Evaluation of the VTA Trial Biodiesel Program

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VTA SANTA CLARA Valley Transportation Authority

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How Do Biodiesel Fuel Blends Affect the Operation and Maintenance of Urban Transit Buses?

VTA Trial Biodiesel Program, October 2008 through February 2015

Daniel Hecht, P.E.
Maintenance Superintendent
Santa Clara Valley Transportation Authority
3990 Zanker Rd. Bldg G
San Jose, CA 95134

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Mineta Transportation Institute
San Jose State University
210 N. 4th Street, 4th Floor
San Jose, CA 95112

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TABLE OF CONTENTS

ACRONYMS

ADF – Alternative Diesel Fuel
AFV – Alternative Fueled Vehicle
ASTM – American Society of Testing and Materials
B5 – 5% biodiesel 95% petroleum diesel blend (exclusive of additives)
B20 – 20% biodiesel 80% petroleum diesel blend (exclusive of additives)
B100 – "Neat" or pure biodiesel
BQ-9000 – National Biodiesel Accreditation Program's Quality Assurance Program
CARB – California Air Resources Board
CEC – California Energy Commission
CFPP – Cold Filter Plug Point
CO – Carbon Monoxide Emissions
CO_2 – Carbon Dioxide Emissions
CO_x – Carbon Emissions
D1 – standard federal type-1 diesel fuel (petroleum diesel, now phased out)
DOE – United States Department of Energy
DPF – Diesel Particulate Filter
DEF – Diesel Exhaust Fluid
DTC – Diagnostic Trouble Code
ECM – Engine Control Module (or Engine Computer Module)
EISA – Energy Independence and Security Act of 2007
EPA – United States Environmental Protection Agency
FIS – Fleet Information System
GHG – Greenhouse Gas Emissions
GVW (or GVWR) – Gross Vehicle Weight or Gross Vehicle Weight Rating
HC – Hydrocarbon Emissions
ICV – Injector Control Valve (part of fuel pump system)
ISB, ISC, ISL, ISM, ISX – Cummins codes for on-road diesel engine series
Metro – St. Louis Metro Transit, St. Louis, MO
MTI – Mineta Transportation Institute, San Jose State University, San Jose, CA
NBB – National Biodiesel Board
NO_x – Nitrogen Oxides Emissions
NREL – National Renewable Energy Laboratory
PM – Particulate Matter Emissions
PSI – Pounds per Square Inch
RFS – Renewable Fuel Standard Program
RFS2 – Revised Renewable Fuel Standard Program of 2007
RTD – Denver Regional Transportation Authority, Denver, CO
SAP – VTA's internal maintenance and enterprise application software, developed by SAP SE
TCRP – Transit Cooperative Research Program
ULSD – Ultra Low Sulfur Diesel (petroleum diesel)
VTA – Santa Clara Valley Transportation Authority, San Jose, CA
WMATA – Washington Metropolitan Area Transit Authority, Washington DC

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Santa Clara Valley Transportation Authority (VTA) in San Jose, CA has been experimenting with biodiesel fuel blends in a sub fleet of 17 transit buses since October 2008. Initially the trial program used B5 (5% biodiesel) soy methyl ester (SME) fuel blends in the sub fleet for two years. In October 2010, the trial program began using B20 (20% biodiesel) SME fuel blends in the sub fleet. Recently in October 2014, the trial program began experimenting with canola based B20 biodiesel. The 17 vehicles in the trial biodiesel sub fleet are 2001 or 2002 Gillig 40 foot low-floor transit buses, operating on suburban and urban transit routes throughout Santa Clara County.

Concern over how biodiesel affects the operation and maintenance of urban transit buses prompted a thorough research investigation into the VTA trial biodiesel program. Aspects of biodiesel use that required research and data collection include investigating how biodiesel affected component longevity, engine lifespan, road calls, fuel and exhaust system performance, overall vehicle performance and fuel storage, delivery and blending issues. Further research into biodiesel fuel economy and fuel costs is included.

An extensive literature review of existing peer-reviewed reports concludes that biodiesel blends up to 20% that are of sufficient quality do not create insurmountable maintenance or performance impacts on heavy duty diesel vehicles. The critical component is that fuel must be held to quality standards to ensure blending is complete and fuel meets contractual specifications, as out-of-spec fuel causes maintenance impacts including clogged fuel filters and road calls. Further, out-of-spec biodiesel blends cause issues with storage including increased microbial growth and fuel separation issues.

A review of reports from transit agencies experimenting with biodiesel show that using biodiesel blends up to B20 does not significantly impact operation of transit buses to a large degree, if the program has sufficient oversight and fuel quality can be properly managed. No published reports documenting extreme adverse wear on transit vehicles using biodiesel could be found. Though biodiesel can impact the fuel system of vehicles (such as clogged fuel filters and issues with older engines), properly managing maintenance and designing a maintenance program specifically for biodiesel use can mitigate any issues encountered. Further, biodiesel blends do not alter the fuel economy or performance characteristics to a noticeable degree in real world testing.

Additionally, laboratory testing showed that although biodiesel can result in slight performance decreases compared to petroleum diesel, the exhaust impacts are significant. One study shows biodiesel results in up to 27% reduction in exhaust particulate matter, although B20 does not alter NO_x emissions to a noticeable degree.

Six-plus years of biodiesel use at VTA gives the benefit of minimizing statistical variability that is present in shorter biodiesel studies. Problems that may not show up in shorter biodiesel programs become readily apparent the longer timeframe the study examines. At VTA, biodiesel use has resulted in increased maintenance wear on certain fuel system components. Fuel sender units (which reside in the fuel tank and communicate with the fuel gauge) had an average of 187,000 miles between failures on the biodiesel sub fleet, versus over 2 million miles between failures on petroleum-fueled vehicles of the same type. Likewise, fuel pump use nearly doubled on the biodiesel sub fleet compared to the petroleum control group of vehicles. Fuel injector usage on biodiesel vehicles was significantly higher on the biodiesel buses as well, with the biodiesel buses using 54 injectors on unscheduled maintenance compared to only 13 on the control group of petroleum-fueled vehicles.

Conversely, diesel particulate filter (DPF) usage on the 2002 model year biodiesel buses appears to be lower than petroleum-fueled buses, with the biodiesel buses using only 4 DPF filters over the lifespan of the program. The biodiesel buses went nearly 536,000 miles between DPF changes whereas the petroleum fueled vehicles needed a DPF approximately every 187,000 miles. This is likely due to the reduced PM emissions when using biodiesel blends.

Overall engine longevity research yielded interesting results with fuel dilution in biodiesel-fueled buses. On 2 of the 17 biodiesel buses that showed fuel dilution in engine oil samples prior to engine failure, the failure mode necessitated entire engine replacement due to catastrophic internal damage that occurred on the road. Conversely, the petroleum fueled sub fleet of comparable buses showed many more instances of fuel-oil dilution but did not have any catastrophic engine failures as a result of fuel in the engine oil. This indicates that although biodiesel may not necessarily infiltrate engine oil as readily as petroleum fuel, when biodiesel does get into engine oil the results are often catastrophic. The biodiesel buses also showed significantly higher levels of copper in the engine oil than petroleum-fueled buses.

Road call information over the entire life of the biodiesel program was extensively researched in detail to determine how the fuel system affected the vehicles on route. This is important as road calls directly impact VTA's revenue operations, which affects ridership and overall customer service. Over the program, the biodiesel buses ran approximately 59,000 miles between instances of road calls directly related to the fuel system or aftertreatment system of the vehicle. The petroleum fueled control group of buses ran 43,000 miles between instances of road calls of the same type. Due to the possibility of statistical error accounted by vehicles with repeat road calls, this difference is not significant to a high degree of certainty.

The largest impact to VTA operation and maintenance stemmed from issues relating to the delivery, storage and pumping of biodiesel blends in underground storage tanks. Like other agencies, VTA experienced supplier quality control issues and significant biodiesel/petroleum diesel separation in the underground storage tanks. Tank sampling yielded laboratory results that showed a high degree of fuel separation which was partially mitigated with better blending methods, however fuel blending problems never fully went away. Coupled with supplier and contractual changes from 2008 through 2015, biodiesel delivery and storage problems resulted in the largest impact to the program.

Biodiesel cost VTA approximately $380,000 more from October 2008 through February 2015 compared to using petroleum diesel fuel in the same vehicles. This cost difference is attributed solely to the higher cost of purchasing B5 or B20 biodiesel. Fuel economy between biodiesel buses and petroleum diesel buses is not largely affected to a high degree of certainty.

The VTA trial biodiesel program is one part of VTA's green initiatives to reduce transit's impact on the environment. By using renewable fuel, VTA can help offset the carbon impact of fuel use. Since 2010, VTA has only purchased transit buses that use hybrid diesel-electric powertrains, which result in fuel economy increases near 25%. These hybrid diesel-electric powertrains use smaller engines coupled with energy storage systems (batteries) and electric motors or transmissions combinations. VTA does not plan on purchasing traditional diesel-powered transit buses in the future.

With increasingly stricter emission requirements placed on diesel-powered fleets, VTA is also understanding that renewable fuel requirements up to 20% of total fuel consumed may be imposed on transit operations in California in the foreseeable future. VTA plans to replace transit buses after 15 to 18 years of service life, depending on vehicle reliability and budgeting. With this in mind, and coupled with the information garnered from this research report, the following recommendations are made:

- Terminate the B20 biodiesel project in all 2001 and 2002 model year transit buses. 6+ years of testing have given VTA valuable data on how biodiesel affects traditional low-floor transit buses using Cummins ISL engines. Impacts of biodiesel use on ISL engines are negative but manageable, and part of these negative impacts to the engine system stem from inherent design issues on older ISL-type engines. Further, these buses are planned for retirement in the next few years, and will likely be out of service before renewable fuel requirements are mandated in transit operations.
- Begin a trial B5 and/or B20 biodiesel test in 2010 model year or newer 40 foot low-floor hybrid-electric transit buses using the smaller Cummins ISB engine with the common-rail type fueling system. Since all future purchases will be hybrid-electric powertrains, information on how biodiesel affects the performance and maintenance of these types of buses will be valuable for future operation pending renewable fuel legislation.
- Install an in-tank auger or mixing system that mitigates any separation issues with biodiesel blends. Since significant issues with underground fuel separation occurred with both B5 and B20 blends, the one-time capital expense of adding a biodiesel blend in-tank auger or mixer is justified.
- Strengthen fuel contractual language and implement regular scheduled fuel sampling. Some of the separation and fuel mixing issues stemmed from weak or non-existent quality assurance contract specifications. Mirroring BQ-9000 certification language will hold suppliers accountable to their product while protecting VTA. Periodic and scheduled fuel samples will ensure fuel is of requested quality and mitigate out-of-specification issues.

The VTA trial biodiesel program was a success in that it demonstrated biodiesel use up to B20 is feasible in transit fleet buses if certain aspects of biodiesel use are closely managed. By only experimenting with biodiesel blends in 17 transit buses, negative maintenance impacts to the overall fleet were small but manageable. Lessons learned and obstacles overcome will help steer VTA into the next phase of renewable fuel research in transit bus operation.

SECTION 1: INTRODUCTION AND BACKGROUND

In 2008, the Santa Clara Valley Transportation Authority (VTA) in San Jose, California, began a trial program using biodiesel blend fuel in a sub fleet of transit buses operating on fixed routes throughout Santa Clara County. These buses have operated on various blends of biodiesel, from B5 (5% biodiesel, 95% petroleum diesel) to B20 (20% biodiesel, 80% petroleum diesel). VTA has experimented with soybean-based biodiesel and canola-based biodiesel.

This research report has three primary objectives. The first objective is to analyze biodiesel use in public transit agency fleets and identify common themes from various sources. Since biodiesel use is closely tied with "green" and "sustainable" initiatives, environmental impacts of biodiesel use will be addressed from a big-picture viewpoint. Sources of information include reports from the United States Environmental Protection Agency (EPA), the National Renewable Energy Laboratory (NREL), the Transit Cooperative Research Program (TCRP), the U.S. Department of Energy (DOE), and various independent and published reports from universities, transit agencies, and biodiesel advocacy groups.

The second objective is to analyze VTA's biodiesel trial program and determine what, if any, impacts biodiesel has on VTA's transit fleet vehicles, infrastructure, finances, and bus operations. In particular, research will investigate the impact biodiesel has on maintenance of vehicles. The research will investigate maintenance history of the biodiesel buses and compare the maintenance records with a control group of similar buses operating in a similar environment using petroleum diesel fuel. Work order history, oil analysis, and engine overhaul information will be analyzed in detail for each of the types and blend quantities of biodiesel used. Impacts to VTA's standing infrastructure will be discussed, including issues related to the underground storage of biodiesel and fueling equipment. Lastly, costs of the VTA biodiesel trial program will be quantified, including comparing biodiesel fuel costs to standard petroleum fuel costs over the life of the program.

The third objective is to guide biodiesel policy at VTA and at other interested organizations. With over six years of biodiesel use in 17 vehicles at VTA, the research report will outline the benefits, drawbacks, and costs of biodiesel use in transit buses at VTA's organization and present a holistic study of VTA's experiences. The research will provide valuable factual information to decision makers in determining the future of this program and other similar biodiesel programs in public transportation.

This report is primarily aimed at public transportation industry professionals, executive managers at transit agencies, and fleet maintenance personnel interested in the use of biodiesel fuels in diesel engines. This report will also provide valuable to environmental planners interested in big-picture biodiesel benefits and drawbacks, purchasing department personnel looking at biodiesel fuel cost comparisons, and the general public interested in pros and cons of using biodiesel in publically funded vehicles.

BIODIESEL INFORMATION

Growing concern over environmental emissions and dependency on foreign oil has fostered interest in developing viable alternative fuels that can be domestically produced while being environmentally friendly. Biofuels, such as ethanol and biodiesel, have become popular alternatives to petroleum gasoline and diesel in the past few decades. Legislation promoting alternative fuel use and advances in alternative fuel technologies has helped biofuels become viable in automotive use.

Much of the perceived benefit of using biodiesel is that reliance on foreign and non-sustainable energy sources is reduced. Further perceived benefits in using biofuels are that they produce fewer emissions than petroleum fuels and the net carbon footprint is neutral. The United States Environmental Protection Agency has completed an in-depth study on biofuel use and the environment that details all associated impacts at each stage of biofuel production and use. Biofuel use offers improved environmental sustainability benefits versus traditional fossil-fuel based petroleum products.

Biofuel use in transportation has been steadily increasing in the past few decades. Driven in part by legislation that requires a percentage of fuel sold in the United States to be renewable, biofuel production and investment is on the rise. New refineries are opening up across the country, and research into the development of more efficient and sustainable biofuels is advancing.

Biodiesel in particular has become popular among fleet users, including public transit agencies. Studies show that biodiesel use in fleet environments has proven relatively easy to implement, provides minimal concern over vehicle performance or engine degradation, and is a valuable marketing tool to exhibit a transit agency's commitment to the environment. Various transportation agencies throughout the world have experimented with biodiesel use and experiences are well documented. Considerable research has been completed that details the various effects biodiesel has on standing infrastructure and vehicular components.

Whereas traditional petroleum fuel is based on crude oil derived from fossil fuels, biofuel is created from organic biomass that is derived from a variety of feedstock (Schiavone, 2007). Although biofuels can be created from waste oils generated from restaurant industries or animal byproducts, the majority of biofuel production stems from plant-derived material. Biomass feedstock used for biofuel production includes corn, soybean, switch grass, algae, rapeseed, and other photosynthesis based organic plants (Schiavone, 2007). A driving benefit of deriving fuels from living, organic matter is that the energy source is renewable and can be domestically grown and produced.

Biofuels are produced from feedstock by commercial production processes depending on the type of biomass being converted. Similar to petroleum fuel, the origin and type of the natural biomass feedstock can vary depending on location and growing conditions. With the inherent variance in type and quality of biofuel use, standards have been developed that biofuels must meet before they be used in a vehicle engine (Schiavone, 2007). For biodiesel, the American Society of Testing and Materials (ASTM) develops and maintains ASTM D6751, which is the specification that prescribes the required properties of biodiesel fuel blend stock at the point of delivery (ASTM, 2014). The resulting biodiesel is known as B100 or 'neat' biodiesel, and denotes that the product is 100% produced from biomass sources.

Biofuel commercial production has been exponentially growing in the past decade. According to the National Biodiesel Board, biodiesel production has increased from 25 million gallons in the early 2000s to almost 1.1 billion gallons in 2012 (National Biodiesel Board, 2015).

Once the biofuel is produced, and quality assurance checks are completed, the resulting fuel is transported to distributors where it is commonly blended with traditional petroleum fuels to create a blended fuel product (Schiavone, 2007). Biofuel blends follow a standard nomenclature format where the amount of biofuel per unit volume total is expressed as a percentage of the total product, and a letter indicates the type of biofuel used. B100 or ‘neat’ biodiesel is 100% biodiesel containing no petroleum fuel. B20 is 20% biodiesel blended with 80% petroleum diesel. B5 is 5% biodiesel blended with 95% petroleum diesel, and so on. B20 and B5 are the two of the most commonly used biodiesel blends.

Ethanol follows a similar format, where “E” replaces the “B.” The number following “E” indicates the percentage of ethanol by volume (DOE, Fuel Economy Website, 2015). Ethanol, the most widely used biofuel in the United States, is blended with petroleum gasoline and is commonly sold at gas stations as E10 or E15 (DOE, Fuel Economy Website, 2015). While this report focuses on biodiesel in transit use, it is important to note that ethanol fuel use in the United States has increased from 1.7 billion gallons in 2001 to 13.2 billion gallons in 2013 (DOE, Fuel Economy Website, 2015).The national commitment and continued growth of all types of biofuel use in the United States is encouraging.

The majority of biodiesel used in the United States comes from first-generation feed stocks, which are predominantly corn or soybean based. Second-generation feed stocks include corn stover, perennial grasses, woody biomass, algae, and waste. Since the revised Renewable Fuel Standard (RFS2) developed by the Environmental Protection Agency (EPA) puts a limit on the amount of first-generation biofuels that may be developed from corn, considerable research is going into the development, production and distribution of second-generation feed stocks (EPA, 2011). The EPA estimates that the greatest positive environmental benefit of using alternative biofuels will be from using second-generation feed stocks (EPA, 2011).

The best approach to reducing harmful exhaust emissions is to combine technologies and strategies. Newer clean diesel engines utilize exhaust gas recirculation which reduces NO_x emissions. Further, use of diesel exhaust fluid (DEF) in newer engines also reduces NO_x emissions. Diesel particulate filters lower PM and soot emissions, and using B20 fuel can further lower PM and HC emissions. Lastly, using hybrid electric technology can result in increased fuel economy, lowering the amount of fuel burned and subsequently reducing exhaust emissions.

BACKGROUND OF THE VTA TRIAL BIODIESEL PROGRAM

Santa Clara Valley Transportation Authority (VTA) is an independent special district that provides bus, light rail, and paratransit services to the County of Santa Clara and the South Bay region of the greater San Francisco Bay Area. VTA operates one light rail operations and maintenance division, three bus operations and maintenance divisions, and one bus overhaul and repair facility. VTA Chaboya Division is located in south San Jose, and serves as the largest bus division. VTA Cerone Division is located in north San Jose. The Cerone Division shares property with the Bus Overhaul and Repair Division, which provides heavy maintenance activities including bus engine rebuilds, major body damage repair, and other maintenance activities. VTA North Division is located in Mountain View, in the northwestern portion of Santa Clara County, and is the location of the biodiesel trial program.

VTA North Division is located at the intersection of U.S. Route 101, California State Route 85, and Shoreline Blvd in Mountain View, CA. This strategic location allows quick service to fixed route corridors in the northwestern sections of Silicon Valley. Widening of the Shoreline Blvd off ramp in the early 2000s prompted a total rebuild of the North Yard Operations and Maintenance facility. The bus yard was rebuilt from the ground up as a modern maintenance and operations facility. The fuel island structure was rebuilt and modernized during the construction, including two new underground diesel storage tanks and fueling infrastructure.

In 2008, VTA added two additional underground storage tanks to North Division in support of additional bus service and growing fleet size. One of the underground tanks was dedicated to unleaded gasoline use for cutaway-style “Community Buses” that were implemented. The second tank was originally slated for surplus diesel fuel storage. Installing a new tank offered VTA the opportunity to experiment with alternative fuel mixtures at the North Division. With the rising popularity of biodiesel, VTA executive managers proposed to use the new underground storage tank to house biodiesel blends for experimental use in a small sub-fleet of transit buses at VTA’s North Division.

VTA maintenance staff investigated which buses at North Division would be ideal candidates for a biodiesel trial program. VTA was concerned that using biodiesel on high-performing routes or routes with significant publicity would be risky if biodiesel were to cause unanticipated maintenance issues. Maintenance staff agreed that the heavy-passenger loadings on the 60-ft articulated buses and the high publicity of the 522 Rapid Line were not to be used for biodiesel testing. The remaining buses at North Division were gasoline-fueled community buses, high-floor 40-ft transit buses, and low-floor 35 or 40-ft transit buses. Since biodiesel had not been certified for use in older diesel engines, it was decided to only run the biodiesel trial program in newer low-floor transit buses that operate on conventional fixed-route bus service.

Initially, 22 buses were chosen for the trial program. The buses were either 2001 or 2002 model year Gillig Low Floor buses with an 8.9 liter Cummins ISL straight-six diesel engine mated to a 4-speed Voith automatic transmission. The 2001 model year buses do not have an exhaust after-treatment system, and use conventional engine exhaust systems. The 2002 model year buses have a selective catalytic reduction device (SCR) manufactured by Cleaire that reduces nitrogen oxide emissions.

At the time of program approval in 2008, B5 was approximately 5-6% more expensive than standard diesel. The initial estimates of converting 22 buses to run on B5 were approximately $50,000 more per year than using standard petroleum diesel. In 2008, a biodiesel contract for supplying B5 to a sub-fleet of 22 buses was developed and subsequently awarded to Coast Oil Company of San Jose, CA.

Concern was raised that fueling biodiesel buses on the same fueling lane as standard diesel buses would allow the potential for cross-contamination. To alleviate the issue, the sub fleet of biodiesel buses received modified fuel filler caps that use a four-prong connection, instead of the common three-prong connection petroleum diesel buses use. The biodiesel pump nozzle was also changed to a four-prong nozzle, making the biodiesel pump compatible only with the 22 buses in the biodiesel sub-fleet. Each one of the buses received a small decal on the front of the vehicle that could be used by fuel island staff to stage buses in the appropriate fueling lane and fueling pump. A larger biodiesel marketing decal was placed on the sides and rear of each of the biodiesel buses.

Figure 1 - decals on bus that indicate vehicle uses biodiesel

After the new underground storage tank was completed and certified for use, the first biodiesel delivery occurred in September of 2008 and the vehicles began being fueled with B5 in early October 2008. In May 2009, shortly after implementation of biodiesel, five of the trial buses were moved to another operational role to support changes in bus runs and scheduling, and the biodiesel trial program was reduced to 17 buses. For the purposes of this report, the biodiesel trial program will only focus on the 17 buses that have consistently run on biodiesel blends for the duration of the program, and will not use any data or information on the 5 buses that were dropped from the program early on. In October 2010, the trial biodiesel program went from a soy-methyl-ester B5 blend to B20 to further investigate the impact of higher-concentrations of biodiesel in transit use. In October 2012, due to supplier issues, the soy-methyl-ester biodiesel was replaced with canola-based B20 biodiesel. As of report writing, the 17 buses are still operating on B20 biodiesel.

The VTA biodiesel trial program is part of VTA's commitment to sustainable initiatives in transportation and represents one approach to reducing transit's environmental impact. For a period between 2004 and 2010, VTA ran a hydrogen fuel cell bus demonstration with three fuel-cell powered transit buses. VTA is currently partnering with other Bay Area transit operators in the Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration project. Since 2010, VTA has exclusively purchased hybrid diesel-electric transit buses that increase fuel economy by 25% compared to standard diesel buses. VTA purchased large solar panel arrays that are installed at three of our operating divisions that offset electricity used by the light rail system. Currently, VTA is researching other alternative low-emission fuels that may be used in transit, including the possibility of switching to natural gas fueled vehicles. VTA also has sustained interest in the development and implementation of all-electric vehicles, including electric transit buses.

SECTION 2: LITERATURE REVIEW

The literature review is divided into the following sections, each with an emphasis on specific attributes of biodiesel use in transit bus fleets: Legislative initiatives; environmental benefits; biodiesel blending, quality and storage; cold weather performance; material compatibility; compatibility with Cummins engines; other biodiesel considerations; and selected case studies.

LEGISTLATIVE INITATIVES

The United States EPA develops, implements, and manages the Renewal Fuel Standards (RFS) program. Created under the Energy Policy Act of 2005, the original RFS established the first renewable fuel volume mandate for the United States, and specifically called for 7.5 billion gallons of renewable fuel to be blended with petroleum fuels by 2012 (RFS, 2015).

In December 2007, President Bush signed the Energy Independence and Security Act of 2007 (EISA, 2015). One of the main provisions of EISA is to reduce U.S. dependence of foreign oil and increase the production and use of clean renewable fuels (EISA, 2015). As part of the EISA, the EPA revised the RFS to include major increases in the amount of renewable fuel blended into transportation fuel, and set limits for each type of fuel (RFS, 2015). In 2010, the EPA finalized revisions to the RFS program and established new specific annual volume standards for biofuel in the United States. Commonly called RFS2, the revised standards required massive increases in the amount of biofuel used in the United States by year 2022 (EPA, 2011). By 2022, renewable fuel will increase to 36 billion gallons per year (EPA, 2011).

As part of the EISA, the EPA must report to Congress every three years on the environmental impact of the RFS program. The environmental impacts studied by the EPA include extensive research into the lifecycle emissions of biofuel, ranging from land use impacts to production and logistics, distribution and use. This lifecycle analysis presents a holistic view of biofuel in general, and analyzes various positive and negative environmental impacts of using biofuels (EPA, 2011).

