the cost of maintenance and supplies have increased substantially as well. Total costs increased by 36%, but the total cost variability decreased over the same period. This is a notable achievement on the part of MAT when considering both the increase and fluctuation in 2007 diesel fuel prices compared to 2004.

Table 5.3 Yearly averages for standard transit buses

		MPG	SD	Fuel	SD	M & R	SD	Total	SD
2004	Buses	4.46	1.00	0.342	0.066	0.636	0.762	0.978	0.778
2007	Buses	4.37	0.90	0.631	0.195	0.699	0.661	1.330	0.744
	% Change	-1.9%		84.3%		10.0%		36.0%	

5.4 Total Cost

Figure 5.3 illustrates cost estimates for fuel, M&R, and total cost for 2007 and 2004. These values are based on calculations of total miles driven in both years and the previous cost categories in cents per mile. They only take into consideration fuel and M&R costs for the 23 vehicles that operated during 2004 and 2007, and do not include administrative, labor, or other costs incurred during this same time period. Fuel costs nearly doubled between 2004 and 2007. Maintenance costs also increased by almost $230,000 over the same period. This was primarily due to the 78% increase in M&R costs attributed to cutaway buses

(Table 5.2). Overall, total cost for these 23 vehicles increased by more than $520,000 between 2004 and 2007. Nearly $300,000 of this increase can be attributed to the rise in fuel costs, as well as its variability being three times higher in 2007 compared to 2004.

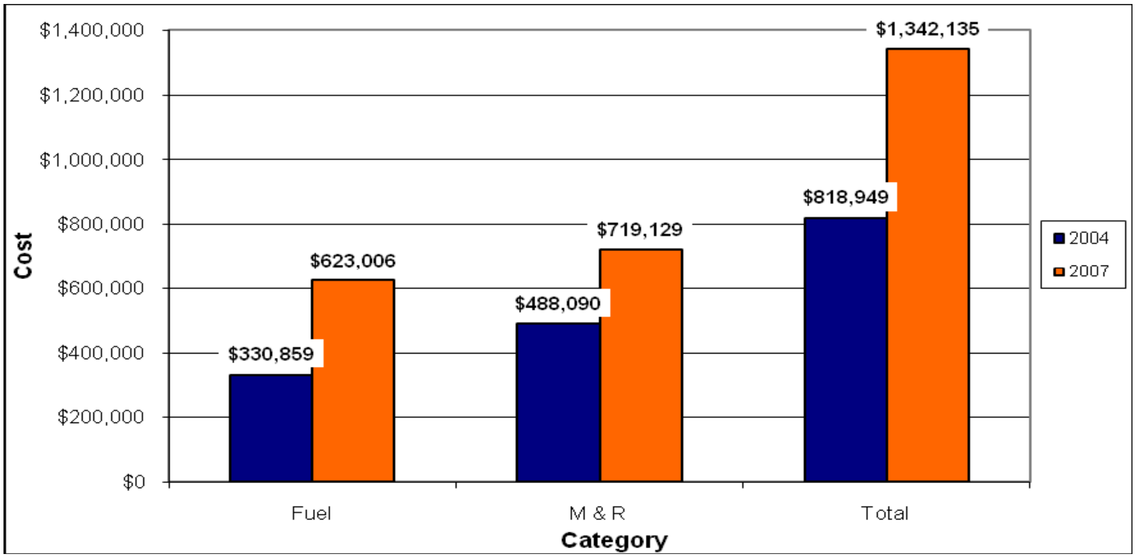

Figure 5.3 2007 and 2004 cost estimates

5.5 Fuel Efficiency

Decreased fuel efficiency is a concern when switching from conventional diesel to biodiesel. Conventional diesel has been found to be 2% to 5% more fuel efficient than biodiesel (Schiavone 2007). This small difference may seem trivial, but a 5% decrease in fuel efficiency would have cost MAT over $30,000 in 2007 ($623,000 x 5%). Also, as fuel prices continue to rise, a five percent decrease in fuel efficiency becomes even more significant. For example, 5% of $2.00/gallon is just 10 cents per gallon, while 5% of $3.50/gallon is 17.5 cents per gallon. Taking into consideration the thousands of gallons of fuel MAT uses each year, seemingly small decreases in fuel efficiency can increase total fuel costs significantly.