In general, the EPA concluded that evidence from scientific literature suggests that “current environmental impacts from increased biofuel production and use associated with EISA 2007 are negative but limited in magnitude” (EPA, 2011). In particular, environmental impacts were largely due to increased corn production used to make ethanol. The EPA suggests that the greatest environmental benefit of using biofuels will come from the use of second-generation feedstock, not corn or soybean based biofuel feedstock. Since production levels of second-generation feedstock are negligible compared to corn and soybean biofuel production, these positive improvements are limited (EPA, 2011).

It should be noted that the RFS program targets increased production of second-generation feedstock. With increased production of second-generation feedstock and improvements in the production, processing, logistics and distribution of such fuels, the environmental benefits of biofuel use will continue to become increasingly positive. Further implementation of sustainable land use practices that minimize environmental impacts of biofuel production will also help reduce environmental impacts, and inter-departmental coordination between the EPA, the U.S. Department of Agriculture and the U.S. Department of Energy will continue to see greater increases in environmental sustainability (EPA, 2011).

At the state level, California recognizes that 95% of transportation fuel is dependent on petroleum, with over 60% of the nation's petroleum coming from foreign sources (Olson et al., 2007). California Assembly Bill 1007 requires that California develop a State Alternative Fuels Plan that presents strategies to reduce petroleum fuel use (Olson, et al., 2007). Milestones are set for reductions of petroleum fuel use and exhaust emissions. The California Bioenergy Action Plan outlines goals, strategies, objectives and actions to increase bioenergy development, including increasing the use of biodiesel in the state (O'Neill, 2012). California currently produces 50 to 100 million gasoline-gallon-equivalent at in-state ethanol and biodiesel facilities, indicating a strong push for renewable fuel production and implementation at the state level (O'Neil, 2012).

The California Air Resources Board (CARB) is currently proposing regulation governing alternative diesel fuels (ADF) (CARB, 2015). Currently, CARB fuel regulations focus on petroleum diesel fuels and no regulation is in place for ADFs such as biodiesel (CARB, 2015). CARB is currently soliciting information regarding the need for regulating biodiesel in California (CARB, 2015).

ENVIRONMENTAL BENEFITS

Environmental sustainability is one of the main reasons organizations develop and implement a biodiesel program. Biodiesel can reduce the overall carbon footprint of diesel engines by offsetting the carbon that is generated when biodiesel is burned (DOE, 2006). The lifecycle of the fuel oil does not add to the net carbon balance in the air, unlike when petroleum fuels are burned and excess carbon is released into the atmosphere (DOE, 2006).

Biofuels have been shown to reduce tailpipe emissions. Biodiesel reduces particulate matter (PM), hydrocarbons (HC), and carbon monoxide emissions (CO) from internal combustion engines (DOE, 2006). Biodiesel burns efficiently and completely, which allows fewer unburned emission into the environment (DOE, 2006). The high oxygen content of biodiesel was found to be a contributing factor of reducing PM, as combustion pressure and temperature increases using biodiesel in higher concentrations (Kumar et al., 2014). The cetane number of biodiesel (B100) is higher than ultra-low sulfur petroleum diesel fuel, which allows fuel to ignite rapidly with short ignition delay (Kumar et al., 2014). The effect this may have on engine longevity and performance will be discussed later.

Biodiesel reductions in PM and HCs has a positive effect on human health as well by reducing harmful air toxins (DOE, 2006). Laboratory studies and field studies have shown that generally PM emissions decrease as the volume percent biodiesel increases in biodiesel blends. For example, one study completed by the Mineta National Research Consortium showed a 17% reduction in PM emissions from a fleet of transit buses running on B20 compared to petroleum diesel (Kumar et al., 2014). Another study completed by the National Renewable Energy Laboratory found a 24% reduction in PM for B20 without a diesel particulate filter (DPF) installed compared to a similar petroleum diesel fueled engine without a DPF (Williams, 2006). The same study showed a 27% decrease in PM for B20 with a diesel particulate filter installed compared to a similar petroleum diesel fueled engine with a DPF (Williams, 2006). It should be noted that B20 biodiesel blends show little to no impact on nitrogen oxides (NO_x) emissions, although some reports indicate B20 use coincides with a slight increase in NO_x (McCormick et al., 2006).

BIODIESEL BLENDING AND FUEL STORAGE

Biodiesel blends up to B20 are simple to implement and are compatible with most existing diesel storage infrastructure (DOE, 2006). B5 and B20 are popular biodiesel blends that offer a balanced tradeoff between emissions reductions, engine performance, cold weather use and compatibility with existing infrastructure and vehicular components (DOE, 2006). There are no special or specific handling characteristics of biodiesel that vary significantly from petroleum diesel (Schiavone, 2007). Unlike many other alternative fuel sources that have been experimented and tested in fleet environments the infrastructure needs very little modification to handle biodiesel blends (Schiavone, 2007). Most diesel pump technology works equally well with biodiesel blends and petroleum diesel (DOE, 2006).

Biodiesel and petroleum diesel are compatible, but their different chemistry makes them difficult to homogenously blend properly unless blending is done in a specific manner. B100 biodiesel has a higher density than petroleum diesel, and if petroleum diesel and biodiesel are not mixed properly, the biodiesel will settle at the bottom of the tank (Schiavone, 2007). Since most underground storage tanks pick up fuel near the bottom of the tank, there is the potential of pulling higher concentrations of biodiesel into the pumping infrastructure and vehicle if the fuel is not properly blended.

Further complicating biodiesel blending is that higher concentrations of biodiesel at the bottom of fuel tanks have the capability of degrading certain components (Shiavone, 2007). As will be discussed later, B100 has the ability to degrade certain types of rubber gaskets and seals that may be used in older underground storage tanks.

Cold weather makes biodiesel blending increasingly difficult. Blending biodiesel and petroleum diesel homogenously depends on the cold flow properties of the diesel fuel that is being blended, the properties of the biodiesel (including feedstock type), additives that may be added to either fuel or the blend, and the blend amount (DOE, 2006). Since many transit agencies across the country are subjected to wide temperature variation between summer and winter months, it is recommended that distributors tailor the biodiesel blends, composition, and additive components to the season of operation (DOE, 2006).

There are a few different and proven ways of blending biodiesel and petroleum diesel that result in a homogenously blended product, each method with benefits and drawbacks. The first method is splash blending. With splash blending, biodiesel and petroleum diesel are delivered in the appropriate amounts inside the fuel tank of the vehicle, or the fuel compartment of the delivery truck. For example, a delivery truck may contain 800 gallons of petroleum diesel and 200 gallons of biodiesel (not counting fuel additives). These amounts are added to the same compartment of the delivery truck, and the action of driving from the distributor to the customer agitates the fuel enough that sufficient homogenous blending occurs (DOE, 2006). Splash blending is generally successful in creating a homogenous biodiesel blend, but under cold weather conditions or with drastic temperature differences between biodiesel and petroleum diesel the blend could still separate out after being splash mixed (DOE, 2006).

The splash blending method may also be used in individual vehicles by filling the vehicle fuel tank with the appropriate amount of each fuel and allowing the biodiesel and petroleum diesel to splash mix in the vehicle fuel tank while driving down the road (Schiavone, 2007). This method is not widely used in fleet environments due to the time-consuming nature of filling each vehicle fuel tank with two separate fuel types.

A second method of blending biodiesel and petroleum diesel is via in-tank blending. With in-tank blending, the biodiesel and petroleum diesel are typically delivered separately and “dropped” (pumped) into the storage tank separately in the appropriate quantities. If B100 biodiesel is sourced from a separate supplier than the petroleum diesel, each fuel type may be dropped into the tank at separate times, further complicating logistics (DOE, 2006). The benefit of delivering product separately is that distributors can deliver different blends to different customers from the same truck loading. A major drawback to in-tank blending is that if the biodiesel is dropped into the storage tank first, and the petroleum diesel is dropped on top, there is virtually no way the fuels will homogenously mix, even with agitation from the fuel being pumped into the tank at a high rate of volume (DOE, 2006). Since the biodiesel and petroleum diesel have different specific gravities, if homogenous mixing is not immediately achieved during delivery the biodiesel and petroleum diesel will remain separated in the storage tank.

In-tank mixing can be used in cases where biodiesel is dropped directly on top of petroleum diesel, and the tank geometry, temperature and infrastructure work together to create a homogenous blend (Schiavone, 2007; DOE, 2006). Other methods of ensuring homogeneity include adding an in-tank agitator or mixer that periodically or constantly recirculates the fuel blend in the tank, ensuring no biodiesel settling occurs (DOE, 2006).

Rack mixing (also called in-line mixing) is blending that occurs at the point of distribution and offers the most controlled environment to ensure biodiesel and petroleum diesel properly mixes. In this method, biodiesel is added to a moving stream of petroleum diesel via a system of pipes or hoses or in pulsed quantities that ensure the proper blend is achieved. The biodiesel is mixed slowly and thoroughly under controlled temperature and flow conditions (DOE, 2006). Rack mixing allows for very homogenous biodiesel blends but can be costly for distributors to implement.

BIODIESEL QUALITY AND SPECIFICATIONS

In all cases of blending, end users need to be ensured that the product they receive and use is of sufficient homogeneity and quality to be used in their storage tanks and vehicles. While ASTM develops the standards for B100 blend stock and associated standards for testing biofuels, the National Biodiesel Accreditation Program, also called the BQ-9000 Quality Development Program (BQ-9000), develops a quality assurance program that combines many ASTM standards for biodiesel along with additional quality systems programs for the handing, blending, storage, shipping, distribution, and testing of biodiesel (BQ-9000, 2015). BQ-9000 develops quality standards in three major areas; biodiesel producer, biodiesel marketer, and biodiesel laboratory (BQ-9000, 2015).

BQ-9000 standards for marketers include quality assurance checks so the end customer knows that the biodiesel blend meets quality standards above and beyond what ASTM standards dictate. Biodiesel that is BQ-9000 certified comes from marketers that adhere to laboratory testing and auditing of biodiesel samples to ensure fuel quality meets or exceeds industry standards (BQ-9000 Marketer, 2014). While contracts for biodiesel purchase can include specific requirements for ASTM testing, specifying BQ-9000 certified biodiesel is one of the easiest ways of ensuring that biodiesel delivered to end-users is of sufficient quality. Further, since use of inferior or substandard biodiesel can adversely affect standing infrastructure or vehicular systems, using BQ-9000 certified biodiesel from a BQ-9000 certified marketer avoids many potential areas of concern.

Even with BQ-9000 certified biodiesel, end-users should periodically pull random samples of biodiesel from storage tanks to ensure their product does meet BQ-9000 specifications. Tank sampling to test biodiesel quality is normally done by pulling fuel samples from the top, middle and bottom of the storage tanks and sending each sample to a lab to determine the percentage of biofuel in each of the samples (NREL, 2009). ASTM D4057 specifies the proper way to take samples from the storage tank, and ASTM D7371-07 specifies the test procedure for the percent biodiesel by infrared spectroscopy (NREL, 2009).

Another method of quickly determining the degree of biodiesel blend is by pulling samples from the top, middle and bottom of the storage tank and putting each sample in a freezer. Once fuel in a sample begins to crystallize, the temperature is recorded. Once all three samples show crystallization, the temperatures are compared. All three samples should begin to show crystallization within 3°C of each other (NREL, 2009).

BQ-9000 specifies that for blends B5 and below, the percentage of methyl ester in each of the level samples must be within 0.50% by volume for blends less than or equal to B5 and 1.0% by volume for blends greater than B6 (BQ-9000 Marketer, 2014). For a BQ-9000 certified B20 fuel, samples taken at the bottom, middle and top of the storage tank will need to be between 19% and 21% biodiesel by volume, certified by laboratory testing.

COLD WEATHER PERFORMANCE

One of the biggest concerns transit agencies have in implementing biodiesel blends is cold weather performance. As diesel fuel temperature lowers, the fuel tends to thicken and become problematic in storage infrastructure and engine use. Pure petroleum diesel tends to show this effect, which is why many truck drivers will leave diesel engines running in cold weather or use glow plugs and engine block heaters to keep diesel fuel systems warm while operating in colder weather.

Pure biodiesel and biodiesel blends in very high quantity show considerable problems in cold weather, more so than petroleum diesel. Biodiesel begins to gel at higher temperatures than petroleum diesel, which causes issues as the fuel travels through fueling infrastructure and vehicle components (Schiavone, 2007). Fuel filters become easily clogged and engine performance suffers. While blending biodiesel with petroleum diesel alleviates some cold weather issues, operation in cold weather requires extra precautions.

“Gelling” of diesel fuel refers to various terms that characterize low temperature operability of diesel and biodiesel fuels (Schiavone, 2007). The first term is cloud point, which is the temperature at which small solid crystals are first observed, and the fuel looks cloudy to the eye (Schiavone, 2007; NREL, 2009). The pour point is the temperature where so much of the fuel is crystallized that it becomes a gel and no longer flows (NREL, 2009). Cold filter plugging point (CFPP) is the temperature under a standard set of test conditions defined by ASTM D6371 at which fuel filters begin to plug (NREL, 2009). When fuel filters plug or the fuel reaches the pour point, vehicle engines may stop running altogether.

Issues with cold weather performance have prevented biodiesel blends from widespread implementation across the country (NREL, 2012). Various fuel additives may be used to mitigate cold weather operability issues, however additives may be costly (Schiavone, 2007). Using specific feedstocks (such as soy) with specific properties can also lower the cloud point of the fuel and enhance cold weather performance (NREL, 2009). Other methods of mitigating cold weather performance are using fuel heaters for storage tanks and vehicle fuel tanks, storing vehicles indoors or near buildings, blending fuel with kerosene or by switching to lower biodiesel blends such as B5 in winter months (Schiavone, 2007).

End-users can specify cloud point temperatures for biodiesel that they purchase (NREL, 2009). The producer, marketer or fuel blender can tailor the fuel deliveries based on the season and the weather forecast to ensure that the fuel performs under anticipated conditions. Further research into cold weather additives and low-temperature biodiesel performance is being completed with the hopes of lowering fuel processing expenses while making biodiesel suitable for use in cold regions during winter months (NREL, 2012).

MATERIAL COMPATIBILITY

B100 biodiesel can degrade certain materials including hoses, gaskets, seals, glues and plastics if the material is subjected to prolonged exposure to the biodiesel (NBB, 2015). Natural and nitrile rubber, polypropylene, polyvinyl, and Tygon are vulnerable to pure biodiesel and show considerable degradation when exposed to high biodiesel concentrations over prolonged periods (NBB, 2015).

Most elastomers manufactured after 1993 are safe to use with biodiesel (NBB, 2015). Engine and storage components such as brass, bronze, copper, lead, tin, and zinc can show accelerated oxidation in the presence of biodiesel creating insolubles or gels and salts, which in turn affects performance (Schiavone, 2007). Stainless steel, aluminum, and carbon steel are generally not affected by biodiesel (Schiavone, 2007). Engines manufactured after 1994 use materials that are generally biodiesel resistant (NBB, 2015). While using biodiesel in older components or in engines that use natural and nitrile rubber is not recommended, biodiesel is generally compatible with modern materials used in engines and underground storage tanks (Schiavone, 2007).

End-users should periodically check oil samples from engines operating on biodiesel to ensure that engines are not being adversely affected. Comparing oil samples with vehicles operating on standard diesel and monitoring trends in oil quality can identify issues before they become catastrophic. Oil sampling can detect the presence of coolant, trace metals and other contaminant in engine oil that may be an indication of material failure due to biodiesel use.

Biodiesel blends of B20 and less have fewer effects on materials. A study completed by the U.S. Army TARDEC Fuels and Lubricants Research Facility in 1997 shows the effects of B20 on vulnerable materials is diluted compared to pure biodiesel (NBB, 2015). It is for this reason many equipment manufacturers recommend B20 as the highest concentration of approved biodiesel for use without adversely affecting performance, longevity or equipment warranty.

End-users should check with manufacturers and suppliers of equipment to ensure that biodiesel is compatible with equipment. In particular, end-users should check with underground tank manufacturers to ensure that the storage tanks (particularly older storage tanks) do not use materials that may degrade in the presence of biodiesel causing underground fuel leaks. End-users need to check with local, state and federal requirements for the underground storage of biodiesel in any concentration and ensure that biodiesel is compatible with all systems that come in contact with fuel, from storage tanks to dispensing equipment to the vehicles themselves. The EPA provides resources regarding the underground storage tank system compatibility with biodiesel-blended fuels.

COMPATIBILITY WITH CUMMINS INC. ENGINES

Generally, engine manufacturers certify newer diesel engines may use biodiesel blends up to B20 (Schiavone, 2007). Using biodiesel blends in higher percentage-volume blends than recommended by engine manufacturers is not recommended and may void manufacturer warranties.

Since most new diesel transit buses built in the United States use Cummins Inc. diesel engines, focus will be on the use of biodiesel blends in Cummins engines manufactured in 2002 and later emission-compliant ISB, ISC, ISL, ISM and ISX engine series (Schiavone, 2007). Cummins now approves use of biodiesel fuel up to B20 if it meets certain requirements (Cummins, 2009).

Customers choosing to run biodiesel blends above B5 and up to B20 in Cummins engines must adhere to strict requirements spelled out by Cummins in their “Fuels for Cummins Engines” service bulletin. First, the biodiesel blend must be purchased from a BQ-9000 Certified Marketer, meeting all requirements discussed above for fuel and blend quality, ASTM fuel standards, and quality assurance checks (Cummins, 2009). B100 used for blending must be sourced from a BQ-9000 Certified Producer (Cummins, 2009).

Users with ISB and ISC or ISL products are required to use oil sampling during the first six months of operation with biodiesel to monitor engine oil condition and fuel dilution of lubricating oil. Oil change interval schedules may need to be modified based on findings (Cummins, 2009).

Cummins requires that storage tanks must be equipped with a fuel water separator to make sure that water is stripped out before entering the vehicle fuel tank (Cummins, 2009). Cummins recommends fuel tanks are kept full to minimize the potential for condensation to develop and accumulate in the fuel tank (Cummins, 2009).

Cummins also requires the use of specific fuel filter media and requires new fuel filters be installed when switching over to biodiesel from petroleum diesel (Cummins, 2009). Since biodiesel can have a cleansing effect on fuel system components, fuel filter change schedules may need to be modified in the early stages of switching to biodiesel. Cummins requires fuel filters be replaced at half the standard interval for the following two fuel filter changes after switching to biodiesel blends (Cummins, 2009).

Cummins offers various recommendations pertaining to biodiesel blend use in Cummins engines. Cummins does not recommend biodiesel use in low-use applications and states biodiesel needs to be used within six months of its manufacture due to the poor oxidation stability of biodiesel (Cummins, 2009). Cummins advises that since biodiesel has lower energy content than conventional diesel fuels, engine performance may degrade slightly when using B20 (Cummins, 2009). Cummins recommends the use of various fuel additives to enhance performance and characteristics of biodiesel, including the use of winter conditioners, fuel conditioners and biocides that prevent microbial growth in biodiesel that may cause fuel filter plugging (Cummins, 2009).

OTHER BIODIESEL CONSIDERATIONS

Biodiesel is more susceptible to water contamination problems compared to petroleum diesel (Schiavone, 2007). With a greater water presence, biological and microbial growth can become problematic. As a result, biocide additives are generally added to biodiesel blends that dry up water present in the mixture and kill microorganisms (Schiavone, 2007).

Biodiesel in pure form does have a lower energy content than ultra-low sulfur diesel fuel. While performance issues may be encountered using B100, use of B20 will typically not result in significant performance, drivability or fuel economy impacts. B20 may reduce power, torque and fuel economy by 2% according to laboratory testing (Schiavone, 2007). A study completed by the National Renewable Energy Laboratory found a 3% increase in fuel consumption for engines using B20 (Williams, 2006). Other sources cite anywhere from no decrease in fuel economy to up to 8% decrease in fuel economy when switching to biodiesel blends. However, real world testing as described later in this report often cannot determine with confidence that performance or fuel economy variability in transit bus environments is due solely to the use of B20. Passenger loads, route selection, traffic conditions, bus mechanical component condition and many other factors can impact performance and fuel economy. Measuring a projected 2% decrease in any manner on a transit bus is difficult with such operation and equipment variability.

Biodiesel has a cleansing effect that releases sludge and sediment from storage tanks, fuel tanks, fuel lines and engine components (Schiavone, 2007). For this reason, engine manufacturers typically recommend increased fuel filter changes when first switching to biodiesel blends, as sludge and sediment that was unaffected by petroleum diesel can become dislodged and affect engine performance and longevity. Biodiesel does replace some of the lubricity of fuel that was lost when switching to ultra-low sulfur diesel (ULSD) in the 2000s. This added lubricity helps reduce wear and tear on fuel system components and keeps fuel pumps and injectors running smoothly and properly. Blends as low as B2 can reduce the need for lubricity additives to ULSD (Schiavone, 2007).

BIODIESEL CASE STUDIES

Considerable research has gone into biodiesel use in fleet environments in the previous few decades. While biodiesel has the potential of displacing a significant portion of imported petroleum fuels, it has yet to be implemented on a wide scale. Biodiesel use is increasing and many transit agencies and fleet users are switching over to B5 or B20 biodiesel blends. While implementation is not yet widespread, there are well-document tests, trials, studies and reports on the implementation and use of biodiesel in various transportation environments.

The following represent a review of selected biodiesel programs in various transportation fields directly or closely related to public transit operating environments. Some of the cases are studies that detail biodiesel trial programs in public transit buses, similar to VTA's trial biodiesel program. Other studies are laboratory tests of emissions reductions from diesel engines using B20. A thorough review of existing case studies is necessary to compare VTA's biodiesel trial program results with those of other transit and transportation agencies.

Denver Regional Transportation District: 100,000-Mile Evaluation of Transit Buses Operated on Biodiesel Blends B20 (Proc et al., 2006)

The Denver Regional Transportation District (RTD), the National Renewable Energy Laboratory (NREL) and Cummins Inc. tested five buses using B20 and four buses using petroleum diesel for a period of two years between 2004 and 2006. The buses were model year 2000 Orion V vehicles with Cummins ISM engines, operated over the same bus route. After 100,000 miles, the program was evaluated to see if any discernable maintenance issues were encountered with the use of B20 in transit buses.

RTD found no difference between on-road fuel economy between B20 and petroleum diesel buses, averaging 4.41 mpg for each bus in the test program. Engine and fuel system maintenance costs were found to be nearly identical between B20 buses and petroleum diesel buses until the final month of the program, when maintenance issues and component replacement on one B20 bus caused the average maintenance costs to be higher for the B20 buses. There was no significant difference in the miles between road calls between B20 buses and petroleum diesel buses. Miles between road calls is the metric of how many miles a vehicle travels before it experiences a maintenance malfunction that affects the operability of the transit bus in revenue service.

RTD experienced issues with fuel blending early in the program, with samples showing blend levels between 1% to over 80% biodiesel by volume. The fuel supplier changed blending methods in 2005 to include recirculation of fuel in the delivery truck, which seemed to help blending issues with a few erratic measurements found in late 2005. By 2006, blending issues were largely resolved. B20 samples taken from the vehicles however showed consistently at or near 20% biodiesel by volume, indicating that complete blending had occurred during delivery and offloading of the product.

Oil analysis of the RTD buses showed no additional wear metals as a result of B20 use, and interestingly found that soot levels in B20 oil were lower than those on petroleum diesel fueled buses. Fuel dilutions of oil samples was low for all buses tested, and lower for B20 buses, indicating no potential issues with fuel system problems or leaks into engine components for buses running on B20.

RTD did experience fuel filter plugging on B20 buses, which resulted in road calls. Though the overall number of road calls between the buses was statistically insignificant, road calls due to fuel filter plugging were clearly the result of using B20 and had a negative impact on transit service. Buses were reported as having engine misfires or stalling on multiple occasions. As a result, RTD removed the fuel filters and found brown grease-like material on the filter. Analysis of fuel removed from the vehicle fuel tanks revealed no excessively high levels of cold filter plugging point or excessively high levels of water infiltration. The fuel filter plugging events were likely caused by out of specification biodiesel, although the exact cause is not conclusively determined. RTD did spend an extra $1,054.81 on extra fuel filter replacements, although this amount is considered small compared to overall maintenance costs.

Emissions testing on two of the RTD buses showed that oxygen presence in biodiesel is primarily responsible for reductions in HC, CO, and PM. Laboratory tests showed fuel economy decreases of 2% with B20, although in-field testing showed no discernable difference.

Overall, the RTD biodiesel evaluation showed no insurmountable issues with using B20 in transit bus operation. Maintenance costs were negligible, and by specifying high-quality biodiesel and adjusting maintenance schedules appropriately, maintenance issues such as fuel filter plugging can be reduced or eliminated. Performance and fuel economy of B20 fueled transit buses was not significantly different from standard diesel transit buses, and clear environmental benefits of using B20 were noted in laboratory emissions testing.

St. Louis Metro Biodiesel (B20) Transit Bus Evaluation: 12-Month Final Report (Barnitt et al., 2008)

The St. Louis Metro Transit (Metro) conducted a biodiesel transit bus evaluation project for 12 months using 2002 model year Gillig transit buses with Cummins ISM 2004 emissions compliant diesel engines. Eight of the buses in the study operated exclusively on B20, and seven buses in the study group operated on petroleum diesel. Routes the buses travelled on were matched for duty cycle similarity.

Metro compared fuel economy, vehicle maintenance, engine performance, component wear and lube oil performance. In summary, Metro found that B20 buses exhibited 1.7% lower fuel economy than petroleum diesel buses. This difference is expected since biodiesel has approximately a 2% lower energy content compared to petroleum diesel, and similar decreases in fuel economy have been shown in laboratory settings.

There was no significant difference in total maintenance costs between the two study groups, and reliability measured by miles between road calls was comparable between B20 buses and petroleum diesel buses. Metro did find that engine and fuel system maintenance costs were 35% higher for the B20 buses, although analysis showed this difference to not be significant with a high level of confidence due to variability in bus-to-bus maintenance costs. Fuel system component replacements were higher with B20 buses, in part because Metro implemented a 3:1 fuel filter change frequency in the first two months of using B20. In February 2007, 10 fuel filters were replaced for unknown or various reasons, likely due to extremely cold weather during this time period which affected the cloud point of the B20 fuel.

Metro did see a high incident of fuel injector replacements with B20 use. Injectors on their test group of B20 buses showed injector failure as early as 100,000 miles. Although, it is noted that there was an unknown number of miles on fuel injectors prior to switching to B20 fuel, so some of the failures may be due to age and not fuel type. Therefore, the Metro study cannot conclude that the use of B20 was solely responsible for the increased use of fuel injectors.

Lube oil analysis showed soot and wear metals were lower in the B20 buses. There appeared to be no overall harm to lube oil with B20 use, and potential benefits of using B20 as it showed lower soot levels in the engine oil.

Due to the inconclusive nature of the Metro biodiesel evaluation, the biodiesel program was extended for an additional year to determine long term effects of using B20. By only running B20 in a small sub-fleet of buses for a relatively short period of time, results were inconclusive or heavily skewed due to maintenance issues that could not be attributed solely to B20 use.

Washington Metropolitan Area Transit Authority: Biodiesel Fuel Comparison Final Data Report (Lyons, 2002).

Washington Metropolitan Area Transit Authority (WMATA) and the West Virginia University tested emissions using two separate petroleum diesel types and B20 biodiesel from a 1990 Flxible [sic] Transit bus with a Cummins L10 diesel engine. Dynamometer tests were completed, as well as in service testing during normal passenger service. Though WMATA tested both federal type-1 diesel (D1) and ultra-low sulfur type-1 diesel (ULSD), currently almost all diesel fuel sold in the United States for use on public roads is ULSD. California currently requires use of ULSD that meets CARB specifications.

WMATA found that NO_x emissions increased slightly when using B20 biodiesel, as various lab results and tests had predicted. Testing also showed that catalyzed particulate filters installed on the engine did not affect NO_x emissions, but does affect the balance of NO and NO_2 in the exhaust.

Particulate matter (PM) emissions were not significantly changed when switching to B20 versus petroleum diesel. However, the addition of a catalyzed particulate filter had a drastic impact on particulate emissions for both petroleum diesel fuel and B20. Carbon monoxide (CO) emissions and hydrocarbon (HC) emissions were reduced by 90% and 92%, respectively, compared to petroleum diesel. Fuel economy was not significantly affected by using B20.

The WMATA study showed that B20 use coincides with small increases in NO_x emissions and reductions in CO and HC emissions. Although PM emissions showed no significant reduction with B20, other technologies can mitigate PM emissions and NO_x emissions from diesel transit buses.

Other Related Studies

In 2014, the Hepburn, Golden Plains and Pyrenees Shire Councils in Victoria, Australia completed a feasibility study for switching heavy fleet vehicles to biodiesel to help reduce emissions. Test results showed that a vehicle running on B20 could expect greenhouse gas (GHG) emissions of approximately 20% at the exhaust with no major impacts to vehicle performance and little or no additional costs to maintenance or operations (Smith & Ditchfield, 2014).

An analysis on diesel-fueled dump trucks was completed by the North Carolina Department of Transportation and the Center for Transportation and the Environment. The analysis selected two vehicle sizes; single-rear axle dump trucks with a 33,000 gross vehicle weight (GVW) and tandem dump trucks with 50,000 GVW (Frey & Kim, 2005). The study found that average emission rates of dump trucks were reduced when using B20 versus petroleum diesel. Of note, NO, CO, HC and PM were all reduced when using B20 compared to petroleum diesel (Frey & Kim, 2005).

Engine operability issues and engine wear as a result of B20 use was studied by the National Renewable Energy Laboratory, the U.S. Postal Service, Battelle, and the Lawrence Livermore National Laboratory. Four 1996 Mack tractor-trucks and four 1993 Ford cargo vans used by the U.S. Postal Service in Miami, FL were operated on B20 or regular diesel (two of each vehicle type for B20 and petroleum diesel). The engines were torn down after four years of operation and more than 600,000 miles accumulated on B20 use. Results indicate that there was little difference in maintenance costs or operational costs that could be directly contributed to fuel type. No differences in engine wear or other issues were noted during engine teardowns, and while B20 engines exhibited higher levels of fuel injector replacement, failure and replacement of fuel components was likely due to out-of-specification fuel. Cylinder heads of B20 engines contained heavy amounts of sludge around rocker assemblies that was not found on diesel engines, and was attributed to out-of-specification fuel. Overall, maintenance costs between petroleum diesel-fueled vehicles and B20 fueled vehicles was nearly identical (Fraer et al., 2005).

LITERATURE REVIEW CONCLUSION

Review of transit agencies and similar heavy-duty industries operating B20 biodiesel blends shows that no insurmountable issues are encountered when switching to a low-level blend of biodiesel. Blends equal or less than B20 typically show little or no operational impact to vehicles, while dependence on foreign oil is reduced and emissions are generally reduced.

B20 does need special considerations when implementing as engine manufacturers may recommend altering maintenance intervals based on biodiesel's effects on internal engine components. No case study reviewed found significant or conclusive findings indicating use of B20 lower engine or component lifespan, although issues with sludge in engines was reported. Reliability is generally unaffected, but road calls impacting customer service that were ultimately due to clogged fuel filters were reported by one agency. Maintenance costs per mile were unaffected and no conclusive links to increased maintenance costs were found due to using B20.

Fuel filter issues were found, although issues may have been mitigated through the use of a fuel filter-changing program. Additional fuel filter changes are of minimal cost and mitigate potential issues during in-service transit bus use. Fuel quality issues may have been a contributing factor to filter plugging and well-known cold-weather problems with biodiesel and vehicle operation are expected. Of note, VTA operates transit service in a mild Mediterranean climate with cool, wet winters and dry hot summers. As such, cold fuel operability issues with biodiesel have not been experienced in a large degree at VTA.

Problems with B20 fuel quality and fuel delivery were found. Many of the issues were mitigated through a quality assurance program and adjusting delivery methods and fuel specifications. This issue is important as VTA has experience multiple issues with fuel quality, blending problems, laboratory test results and fueling issues stemming from product delivery and storage. These issues will be discussed in detail further in the report, but the literature review findings are consistent with what VTA is experiencing.

Emissions testing generally showed reductions from use of B20. Laboratory testing indicates that NO_x emissions are unaffected or may slightly rise with B20 use, while PM, HC and CO emissions are reduced. Field-testing of transit buses generally agreed with laboratory results. Laboratory testing also indicates use of B20 may result in a slight decrease in fuel economy, although real-world testing showed that fuel economy is not significantly or measurably altered with a high degree of certainty. Although VTA has not conducted in-depth emissions testing of the biodiesel trial program test fleet, results from the literature review indicate that VTA can reasonably expect emissions reductions in PM, HC and CO from using B5 and B20 throughout the trial period. As environmental stewardship is one of the driving reasons for implementing the VTA trial biodiesel program, such promising emissions reductions experienced by other B20 users indicate that VTA's biodiesel trial program has helped reduce tailpipe emissions throughout the region.

SECTION 3: RESEARCH DESIGN

This research study involves comparing VTA's sub fleet of biodiesel buses to a similar sub fleet of standard petroleum-fueled low-floor buses (control group), operating on similar routes through a similar region of Santa Clara Valley. The sub fleet of biodiesel buses are compared to petroleum diesel buses in all aspects of the maintenance and operation of the vehicles.

The VTA trial biodiesel program has consisted of running 17 vehicles exclusively on biodiesel since October 2008. Initially, 22 buses were chosen for the biodiesel trial program, but due to various operational changes and moving buses between operating divisions some of the biodiesel-fueled buses were returned to petroleum diesel. The biodiesel trial program began by using B5 soy-methyl-ester (SME) biodiesel, and later switched to B20 SME after a preliminary analysis showed no adverse issues when using B5. In 2014, the fuel switched from SME biodiesel to canola-based biodiesel.

Maintenance issues with the biodiesel buses are compared to the control group of petroleum-fueled vehicles. Metrics such as miles between fuel system related road calls, fuel system parts replacement, engine longevity, fuel economy, and other fuel system issues are explored to see how biodiesel in any quantity or blend amount has caused adverse maintenance or operability issues. Further, oil analysis is investigated to see if there are definable trends in oil sampling between the biodiesel buses and the control group.

Beyond comparing biodiesel bus maintenance and operational issues to that of the petroleum diesel control group, the research report catalogs and documents issues relating to the delivery, storage and handling of biodiesel at VTA throughout the duration of the program. In particular, biodiesel separation issues are documented and extensive analysis of fuel tank sampling is compiled to determine what caused biodiesel separation issues.

Data for the above is compiled from various sources. VTA's internal maintenance system uses SAP operating software to track component usage, work order history, vehicle history and other important maintenance data. VTA's Quality Assurance Department tracks road call data by type and by vehicle from mining information from the Operations Control Center and compiles information in Excel format for analysis. VTA's Operations Analysis and Reporting Department tracks information such as fuel economy, miles travelled and other important operational metrics via the SAP system, Oracle Reports, and other data information systems.

MAINTENANCE COMPONENT LONGEVITY ANALYSIS

The first metric that is investigated is determining what adverse effects biodiesel has caused to bus system components, such as fuel injectors, fuel pumps and fuel lines. A list of all part numbers relating to the fuel system on the vehicle has been compiled. These internal part numbers correspond to manufacturer part numbers for fuel injectors, fuel lines, fuel pumps, related gaskets and seals, etc. Any part that comes in contact with the biodiesel or petroleum diesel fuel has been analyzed for failure rates, particularly focusing on fuel injector, fuel pump and fuel accumulator issues, as these are high-value components.

SAP was queried to determine which parts were used on which bus and the date of part replacement. The data has been analyzed and outlying information investigated to determine if biodiesel was a possible contributing cause of the component failure. Miles are also tracked and compared to component replacement schedules, such as engine rebuilds.

The same data is also developed for the control group of petroleum diesel buses over the same timeframe. Results between the biodiesel buses and the control group of petroleum diesel buses are compared and normalized to account for miles travelled variations. Finally a comparison is completed that describes if biodiesel use contributed to higher levels of component failure compared to petroleum diesel.

A holistic analysis over the entire 6-year program is compiled to see if biodiesel or petroleum diesel buses showed any other interesting trends over the timeframe. Any anomalies or issues are investigated to see if other factors were at play in component usage or failure rates, such as contractor issues, supplier problems, quality assurance issues or modified maintenance practices.

This section of the research project answers important questions of whether biodiesel affects fuel system components on the vehicles. It is prudent for VTA to determine whether the biodiesel trial program is causing adverse effects to engine components, resulting in increased maintenance costs.

ENGINE OVERHAUL ANALYSIS

VTA completes engine rebuilds in-house, and VTA operates an overhaul and repair facility that removes engines from vehicles, rebuilds them with new or remanufactured components, and installs the engines back in the vehicle.

While some biodiesel demonstration programs analyzed in the Literature Review section of this report had completed analysis of engine wear or failure over a relatively short timeframe, due to the inherent variability in maintenance issues between individual buses, a single maintenance anomaly could skew the data with regard to engine longevity and overall maintenance costs. Since VTA has been running the biodiesel trial program for six years, many of the anomalies or statistical variability will have been reduced or eliminated. As such, engine longevity and miles-between-engine-replacements is investigated for the biodiesel buses and compared to the control group of petroleum-fueled buses.

Each one of the vehicles had a complete engine overhaul (or two) during the trial program or had major engine work completed over the life of the program. As such, this section looks at each individual bus and analyzes when the last major engine overhaul was completed and how that coincides to what fuel was being used or what failure mode (if any) contributed to engine failure. This is completed for the 17 biodiesel buses and for 17 petroleum-fueled buses in the control group.

Any issues or obvious trends in overall engine longevity or miles between major engine failures has been investigated for underlying causes. Issues that were obviously not the result of fuel type are noted as the failure mode but disregarded in the context of this report. Issues that may have been due to fuel type are documented and further explored to determine what other factors may have contributed to premature engine failure.

Engine overhaul information is kept in the SAP system and detailed records are kept regarding engine serial numbers, rebuild information and dates components are installed. Gathering engine overhaul information is time consuming since automatic queries do not sufficiently provide detail into problems that contributed to engine failure. Therefore, after the engine overhaul data was compiled, each bus received a detailed investigation on each of the major engine overhaul work orders to determine the root cause of the issue and if it was related to fuel type.

Whereas the previous research section focuses solely on fuel system components, this section answers if and how biodiesel affects overall engine longevity and life. This is important as reduced engine life increases maintenance costs.

OIL ANALYSIS

VTA conducts oil sampling at each major preventative maintenance cycle, which corresponds to approximately 6,000 miles. Engine oil samples are taken from a sample port on the oil pan of the engine block before the oil is flushed and changed. The samples are labeled with the date and bus number and sent to a lab, which completes analysis on the chemical compounds of the engine oil.

Oil analyses are returned to maintenance staff in a matrices that shows the current level of chemicals or trace metals in the oil and displays trends in the past two to five samples taken from the same bus. In this manner, maintenance staff is able to quickly look at the matrix and determine if, for example, brass has been steadily increasing in the engine oil, indicating bearing failure is taking place.

Oil analysis is an extremely helpful tool in which maintenance managers can quickly determine if catastrophic engine failure is occurring or is likely to occur in the near future. Critical levels of trace metals or chemical compounds that are above a certain threshold are emailed to VTA's Quality Assurance Department within a day of analysis being completed. Extremely critical issues like high levels of coolant in the engine oil are immediately addressed, buses pulled off the road and the bus engine examined before catastrophic engine failure occurs.

The oil analysis helps to determine if any abnormal engine wear resulted from using biodiesel blends in Cummins ISL engines. Data from every oil sample taken has been compiled and analyzed between the control group of petroleum-fueled buses and the biodiesel buses. Trends were analyzed over the entire life of the biodiesel trial program to determine if there were spikes in oil chemical compounds when switching to biodiesel for the first time (due to the cleaning effect of biodiesel) or long-term trends in abnormal engine wear, such as trace metals in the oil.

A sample sheet of an engine oil analysis test report from Ana Laboratories, Inc. is included in Appendix C. Engine oil analysis examines the following list of elements in parts per million (PPM) by weight:

Antimony	*Titanium*	*Silver*
Copper	*Lead*	*Tin*
Aluminum	*Nickel*	*Iron*
Chromium	*Cadmium*	*Sodium*
Boron	*Silicon*	

In addition, oil analysis examines the following attributes of oil quality:

Water % by Volume	*%Soot*	*Glycol*
Fuel	*SAE/ISO Grade*	*Total Base Number (mg/g)*
Viscosity @ 40°C	*Viscosity @ 100°C*	

Wear metals such as iron can indicate premature failure or excessive wear on cylinders, pistons, engine blocks or the valve train. Aluminum indicates bearings, bushings, or housings may be wearing out. Copper generally indicates bushing or bearing failure. Other wear metals generally indicate specific items are being subject to wear.

Silicon is indicative of engine ingestion of dirt and other atmospheric particles. Silicon can also be introduced into oil samples during the oil sampling process as small amounts of grime stuck to the bottom of the engine oil pan can fall into the oil sample bottle during sampling. Usually, these anomalies are only present on a single oil sample and disappear quickly if proper sampling techniques are used.

VTA does experience higher levels of silicon readings during the dry summer months when more dust is in the atmosphere. These seasonally high levels of silicon in oil readings are not concerning as they do not correspond to associated failure rates of components.

In addition to contaminants and wear metals, water percent by volume and glycol are two of the most critical attributes of engine oil. Water and glycol in the oil indicate a problem with the cooling system of the engine. This can be caused from numerous locations, such as water pump seals or EGR coolers. Often, if high amounts of glycol or water are present in the oil, the bus will be immediately taken out of service before catastrophic engine failure occurs.

Fuel in the oil is particularly important to this study. Since B20 uses 80% petroleum diesel, the oil analysis is still able to detect any diesel fuel leaking into the oil system. Fuel-oil dilution issues are closely examined since fuel in the oil is almost always a sign of fuel system problems with the fuel pump or injectors. Trends of fuel in the oil are closely examined and compared to the control group of petroleum buses. Often, fuel component failure (such as injector failure) corresponds to increases of fuel in the oil.

Oil analysis is important as it gives VTA the opportunity to investigate failure modes before they become catastrophic. By understanding which engine components are made of which metal and what possible causes contribute to overall oil quality, oil analysis can point technicians in the right direction when troubleshooting problematic engines. Further, oil analysis often saves costly repairs as problems are found before they reach a catastrophic failure mode requiring replacement of the entire engine system.

This section of the report answers if biodiesel is noticeably affecting internal components of the engine. In addition to the previous two sections, the oil analysis will give a clear picture of what internal components may be affected by biodiesel use. Ties between oil analysis and engine failure will also be made to determine if engine oiling issues may be affected by fuel type.

MILES BETWEEN ROAD CALLS

The last research section specific to the transit buses themselves analyzes miles between road calls for the 17 biodiesel buses and the 17 petroleum-fueled buses in the control group. Again, since the buses have been running on some type of biodiesel for 6 years, any maintenance anomalies are likely to have been mitigated by the length of the study and the many miles each bus has travelled.

Miles between road calls may not have anything to do with the fuel system of the bus, so the analysis only look at road calls that resulted from issues directly related to fuel system or engine problems. Issues stemming from doors or mirrors or transmissions or driveline issues are not compiled.

While other maintenance activities affect the cost or the longevity of the vehicles themselves, road calls directly affect the customer as they almost always result in service delays. Quantifying an impact to the customers is valuable for decision makers to determine if and how biodiesel affects the actual revenue operation of transit buses.

BIODIESEL UNDERGROUND STORAGE TANK SAMPLING ANALYSIS

Throughout the VTA trial biodiesel program, periodic random samples from the underground storage tank have been taken to determine if any separation issues or quality issues were occurring. As described in the literature review, biodiesel quality sampling is important, as out-of-spec biodiesel can be a contributing factor to many other operational or maintenance issues, such as fuel filter plugging, poor performance, and component failure. In extreme cases, manufacturers may choose to void warranties if biodiesel does not meet specifications set forth in service bulletins. Further, biodiesel sampling is wise in that purchasing personnel are assured that the biodiesel specified by purchasing contracts is what is actually being delivered. Since biodiesel often has a higher cost than regular diesel, it is prudent to ensure that the proper fuel is being delivered in the proper quantity and distributors are not “short changing” end customers.

VTA uses the sampling method that pulls samples from the top, middle and bottom of the underground storage tank to determine if separation issues were occurring. The samples were taken one to four days after a large biodiesel delivery, giving the fuel enough time to properly settle in the underground tank. If the biodiesel had mixing issues, one to four days was enough time for the biodiesel to exhibit separation. Waiting longer than four or five days often meant the fuel level was dropping in the tank, and separation issues would be harder to detect as high levels of biodiesel were being pumped off the bottom of the tank.

Initially, the samples were taken to determine if VTA was received B5 or B20 that was specified in the contract. Early sampling of the B5 fuel showed issues with separation not unlike those at other agencies described in the literature review. Biodiesel was being splash mixed in the underground storage tanks, resulting in a non-homogenous mixture. Methods of mixing and delivery were changed, and the fuel separation issues largely went away.

Random sampling began again when VTA switched to B20 fuel. Again, deliveries were changed and mixing methods were modified to ensure VTA was received biodiesel as specified in the purchasing contract. Random sampling continued throughout the life of the program.

VTA took random samples from underground storage tanks periodically and randomly to ensure the contracted fuel supplier was delivering the proper fuel. Samples were not taken on set intervals to ensure randomness. When switching between suppliers or fuel types, sampling was taken again and issues were mitigated until random sampling showed a homogenous 20% biodiesel mixture.

Since underground storage tank sampling was taken at random intervals, this analysis documents each sample taken and charts the date, fuel type and percent biodiesel found at the sampling date. These samples are analyzed and large trends in separation or quality issues are documented, along with narrative about what VTA and the fuel supplier did to mitigate any issues. Sample laboratory results are included in the appendices.

This analysis is critical to the overall VTA biodiesel trial program, since separation issues with biodiesel caused tremendous impact to VTA. Not only was significant and unquantifiable staff time and resources expended on solving separation issues, severe levels of separation often required holding off on the trial biodiesel program altogether for a short period of time while problems were solved. Each of these cases are documented in detail, including the length of time biodiesel was not being used in the trial fleet and the causes for it. Costs are difficult to apply to the sampling and biodiesel quality issues but the issues are well documented so managers and decision makers at other agencies understand the true impact to maintenance as a result of out-of-spec biodiesel deliveries and separation problems with underground storage of biodiesel.

This research section answers questions about how underground storage infrastructure was impacted and what was done to mitigate separation issues. This analysis is crucial to decision-makers when implementing similar biodiesel programs or expanding current programs, as lessons learned from VTA are shared so others can learn from these mistakes.

BIODIESEL COST ANALYSIS

Biodiesel generally costs more than regular diesel. While local, state and federal subsidies can help offset additional costs, the overall cost of running the VTA trial biodiesel program resulted in increased spending on fuel. Initial estimates were that using B5 in a sub fleet of 22 buses would cost an additional $50,000 per year.

This aspect of the study goes back to the start of the biodiesel trial program and quantifies the additional cost compared to regular diesel. Cost-per-gallon will be analyzed against petroleum diesel over the same timeframe. Total cost of fueling the biodiesel sub fleet will be calculated and compared to the total cost of fueling with petroleum diesel.

Since the cost of fuel varies day-by-day, the analysis looks at the average cost of diesel and/or biodiesel over a one-month period. Each time a bus is fueled, the amount of fuel and the miles on the vehicle are logged. Each bus in the biodiesel test fleet and control group have their monthly miles travelled and fuel consumption numbers calculated based on fueling records. This not only gives the opportunity to calculate fuel economy, but the fuel consumed per month can be multiplied by the average per-gallon cost of fuel over the month to get a calculation of how much it cost to fuel each bus with each specific fuel type over each month of the trial program.

Fuel economy is also analyzed. It is expected that biodiesel can cause a decrease in fuel economy on account of biodiesel having a lower energy content. This analysis looks at the fuel economy of the biodiesel buses on B5 and B20 fuel and compares it to the control group of petroleum-fueled buses, operating on similar routes through similar portions of the service area.

The total additional cost of running the biodiesel trial program in fuel costs alone is a valuable tool for decision makers to use when determining the fate of similar programs. Further, this information can be extrapolated out to determine the overall financial burden of switching an entire fleet over the B20, based on fleet-wide miles travelled, fuel consumption and fuel costs. Since VTA uses public funds for much of its operational expenditures, this information is valuable to high-level managers at the organization.

RESEARCH DESIGN CONCLUSION

Each of the above research sections answers a specific question on what components, infrastructure, or system is affected by using biodiesel in transit operations. This holistic research study paints a clear picture of how biodiesel affects the buses, the maintenance, the operation, and the finances of VTA. By looking at various data sources and researching specific issues such as component lifespan, engine longevity and oil analysis, it is determined what, when, how and why biodiesel had a positive or negative effect on maintenance and operation of transit buses. Graphs, tables and figures are developed to aid in understanding technical findings.

SECTION 4: ENGINE COMPONENT ANALYSIS

ENGINE SYSTEM BACKGROUND AND OPERATION

Before analyzing the component analysis between the two study groups, it is prudent to understand some basic operation of the engine, fuel and exhaust systems on the buses. Inherent design issues with bus, engine and exhaust systems may help understand anomalies and failures.

The 34 buses that are investigated as part of this section all use the same basic engine design and system layout. Buses use a Cummins ISL 8.9 Liter straight-six diesel engine mated to a Voith 4-speed automatic transmission. The bus itself is built by Gillig in Hayward, CA, and is a conventional 40 foot low-floor type transit bus. As part of the trial program, buses from the 2001 and 2002 model year were included. Though the buses themselves have the same engine, one important difference in model year is the addition of an exhaust after-treatment system manufactured by Cleaire for the 2002 model year buses. Table 1 shows a breakdown of the buses used in the study with the type of fuel used and if it has an exhaust after-treatment system or not.

Bus Number	Model Year	Cleaire System	Fuel Type		Bus Number	Model Year	Cleaire System	Fuel Type
1012	2001	No	Biodiesel		1047	2001	No	Petroleum
1013	2001	No	Biodiesel		1048	2001	No	Petroleum
1014	2001	No	Biodiesel		1049	2001	No	Petroleum
1015	2001	No	Biodiesel		1050	2001	No	Petroleum
1044	2001	No	Biodiesel		1051	2001	No	Petroleum
1045	2001	No	Biodiesel		1052	2001	No	Petroleum
1046	2001	No	Biodiesel		2040	2002	Yes	Petroleum
2011	2002	Yes	Biodiesel		2041	2002	Yes	Petroleum
2012	2002	Yes	Biodiesel		2042	2002	Yes	Petroleum
2013	2002	Yes	Biodiesel		2043	2002	Yes	Petroleum
2014	2002	Yes	Biodiesel		2044	2002	Yes	Petroleum
2015	2002	Yes	Biodiesel		2045	2002	Yes	Petroleum
2016	2002	Yes	Biodiesel		2230	2002	Yes	Petroleum
2017	2002	Yes	Biodiesel		2231	2002	Yes	Petroleum
2018	2002	Yes	Biodiesel		2232	2002	Yes	Petroleum
2019	2002	Yes	Biodiesel		2233	2002	Yes	Petroleum
2020	2002	Yes	Biodiesel		2234	2002	Yes	Petroleum

Table 1 - buses used in the research study, fuel type and exhaust system

Understanding how fuel flows from the tank into the engine, and understanding the flow of exhaust from the engine to the tailpipe is equally important and will help the reader understand different aspects of the engine function. The basic fuel system is a Cummins designed “CAPS” fuel system in which fuel is pressurized before being sent to individual cylinder injectors. These buses do not use a “common-rail” type fuel injection system.