Figure 5.4 illustrates the MPG fuel efficiency for all 23 transit vehicles in 2004 and 2007. As seen in Table 5.1, MPG was 4% lower in 2007 than 2004 with slightly higher variability. However, there is almost no correlation between the MPG observations in 2004 versus the same observations in 2007. MPG were greater in January, April, May, August, and December of 2007 compared to 2004, while MPG were higher in February, March, June, July, September, October, and November of 2004 compared to 2007. With this result, it is impossible to conclude what, if any, effect biodiesel use had on fuel efficiency. The only noteworthy observation that can be drawn from Figure 5.4 is that fuel efficiency decreased in the summer months of both 2004 and 2007. This is usually attributed to the use of air conditioning in transit vehicles during this period. However, MAT uses higher blends of biodiesel (B20) during warm weather months, which may account for part of this decrease, although the decrease was not enough to be significant.

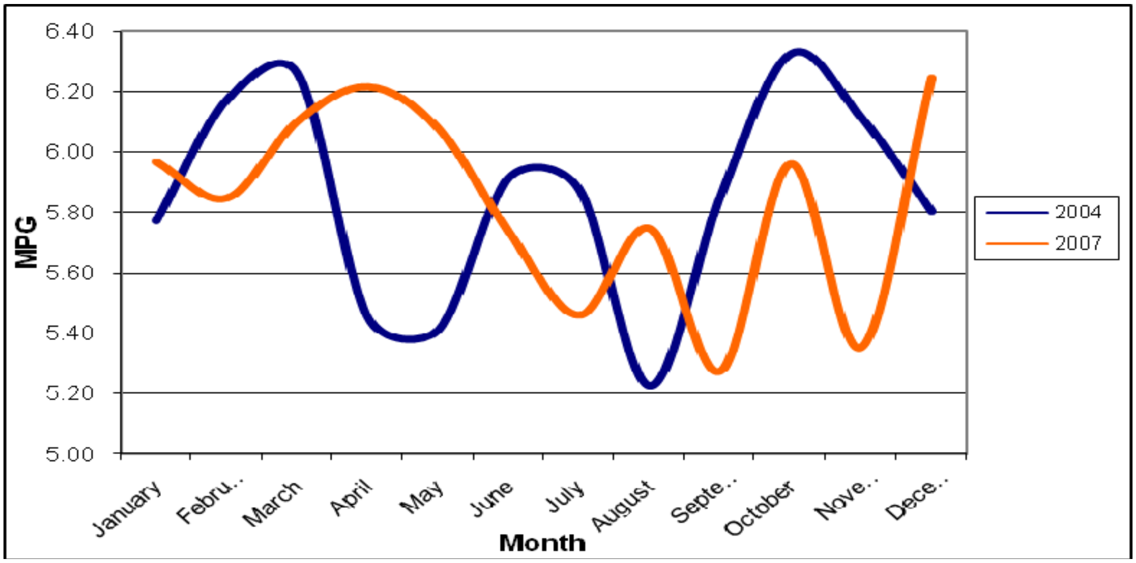

Figure 5.4 MPG 2004 vs. 2007

Taking a closer look at the warm weather months of May through September also did not provide a better understanding of fuel efficiency. Figure 5.5 shows the MPG data for these five months in Fargo-Moorhead. MPG were greater in May and August of 2007 compared to 2004, while MPG were greater in June, July, and September of 2004 compared to 2007. Biodiesel use did not have a significant effect on fuel efficiency in any of these months.