Fuel from the tank is suctioned via a fuel transfer pump (sometimes called a “booster” pump) that is located on the left side of the engine block. From here, fuel is sent to a high-pressure fuel pump. The fuel pump, also located on the left side of the engine block, takes low pressure fuel sent from the tank and increases the pressure by way of a two-cylinder gear-driven fuel pump accumulator. The fuel pump gear module is driven by the engine camshaft and is lubricated with engine oil. The fuel pump accumulator module then sends high-pressure fuel to an injection control valve (ICV) distributor module. This module then individually sends regulated high-pressure fuel to one of six injector lines at a time. The fuel is distributed via timing based on engine cylinder position, so fuel is injected into the cylinder at precisely the correct moment. At the cylinder head, fuel is injected into the cylinder, at which point it is ignited. Exhaust is directed out of the exhaust manifold, and into an after-treatment system where they are installed. See figures 2 through 5 for a general layout of the Cummins ISL fuel system major components.

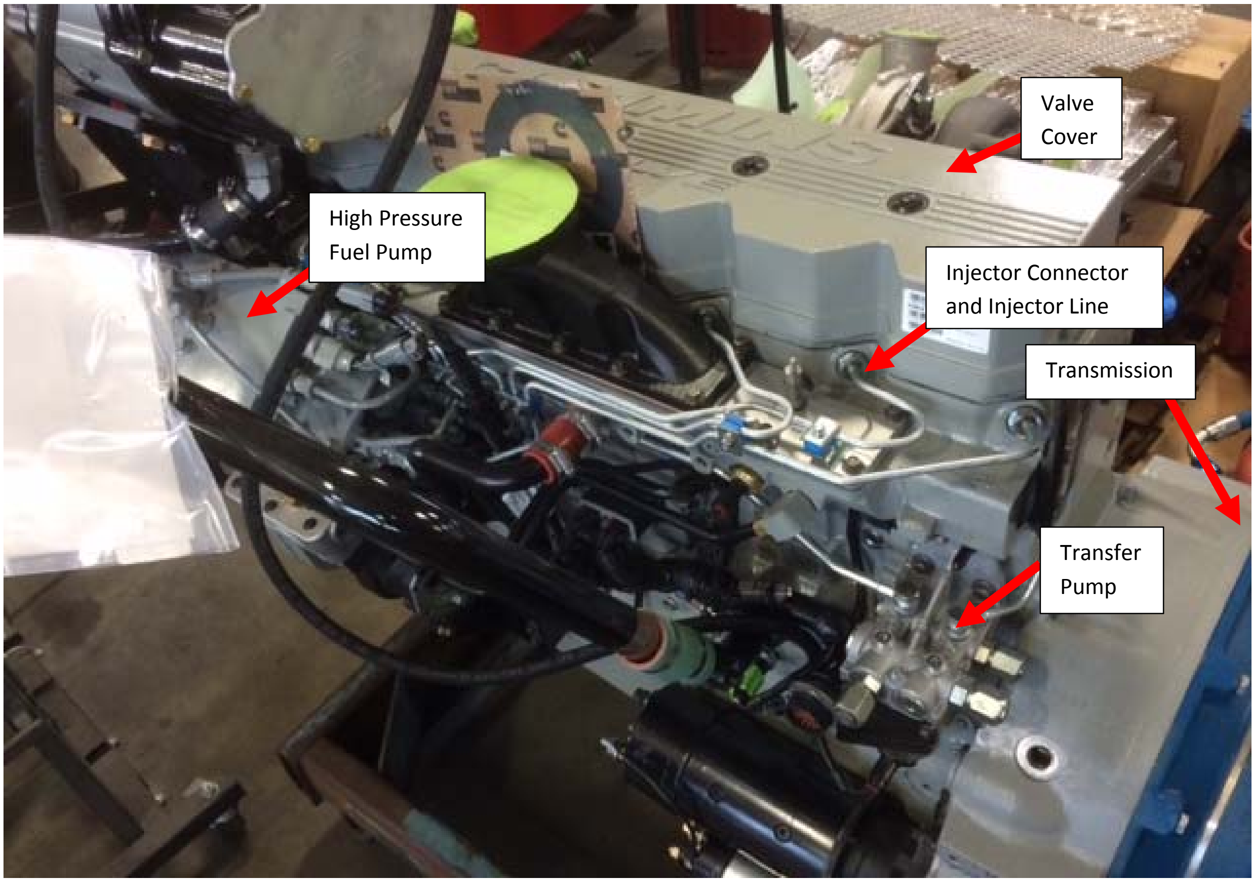

Figure 2 - overall left-side view of Cummins ISL engine

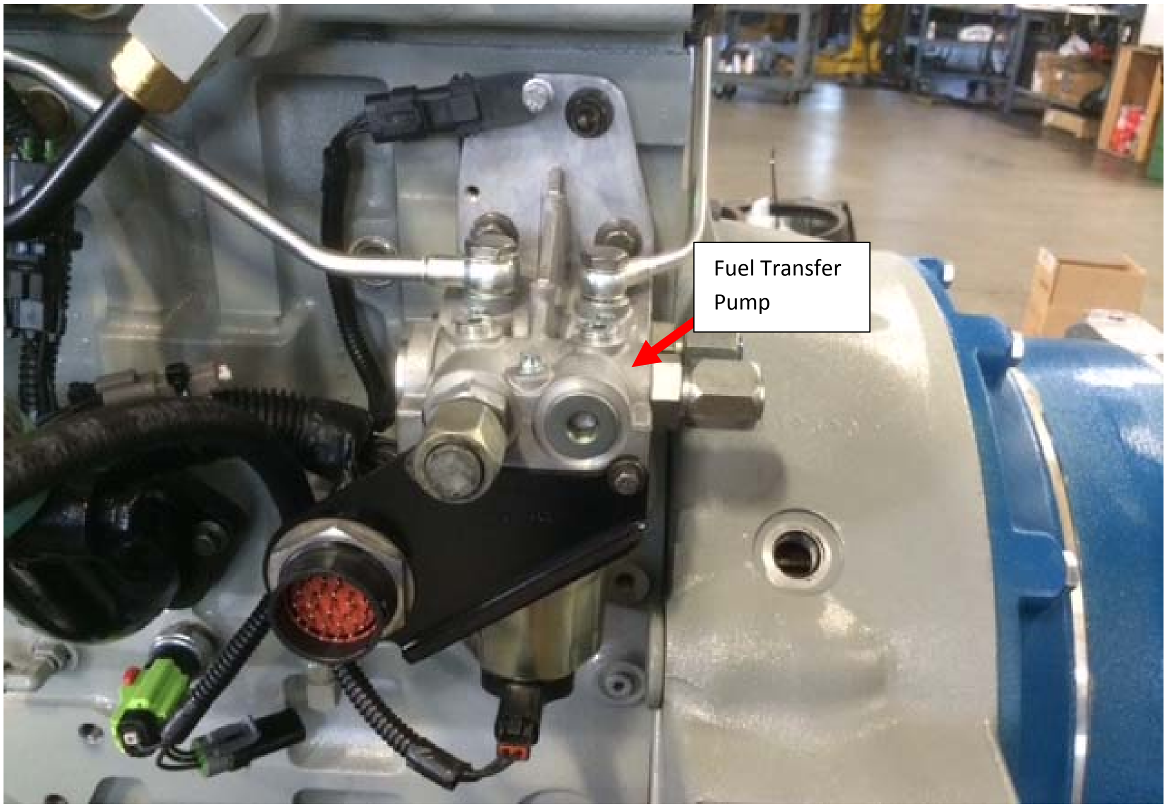

Figure 3 - fuel transfer (or booster) pump

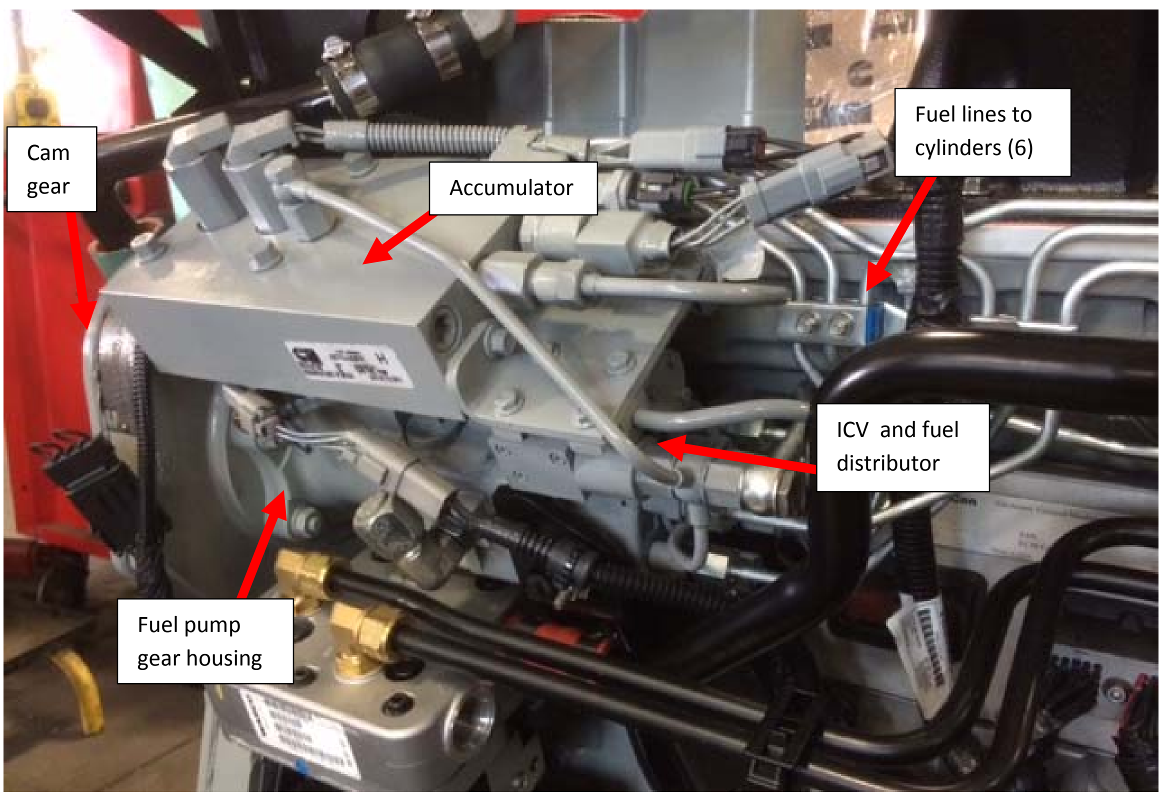

Figure 4 - ISL fuel pump major components

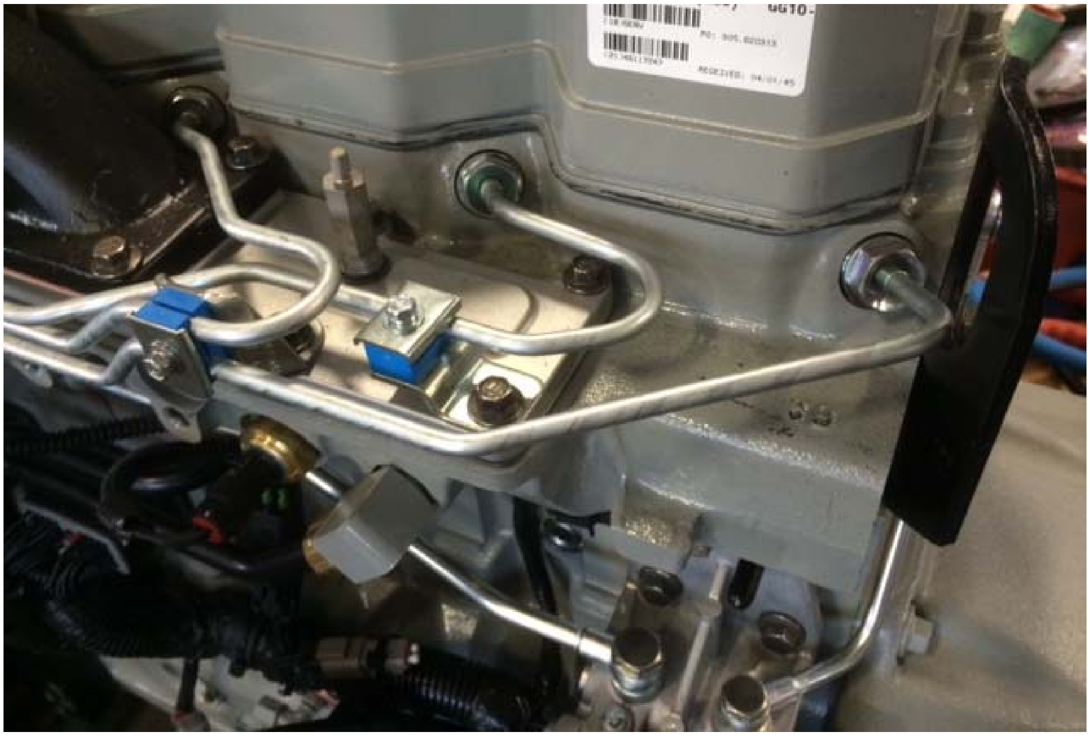

Figure 5 - cylinders 4, 5 and 6 fuel lines

The Cleaire aftertreatment system consists of a diesel particulate filter (DPF) that traps particulate matter and soot. The DPF aftertreatment system consists of a regeneration (also known as 'regen') system that injects diesel fuel into the exhaust stream via a fuel injector. The purpose of regeneration is to elevate the exhaust stream to a high temperature which burns exhaust soot and makes it into smaller particulates. The DPF itself captures the soot and ash before it can be released into the atmosphere. Ash primarily comes from burning engine oil. DPFs require maintenance and periodic cleaning or replacement to ensure proper function. Since the aftertreatment system on the 2002 model year buses involves fuel system components, aftertreatment parts and DPF usage are investigated as well.

This section analyzes 44 different fuel system, engine and exhaust system components and compares usage to the control group of petroleum fueled buses over the life of the program. Any component that has the potential for failure due to direct contact with fuel, or associated contact with fuel-combustion issues (such as the diesel particulate filter, or DPF) is examined in detail.

FUEL SYSTEM COMPONENTS

Component usage information is logged in VTA's SAP maintenance system database. Each time a bus has a failure of a component, the mechanic doing diagnostics and repair orders the appropriate part from VTA's parts department. Once the reservation for a part is made via SAP, the parts department either orders the part or issues a part out of inventory to the mechanic for use on the vehicle. Thus, every part issued at VTA that uses an internal inventory part number is logged and tracked by usage.

Gathering parts usage raw data via SAP is straightforward by means of queries and computer commands, but analysis of the root-cause of component failure takes investigation. Often, parts are replaced or changed as a result of other maintenance issues. For example, due to the tight placement of parts within the engine compartment, when a fuel pump fails, engine air intake parts are routinely removed to get easier access to the fuel system components. When the mechanic reassembles the system, a new intake gasket is likely to be used since often times the gasket or seal is damaged during the removal process. So, although the root cause of failure is the fuel pump (and the fuel pump is replaced), often ancillary components are also replaced as a result.

When investigating main fuel system failures, the 44 parts listed in Table 2 were the most commonly replaced as a result of a fuel system malfunction. The part number is the VTA internal part number allocated to the component and corresponds to a specific OEM part number used for purchasing. The description listed in the OEM parts catalogs has been abbreviated below for clarification purposes.

PART No.	DESCRIPTION	PART No.	DESCRIPTION
106101	Fuel Pump, ISL	106125	Fuel Injector, ISL
125528	Fuel Booster Pump	125529	Fuel Transfer Pump
117691	Fuel Line #1 Cylinder	117750	Fuel Line #2 Cylinder
117751	Fuel Line #3 Cylinder	117752	Fuel Line #4 Cylinder
115732	Fuel Line #5 Cylinder	117753	Fuel Line #6 Cylinder
119171	Fuel Drain Tube	118890	Gasket Connection
115702	Gasket Air Intake	119242	ISO Vib Washer Seal
119183	Seal, Rectangular Ring	115258	Sealing Washer
119960	Fuel Injector O-Ring	108750	Fuel Sender
119245	Injector Connector, Male	114210	Accumulator Fuel Drain Tube
120651	Seal, Rectangular Ring	103344	Fuel Sender
117789	Accumulator Module, Fuel Pump	108531	Position Sensor, ISL
107940	Fuel Sender	400114	Cleaire Fuel Pump Filter
121569	Cleaire Check Valve, Calibrated	121801	Cleaire Fuel Pump Filter
108761	Gasket, Lower Pressure Valve	108760	Gasket, Level Control Valve
106490	Level Control Valve	106427	Pressure Release Valve
118831	Fuel Accumulator Pressure Sensor	114211	Accumulator Washer Seal
114212	Accumulator Washer Seal	115258	Washer Sealing, Fuel Plumbing
45882	Gasket, Fuel Tank Gauge	108762	Gasket, Upper Pressure Valve
119023	DPF Catalyst	119024	Diesel Particulate Filter (DPF)
107220	Transient Suppressor	115922	Injector Control Valve
407530	Fuel Injector, Cleaire	117462	Accumulator Temperature Sensor

Table 2 - fuel system parts investigated

Immediately it should be noted that there are variations on parts based on model year and build, such as the fuel sender. Gillig changed the design of the fuel sender between 2001 and 2002, so the parts are not interchangeable. This is taken into account when researching how many parts were used by sub fleet and explains why multiple parts appear with the same description but different part numbers. The same is true of the Cleaire fuel pump filters; there are two sizes according to the size of the Cleaire filter housing and they are not interchangeable. Of other note is that some parts have the same description for lack of a better descriptor, such as the accumulator washer seal. There are two accumulator washer seals with different part numbers, but they are given the same description for lack of better terminology.

All pertinent information regarding part numbers, number used by vehicle fuel type, and miles between parts usage by fuel type and model year is included in Appendix A.

MILES BETWEEN COMPONENT FAILURES

Each one of the 34 buses in the research study was queried in SAP for how many and when any of the listed parts were used, by date. SAP returned raw data that was converted into Microsoft Excel format and analyzed for trends in parts usage. The biodiesel sub fleet and petroleum diesel control group parts used were tallied, and then normalized for variation in miles travelled (the petroleum diesel control group travelled roughly 4.8 million miles over the time period of the test, whereas the biodiesel buses travelled roughly 3.6 million miles over the same time period). The end result was a calculation of how many miles each sub fleet travelled before a part was used. Extreme differences in miles between component failures are highlighted in Table 3, and each will be described in detail.

DESCRIPTION	BIODIESEL # USED	PETROLEUM # USED	BIO MILES B/W FAILURES	PETRO MILES B/W FAILURE
Fuel Sender(s)	19	2	187,000	2,395,000
Fuel Pump	36	27	99,000	177,000
Fuel Injectors	54	13	66,000	368,000
Fuel Injector O-Ring	91	66	39,000	73,000
Accumulator Washer Seal	74	124	48,000	38,000
Accumulator Module	13	15	275,000	319,000
Injector Connector, Male	102	85	35,000	56,000
Injector Control Valve	7	21	510,000	228,000
Accumulator Temp Sensor	3	23	1,190,000	208,000

Table 3 - extreme variation in miles between fuel system component failures

There are other instances of variation in miles between component failures of the biodiesel sub fleet and the petroleum diesel control group. However, the usage was so small as to be statistically insignificant or could be attributable to other issues with the fuel system.

FUEL SENDER AND FUEL TANK COMPONENTS

The fuel sender resides in the fuel tank and sends an electronic signal to the fuel gauge on the dashboard of the vehicle, indicating the level of fuel in the tank. Often, a bus driver will report on the daily defect card that the fuel gauge was fluctuating or not working correctly. This sometimes resulted in a road call, especially in circumstances where the fuel gauge was reading empty and the bus driver did not want to have stranded passengers in the middle of a route.

Mechanics generally check operation of the gauge, as faulty electrical connections or a gauge malfunction could cause fuel gauge fluctuations. Since the fuel gauge operates independently of the fuel type used, the number of dashboard fuel gauges used was not investigated. If the fuel gauge functions properly, then the fuel sender in the tank is the culprit of malfunctioning fuel readings.

The biodiesel sub fleet used significantly more fuel senders than the petroleum diesel control group. The biodiesel buses had 187,000 miles between replacements of the fuel sender, whereas the petroleum diesel buses ran nearly 2.4 million miles between fuel sender replacements. Out of the 19 total fuel senders replaced on the biodiesel buses, over half (10) were replaced in the first 9 months of the biodiesel test program between October 1, 2008 and July 1, 2009. This indicates that the switchover to B5 biodiesel may have contributed to a significant rise in fuel sender usage during the first few months of biodiesel use.

This rise in fuel sender use may be attributed to the cleansing effect of biodiesel. As noted in the literature review, biodiesel can “clean” accumulated grime, grit and particulates out of fuel system components, causing issues when first switching over between fuels. Agencies reported increases in fuel filter plugging during preliminary switchover to biofuels. When the biodiesel program was begun in October 2008, the vehicles were approximately 6 or 7 years old, and significant amount of deposits and other foreign objects can make their way into the fuel system via contamination from underground storage tanks, biological growth, etc. While the fuel filter catches many of these contaminants before they reach the engine, the fuel filters are located downstream from the fuel tank, and the fuel tank components are thus subjected to significantly more fuel contaminants than engine components.

Of the remaining 9 fuel senders used on the biodiesel sub fleet, 6 were attributed to a single bus, vehicle number 2014. Over two years, the fuel sender on bus 2014 was replaced 6 times, but no other instances of multiple fuel sender issues were reported on the 16 other biodiesel buses over the same timeframe. Bus 2014 likely had an electrical problem that caused issues with the fuel gauge, and in each instance the fuel sender was likely unnecessarily changed to try and remedy the issue.

The remaining 3 fuel senders used on vehicles after the first 9 months of the program are comparable to the 2 fuel senders used by the petroleum fueled vehicles, and the difference is statistically insignificant. Therefore it be reasonably assumed that the switchover to biodiesel caused a drastic rise in fuel sender failure rates for the biodiesel buses in the first 9 months of the program, but usage leveled off and stayed comparable to petroleum fueled bus failure rates for the remainder of the trial program. It should be noted that the switchover to B20 in October 2010 did not result in another round of increased fuel sender failures on the biodiesel sub fleet in the months following initial B20 use.

FUEL PUMP, INJECTOR CONTROL VALVE AND ACCUMULATOR USAGE

The main high pressure fuel pump for the engine elevates the fuel pressure for distribution to the cylinder injectors. While some major components of the fuel pump can be replaced, and most external lines and sensors on the fuel pump may be replaced, when a fuel pump fails often the entire pump assembly is removed and replaced with a new or rebuilt fuel pump.

Fuel pumps are an expensive component. In addition to the cost of the component, ancillary components such as lines, fitting and seals must also be changed out, and the cost of labor to replace the fuel pump and associated components is pricey. On average, when a fuel pump fails on an ISL engine in a low-floor Gillig transit bus, VTA spends anywhere from $5,000 to $10,000 in total maintenance costs to get the bus in running condition.

In addition, since the fuel pumps are not rebuilt by VTA's internal Overhaul and Repair facility, the fuel pumps must be sent out for reconditioning. Thus, even with a small internal component failure of a fuel pump, VTA is burdened with the cost of replacing the entire unit.

When a bus has its engine replaced either due to failure or high mileage, the engine is rebuilt entirely by VTA's Overhaul and Repair shop. The engine is removed from the bus, torn down, cleaned, and rebuilt using new, reconditioned, or reused parts where necessary. As part of the rebuilding process, old fuel pumps are replaced if they are 3 years old or older. If the fuel pump was replaced within 3 years of the engine rebuild, the fuel pumps are put back on the vehicle.

With the high cost of fuel pumps and the fact that many fuel pump failures happen on-route (which directly affects customer service), fuel pump usage is an important metric to this study. As noted by Table 2, the biodiesel buses on average ran 99,000 miles between fuel pump failures, whereas the petroleum-fueled control group of buses ran 177,000 miles between fuel pump failures. The failures are roughly equally spread throughout the timeframe of the biodiesel program, indicating that higher fuel pump failures were not necessarily due to the switchover from petroleum to B5, or from B5 to B20 fuel. There were noticeably fewer fuel pumps changed on the biodiesel sub fleet in 2010 than other years, even though the switchover from B5 to B20 happened in October of 2010.

Of note is that the fuel pump failures on the biodiesel sub fleet to do not correlate to either 2001 or 2002 model year vehicles, with approximately 40% of fuel pump failures belonging to 2001 model year vehicles and 60% belonging to 2002 model year. This is roughly equal to the spread of 2001 to 2002 model year vehicles for the sub fleet. Bus 2015 did have the fuel pump changed 5 times over the trial period, and bus 1045 had its fuel pump changed 4 times. However, no other spikes in usage appear in the data. This indicates that fuel pump failures are not isolated to a specific series, model year or vehicle type based on manufacture or presence on an aftertreatment exhaust system.

The fuel pump usage on the petroleum fueled control group of buses is likewise roughly equally spread throughout time and bus series type, with a brief drop in fuel pump usage in 2012 but otherwise equally distributed throughout the control group. Although bus 1049 had its fuel pump changed 5 times over the trial program period, and bus 2234 had its fuel pump changed 4 times, no other major trends are evident in the data that indicate a small group of buses caused most of the control group sub fleet fuel pump failures.

The fuel pump on the ISL CAPS fuel system utilizes a porcelain-type material for the accumulator pistons. These two pistons drive the fuel pressure up to 24,000 psi. One of the main causes of failure is that the porcelain pistons will allow fuel to bypass the piston seals, and fuel will infiltrate the fuel pump gear housing. The gear housing is lubricated with engine oil, and fuel dilution of the oil can occur. This often shows up on the oil lab results. It is possible that the biodiesel has a material compatibility issue with the cylinders of the fuel pump, causing increased failures. However, the oil lab (as will be discussed further in the report) does not correlate the biodiesel sub fleet to increased amounts of fuel oil dilution, as would be expected if the majority of fuel pump failures were due to biodiesel bypassing the pistons.

The injector control valve (ICV) and fuel distributor take the high pressure fuel from the accumulator and reduce its pressure to 10-14,000 psi (depending on engine operating parameters) and send the fuel to individual injector lines for distribution to the cylinders. Since VTA does not rebuild the fuel pumps and only replaces a few components on the pumps, it's worth noting here that the biodiesel buses used less injector control valves than the standard diesel buses. The biodiesel sub fleet ran 510,000 miles between replacements of the ICV, where the petroleum diesel control group ran 228,000 miles between replacements. When ICV failure is imminent or there are issues with fuel pressure, the engine computer (ECM) can activate a diagnostic trouble code (DTC) which illuminates a check engine light on the dash. Performance issues often accompany ICV failure. Figure 6 shows the location of the ICV on the fuel pump.

Likewise, the accumulator module itself can be replaced independently of the entire fuel pump. The biodiesel buses ran 275,000 miles between accumulator replacements, and the regular diesel buses ran 319,000 miles between accumulator replacements. The accumulator is also shown in Figure 6.

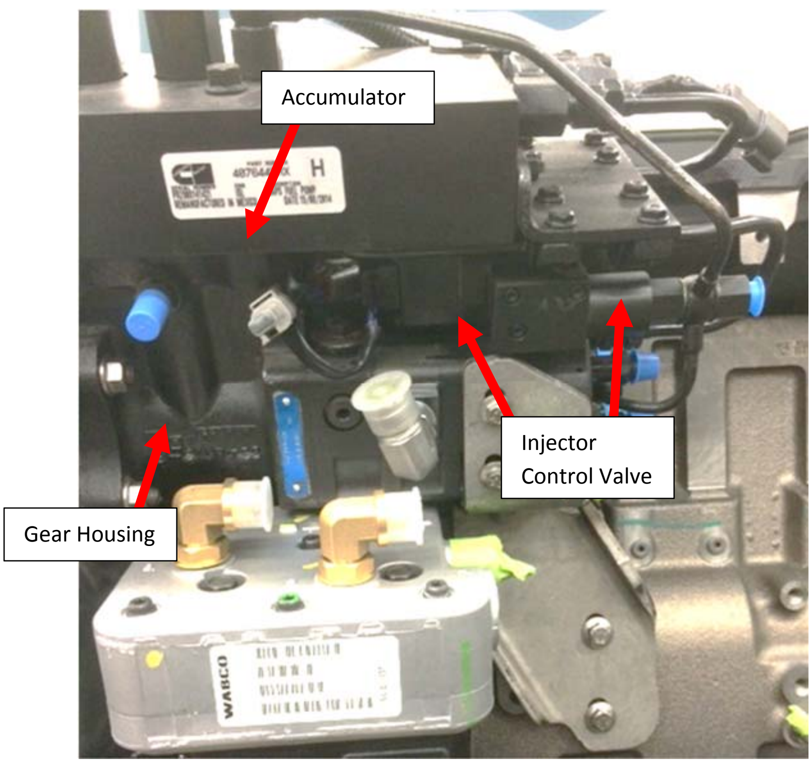

Figure 6 - ICV, accumulator and gear housing detail

Since the accumulator and the ICV are two major components of the fuel pump assembly that can be replaced instead of replacing the entire fuel pump, this study sums the amount of accumulators, ICVs and fuel pumps together to see if the discrepancy between the biodiesel buses and the petroleum control group can be attributed solely to maintenance practices and not component failure. The biodiesel buses used 56 major fuel pump components over the timeframe of the study, whereas the petroleum control group used 63. Normalized for mileage, the biodiesel buses ran 63,000 miles between failures of a major fuel pump component, and the petroleum diesel buses ran 76,000 miles between failures of the same components. While there is still variation in the biodiesel sub fleet compared to the control group, the difference is somewhat mitigated when looking at major fuel pump components as a whole.

Maintenance personnel vary in training and experience, and often a mechanic or foreman may choose to replace the entire fuel pump assembly instead of an individual component like the ICV or accumulator module, due to varying reasons. This discretion is left to the technicians, and factors that play into the decision include other fuel system problems arising at the time of repair, fuel pump life, or replacement of other fuel system components like injectors and lines.

Analysis of major fuel pump component usage and fuel pump replacement shows that biodiesel does cause an increase in fuel pump failures compared to petroleum fuel, and that the average miles between fuel pump failure (or fuel pump major component failure) is less than that of petroleum fuel. This is important as fuel pump failures are costly to repair and equate to significant downtime of the vehicle.

FUEL INJECTORS AND ASSOCIATED COMPONENTS USAGE

Fuel injectors often cause performance problems with the engine, and can fail due to a number of causes. Fuel injectors have the capability of clogging due to fuel type or combustion problems and fuel injectors can leak. This study looks at fuel injector usage between the biodiesel buses and petroleum diesel buses, including injector seals and injector fuel lines.

The Cummins ISL uses 6 fuel injectors, each threaded into the cylinder head and sealed with an injector O-ring. The fuel lines themselves are hard stainless lines, pre-bent to shape and connected with fuel line fittings. Due to the length and size of the engine block, fuel lines are held in place with isolator blocks and clamps which keep fuel line vibration to a minimum. Figure 5 shows detail of the injectors, line and isolators.

The biodiesel buses used significantly more fuel injectors than the standard petroleum diesel control group of buses over the same timeframe. The biodiesel buses averaged 66,000 miles between injector replacements, whereas the petroleum diesel buses average 368,000 miles between replacements. Since all six fuel injectors are often changed on a bus when fuel system problems are present (such as fuel in the oil), instead of looking at miles between failures, it is helpful to look at how many buses had all fuel injectors changed over the life of the program.

For the 6+ years of the biodiesel trial program, 8 of the 17 biodiesel fueled buses had all 6 fuel injectors replace, with bus 2018 having all injectors replaced twice within 3 months of each other (indicates a maintenance personnel issue, not necessarily a fuel system component failure). The petroleum diesel control group only showed 2 buses with full injector replacements, and 1 bus (1051) with a single injector replaced.

This trend is concerning since there is clear evidence that biodiesel caused an increase in fuel injector replacements compared to petroleum diesel. While fuel injector replacements are not as involved as fuel pump replacements, fuel injector failure often relates to other maintenance risks, such as fuel in the oil or risk of fire if the injector body is leaking.

In addition to injector replacement, the injector O-ring which seals the injector body to the cylinder head also has a disturbing trend of lower life expectancy on the biodiesel buses compared to petroleum diesel buses. The biodiesel buses ran 39,000 miles between replacements of the injector O-rings, where the petroleum buses ran 73,000 miles between replacements of the same component. This correlates with the increased injector usage, however it should be noted that if a mechanic can determine an injector-area fuel leak is due to the seal and not the injector itself, the mechanic may just change the injector seal.

11 of the 17 biodiesel buses had injector O-rings changed, with bus 1045 having the seals changed 3 times over the span of the trial program. Comparably, 10 of the 17 petroleum control group buses had injector O-rings changed over the same time frame, with buses 1049 and 2040 each having 3 instances of injector seals being replaced. The buses that have had repeat injector O-ring replacements do not correlate to a specific defined date range, indicating the injector O-ring failure occurred every few years and did not peak due to another issue (such as cylinder head issues). O-rings that were replaced without a corresponding injector replacement amount to 37 for the biodiesel buses and 53 for the petroleum diesel buses.

One trend that is noticeable is that the biodiesel buses typically had all 6 injector O-rings replaced on the same work order, whereas the petroleum control group showed more instances of individual injector O-ring replacements. Since the biodiesel buses are all located at the North Maintenance Division, it can be assumed that the North Maintenance personnel generally replace all injector O-rings if leaking, whereas the other two divisions may only replace 1 to 3 injector O-rings, or all 6, depending on the severity of the fuel system problem.

The O-rings are made of biodiesel compatible material, so there is no scientific reason for an increase in O-ring usage due to failure of the O-ring material itself. However, as noted above, with the increased fuel injector usage on the biodiesel buses, the O-rings are replaced at the same time. So, a rise in injector usage would see a corresponding rise in injector O-ring usage as well.

The male injector connector is another part which sees increased usage on the biodiesel sub fleet. The biodiesel buses ran on average 35,000 miles between injector connector replacements where the petroleum control group ran 56,000 miles between replacements. Again, as in the injector O-ring scenario, the North Division typically replaced all 6 injector connectors when a bus was in the shop, where the other divisions would replace anywhere from 1 to 6 connectors, depending on the severity of the leak. Looking specifically at the number of work orders for fuel connector leaks (not the number of connectors used from inventory), there were 18 work orders for the biodiesel buses and 18 work orders for the petroleum buses. These are quite comparable, so the overall number of work orders for injector connector replacements was roughly the same between the two groups. With this knowledge, it is assumed that the overall increase in injector connector usage on the biodiesel buses is due to the North Division maintenance practice of replacing all connectors instead of just a few.

EXHAUST AFTERTREATMENT COMPONENTS

As described above, the exhaust aftertreatment on the 2002 model year vehicles (which constitute 10 of the biodiesel buses and 11 of the petroleum diesel buses) utilize diesel or biodiesel fuel to burn off soot in the exhaust stream. Likewise, since biodiesel has a slightly different combustion chemistry than petroleum diesel, the DPF and exhaust aftertreatment parts usages are analyzed to determine if biodiesel causes increased wear or damage to the exhaust system.

The 2002 model year biodiesel buses traveled 2.14 million miles over the span of the trial biodiesel program study. The 2002 model year petroleum buses travelled 3.19 million miles over the same span of time. Whereas the prior maintenance component checks looked at all 17 buses and averaged parts usage per mile of each of the entire sub fleet, this section will only look at model year 2002 vehicles and compare the miles between component replacement for those vehicles. The parts used are normalized by miles travelled of each of the sub fleets. The following extreme variations in aftertreatment parts used from inventory are noted in Table 4.

DESCRIPTION	BIODIESEL # USED	PETROLEUM # USED	BIO MILES B/W FAILURES	PETRO MILES B/W FAILURE
Fuel Pump Filter, Cleaire SMALL	83	24	26,000	133,000
Fuel Pump Filter, Cleaire LARGE	5	6	429,000	531,000
Fuel Pump, Cleaire	3	23	715,000	139,000
DPF Catalyst	4	17	536,525	187,461

Table 4 - extreme variation in miles between exhaust aftertreatment part failures

Typically on exhaust aftertreatment system problems, the first indication of component failure is an exhaust system check engine light on the dash, which gets reported on the driver's daily defect card. Maintenance crews check the bus computer system for diagnostic trouble codes (DTCs), which may be related to excessive exhaust backpressure or fuel delivery problems to the exhaust system. Components are replaced as necessary.

Immediately, it is apparent that the biodiesel buses used significantly more small-size Cleaire fuel pump filters than the petroleum fueled sub fleet. However, it is also immediately apparent that the more costly Cleaire fuel pump (which also contains a fuel filter and filter housing) was replaced significantly more on the petroleum diesel buses compared to the biodiesel buses.

This is due to two main reasons. First, the Cleaire system utilizes two different fuel filter sizes in these fleets of buses. The Cleaire fuel filter pump and filter come in a small size and large size to fit the two different housings. Use on the large filters was not significantly different between the biodiesel buses and the control group (5 and 6, respectively). When the Cleaire system has a fault, indicated by a Cleaire light on the dashboard or a performance issue, the mechanic may determine that the fuel filter is clogged. If the mechanic puts a small filter in a large filter housing and tests the bus, fuel issues will continue. At that point, the mechanic may determine that the Cleaire fuel pump is bad, and change the entire pump, even though the pump is good but the filter was the wrong size. The second reason is that the mechanic may find trouble with the fuel delivery to the Cleaire system, and instead of changing just the filter, may change the entire pump and filter assembly to streamline the repair. While this is more costly than a simple filter change, this practice does occur.

Both of these reasons helps to explain the abnormal filter and fuel pump usage on the exhaust aftertreatment system. At North Division on the biodiesel buses, staff likely just changes the Cleaire filters (predominantly the small-size filter), which seems to resolve most fuel delivery issues to the aftertreatment system. At the other two Divisions, staff likely changes the entire fuel pump system.

Even with these mitigating factors however, the biodiesel buses did see considerably more fuel filter issues on the Cleaire system than the petroleum fueled vehicles. This is notable since most Cleaire issues result in performance problems and engine warning lights that affect operation of the buses on route, and result in road calls.

An equally important note is that the biodiesel buses used considerably fewer DPFs over the life of the program. The fact that the biodiesel buses used fewer DPFs indicates that biodiesel blends can increase the life of the diesel particulate filter compared to petroleum diesel fuel, likely due to the decreased PM emissions biodiesel buses emit as referenced in the literature review. Since DPFs are costly to replace and costly to clean for reuse, the reduction in DPF usage based on fuel type could result in cost savings to the organization and obvious environmental benefits.

REMARKS ON FUEL LINE USAGE

A large majority of fuel system problems on the Gillig buses are due to fuel line breakage. The fuel lines are hard stainless steel, pre-bent to shape and held in place with isolators. In 2008 and 2009, VTA saw an increase in fuel line failures on Gillig buses with ISL engines. These fuel line breakages caused great potential for fire damage, as the high pressure fuel lines were spraying high pressure and high temperature diesel fuel throughout the engine area and typically occurred on route where bumps or vibration caused the final failure mode.

VTA's Engineering Department investigated the issues and determined that the majority of fuel line breakages were occurring because during engine servicing or when a fuel injector or line were replaced, the small rubber isolators that hold the fuel lines secure were not being replaced. The lack of isolators, bracing and associated hardware allowed fuel lines to vibrate and move to an excessive degree, causing stress on the stainless steel lines until they fractured.

VTA's Engineering Department released a Service Information Bulletin (SIB) in November, 2009 that included pertinent information on replacing fuel lines, isolators, and injectors, and included all necessary parts and torque values to properly replace lines. This SIB is included in Appendix B.

As part of the component usage analysis, fuel line usage was compared between the biodiesel buses and the control group of regular buses. However, the analysis shows that there is no noticeable difference in fuel line failure between the biodiesel buses and petroleum fueled control group. This is expected, as the majority of fuel line failures that require line replacement are due to fractures of the stainless line itself. Although fuel line fittings do sometimes leak, often they are tightened to the proper torque spec and the leak issue is resolved.

This is important to note since one of the principle risks of fire on a bus comes from fuel line breakage. Had either group demonstrated a noticeable spike in fuel line rupture due to line breakage, it would be worth further exploring. However, the biodiesel buses and regular petroleum diesel control group showed comparable fuel line usage numbers throughout the duration of the trial program.

COMPONENT USAGE CONCLUDING REMARKS

On the whole, most fuel system parts usage between the biodiesel buses and petroleum diesel buses were comparable or varied with a high degree of statistical insignificance so as to not raise suspicion that biodiesel causes increased fuel system component failures. There are two noticeable and costly differences though.

First, fuel pump usage is increased with the use of biodiesel. All factors considered, the biodiesel buses did have a higher rate of fuel pump replacement compared to the petroleum fueled control group. Since fuel pump repairs are costly and equate to long bus downtime, this is an important note. Even after mitigating factors were taken into account, and major fuel pump individual components were analyzed, the biodiesel buses still ran approximately 13,000 miles less between fuel pump component failures compared to the petroleum control group.

Second, the fuel injector usage on the biodiesel buses is higher than on petroleum diesel buses. Of the 17 biodiesel buses in the trial fleet, 8 required injector replacements, where only 2 of the 17 petroleum fueled control group buses needed all 6 fuel injectors replaced.

Lastly, while the biodiesel buses used noticeably more exhaust aftertreatment system fuel filters, the DPF itself appears to show less problems on the biodiesel buses compared to petroleum diesel vehicles, likely a result of the biodiesel emitting fewer particulate matter into the exhaust stream. The benefits of the DPF filter lasting longer on biodiesel buses is offset, however, with the increased fuel pump and injector issues.

SECTION 5: ENGINE REBUILD INFORMATION AND OIL LAB ANALYSIS

VTA maintenance attempts to rebuild diesel engines on a preventative basis. Ideally, Cummins ISL engines on the 2001 and 2002 model year Gillig transit buses are rebuilt at approximately every 350,000 mile interval. Typically buses will receive one or two engine midlife overhauls in their service life before being retired from the fleet.

Due to scheduling constraints, the fact that new buses are delivered within a short timeframe but cannot all be rebuilt at the same time, and the overall variable workload of maintenance personnel, engines may run over 500,000 miles before being sent to the Overhaul and Repair Division for an engine change. One goal of maintenance personnel is to identify buses with high mileage engines, and send them in for rebuilding before the engine suffers catastrophic damage due to internal engine wear.

Buses may be sent for engine overhauls based on mileage alone or due to internal or major engine problems. If one operating division has many buses at the Overhaul and Repair facility, they may choose to hold-off sending a high-mileage bus in for overhaul in order to meet daily operational requirements. The amount, time and number of buses any division sends to Overhaul and Repair varies significantly throughout the year.

ENGINE OVERHAUL PROCEDURE

When a bus is identified as needing an engine replacement, it is sent (or towed) to the Overhaul and Repair facility, which is a stand-alone heavy repair and replacement facility connected to the Cerone Operating Division. Buses are brought into the shop, and the entire engine bay at the rear of the bus is stripped of major components. The engine core itself is delivered to the parts department.

The mechanic completely rebuilds the engine bulkhead while the engine is out, and performs repairs on any standing components, such as fuel lines from the fuel tank, air lines, etc. All coolant hoses and most fluid lines connected to the vehicle (and not to the engine) are replaced at this time. When the internal engine bay is prepped, a rebuilt (or rarely, a new) engine is delivered from parts and the mechanic installs the engine in the bus.

At any time, there are a number of swing engine units for use by Overhaul and Repair personnel. This limits the amount of downtime the bus experiences while getting an engine replacement. The engine a bus arrives at Overhaul and Repair with will not be the engine the bus departs with.

Meanwhile, the old engine block core (and all associated components) is issued to the Component Room. The Component Room tears the engine completely down to the bare block. The Component Room cleans, rebuilds or replaces every component on the engine before the engine is rebuilt from the ground up. High-dollar parts are reused where practical, and damaged parts are discarded or sent to manufacturers as core items for rebuilding.

Pertinent to the fuel system, the Component Room will only install a new high pressure fuel pump on the engine if the existing fuel pump is 3 years old or older. The fuel pump is the only major fuel system component (other than the fuel tank in the bus) that is reused during an engine rebuild. Engines receive new fuel lines, new fuel injectors, new fuel sensors, etc. If a new fuel pump was installed on the bus at the division within 3 years, the Component Room will clean, inspect, test and reinstall the fuel pump if it checks out as functional.

The vast majority of fuel pumps used both at the Divisions and at Overhaul and Repair are rebuilt fuel pumps. Defective fuel pumps are sent back to the manufacturer as a core item. Cummins Inc. has been rebuilding VTA's fuel pumps for the duration of the trial biodiesel program. Quality Assurance testing on some of the Cummins fuel pumps that are returned to VTA as "new" show that often Cummins quality is lacking. New fuel pumps have been found to leak or fail outright when being installed on an engine in the Component Room. These defective items are sent back to the manufacturer under warranty.

VTA has investigated rebuilding high pressure fuel pumps in-house, however cost issues and parts availability have hampered these efforts. With the age of the fleet and the transition on newer buses to a common-rail-type fuel system, it is unlikely VTA will rebuild high-pressure CAPS-type fuel pumps in the future.

Once an engine is rebuilt, it is dynamometer tested to ensure performance requirements are met. After testing and quality assurance checks are completed, it is placed back into the parts warehouse for distribution to the heavy repair mechanics. Buses with rebuilt engines are road tested extensively before being released from the Overhaul and Repair Division.

ENGINE COMPONENT FAILURE MODES

When questioning Overhaul and Repair mechanics, a few notable design flaws with the ISL engine were found that can contribute to premature engine failure. Bus drivers may note that an odd engine sound occurs while on route, after which it is investigated by mechanics. Internal engine problems or complete engine failure (such as connecting-rod failure) usually require an engine change.

First, the number 2 and number 5 cylinder heads are not cast with the same oiling channels as the 1, 3, 4 and 6 cylinders. The number 2 and number 5 cylinder heads are missing a valley cut which allows oil to flow from the cylinder head down the lifter tubes. This lack of oil flow on these two cylinders can cause cam shaft roller seizures, necessitating entire replacement of the camshaft (and often rebuilding of the entire motor in the process). Figures 7 and 8 detail issues with the cylinder head design.

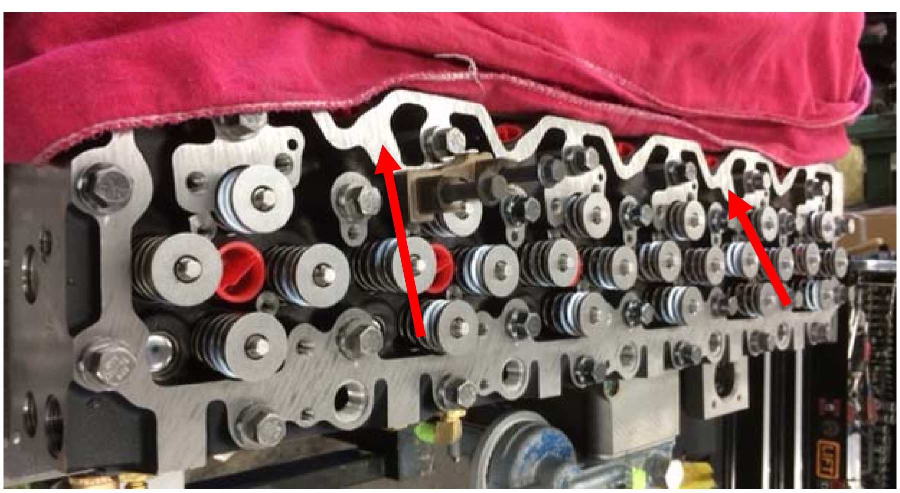

Figure 7 - cylinder head detail, red arrows point to 2 and 5 cylinder oil channels

Figure 8 - close-up showing lack of oil channel on #5 cylinder
Technician's purple-gloved fingers point to oil channel locations. Note the lack of a oil-channel on the left #5 cylinder. #6 cylinder on right.

Second, the tappets on the engine initially came in two different sizes; small tappets and large tappets. Oiling issues on the smaller tappets on early engines were mitigated by changing the smaller tappet design to include addition oiling passageways. If an engine block designed for small tappets is rebuilt, the new small-tappet design is exclusively used. If a new engine block is required, it will automatically arrive sized for the large tappets. See Figure 9 for a picture of the two tappet sizes. The rollers on the tappets can seize, as indicated on the large tappet in Figure 9. When this happens, the engine cam and tappets are removed and replaced, unless catastrophic damage was incurred which necessitated an entire engine rebuild.

Figure 9 - large tappet on left, two small tappets on right
Large tappet roller has seized.

Third, the bushing on the wrist pin at the connecting rod can fail, causing a catastrophic failure of the piston system. When the bushings fail, it is often at high engine speed, which causes significant risk of serious damage to the engine. In one case, an internal engine failure on a bus travelling on a local highway caused the entire engine compartment to catch on fire. The exact cause of engine failure is not known, but a connecting rod burst through the side of the engine block, causing high temperature oil to spray and immediately ignite on hot engine surfaces. Figure 10 shows damaged pistons due to internal engine failure.

Figure 10 - damaged pistons due to internal engine failure

In addition to these common reasons for engine rebuilding, other mechanical factors necessitate engine repair, such as seized main bearings on the crankshaft and dropped valves. If a valve stem breaks, the valve head itself is free to drop into the cylinder, causing piston damage as seen above. See Figure 11 for a picture of valves with broken stems. In addition, main bearing seizure necessitates rebuilding of the entire engine, and is often caused by oiling issues. Figure 12 shows the main bearing on a newly-rebuilt ISL engine.

Figure 11 - broken valves

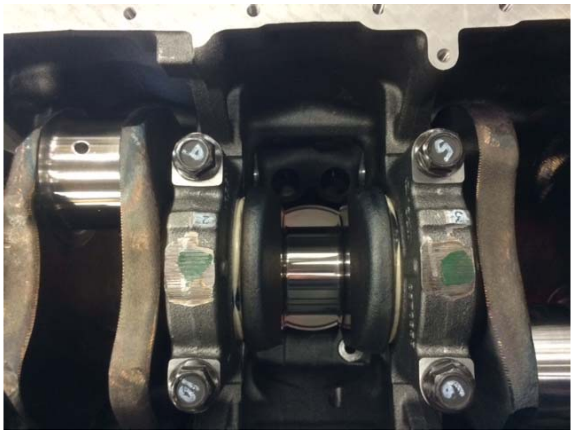

Figure 12 - crankshaft main bearings

All of the above information is important to the biodiesel trial program since many catastrophic engine failures can be attributed to an engine lubrication problem. Since the fuel pump is gear-driven off the engine camshaft and shares engine oil with the engine block sump, issues arising with the fuel pump and the possibility of fuel bypassing the fuel pump pistons can cause fuel-oil dilution, which reduces oils viscosity. Therefore, a detailed look at engine oil analysis throughout the trial biodiesel program is timely.

ENGINE OIL LAB ANALYSIS

VTA completes major preventative maintenance (PM) cycles every 6,000 miles. At each 6,000 PM cycle, an engine oil sample is taken from a port on the engine oil pan and sent for laboratory testing. Lab testing is described in detail in the research design section of the report. A sample testing report is shown in Appendix C.

As part of the biodiesel trial program, oil lab samples were analyzed for the entire time period of the trial program, from October 2008 through the end of February 2015. Due to the sheet number of samples taken from both the biodiesel sub fleet and the petroleum diesel control group, only lab results that meet a severity level 3, 4 or 5 are included in this review. Levels 1 and 2 are normal, and level 5 is the most critical severity level. Level 3 samples have an oil contaminant at a moderately high level, whereas level 5 samples are at a critical and excessive level of contamination and often require immediate maintenance action.

For the biodiesel buses, there were 111 instances of trace metals at moderately high to critical levels in the engine oil, with almost all cases being copper as the contaminant. For the petroleum diesel buses, there were only 49 such samples returned for investigation. This results in a miles between oil anomaly instance of 32,000 for the biodiesel trial fleet, and almost 98,000 miles for the petroleum control group. The petroleum fueled buses went on average three times longer than the biodiesel buses before a trace metal was found in the engine oil sample.