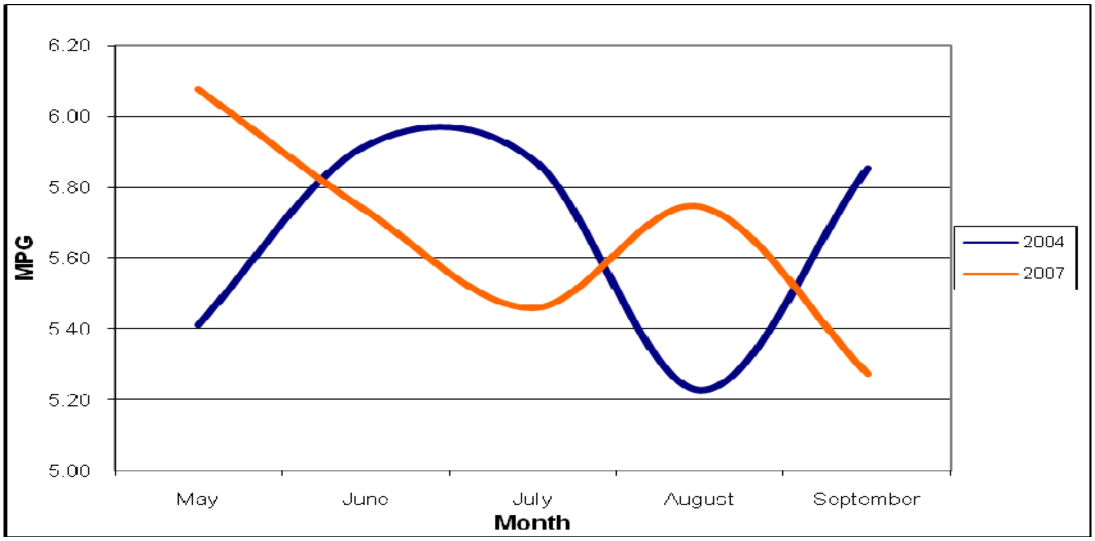

Figure 5.5 MPG May – September 2004 vs. 2007

The MPG data were also partitioned by vehicle type. Figure 5.6 illustrates the 2004 and 2007 MPG data for cutaway buses. Once again, there is very little correlation when comparing the two years. MPG were greater in January, April, May, August, and December of 2007, while MPG were greater in 2004 for all other months except June, when MPG were almost identical. The high variability of MPG for cutaway buses is visually evident in 2007 versus 2004. The 2004 data varies less dramatically with a maximum of nearly 8.5 MPG in September and a minimum of 7.2 MPG in April, a range of 1.3 MPG. The 2007 data has a maximum of 8.7 MPG in May and a minimum of almost 6.5 MPG in September, a range of 2.2 MPG. Thus, there was a 70% increase in the variance of MPG in 2007 compared to 2004.

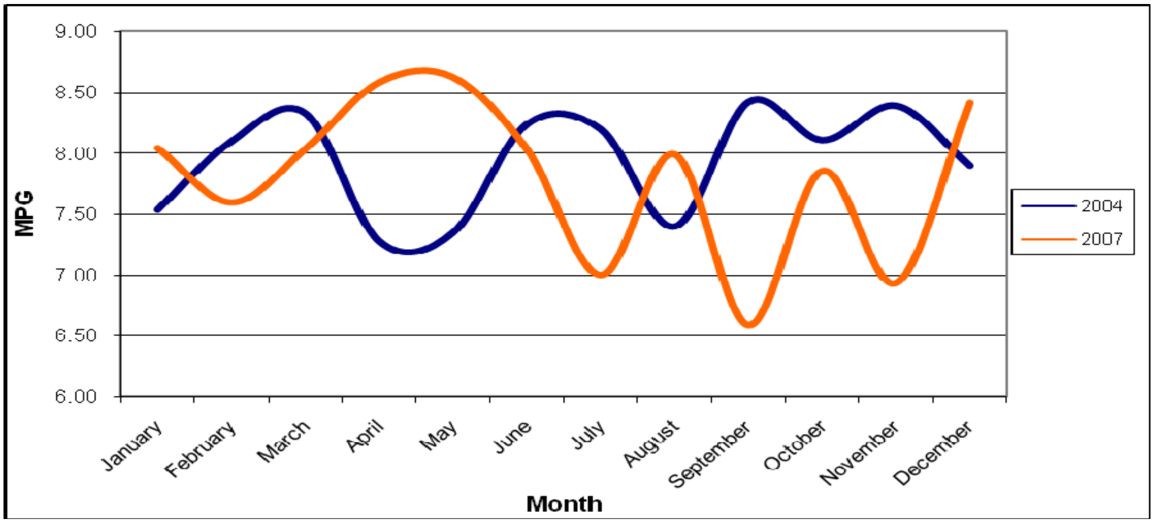

Figure 5.6 MPG cutaway buses 2004 vs. 2007

The MPG for cutaway buses were then analyzed by vehicle. Figures 5.7 and 5.8 show the same cutaway buses and their fuel efficiency for each month in 2004 and 2007. Each black dot signifies an MPG reading in a given month for every vehicle. The red plus sign (+) shows the yearly average MPG, and the red hyphen (-) shows the yearly median for each individual vehicle. A line has also been drawn between each average value to visually illustrate the variability in MPG among cutaway buses. A relatively flat line signifies minimal variability in MPG, while a non-uniform line would indicate substantial variability among vehicles. The average MPG lines in Figures 5.7 and 5.8 show that there was considerably less variation in MPG among cutaway buses in 2004 compared to 2007 (flat line versus jagged line). Also, the individual dots are much more spread out in Figure 5.8 than in Figure 5.7. As these cutaways have aged, their fuel efficiency has become more unpredictable. When this occurs, along with the substantial increase in fuel cost variability in 2007, budgeting for fuel expenses can become very difficult. This increased variability in MPG among cutaway buses is to be expected as cutaways become more costly to operate and maintain much earlier in their life cycle compared to standard transit buses (Peterson and Molloy 2007).