Copper in the engine oil is indicative of bearing failure, since most bronze-alloy bearings contain copper and are subject to wear. Copper primarily comes from cam bushings, main bearings, connector rod bearings or cooling system components, and is typically due to oiling issues in the engine or cooling system corrosion. The fuel pump does not contain significant amounts of copper that would correspond to increased copper in the oil. Further, the separation of the fuel pump from the engine (with the exception of the accumulator gear housing) would indicate that significant copper shedding in the fuel system components would not correspond to higher instances of copper in the engine oil. It is unknown what is causing the high copper readings in the biodiesel sub fleet of buses, but it is worth noting that there is a noticeable increase in copper wear in the oil.

Conversely, the biodiesel buses showed 6 instances of fuel-oil dilution, whereas the petroleum fueled buses showed 13 instances of fuel in the engine oil. Normalized for miles travelled, the biodiesel buses went on average 595,000 miles before fuel was found in the engine oil, and the petroleum buses only made it 369,000 miles before fuel oil dilution occurred.

For the petroleum group, multiple buses showed multiple instances of fuel-oil dilution, often in subsequent samples which helps account for why there are 13 fuel-oil dilution results instead of an expected lower amount. This indicates that when the lab results were sent back to the yard so the bus could be repaired, repairs were often not made or the correct repair was not made. Buses 1048, 2041, and 2043 had multiple fuel-oil dilution lab results. In total, accounting for the likelihood that the same maintenance issue caused multiple oil lab anomalies within a small date range, the petroleum fueled control group had 9 instances of fuel-oil dilution.

Looking at the detailed specifics and dates for fuel-oil dilution, only bus 1013 from the biodiesel sub fleet showed fuel-oil dilution twice, with both instances occurring in late 2014. The other 4 instances of fuel dilution were on 4 different biodiesel-fueled buses. In total, the biodiesel buses had 5 separate instances of fuel-oil dilutions. All instances of fuel-oil dilution for the biodiesel buses occurred in 2014, indicating that the switchover from standard diesel to B5 and from B5 to B20 did not correspond to a rise in fuel-oil dilution. Knowing that the biodiesel buses did not correspond to an increase in fuel-oil dilution negates the possibility that biodiesel causes increased wear on the seals between the fuel pump accumulator and the pump gear housing.

ENGINE OVERHAUL REBUILD MILEAGE

As discussed previously, engines are changed and rebuilt in-houses at the Overhaul and Repair division. Each time an engine is changed in the vehicle, the new engine installation mileage is tracked via VTA's Fleet Information System (FIS).

Tables 5 and 6 show the elapsed mileage on engines as of early March, 2015. Detailed information regarding the failure mode and prior issues with the vehicle is included in Appendix C. The majority of the buses have only had their engine replaced one time, but a few of the vehicles in the biodiesel fleet and in the petroleum diesel control group have had multiple engine changes.

BIODIESEL BUS NUMBER	ENGINE INSTALLED MILES	LIFE TO DATE MILES	ELAPSED ENGINE MILES	DATE LAST ENGINE INSTALLED
1012	364,095	540,644	176,549	8/31/2009
1013	545,412	561,649	16,237	4/25/2011 8/27/2014
1014	488,110	546,804	58,694	1/24/2013
1015	458,396	535,455	77,059	6/8/2012
1044	494,968	549,150	54,182	3/25/2013
1045	517,715	524,073	6,358	10/30/2014
1046	457,457	501,480	44,023	8/26/2013
2011	493,778	504,719	10,941	9/17/2014
2012	310,197	531,782	221,585	9/2/2011
2013	488,629	520,844	32,215	2/11/2014
2014	457,254	519,763	62,509	1/23/2013
2015	502,800	508,189	5,389	5/16/2011 11/5/2014
2016	394,458	442,459	48,001	11/23/2010 6/24/2013
2017	471,025	525,821	54,796	3/26/2013
2018	467,473	507,444	39,971	12/6/2013
2019	395,712	501,055	105,343	7/8/2011
2020	470,967	503,116	32,149	3/4/2014

Table 5 - biodiesel sub fleet engine rebuild information

PETRO DIESEL BUS NUMBER	INSTALLED MILES	LIFE TO DATE MILES	ELAPSED ENGINE MILES	DATE ENGINE INSTALLED
1047	103,061	607,688	504,627	Pre-2008
1048	567,529	568,567	1038	8/16/2013 1/22/2015
1049	275,566	574,078	298,512	11/17/2009
1050	536,610	607,279	70,669	6/17/2013
1051	377,921	607,394	229,473	12/17/2009
1052	357,984	563,140	205,156	6/7/2010
2040	583,670	637,232	53,562	1/24/2014
2041	443,245	610,547	167,302	6/10/2011
2042	587,894	625,339	37,445	4/16/2012 5/19/2014
2043	484,238	597,879	113,641	5/29/2012
2044	399,282	606,651	207,369	6/7/2010
2045	524,369	591,849	67,480	10/17/2013
2230	496,846	578,584	81,738	2/7/2013
2231	514,767	591,515	76,748	1/30/2013
2232	587,174	602,829	15,655	9/26/2011 8/1/2014
2233	473,042	628,199	155,157	1/10/2012
2234	496,879	615,643	118,764	8/7/2012

Table 6 - petroleum diesel control group engine rebuild information

It is difficult to determine if biodiesel directly causes overall engine life to decrease due to the sheer number of reasons an engine may be changed. Most commonly, engines are changed due to high mileage. Therefore, each one of the engine replacements listed above was investigated to determine if the mode of replacement for the engine was due in any part to the fuel system or fuel type used. Work orders were investigated for months prior to the engine being replaced, and the primary failure mode, if any, was noted.

Two immediate exceptions jump out when investigating why engines were changed on the biodiesel buses. The first case is with bus 1013. Bus 1013 had an engine replaced in April 2011 likely due to high mileage and minor defects. In August 2014, the bus had multiple issues with the engine, including coolant leaks in the cylinder, major fuel leaks, broken head bolts and other issues. In August 2014, before the engine suffered crippling damage, an oil lab analysis was returned that showed fuel oil dilution, with the sample taken only 5 days before the bus was diagnosed with engine failure. Though broken head bolts could be the result of any number of issues, the presence of fuel in the oil coupled with the fuel pump issues indicate that the primary mode of failure for this engine could be due to fuel system problems.

The second case with the biodiesel buses centers on bus 2015. Bus 2015 had an engine replaced in May 2011 due to camshaft issues, a problem very unlikely related to the fuel system. However, in November 2014, the bus had another engine replaced primarily due to the #1 exhaust bridge failing and associated camshaft issues. What is interesting is that the prior two oil lab results in August 2014 and October 2014 returned with fuel dilution in the engine oil (level 3 and level 5, respectively). Like bus 1013, the failure mode may have been due to the camshaft failure. However, the presence of fuel in the oil in the months preceding the camshaft failure indicates that the fuel could have been affecting the lubricity of the oil, and the fuel in the oil may be responsible for the camshaft failure.

On the petroleum fueled vehicles, only one bus appears to have had an engine failure that may be directly related to the fuel system. Bus 1048 had an engine replaced in August 2010. In January 2015, the engine was replaced again. The motor was diagnosed as running rough and the fuel pump had failed. In May 2014 and September 2014, the bus showed signed of fuel in the oil. Contrasting with the biodiesel buses that had engine failures with associated fuel dilution, the petroleum-fueled bus did not catastrophically fail. Bus 1048 (fueled with petroleum diesel) had the engine changed due to a knocking sound, whereas the biodiesel buses 1013 and 2015 were catastrophically damaged with major camshaft problems.

As described earlier, the camshaft, tappet and oiling issues with these buses may be a weakness of the engine design. Notably, 2 of the 17 buses in the biodiesel trial program fleet experienced camshaft issues that are also related to fuel dilution in the same timeframe. This indicates that biodiesel may accelerate or worsen the already weak camshaft and oiling system on the ISL engine.

SECTION 6: ROAD CALL INFORMATION

VTA employs a group of roving mechanics that assist in helping with bus road calls. A road call is where a driver feels that a defect or problem with the bus is severe enough that it should be addressed before the bus is put back into full regular service. Often times, a road call may be a minor defect that the road call mechanic can quickly fix using tools from their truck. Other times, the road call is serious enough that the bus is immediately pulled out of service and towed or driven back to the division for repairs.

Road calls are an important metric as it defines maintenance impacts to customers. Since road calls are often accompanied with service delays due to having to hold the bus on-route for repairs, customer service is affected, which has the potential of impacting ridership.

ROAD CALL CLASSIFICATION

When a bus is road called, the Operations Control Center (OCC) logs the road call and assigns a failure category to each call they receive. Failure categories are listed in Table 7. Road call data is collected and analyzed by the VTA Operations Analysis and Reporting Department, and is used for a variety of metrics including overall maintenance miles-between-road-call metrics which define maintenance performance for federal reporting.

ENGINE COOLING			**EXHAUST**		
	EC COOL	Coolant Leak		EH LEAK	Exhaust Leak
	EC MISC	Cooling Miscellaneous		EH MISC	Exhaust Miscellaneous
				EH SMOK	Excessive Exhaust
ENGINE					
	EN BCKF	Engine Backfire	**ENGINE FLUIDS**		
	EN HEAT	Engine Overheat		EO LOIL	Low Engine Oil Pressure
	EN LITE	Check Engine Light		EO MISC	Engine Oil Miscellaneous
	EN MGOR	Engine Override		EO OILL	Engine Oil Leak
	EN MISC	Engine Miscellaneous			
	EN NOST	Engine No Start	**FUEL SYSTEM**		
	EN POWR	Engine Power Loss		FL LKFU	Fuel Leak
	EN STAL	Engine Stalling		FL LOFL	Low Fuel
				FL MISC	Fuel Miscellaneous
TRANSMISSION				FL NOFL	Out of Fuel
	TR GEAR	No Gear Shift			
	TR LKFL	Trans Fluid Leak	**ELECTRICAL**		
	TR MISC	Trans Miscellaneous		EL MISC	Miscellaneous Electrical
	TR SLIP	Trans Slipping			

Table 7 - road call types for engine or performance

The road call classification primarily helps maintenance staff keep track of what breaks down the most on the road, and help identify areas of needed improvement. For example, a rise in road calls for doors would necessitate increased maintenance on door problems.

Initially, this report only investigated road calls that were attributed to the engine system of the bus. However, after further investigation, it was found that often times a bus would be road called for one reported or alleged defect but maintenance staff would find the root cause of the problem is attributed to a different defect. For example, a bus would be road called for an engine problem because it would not go faster than 25 miles per hour, however when mechanics troubleshot the bus they found that the transmission had failed and the bus would not shift out of second gear. Although the road call is still coded and classified as an engine road call, the root cause was transmission failure.

Likewise, some road calls originated as exhaust leaks that turned out to be fuel leaks. And some road calls originated as transmission problems that turned out to be fuel delivery issues. Further, many road calls are simply logged due to the presence of a check engine light. The driver has no way of checking the diagnostic trouble code (DTC) to determine what the engine computer module (ECM) is finding fault with, so the road call is generically logged as a "check engine light." When the mechanic troubleshoots the bus and reads the DTC off the ECM, he can quickly determine if the DTC was due to a fuel system problem, an exhaust aftertreatment (Cleaire) system problem, or another issue with the bus.

With the high degree of uncertainty in road call classifications and how they relate to the fuel system of the bus, this report quickly expanded the breadth of road call analysis to include virtually every road call for each bus in the program and the control group for the entire length of time of the report. In total, over 3,000 individual road calls were gathered and analyzed to determine if the fuel system or fuel type was a contributing factor to the road call.

Road calls due to doors, windows, mirrors or seats were quickly discarded after a brief review, but every road call relating to exhaust, engine, transmission, check engine lights, stalling or performance problems was analyzed in detail and then tied to a specific maintenance work order. The work order was reviewed in SAP, components that were issued as part of the work order were reviewed, and the detailed report from the mechanic doing the repair was analyzed to determine what the true root cause of each road call turned out to be. If the fuel system was found to be a determining cause, the work order and bus history was reviewed to greater detail to determine if a maintenance trend exists and if the fuel type (biodiesel or petroleum diesel) could be a contributing factor. In total, over 550 road calls were reviewed to this stringent level of detail to get a true count of how many road calls are directly related to fuel system problems. This analysis was completed for both the 17 biodiesel fueled buses and the 17 petroleum-fueled control group of buses. Road call information detail is shown in Appendix D.

ROAD CALL ANALYSIS

From October 2008 through the end of February 2015, the 17 biodiesel fueled sub fleet had 60 road calls that were directly related to the fuel system of the bus, including road calls relating to the DPF filter that were the result of fuel delivery or performance problems with the aftertreatment system. A significant portion of these road calls were due to fuel leaks from injector lines or fittings. Many other road calls were the result of poor bus performance, which was later determined to be an issue with the fuel system of the vehicle.

Road calls due to fuel leaks are concerning as there is a potential of fire due to fuel leaking on hot engine components. Each work order for a fuel leak was reviewed, but unfortunately the SAP maintenance data system often did not include sufficient detail to determine conclusively where the leak originated from. Many road call work orders were closed with the comments "leak repaired," without detail as to where the fuel was leaking. Other fuel leak work orders used parts from inventory, such as fuel lines or fittings, indicating that a particular line or gasket failed.

A few of the biodiesel bus road calls were originating from faulty fuel gauge readings. Road calls that were due to the gauge malfunctioning and not due to fuel sender issues were discarded. Likewise, road calls due to lack of fuel (such as the fuel island not fueling the bus the prior day) were discarded.

Road calls due to clogged DPFs were also tracked, as the DPF clogging could be the result of combustion chemistry issues on the biodiesel buses. The biodiesel sub fleet had 22 road calls directly attributable to exhaust aftertreatment problems. Exhaust aftertreatment issues result in check engine lights but also performance problems with poor vehicle acceleration being a primary complaint.

The petroleum fueled control group of buses over the same time period had 111 road calls that were directly related to the fuel system or exhaust aftertreatment system. Like the biodiesel sub fleet of buses, many of these road calls are the result of fuel leaks, faulty fuel gauges or performance problems that were the result of exhaust aftertreatment issues. The control group had 31 road calls that were attributable to exhaust aftertreatment problems.

Normalized for mileage, the biodiesel sub fleet ran 59,000 miles between road calls related to fuel leaks, exhaust aftertreatment issues, fuel system problems or performance problems relating to the fuel type on the vehicle. The petroleum control group ran 43,000 miles between road calls relating to similar metrics.

There are single buses that resulted in multiple road calls due to the same underlying root cause. For example, the petroleum-fueled bus 2230 had 11 road calls for multiple issues (on average 1-2 road calls per month for a period of 6 months) before fueling issues were found to be causing intermittent power loss on the road. Similarly, buses 2040 and 2045 in the petroleum control group each had multiple instances of DPF road calls before the DPF was finally replaced or repaired to solve the underlying issue. In the biodiesel sub fleet, notably bus 2011 had 5 road calls relating to a bad fuel sender, causing intermittent fuel level reading issues. Biodiesel-fueled bus 2017 had 5 road calls due to slow coach acceleration, which appear to have been resolved when the DPF was finally replaced. With these repeat road calls on the same buses, there is a high degree of statistical variability in the numbers. Therefore the difference of 16,000 miles between road calls for fuel or exhaust issues between the two study groups is not significant with a high degree of certainty.

Accounting for mileage variance, the biodiesel-fueled 2002 model year Gillig buses had an average of 98,000 miles between road calls related to the DPF or exhaust aftertreatment system. The petroleum-fueled 2002 model year buses in the control group ran 103,000 miles between exhaust aftertreatment road calls. This indicates that there is no significant difference in biodiesel or petroleum diesel performance of the exhaust aftertreatment as it relates to on-road and in-service vehicle operation.

The exhaust aftertreatment problems encountered most often were the result of clogged diesel particulate filters, which end up causing high exhaust backpressure. High backpressure can cause performance problems with slow acceleration or loss of top speed. Often, the solution to this problem is to clean or replace the DPF and ensure that the Cleaire system is properly going into 'regeneration' mode to burn off excess soot.

The issue of performance on-road is of concern when using biodiesel. Since biodiesel has a lower combustion energy than petroleum diesel (as shown by lab testing), it could be assumed that biodiesel use would cause an increase in performance-related road calls. Detailed analysis of the road call data shows that there was not a single road call relating to performance of the bus (slow coach, poor acceleration, lack of top-speed on freeways, etc.) that was related specifically to fuel type. Each road call on the biodiesel fleet that was related to vehicle performance was directly attributable to a failure of a component, and not due to fuel combustion chemistry alone.

Further, VTA did performance testing of a biodiesel bus using B5 and B20 during the switch-over from B5 to B20 in late September, 2010. Since the B20 was expected to give lower acceleration rates compared to the petroleum diesel buses, concern was raised that drivers would not be able to operate the buses in a manner they were used to. Acceleration tests were completed using B5, B20 and petroleum diesel buses. Each bus in the test was fueled to maximum capacity and had not run on route that day. The bus was started, allowed to warm-up, and drove to the nearest on-ramp. From a stop, the driver applied full throttle and the time it took to reach 55MPH was timed. The results of the testing showed that B5, B20 and petroleum diesel all had comparable performance acceleration rates on the vehicle. These results are consistent with the lack of performance-related road calls on the biodiesel fleet throughout the duration of the trial biodiesel program.

ROAD CALL CONCLUSION

After analyzing thousands of road calls and investigating hundreds of detailed SAP work orders, it was found that biodiesel does not contribute with a high degree of certainty to a higher or lower number of road calls on vehicles compared to petroleum diesel fuel. The variability in maintenance practices between divisions, repeat road calls on the same vehicle before a problem was fixed and normalizing road calls by mile all point to the fact that biodiesel and regular diesel have similar performance characteristics on vehicles during operation.

While biodiesel does have a lower combustion energy than petroleum diesel, the lack of increased road calls relating to performance on the biodiesel fleet indicates that biodiesel does not cause a significant performance problem for operations. Performance testing completed by VTA in late 2010 on B5, B20 and petroleum fueled vehicles support this finding. The data shows that biodiesel use up to B20 concentration does not pose a performance issue for VTA transit operations.

SECTION 7: UNDERGROUND STORAGE AND FUELING OF BIODIESEL

A significant aspect of biodiesel use relates to how biodiesel interacts with existing storage and pumping infrastructure. Closely related is the delivery of biodiesel, biodiesel blend quality, contractual requirements and fuel certifications.

The literature review discussed issues relating to underground storage and separation problems with biodiesel blends. In particular, transit agencies using biodiesel blends have experienced fuel separation and delivery problems relating to the quality of biodiesel they were being delivered. VTA is no exception, and this section will discuss the myriad problems VTA has encountered relating to biodiesel quality, delivery, storage, handling and testing throughout the trial biodiesel program.

BASIC FUEL DELIVERY, STORAGE AND PUMPING INFORMATION

Fuel is supplied to VTA via contracted fuel suppliers, who deliver fuel based on need and usage. Fuel is pumped into tanker trucks at the fuel supplier 'rack,' and delivered (or "dropped") at VTA when fuel levels in the underground storage tanks at each division reach a certain level.

At VTA's North Division, fuel is kept in four separate underground storage tanks (USTs). One tank is dedicated to gasoline, one tank is for biodiesel, and two tanks hold regular diesel. The biodiesel tank holds approximately 20,000 gallons when at capacity and was installed at the North Division Fuel Island in early 2008. The tank was manufactured by Xerxes Corporation and is certified to be compatible with up to B20 biodiesel blends.

The underground tank system monitors fuel level via a Veeder Root monitoring system. The Veeder Root system also monitors tank abnormalities and detects for leaks that could indicate diesel fuel is leaking into the soil surrounding the tanks. Underground storage tank and fuel pump maintenance, servicing and repair is done by outside contractors. VTA staff monitors the tanks daily and logs any defects or alarms that are seen and reports them to the contractor for repair.

Fuel is pumped from near the bottom of the tank (a few inches off the true bottom of the tank) to a distribution piping system which sends fuel to the individual pumps. Biodiesel pumps are located at 3 of the 4 fueling lanes at the fuel island. Biodiesel pumps are fitted with 4-prong connectors as opposed to 3-pronged connectors used on petroleum diesel fueled vehicles.

Throughout the biodiesel trial program, samples were taken from the underground storage tank at random intervals to determine two major points. First, the samples prove that we are getting biodiesel at the blend quantity specified in the contract. Since biodiesel is more expensive than petroleum diesel, VTA wants to ensure it is getting the fuel it is paying a premium for. Second, the samples show any storage separation or contamination issues in the UST. Periodically samples are also pulled directly from the delivery truck and pulled from the fuel pump nozzle. Samples are sent to a laboratory where ASTM tests are completed and results sent back to VTA Quality Assurance staff for analysis. Any issues are then addressed with the fuel supplier for remediation. A couple of examples of laboratory testing results are shown in Appendix E for reference.

B5 BIODIESEL DELIVERY AND SAMPLING RESULTS

The initial biodiesel trial program from October 2008 through September 2010 used a 5% soy-methyl-ester biodiesel and 95% petroleum diesel blend, pumped into the standing infrastructure at the North Division. Samples were periodically taken at random intervals beginning in July 2009 to determine the blend quantity amount and any separation issues that were occurring. Table 8 below shows the sample date, sample location and blend quantity results for the samples during the B5 testing program.

B5 Fuel Sample Results					
Sample Date	**Bottom of Tank**	**Middle of Tank**	**Top of Tank**	**From Nozzle**	**From Truck**
7/1/2009	>35.00%	-	4.11%	-	-
7/27/2009	5.53%	1.03%	-	-	-
8/19/2009	-	-	-	5.06%	-
8/28/2009	5.48%	5.27%	-	-	-
2/17/2010	3.69%	3.65%	2.27%	-	-
4/9/2010	-	-	-	-	4.33%
4/21/2010	-	-	-	4.45%	-
4/28/2010	5.60%	4.40%	3.80%	-	-
6/16/2010	5.38%	5.64%	-	-	-

Table 8 - B5 sample results by date and percentage of biodiesel

As can be seen by the table, the first sample taken in July 2009 showed severe separation. Coast Oil, the contracted supplier, was using splash mixing in the tank by 'dropping' the petroleum diesel first, and adding the biodiesel on top. This is recommended from industry standards, but only if the biodiesel is in fact dropped directly on top of the regular diesel and given sufficient room to homogenize in the tank. However due to the fill tube on the underground storage tanks at VTA going to the bottom of the tank, by dropping biodiesel last, it actually filled up the bottom of the tank since the delivery tube opens at the bottom of the tank. The heavier biodiesel never had a chance to splash mix with the petroleum diesel and stayed on the bottom of the tank.

Coast Oil changed their delivery process in mid-July 2009 to drop biodiesel first and fill the remainder of the tank with petroleum diesel. As can be seen by the July 27, 2009 sample results, the mixture was more slightly more homogenous but still did not meet BQ-9000 specifications. As stated in the literature review, BQ-9000 specifications require a B5 blend to be homogenously mixed anywhere from 4.50% to 5.50% biodiesel.

Around this same time staff at VTA proposed the addition of an in-tank agitator which would mix the fuel in the tank at periodic times throughout the day. This would mitigate any separation issues and allow fuel to be continuously mixed to a 5% blend level (assuming fuel was delivered in 5% blend quantity). The cost estimates for adding an in-tank agitator were deemed too expensive for the trial program and were abandoned in favor or pressuring the supplier to deliver homogenous products without separation problems.

With Coast Oil trying new delivery methods, samples were taken from the tank and from the fuel dispenser nozzle in August of 2009. Sample results showed B5 blends well within BQ-9000 specifications, and Coast Oil continued to use the new delivery method with the approval of VTA.

Six months later in February 2010, random samples were again pulled to ensure quality assurance of the B5 biodiesel. Samples returned consistently below 4% for each three levels in the tank (top, middle and bottom). The likely culprit of this was due to separation, with the heavier biodiesel separating to the bottom of the tank and being siphoned off to the pumps before the samples were pulled. To remedy the issue, Coast Oil increased the amount of biodiesel in the next delivery to ensure that the overall tank blend would equate to 5% after the fuel was dropped.

In April of 2010, a random sample was taken from the nozzle and from the delivery truck with samples returning slightly below the 4.50% threshold of BQ-9000 specifications. Samples taken from the tanks a few days later in late April 2010 showed that separation of the biodiesel was still occurring at moderate levels with the heavier biodiesel staying at the bottom of the tank. In June 2010, once again the delivery was altered to ensure that the end result would equate to a homogenous 5% blend. Samples taken in mid-June 2010 confirmed that the altered delivery method and increased biodiesel quantity in one delivery resulted in Biodiesel at approximately 5.5%.

B20 BIODIESEL DELIVERY AND SAMPLING RESULTS

In September 2010, the author of this report completed a preliminary and abbreviated study looking at the total cumulative effect of using B5 in transit buses and determined that the trial biodiesel program did not result in noticeable or insurmountable issues. A decision was made to switch to a higher concentration B20 biodiesel blend for use in the 17 biodiesel transit buses. The tank monitor was closely watched in the days prior to the switchover, with the tank being pumped to a relatively low level to ensure that the new B20 blend would account for the majority of fuel in the tank. On October 1, 2010, Coast Oil dropped 7500+ gallons of approximately B30 into the UST, bringing the total underground storage tank concentration to 20% biodiesel. The math was checked by various staff at VTA to ensure the end result equated to B20 in the UST.

As with B5, random samples were taken from October 2010 through the end of 2014 to test the blend quantity amount and determine if any separation issues were occurring. Table 9 below shows the sample date, sample location and blend quantity results for the samples during the B20 testing program.

B20 Fuel Sample Results					
Sample Date	**Bottom of Tank**	**Middle of Tank**	**Top of Tank**	**From Nozzle**	**From Truck**
10/12/2010	28.00%	16.42%	17.76%	-	-
11/18/2010 Filler Loc.	27.70%	26.91%	27.67%	-	-
11/18/2010 Sensor Loc.	27.28%	27.89%	26.98%	-	-
7/27/2011	14.12%	0.75%	0.75%	-	-
7/19/2013	0.20%	0.20%	0.40%	-	-
8/21/2013	0.19%	0.11%	0.11%	-	-
9/9/2013	-	-	-	25.19%	-
11/20/2013	0.10%	0.10%	0.10%	-	-
1/21/2014	1.20%	1.01%	0.82%	-	-
1/21/2014	0.35%	4.47%	0.76%	-	-
1/21/2014	22.31%	8.07%	-	-	-
1/21/2014*	8.40%	8.10%	0.00%	-	-
1/21/2015	22.17%	25.65%	24.98%	-	-

Table 9 - B20 sample results by date and percentage of biodiesel
*(*samples on 1/21/2014 were tested by SC Fuels designated test laboratory, not by VTA)*

Shortly after B20 delivery, samples were pulled from the biodiesel UST and tested, and immediately severe separation issues were noted by the sample results returned in October 2010. Coast Oil changed their mixing process to include rack mixing at the delivery plant, and deliver 20% biodiesel to VTA in a single compartment of the delivery truck. This helped increase the amount of mixing due to splash mixing while in the truck when getting delivered and also ensured a more consistent temperature at which mixing occurred.

Samples were pulled again in November 2010, and on the recommendation from biodiesel experts samples were pulled from two separate locations on the tank, at the top, middle and bottom of each location. The first location was the sensor tube. The sensors in the sensor tube were removed and samples were pulled from this location, which is situated near the pump at one end of the tank. The second location was the fuel delivery tube, where fuel is dropped into the tank and where all previous samples were pulled from. By pulling samples from two locations, any separation issues not just vertically in the tank, but horizontally would be found as well. The samples all came back close to each other, indicating the rack mixing was working and also showing that horizontal homogeneity was achieved, but the samples were high in biodiesel concentration.

High biodiesel concentration is a concern for two reasons. First, Cummins only certifies biodiesel up to B20 in their engines, and also specifies fuel must meet BQ-9000 specifications. This means that B20 pumped into the bus fuel tank must be between 19% and 21% biodiesel by volume concentration. Higher concentrations of biodiesel being pumped into the buses brought concern over warranty issues and concern over increase wear or performance issues relating to higher concentrations of biodiesel.

Coast Oil responded and again tailored the delivery to ensure we would end up at exactly 20% on the next delivery. It should be noted that throughout the early stages of the biodiesel trial program, Coast Oil and their VTA representative were generally responsive to issues relating to biodiesel blend quality or fuel delivery issues, and they worked with VTA staff to ensure timely corrective actions were put in place. Positive supplier relations helped ensure success of these early hurdles and contributed to an environment of mutual learning.

The next big issue that faced VTA was in late 2010 when the City of Mountain View ran into problems concerning the permitting for underground storage of B20 biodiesel. VTA applied for a variance with the city to store 20% biodiesel, and initially the variance was denied due to technicality issues with the Veeder Root monitoring system and the tank manufacturer. Plans were made by VTA and Coast Oil to siphon the biodiesel from the tank and fill the tank with B5 until the B20 variance was granted. The city inspector allowed the remaining B20 in the tank to be used up but specified future deliveries need to be B5 until the variance was granted and technical questions were answer.

Veeder Root confirmed that their monitoring system passed functionality checks with B20 by using a third party testing agency. Further, documentation from the tank manufacturer stating that their tanks are compatible with B20 were generated and submitted to the City of Mountain View. VTA's Environmental Health and Safety department spearheaded the process of getting approval with the city to use B20, and in early January 2011, the variance was granted to use B20 biodiesel. The biodiesel trial program resumed with B20 SME biodiesel in early January, 2011.

In July 2011, the next set of random samples were pulled from the UST, with results shown in the table above. Separation issues were still occurring and it appeared the method of blending was sporadic in ensuring consistent blend levels. Coast Oil and VTA met and once again tailored the biodiesel delivery to ensure a homogenous 20% biodiesel blend was met at the next delivery date.

Sampling was largely abandoned after July 2011 due to operational changes and staff reassignments at VTA. In July 2013, after two years of running B20 with little incident to buses or to infrastructure, random samples were again pulled from the underground storage tanks. The results were surprising, showing far less than 1% biodiesel concentration in all three samples. Believing the sample results were erroneous due to laboratory issues, another set of samples were pulled after the next biodiesel delivery in August 2013, sent to a different lab for testing, and results returned showing the same as previous samples at less than 1% biodiesel by concentration for all tank levels. It should be noted between 2011 and 2013, fuel suppliers changed due to contract time limits. The new fuel supplier was SC Fuels based in San Jose, CA.

With sampling issues found in previous testing, VTA pulled a sample directly from the nozzle, which tested at over 25% biodiesel by concentration, far above the B20 requirement. Thinking that the issue was with sampling problems, a fourth sample set was taken from three locations in the tank. Results showed less than 1% biodiesel for these tests as well. Therefore, 3 out of 4 sets of testing showed next to no biodiesel concentration in the tank. Also noted with a few of the samples was the large presence of red dye or red material in the biodiesel. Whereas previous biodiesel samples showed amber-hued biodiesel, the samples taken from SC Fuel-supplied biodiesel were red in color. Red-dyed fuel is typically used for off-road purposes and does not meet on-road fuel requirements set by the EPA and CARB.

Concern was immediately raised to high levels within VTA. First and foremost, VTA was paying a premium price for biodiesel, and it appeared that the new supplier was shortchanging VTA by not delivering biodiesel at all and pocketing the profits from VTA's additional payment for biodiesel. Initial speculation was that upon hearing VTA was completing random sampling, a single drop of high-concentration biodiesel was delivered to mitigate VTA's concerns (which explained the from-nozzle test result of 25% biodiesel), but deliveries of non-conforming biodiesel resumed afterward. Further concern was raised that SC Fuels may have been delivering off-road diesel fuel (red-dye diesel), which is even cheaper than petroleum fuel.

In early December 2013, a formal notice of contract nonconformance letter was sent to SC Fuels and VTA waited for their suggested resolution to the issues that were found. VTA, in the meantime, planned to switch all 17 biodiesel buses back to petroleum diesel and halt all future scheduled deliveries of biodiesel to the division. On December 23rd, 2013 VTA stopped using biodiesel and kept the remaining biodiesel in the tank as evidence of contract non-conformance. All 17 biodiesel buses in the trial program began being fueled with standard petroleum diesel. The biodiesel pumps were electrically shut off so fuel island personnel could not use the pumps, and the pumps and underground tank were sealed closed.

In early January, discussions with SC Fuels led to another round of sampling before corrective action was to take place. SC Fuels wanted to send a set of samples to their own lab and have one of their employees present for the sampling process. 11 samples were pulled in total. The results are shown in the table above, and range from below 1% biodiesel to over 22% biodiesel by concentration.

Figure 13 - January 21, 2014 biodiesel samples from UST

The author of this report was present for the taking of these samples. Of interesting note, when multiple samples were pulled from the same location (i.e. the first, second and third samples consecutively taken from the bottom of the tank), the color of the biodiesel changed, indicating the regional separation of biodiesel was occurring in very small locations in the tank. Figure 13 clearly shows that of the four samples labeled 'mid' (for middle of the tank), separation issues were occurring even at the level where the sample was pulled. Staff confirmed and witnesses at the sampling concurred that the samples were being pulled from the same depth in the tank.

Due to the varied test results, discussions between VTA and SC Fuels in late January 2014 led to the decision to completely drain and siphon the existing biodiesel in the tank, completely scrub the tank clean, and refill the tank with new B20 biodiesel. On February 13, 2014 SC Fuels brought out a tank truck and siphoned all fuel out of the biodiesel tank and credited VTA for the amount of fuel that was removed. Shortly after, a tank cleaning crew came and scrubbed the tank clean of any biological contamination and sludge. The tank was reassembled and fresh B20 SME that met BQ-9000 certification was delivered to the UST. At this point in the biodiesel program, all concern over the quantity of biodiesel was mitigated and fueling of the biodiesel buses resumed.

In October, 2014, SC Fuels advised that they had delivered canola-based B20 biodiesel instead of SME biodiesel. Initially, VTA was not sure that the fuel that was delivered was BQ-9000 certified or tested to meet our contractual obligations. SC Fuels timely responded with a Certificate of Assurance from Whole Energy and Certificate of Analyses from North Star Biofuels and the Renewable Energy Group that certified the canola B100 met all required specifications and was approved to use in place of SME biodiesel.

A benefit of switching to a canola-based B20 blend is that it gives VTA another chance to determine if canola resolves many of the mixing and separation issues experienced with SME biodiesel. Canola could possibly affect the operation or performance of the bus, however since the blend quantity did not change from SME B20 to canola B20, VTA estimates that impacts will be minimal.

In January, 2015, a set of random samples were taken from the UST to determine what the blend quantity of canola B20 was in the tank, with results between 22% and 26% biodiesel by volume. This indicates that separation is occurring. Although interestingly the bottom of the tank, which historically showed higher concentrations of biodiesel during separation, showed the lowest concentration in this round of testing. The error is thus attributed to sampling methods or micro-separation issues at the filler tube, and the general consensus from staff at VTA is that the canola-based B20 is generally mixing well, although the blend amount was high for what was specified.

STORAGE AND FUELING CONCLUSION AND RECOMMENDED ACTIONS

The biggest hurdle VTA encountered in the 6+ years of testing biodiesel blends in transit buses was without question the quality of fuel being delivered. The literature review discusses issues with out-of-spec biodiesel and separation problems using biodiesel blends, and VTA is no exception. Fuel mixing problems accounted for sometimes severe disturbances to the test program and to fueling operations. Shutting down the biodiesel trial program for any length of time equates to lengthy delays in fueling operations (due to having to switch pumps and filler necks on the biodiesel buses) and costs the company time and money trying to solve the issues.

Though costs are difficult to quantify, considerable resources were expended by VTA staff in the resolution of mixing issues. Generally positive supplier relations helped ease some of the issues early on in the program, but later issues when the supplier switched and the severity of problems encountered caused considerable impact on VTA operations.

Without question, this analysis shows that the existing methods of biodiesel delivery, storage and handling with existing underground storage tanks was generally a failure. Multiple issues spanning years and years were not mitigated without fear that separation or quality issues would return. As testing results showed again and again, issues did return and resources were again expended to solve the problem.

Three key recommendations accompany this section analysis. First, good supplier relations can help mitigate issues that are found during the program. Having a supplier who is readily willing to address problems in a timely manner, and work with the customer to develop solutions helped VTA solve issues with early mixing problems. On the converse side, poor supplier relations that tended to 'blame' one side or another for problems only tended to drag out solutions and add delays to the trial biodiesel program.

Second, strong contract language the mirrors existing BQ-9000 certification requirements and engine OEM requirements helps ensure success of a biodiesel program. VTA called for BQ-9000 certified fuel in contract language, and when issues were encountered with quality of fuel delivery or with mixing problems, this language was heavily relied upon to VTA's benefit. While suppliers could have pressured VTA into believing quality control issues with the fuel were a result of tank geometry or sampling methods (as some suppliers tried to do), the contract provided the foundation for putting the onus on them to solve issues, which helped alleviate the burden to VTA.

Third, any serious or long term biodiesel program should give considerable thought to designing underground storage tanks and fueling infrastructure specifically with biodiesel in mind. Whereas early cost projections negated the installation of a fuel tank agitator, looking back at the program, it is clear that this expense likely would have been worth it given the myriad problems encountered. Further, since VTA used a relatively new underground tank for the biodiesel trial program, specifying an agitator during tank installation would have saved cost later on in retrofitting existing tanks.

If agencies are serious about using biodiesel or wish to expand existing programs, it is highly recommended that fuel storage infrastructure be modified up-front to reduce potential mixing or separation issues down the road. This is likely more important in continental climates where temperature swings are more severe than in San Jose, California. The upfront cost of adding in-tank agitators or specifying rack mixing of biodiesel will save the agency time and money in the long run.

For VTA specifically, if the trial biodiesel program is expected to continue for an extended period of time, it is recommended that cost estimates be developed for adding in-tank agitators, and that these costs are built into the capital projects budget for facility improvements. In addition, it is highly recommended that future contract language be further strengthened to give VTA assurances that they can hold suppliers to high quality standards, and also to support suppliers with clear language that specifies what the customer needs to fulfill business objectives.

SECTION 8: BIODIESEL COST & FUEL ECONOMY INFORMATION

First-generation biodiesel (corn and soybean-based biofuels) purchased from suppliers and bought in large quantities generally costs more than regular diesel. It is expected that all aspects being considered equal and without other contributing factors that biodiesel-fueled buses will be more expensive to operate than petroleum-fueled vehicles of the same type.

No biodiesel program analysis would be complete without an investigation into cost impacts of using biofuels, and this report is no exception. Though the main focus of this report is to analyze how biodiesel affects the maintenance, operation and storage of biodiesel in transit operations, a significant aspect of using biodiesel revolves around two cost metrics; miles-per-gallon (which determines overall efficiency and affects costs), and fuel costs compared to petroleum diesel. This section analyzes these two aspects of the VTA trial biodiesel program.

BIODIESEL COST PER GALLON COMPARISON

Biodiesel blends generally are more expensive than petroleum diesel for use in on-road vehicles. As part of this analysis, the overall cost of biodiesel is compared to petroleum diesel. VTA closely tracks fuel costs and keeps records on the price of fuel when orders and deliveries are made. For ease of analyzing the myriad of data over the trial timeframe, the average cost per-gallon of petroleum and biodiesel blends is shown below in Figure 14.

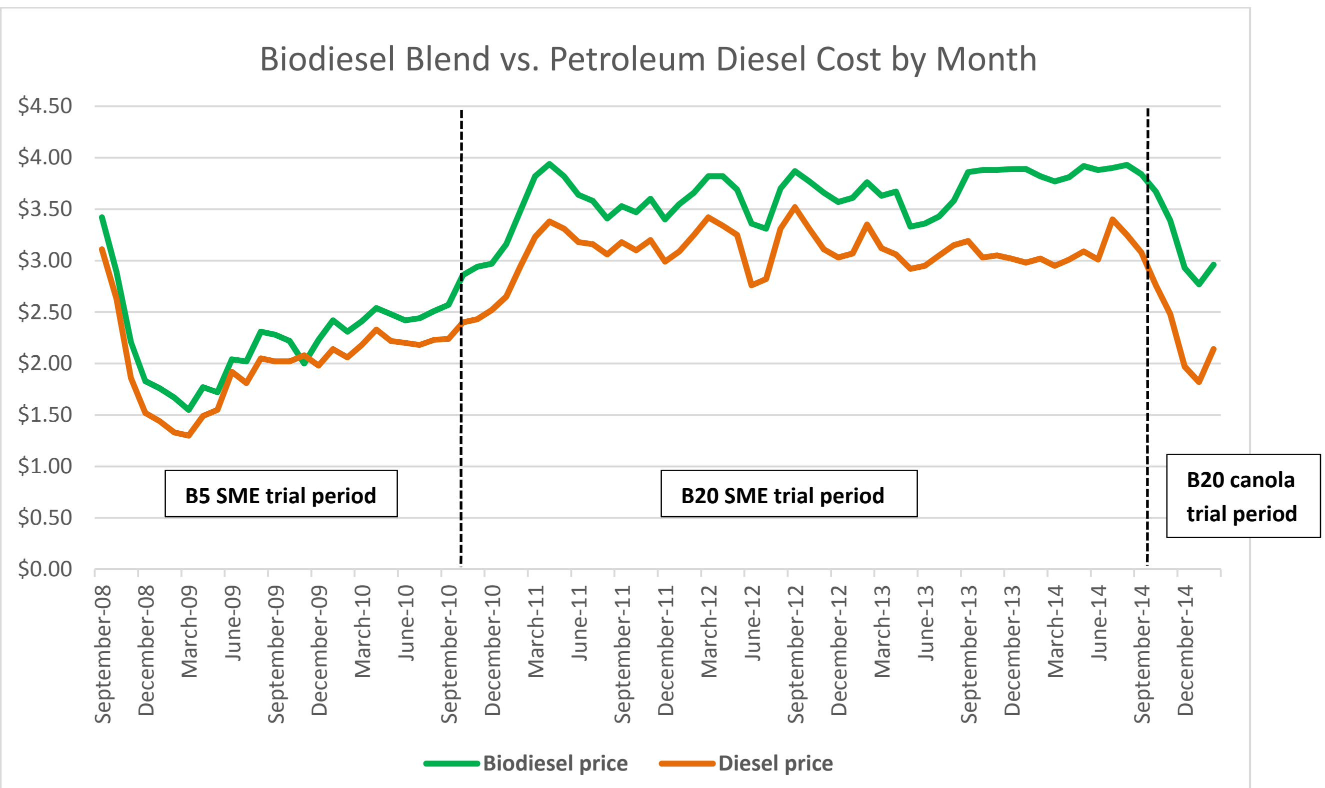

Figure 14 - biodiesel versus petroleum diesel cost by month, Sept. 2008 through Feb. 2015

Of immediate note is that biodiesel has been more expensive than petroleum fuel for the entire duration of the trial program, with a brief exception in November 2009 where B5 biodiesel was 8 cents cheaper than petroleum diesel (averaged over the entire month). Note that in October 2010, VTA switched from a soy-based B5 biodiesel blend to a B20 biodiesel blend, which explains why the cost difference went up slightly from the autumn 2010 through the end of the program. The costs shown in Figure 14 are the average cost paid by VTA for fuel over each month and are not representative of what may be paid at public fuel pumps and may not follow industry pricing.

Biodiesel blend purchasing price closely follows swings in petroleum diesel price, which is expected since up to 80% or more of the fuel blend is made with petroleum diesel. B5 cost an average of $0.25 more per gallon than regular diesel from October 2008 through September 2010. B20 soy-methyl-ester biodiesel cost an average of $0.55 more per gallon than regular diesel during the B20 SME trial period of October 2010 through September 2014. Of interesting note, B20 canola-based biodiesel cost an average of $0.91 more per gallon than regular diesel from October 2014 through February 2015. These costs can be considerable over the life of the trial program. Further cost information is included in Appendix F.

BIODIESEL FUEL EFFICIENCY

As noted in the literature review section of the report, biodiesel can reduce fuel economy due to the lower combustion energy produced when biodiesel ignites in internal combustion engines. With this knowledge, it is prudent to investigate fuel economy losses or gain when switching from petroleum diesel to biodiesel blends. Fuel efficiency directly affects fuel costs, as greater fuel economy translates into fuel savings due to fuel use. This is offset somewhat when comparing biodiesel to petroleum diesel, as biodiesel is typically more expensive than standard petroleum diesel products.

Each night buses are fueled on the fuel island. Depending on daily pullout requirements, bus operational roles and buses in the shop for maintenance, only a portion of vehicles are fueled each night. The information regarding fueling of the buses is logged by Fuel Island personnel, who note the odometer mileage, the amount of fluids (diesel, oil, coolant, etc.) used, and the bus number. The following day, this information is input into VTA's internal data collection system. Each day, a fuel reconciliation report compares the fuel dispensed into the buses with the fuel readings from the tanks. If there are large discrepancies, investigations are completed, but typically fuel reconciliation accounts for approximately 95% or more of the fuel used. The approximate 5% variation is due to error in tank reading equipment or log sheets.

In order to calculate sub fleet fuel efficiency, each vehicle's monthly start and end mileage was gathered, and the difference between the two was calculated to get a value of how many miles the bus travelled in the month. VTA's data system was queried and the amount of fuel each vehicle used per month was gathered. The analysis looks at timeframes of one-month (as opposed to daily) since often vehicles are fueled but do not run the next day, or vehicles run during the day but may not be fueled. By examining fuel efficiency over the entire month, discrepancies are normalized by the overall mileage and fuel used. Month-to-month variations are normalized by looking at the entire 6+ year program and averaging the month-to-month fuel economy for each vehicle.

Once the miles-travelled-per-month and fuel-used-per-month calculations were completed, the fuel economy by month was calculated for each vehicle in each sub fleet. Then, for each vehicle, the fuel economy information corresponding to each trial program start and end date was calculated and averaged for the entire sub fleet. The results are shown in Table 10.

FUEL TYPE	DATE RANGE	FUEL ECONOMY (MPG)
B5 SME Biodiesel	October 2008 through September 2010	4.52
B20 SME Biodiesel	October 2010 through September 2014	4.28
B20 Canola Biodiesel	October 2014 through February 2015	4.48
Petroleum Diesel (control group)	October 2008 through February 2015	4.27

Table 10 - fuel economy by fuel type and date range

It is immediately interesting to note that B5 use showed an increase in fuel economy compared to the petroleum diesel buses. Likewise, the B20 canola-based biodiesel showed an increase in fuel economy compared to the petroleum diesel. The B20 SME biodiesel fuel economy is comparable to petroleum diesel control fleet fuel economy with only a 0.01 difference, which is statistically insignificant.

It is important to the recognize that the biodiesel buses run out of the North maintenance division, whereas the control group of petroleum diesel buses run out of the Chaboya and Cerone divisions. The North division typically sees lighter ridership and less traffic than buses that run from the other two divisions (on normal 40’ standard-service bus routes). This accounts for some of the variation in fuel economy data.

Perhaps of most significant note is that biodiesel did not in any case contribute to a noticeable decrease in fuel economy compared to the control group of buses. This is important as laboratory testing indicates that small decreases in fuel economy could be expected when switching to biodiesel blends.

Further, as noted briefly in the literature review, the large number of differences in operator driving habits, route selection, traffic conditions, ridership information and other factors all affect fuel economy information to varying degrees. For purposes of cost analysis, it will be assumed that fuel economy information between biodiesel buses and regular diesel buses is not affected to a large enough degree to account for significant variation in the amount of fuel purchased at VTA.

BIODIESEL TRIAL PERIOD FUEL COST DIFFERENCES

Knowing the miles each bus travelled and the average cost-per-gallon by month for the duration of the trial program allows for calculation of what was spent total on biodiesel over the life of the program. Further, since the cost of petroleum diesel over the same timeframe is known, a calculation of how much extra was spent on biodiesel for the 6+ years of the trial program is possible. This data is useful as it tells how much of a cost burden the biodiesel program has been and how much may be saved by switching to regular petroleum diesel and abandoning future biodiesel program expansion.

For each bus in the biodiesel program, the cost of fueling each month was calculated. In total, VTA spent approximately $2.54 million to fuel the 17 buses in the biodiesel trial program from October 2008 through February 2015. If these buses had been fueled with petroleum diesel, the cost would have been approximately $2.16 million. The difference of approximately $380,000 is how much additional cost VTA spent on the 17 bus trial program in the six years and four months since the trial began. This equates to an additional $5,000 per month, or $60,000 per year to fuel the buses with biodiesel.

BIODIESEL COST CONCLUSION

Soy-methyl-ester biodiesel blends in B5 to B20 concentration and B20 canola-based biodiesel blends cost more than standard on-road petroleum diesel. Fueling buses with biodiesel brings additional costs to the organization solely on account of increased spending for fuel. Though fuel economy was not altered to a significant degree, the additional $380,000 spend to fuel 17 buses with biodiesel blends is a large cost to the organization.

With increased focus on financial stability and smart spending, it is prudent for organizations wishing to start or expand biodiesel programs to do a full cost analysis and estimate of the cost burden of using biodiesel. While environmental benefits of biodiesel may be argued as the driving reason for using biodiesel, the cost burden should not be overlooked, and may be the determining factor as to whether biodiesel is sustainable in cash-strapped transit organizations.

SECTION 9: CONCLUSION

Biodiesel blend use at the Santa Clara VTA has yielding valuable information that will help guide policy recommendations for the future of renewable fuel use in public transportation. Information learning in the 6+ years of B5 and B20 use in 17 transit buses gives a clear picture of where to head now that results from biodiesel testing are available. This section briefly reviews results from the research report and includes policy recommendations for the future of the biodiesel trial program at VTA.

BIODIESEL IN TRANSIT BUS OPERATION CONCLUDING REMARKS

Whereas other reports on biodiesel in public transit focused on limited timeframes of one or two years or only looked at specific attributes of biodiesel, this report has the benefit of looking at a sustained 6+ year timeframe of B5 and B20 use in transit fleet operation. This long-range picture gives the benefit of normalizing some of the statistical variability present in shorter testing reports and gives a much broader indication of how biodiesel affects transit operations.

Soy-methyl-ester biodiesel blends in B5 to B20 concentration are shown to have negative impacts on ISL-type Cummins diesel engines with the CAPS-type fuel system. High-value components such as fuel pumps and fuel injectors are used more frequently than on petroleum-fueled vehicles of the same make and model. While some fuel system components appear to be unaffected by biodiesel use, the increase in parts like fuel senders shows that B5 and B20 use does correlate to higher instances of component replacement. Use of diesel particulate filters was noticeably lower on biodiesel buses, likely due to the decreased particulate matter biodiesel emits.

Further, two instances of biodiesel fuel dilution that resulted in catastrophic engine damage are concerning as is shows that biodiesel can adversely affect an already weak oiling and camshaft system on Cummins ISL engines. Research shows that when biodiesel gets into engine oil, the engine typically fails in a relatively short amount of time with corresponding major damage. While the petroleum-fueled control group of buses had higher rates of fuel dilution in engine oil, only one case was encountered when fuel in the oil necessitated an engine overhaul, and in that instance the damage was not as catastrophic as on the biodiesel buses.

Road calls were not generally affected by fuel type, with the biodiesel buses experiencing slightly fewer road calls related to fuel system or aftertreatment system issues compared to the petroleum-fueled control group. It should be noted however that the difference is not statistically significant since there is high variability in road calls by vehicle due to repeat problems or repeat complaints on the same vehicle. This is important to note since road calls directly impact customer service, and understanding that biodiesel does not adversely affect the customer riding experience is an important aspect of this report.