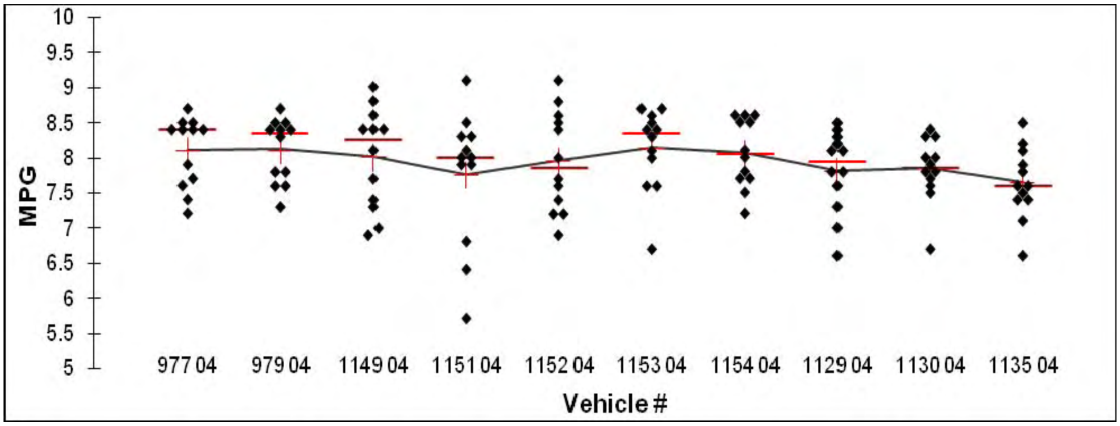

Figure 5.7 MPG cutaway buses 2004

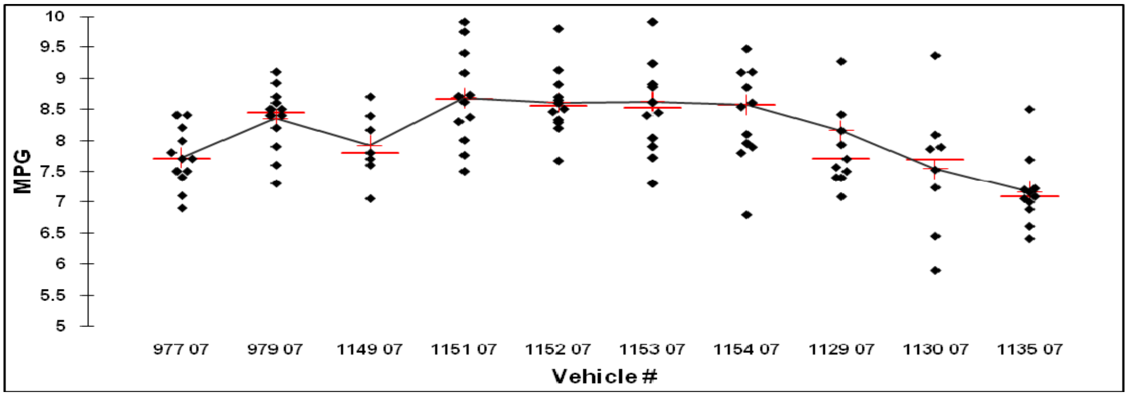

Figure 5.8 MPG cutaway buses 2007

Figure 5.9 illustrates the MPG for standard transit buses in 2004 and 2007. Comparing this figure to the MPG figure representing cutaway buses (Figure 5.6) yields two main points. Standard transit buses show considerably less variability in MPG than cutaway buses, and the yearly average MPG of transit buses are more closely correlated than those of cutaway buses. Fuel efficiency was higher in only April, August, and December of 2007 compared to 2004. Overall, fuel efficiency was 2% less in 2007 than 2004 among standard transit buses, which falls within the 2% to 5% decrease in fuel efficiency due to biodiesel use (University of Houston 2006, Proc, K. et al. 2006).

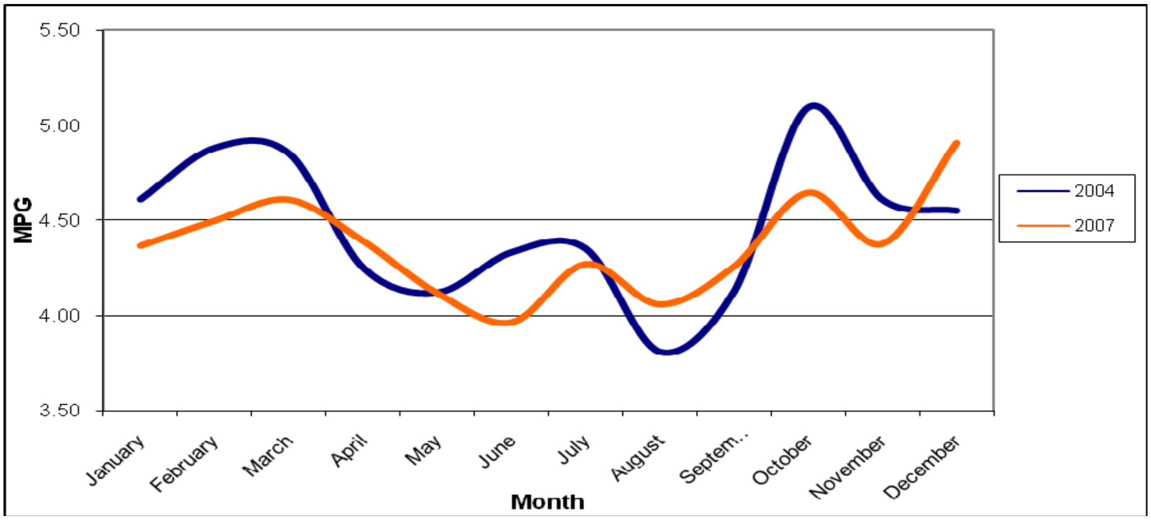

Figure 5.9 MPG standard transit buses 2004 vs. 2007

The MPG for each standard transit bus were also analyzed, with results shown in Figures 5.10 and 5.11. Both of these figures are similar, and each data point is nearly identical. The black line connecting each vehicle's average yearly MPG is also very similar between figures. The variability of MPG data actually decreased for transit buses between 2004 and 2007, even though the fleet was three years older. Vehicle 1131 is the only bus in this figure that shows substantial MPG variability among all standard transit buses. Comparing these two figures to the similar cutaway bus figures (5.7 and 5.8) illustrates sizable differences. While the variability of cutaway buses increases noticeably between 2004 and 2007, that of the standard transit buses varied minimally. Because MPG variability is not an issue with standard transit buses, budgeting for fuel, which is currently a volatile commodity with respect to price, is much more reliable than similar budgeting for cutaway buses.

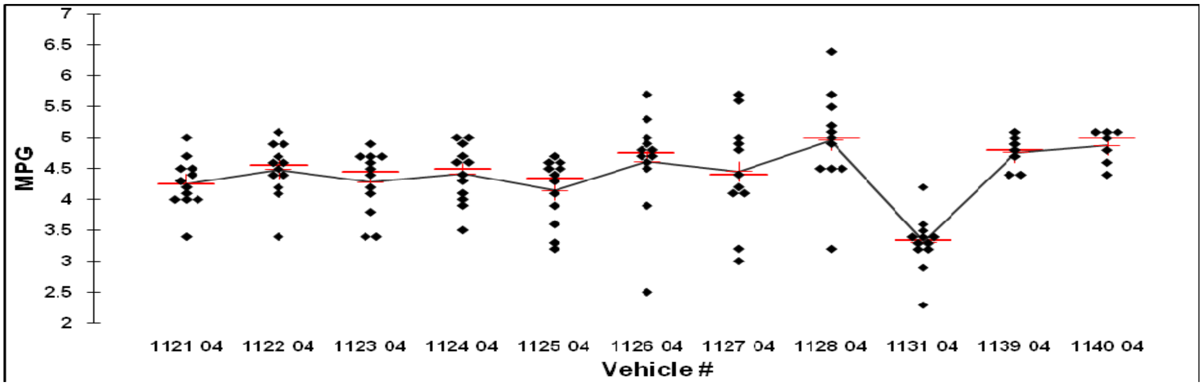

Figure 5.10 MPG standard transit buses 2004

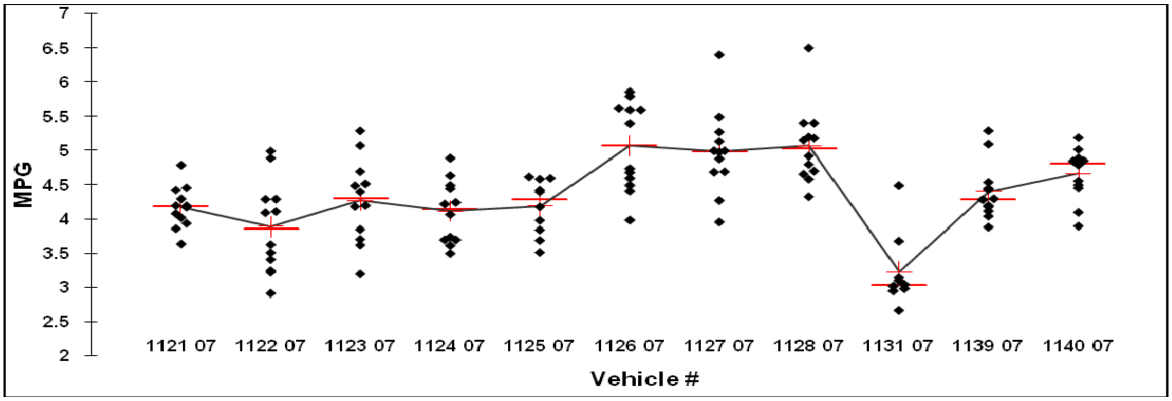

Figure 5.11 MPG standard transit buses 2007

Figure 5.12 illustrates the MPG variability, ± two standard deviations, for cutaway buses and standard buses as well as total yearly averages. The flatter the line, the less variability is present in the data. This is because a flatter line has a smaller range between its minimum and maximum values. The two middle lines show the 2004 and 2007 yearly average MPG along with their variability. Although these lines are nearly overlapping, the 2007 line is slightly steeper, representing a minimal increase in 2007 MPG variability. The top two lines show average MPG for cutaway buses along with their variability to two standard deviations. The 2007 line is much steeper compared to the 2004 MPG line. This further illustrates the nearly 70% increase in 2007 MPG variability compared to 2004. Finally, the bottom two lines represent the same data points for standard transit buses. The 2007 line is actually slightly flatter than the 2004 line, illustrating a small decrease in MPG variability between 2004 and 2007.

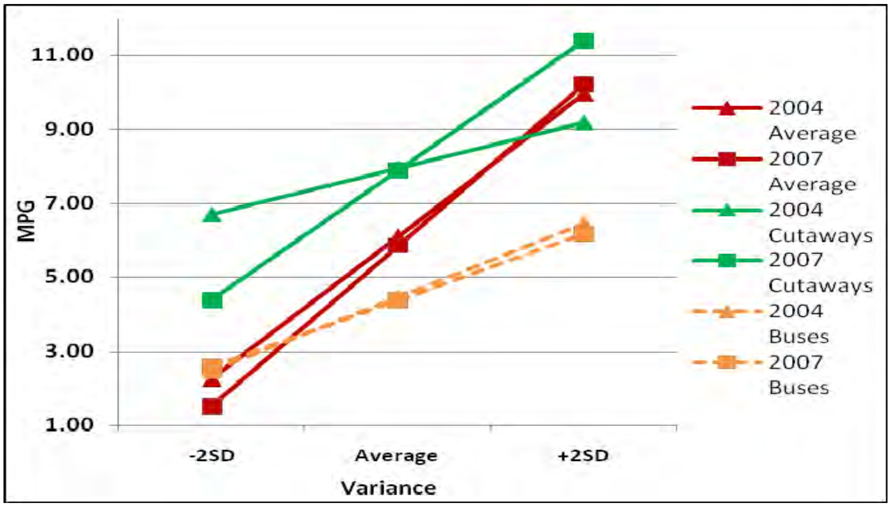

FIGURE 5.12 MPG variability

6. SUMMARY AND CONCLUSIONS

Fargo’s Renewable Energy Committee wanted to be proactive in implementing biodiesel use in all city fleet vehicles, and this has proven to be a successful endeavor. Fargo-Moorhead Metro Area Transit (MAT) began using biodiesel in its bus fleet in 2005 with positive results as well. Minimal maintenance problems have occurred, and marketing of their biodiesel use has resulted in considerable positive exposure throughout the community.

A central element of this research was to determine whether or not biodiesel use at MAT had caused a significant decrease in fuel efficiency. Although overall fuel efficiency declined by 4% in 2007 compared to 2004 (Table 4.1), little of this decrease can be attributed to biodiesel use. Increased vehicle age almost always results in decreased fuel efficiency (Peterson and Molloy 2006), and this was found to be the main factor responsible for the 4% decrease. The increase in fuel efficiency variability can be attributed to vehicle age as well. Because MAT does not use a high concentration of biodiesel (B2-B5) during cold weather months, temperature was not a factor. Using such a small concentration of biodiesel during the period when a fuel efficiency decrease would be most prominent resulted in a very minimal effect on fuel efficiency with respect to biodiesel use.

A main finding of this study was that heightened fuel costs have caused a massive increase in overall operating cost for MAT. Nearly $300,000 in increased fuel costs between 2004 and 2007 are attributable to the 23 vehicles studied alone. This represents a huge cost increase for any transit agency to deal with, yet alone a small urban agency with an already stretched budget such as MAT. Biodiesel prices have remained relatively equal, compared to conventional diesel fuel, providing little relief from soaring energy costs. Further increases in fuel costs will make maintaining and operating a successful transit operation more difficult to manage, as other resources usually dedicated to maintenance, advertising, etc. will have to be used to procure fuel to maintain current operations.

Comparing cutaway performance to that of standard transit buses resulted in two key findings. First, the MPG variability of cutaway buses was much higher than standard buses, making budgeting for fuel procurements more difficult to manage. Second, M&R costs for cutaway buses increased substantially (78%) compared to a 10 % increase for standard transit buses from 2004 to 2007. This shows that as cutaways age, they become more costly to operate much earlier than standard buses. Although cutaway buses may still be useful as they age, their cost per mile increased substantially compared to standard transit buses.

Finally, this study found that the vehicle maintenance staff at MAT is doing an excellent job of keeping maintenance costs minimal and predictable. For example, M&R costs for standard transit buses increased only 10% in 2007 compared to 2004, and even more noteworthy is the fact that M&R cost variability actually decreased by more than 10% during that same period. This shows that the maintenance staff is doing a great job of preventative maintenance on their vehicles and is not ignoring maintenance that could lead to more substantial problems. Ignoring such maintenance would result in more expensive maintenance costs, increasing overall M&R expenses. Thus, the overall success of MAT’s switch to biodiesel is largely attributable to its expert maintenance staff.

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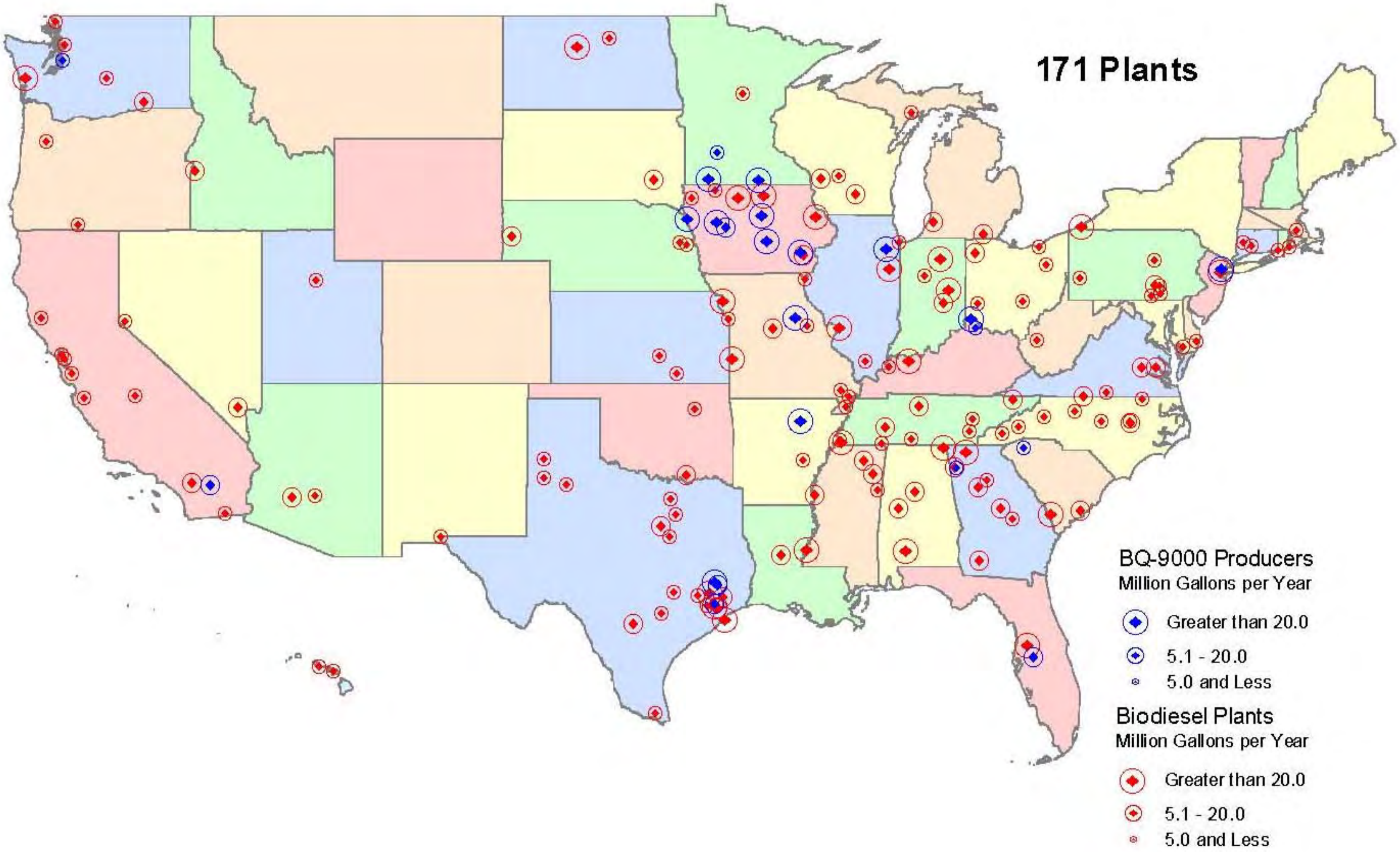
APPENDIX. BIODIESEL PLANT MAPS

Commercial Biodiesel Production Plants (Jan. 25, 2008)



Biodiesel Production Plants Under Construction or Expansion (January 25, 2008)