VTA experienced significant issues with fuel separation and fuel quality. Biodiesel and petroleum diesel separation occurred regularly, and was only mitigated with direct and frequent interaction between VTA and the fuel supplier. Changing mixing methods only partially solved the issues, and when suppliers and contracts changed fuel separation problems immediately occurred again. This aspect of the trial program took significant resources away from other maintenance activities as personnel from various departments had to constantly solve problems relating to fuel separation or quality control issues. This is consistent with what other transit agencies experience in their biodiesel programs.

Lastly, cost impacts were significant and account for considerable expense on only 17 buses. It cost approximately $380,000 in additional costs to fuel the 17 buses with B5 for two years and B20 for 4 years and 4 months compared to regular diesel. Extrapolating this cost increase out to the entire fleet of nearly 500 buses would amount to a considerable cost increase in operations if VTA decided to expand the biodiesel program to the entire fleet. Fuel economy between biodiesel fueled buses and petroleum diesel control group buses was not generally affected with a large degree of certainly, even though biodiesel blends do have less energy than petroleum diesel.

RECOMMENDED ACTIONS

There is ongoing discussion among leaders in transportation that requiring renewable fuels to be a portion of fleet diesel consumption be mandated via state or federal legislation. While the federal government requires a certain percentage of all fuel sold in the United States to be renewable, direct and specific requirements on public transit fleets has not yet been implemented. Discussions at the California Air Resources Board, along with local air quality districts such as the Bay Area Air Quality Management District may require biodiesel use in the future for public transit operations.

It should be noted that the transit buses used for the trial biodiesel program are 2001 or 2002 model year vehicles with a planned retirement sometime in the next 5 years. With this in mind, and having the benefit of clearly knowing how biodiesel affects theses conventional diesel transit buses, it is prudent for VTA to investigate how biodiesel may affect newer transit buses with hybrid diesel-electric powertrains. Since VTA only purchases hybrid diesel-electric transit buses on all vehicle procurements since 2010, understanding and knowing how biodiesel affects these powertrains is important, especially in light of possible future legislation requiring biodiesel blend use at public transit agencies in California.

With this in mind, it is recommended that the biodiesel trial program be terminated in the existing 17 buses at VTA’s North Yard Division. It is recommended these vehicle return to petroleum diesel use and have their conventional diesel fuel filler caps replaced. VTA has learned essentially all that can be learned from using biodiesel in these 2001 and 2002 model year vehicles. With the advent of hybrid buses and the shift towards smaller displacement diesel engines in newer vehicles, it is more important to understand how biodiesel blends up to B20 affect these newer types of engines, especially since these vehicles are planned to run for another 18 years or longer.

VTA purchased 2010 and 2014 model year Gillig low-floor transit buses with Cummins ISB engines and either Allison or BAE hybrid propulsion systems. These buses have low mileage and are approved for use with B20 biodiesel. Starting a similar trial program on these buses will yield important information on how biodiesel affects engines with a common-rail type fueling system, and how biodiesel affects the performance of hybrid vehicles. Further, these buses use an updated exhaust aftertreatment system, and understanding how biodiesel affects the exhaust aftertreatment may be of particular use to air quality management districts in particular. A similar (if not abbreviated) research report can be completed on the 2010 or 2014 model year buses running on biodiesel blends at yearly or bi-yearly intervals to document biodiesel impacts on the newer fleet of vehicles.

Cost impacts of running the biodiesel program on the newer diesel fleet will not be greatly affected from the current spending on biodiesel. Further, since the 2014 buses get approximately 25% improved fuel efficiency, fuel expenditures on biodiesel may be reduced due to using less fuel. Since the biodiesel infrastructure is already in place all that is required to begin this testing is management approval, switching of fuel filler caps to the biodiesel compatible filler neck style and adding the biodiesel decals to the front of the vehicles so fuel island personnel know which fuel type to use.

A second recommendation of this report is that a capital project be put in place for the installation of an in-tank auger or mixing system for biodiesel blends. The cost of such an improvement will directly benefit the quality of fuel pumped into the vehicles, which directly affects the operation and longevity of the vehicles. In addition, the planned removal of gasoline from one storage tank at the VTA North Division allows minimal impact to operations for the installation of an in-tank auger, as biodiesel could still be pumped from the existing tank while the former gasoline tank is converted into the new, upgraded biodiesel tank.

A third recommendation is that contract language be strengthened to include all pertinent information from BQ-9000 certification and information from the Cummins Field Service Bulleting on fuel type. Issues with blending and quality assurance are prevalent, and strong contract language that puts increased pressure on suppliers to deliver the highest quality product will protect VTA in the future.

Fourth, it is recommended that a periodic and regular fuel sampling regiment be put in place. While VTA did complete random sampling of fuel from various locations from the tanks to the truck to the pump, the testing was sporadic. This made analyzing overall fuel quality trends difficult, even though issues are readily apparent with fuel separation. By implementing periodic and scheduled sampling, issues will be found quicker and solutions can be implemented before problems escalate.

Lastly, it is recommended that VTA share information openly with other transit agencies that currently use or are considering using biodiesel. By learning from others, VTA can obtain information that saves the company money and time. Likewise, by sharing successes and failures with other agencies, they may learn from VTA's trial biodiesel program successes and failures. The open flow of information between transit agencies, suppliers, bus-builders and other interested parties will help guide future biodiesel policy as it relates to fleet environments.

The VTA trial biodiesel program has proven very successful. Even where biodiesel results has adverse effects or blatant failures (as in underground storage), the knowledge gained helps guide VTA as it moves to the next step of renewable fuel testing.

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APPENDIX A – PARTS USED BY FUEL TYPE

Table A1 shows the various fuel system, engine, exhaust system and related parts used on 2001 and 2002 model year Gillig Low Floor transit buses with a Cummins ISL engine. The VTA internal part number is shown in the first column, with an associated part description in the second column. The third column shows how many were used on the BIODIESEL-fueled buses over the life of the program, where the fourth column shows how many were used on the PETROLEUM-fueled control group over the same timeframe. Normalized for mileage, the miles-between-component-failure (part usage) is shown in the fifth and sixth column.

Note: Miles b/w parts usage denoted with an asterisk (*) indicate that this part is ONLY used on the 2002 model year vehicles. The miles between usage is normalized for the mileage of the 2002 model year buses, not all 17 vehicles in each sub fleet.

PART NUMBER	DESCRIPTION	BIO No. of Parts Used	PETRO No. of Parts Used	BIO Miles b/w parts usage	PETRO Miles b/w parts usage
45882	GASKET FUEL TANK GAUGE GG20-22	1	2	3,568,870	2,395,901
103344	FUEL SENDER GG99LF/ GG10	1	0	3,568,870	n/a
106101	PUMP FUEL ISL GG10/22 NF23	36	27	99,135	177,474
106125	INJECTORS FUEL ISL GG10/20-NF	54	13	66,090	368,600
106427	VALVE PRESSURE RELEASE GG10	5	3	713,774	1,597,267
106490	VALVE LEVEL CONTROL GG10/20	3	2	1,189,623	2,395,901
107220	SUPPRESSOR TRANSIENT GG10-22	11	26	324,443	184,300
107940	FUEL SENDER GG20/21	10	2	356,887	2,395,901
108531	SENSOR POSITION ISL (2 PER APPL) GG10-22	52	67	68,632	71,519
108750	SENDER FUEL GG20	8	0	446,109	n/a
108760	GASKET LEVEL CONTROL VALVE GG20	3	0	1,189,623	n/a
108761	GASKET LOWER PRESSURE VALVE GG20-NF	2	3	1,784,435	1,597,267
108762	GASKET UPPER PRESSURE VALVE GG20	1	0	3,568,870	n/a
114210	TUBE FUEL DRAIN ACCUMULATOR GG10	7	4	509,839	1,197,951
114211	WASHER SEAL ACCUMULATOR MODULE GG10	74	124	48,228	38,644
114212	WASHR SEAL ACCUMULATOR MOD GG10-NF/GH	93	133	38,375	36,029
115258	WASHER SEALING FUEL PLUMBING GG10-20/NF	148	256	24,114	18,718
115702	GASKET AIR INTAKE CONNECTION GG20-22	42	38	84,973	126,100
115922	INJECTOR CONTROL VALVE (ICV)GG10-22/NF	7	21	509,839	228,181
117462	SENSOR ACCUMULATOR TEMP ISL GG10-22	3	23	1,189,623	208,339
117691	TUBE INJECTOR FUEL (No.1) GG10-22/NF	30	30	118,962	159,727
117750	TUBE INJECTOR FUEL (No.2) GG10-22NF23	32	35	111,527	136,909
117751	TUBE INJECTOR FUEL (No.3) GG10-22NF23	31	30	115,125	159,727
117752	TUBE INJECTOR FUEL (No.4) GG10-22NF23	30	34	118,962	140,935
115732	TUBE INJECTOR FUEL(No.5) GG10-22/NF23	32	36	111,527	133,106
117753	TUBE INJECTOR FUEL (No.6) GG10-22/NF23	30	36	118,962	133,106

117789	ACCUMULATOR MODULE FUEL PUMP CAP GG10	13	15	274,528	319,453
118831	SENSOR FUEL PRESSURE ACCUM GG10-NF23	14	21	254,919	228,181
118890	GASKET CONNECTION GG10-22	59	51	60,489	93,957
119023	CATALYST 11.1"OD CERAMIC NRC GG21 SCB359	4	17	536,525*	187,461*
119024	FILTER CLEAIRE DPF CHECKER GG20-22	144	202	14,903*	15,776*
119171	TUBE FUEL DRAIN ISL GG10-22	14	7	254,919	684,543
119183	SEAL RECTANGULAR RING ISL GG10-22	35	26	101,968	184,300
119242	ISO VIB WSHR SEAL FUEL PLUMBING GG10-22	172	143	20,749	33,509
119245	CONNECTOR MALE INJECTOR GG10-NF	102	85	34,989	56,374
119960	O-RING INJECTOR GG10-NF23	91	66	39,218	72,603
120651	SEAL RECTANGULAR RING GG20-22	20	36	178,444	133,106
121569	CHECK VALVE CALIBRATED CLEAIRE GG20-22	1	3	2,146,099*	1,062,279*
121801	FILTER FUEL PUMP CLEAIRE GG20-22 SMALL	83	24	25,857*	132,785*
125529	PUMP FUEL TRANSFER (Not a Core) GG10-22	26	34	137,264	140,935
400114	FUEL PUMP / FILTER CLEAIRE GG20-22	3	23	715,366*	138,558*
407530	FUEL INJECTOR DPF CLEAIRE GG10-22	7	8	306,586*	398,355*
400084	FILTER FUEL PUMP CLEAIRE LARGE	5	6	429,220*	531,140*

Table A1 – Engine, Fuel System and Exhaust System Parts Used by Fuel Type and Miles between Failures

Where only a few parts were used on each of the sub fleets over the life of the program (for example, part no. 121569, CHECK VALVE CALIBRATED CLEAIRE, where only 1 and 3 were used on the Bio and Petro fleet, respectively) are encountered, the relatively rare and small occurrence of these parts requiring replacement does not allow for statistical significance, even though the miles between failure is drastically different.

APPENDIX B – SERVICE INFORMATION BULLETIN

The below Service Information Bulletin was created by VTA Engineering in November 2009 to mitigate fuel system issues or fuel leaks.

MAINTENANCE SERVICE INFORMATION BULLETIN

***SIB#* 406**

SUBJECT: Fuel Line Installation Cummins ISL   **Issued** 11/23/2009   **Prepared By:** D. Hecht

Supersedes ______   **Approved By:** J. Wilhelm

MODEL: Gillig 1000-2200, New Flyer 2300

DESCRIPTION/PURPOSE:

When installing fuel lines on Cummins ISL engines, the torque on the line connector nuts is critical to ensuring the line will not leak and prematurely wear out. Also, the fuel line clamps and isolators must be reinstalled to eliminate excessive fuel line vibration, contact, and wear.

REV A adds torque value references for fuel system components and general fasteners.

HIGH PRESSURE FUEL LINE INSTALLATION:

On all fuel lines that utilize a ferrule and fuel line nut, ensure that the mating surfaces of the connector and ferrule are clean and free of debris. Lubricate the threads of the high pressure line nuts with engine oil before tightening.

1. After all fuel lines and connectors are removed, inspect fuel connector. Look for burrs or deformation around the inlet and outlet sides of the connector, and replace if necessary. Replace the o-ring on the high pressure connector. Carefully push the fuel connector into the cylinder head until it stops against the injector. Be sure to not tear the o-ring as the connector is being installed.

2. Install high pressure fuel lines by first connecting the high pressure line to the cylinder head connectors. Torque to **28 ft-lbs**. DO NOT OVERTORQUE! See fig. 1.

Figure 1 – Fuel line connectors and high pressure fuel lines

3. Ensure all fuel line clamps, screws, and isolators are in place. See figs. 2-4. For part numbers, see Parts section on pg 4. For information on fastener torque values, see Reference section on pg 4.

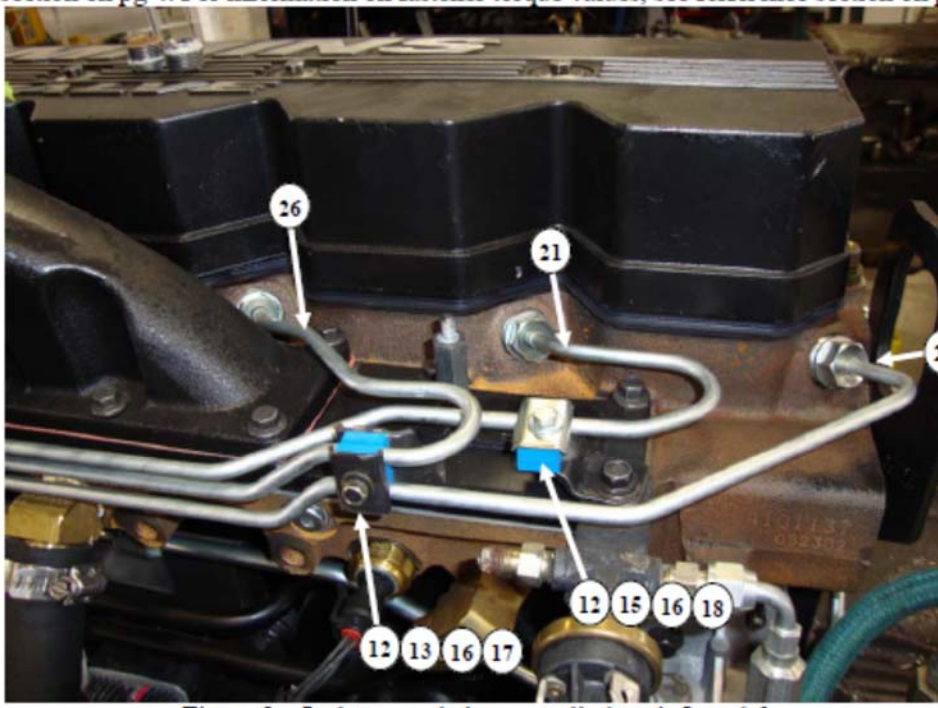

Figure 2 – Isolators and clamps, cylinders 4, 5, and 6

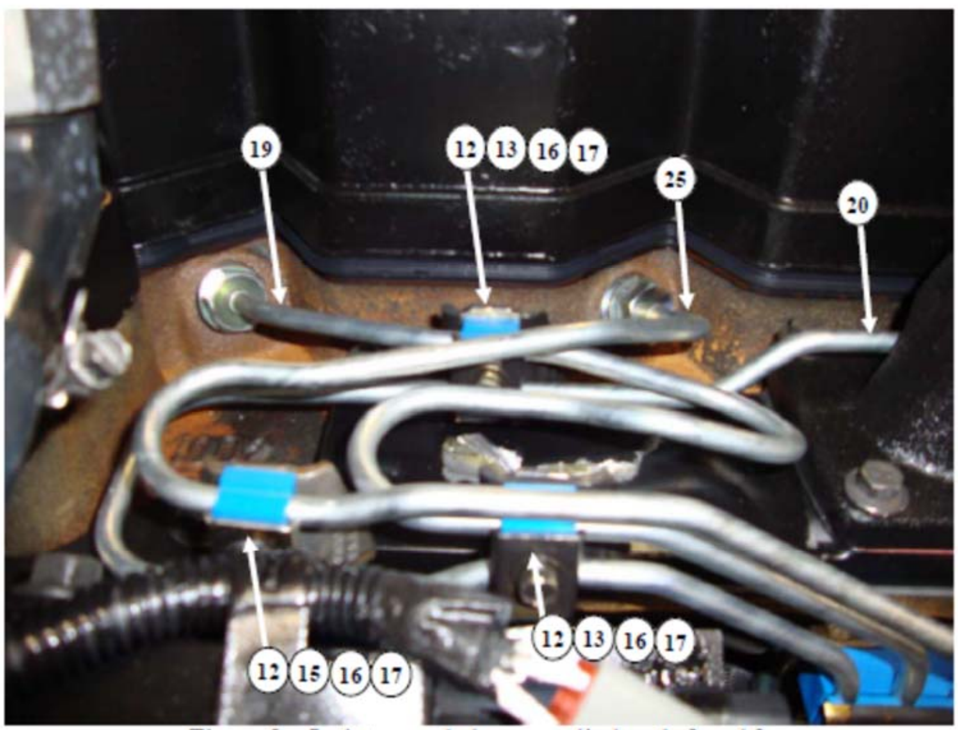

Figure 3 – Isolators and clamps, cylinders 1, 2 and 3

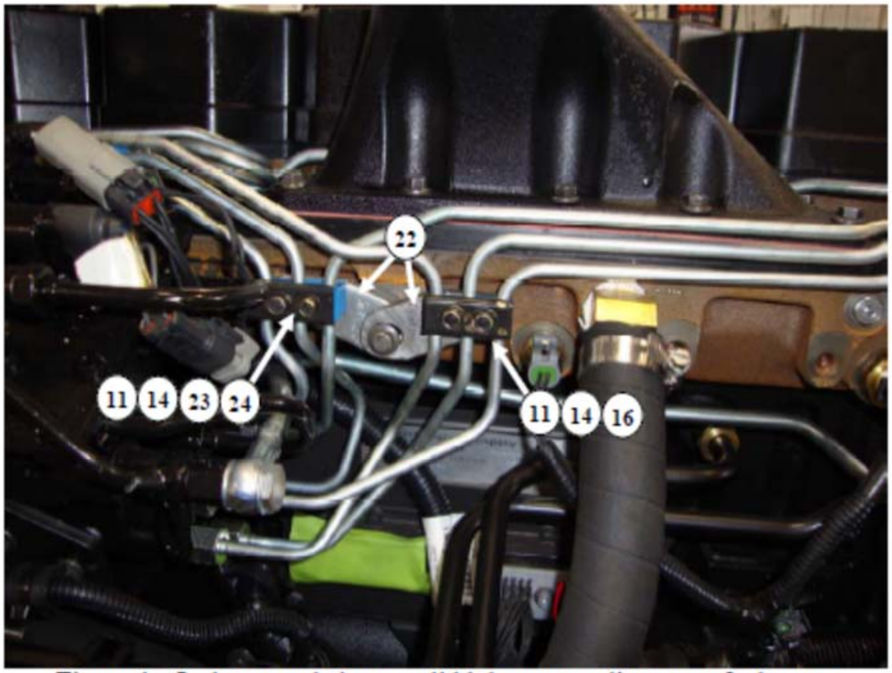

Figure 4 – Isolators and clamps, all high pressure lines near fuel pump

4. Install the fuel line at the injection pump. Torque to **18 ft-lbs**. DO NOT OVERTORQUE!

DOCUMENTATION:

A copy of the SIB will be placed on the SOS section of the VTANet under SOS/Operations/Bus Maintenance Service Bulletins. It will also be sent by e-mail to O&R and the Maintenance Yards.

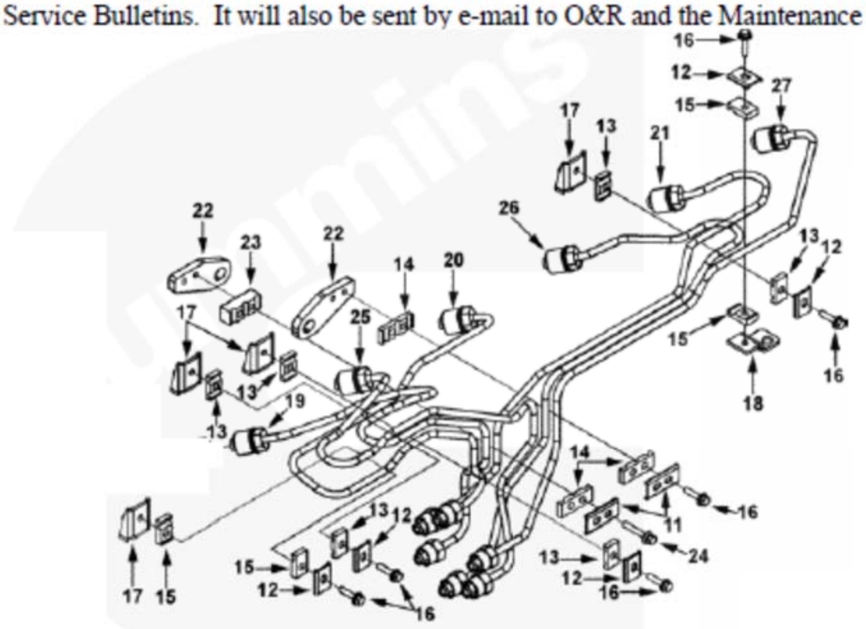

Figure 5 – High pressure fuel injector lines, isolators, and clamps

PARTS:

NOTE: **REFERENCE ALL PARTS TO REFERENCE NUMBERS ON FIGURE 5**

REF.#	VTA PART #	PART NAME / DESCRIPTION	QTY	REMARKS
11	121101	BRACE, TUBE	2	
12	115631	BRACE, TUBE	5	
13	121313	ISOLATOR, VIBRATION	6	
14	121100	ISOLATOR, VIBRATION	3	
15	115630	ISOLATOR, VIBRATION	4	
16	115632	SCREW, CAPTIVE WASHER CAP	7	M5 x 0.80 x 20
17	122842	BRACE, TUBE	4	
18	122840	BRACE, TUBE	1	
19	117691	TUBE, FUEL INJECTOR No. 1	1	No. 1 CYLINDER
20	117751	TUBE, FUEL INJECTOR No. 3	1	No. 3 CYLINDER
21	115732	TUBE, FUEL INJECTOR No. 5	1	No. 5 CYLINDER
22	121315	BRACE, TUBE	2	
23	121102	ISOLATOR, VIBRATION	1	
24	126358	SCREW, CAPTIVE WASHER CAP	1	M5 x 0.80 x 30
25	117750	TUBE, FUEL INJECTOR No. 2	1	No. 2 CYLINDER
26	117752	TUBE, FUEL INJECTOR No. 4	1	No. 4 CYLINDER
27	117753	TUBE, FUEL INJECTOR No. 6	1	No. 6 CYLINDER

REFERENCE:

VTA North Yard Mechanics for identification of the problem, and Cerone Maintenance personnel for identification of correct fuel line components.

High Pressure Fuel Line Replacement: Cummins Troubleshooting and Repair Manual: ISL and QSL9 Engines; pgs. 6-15 through 6-23

Fuel System Torque Values: Cummins Troubleshooting and Repair Manual: ISL and QSL9 Engines; pgs. V-13 through V-17

General Cap Screw Torque Values: Cummins Troubleshooting and Repair Manual: ISL and QSL9 Engines; pgs. V-35 through V-36

APPENDIX C – ENGINE INFORMATION

Biodiesel Engine Rebuild Information, Table C1

BIODIESEL BUS NUMBER	ENGINE INSTALLED MILES	LIFE TO DATE MILES	ELAPSED ENGINE MILES	DATE LAST ENGINE INSTALLED	NOTES ON WHY ENGINE WAS REPLACED
1012	364,095	540,644	176,549	8/31/2009	Transmission issue, transmission was replaced and engine had relatively high mileage – engine replaced at same time transmission was removed.
1013	545,412	561,649	16,237	4/25/2011 8/27/2014	Initial engine replacement likely due to high mileage, no issues prior to engine replacement. Second replacement had coolant in engine oil, fuel pump leaks, broken head bolts, and severe engine damage. Presence of fuel-in-oil prior to engine failure indicates fuel could be a contributing factor in failure.
1014	488,110	546,804	58,694	1/24/2013	Engine replacement likely due to high mileage, no issues prior to engine replacement.
1015	458,396	535,455	77,059	6/8/2012	Engine replacement likely due to high mileage, no issues prior to engine replacement.
1044	494,968	549,150	54,182	3/25/2013	Cracked outrigger on rear frame – engine removed for outrigger repair and engine was replaced due to high mileage when outrigger repair complete.
1045	517,715	524,073	6,358	10/30/2014	Cracked outrigger on rear frame, also possible camshaft issues. Engine replaced when outrigger repair complete.
1046	457,457	501,480	44,023	8/26/2013	Cracked outrigger on rear frame – engine removed for outrigger repair and engine was replaced due to high mileage when outrigger repair complete.
2011	493,778	504,719	10,941	9/17/2014	Internal engine damage to the #3 cylinder, likely that fuel system issues or fuel type did NOT cause the engine damage.
2012	310,197	531,782	221,585	9/2/2011	Transmission issue, transmission was replaced and engine, though not very high mileage, was replaced at the same time transmission was removed.
2013	488,629	520,844	32,215	2/11/2014	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2014	457,254	519,763	62,509	1/23/2013	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2015	502,800	508,189	5,389	5/16/2011 11/5/2014	Initial engine replacement due to #6 exhaust camshaft failure, cannot determine if fuel system had a cause in failure. Second failure however showed fuel dilution in oil in two previous oil samples, and engine failure due to #1 exhaust bridge failing and camshaft problems. Fuel in oil prior to failure indicates fuel could be a contributing factor in failure.
2016	394,458	442,459	48,001	11/23/2010 6/24/2013	Initial engine replacement due to cam and tappet issues and noisy engine complaints. Second engine replacement due to broken crankshaft in engine. Possible oiling issue or bearing problem, however

					no fuel-oil dilution in prior oil samples. Fuel likely not a contributing factor.
2017	471,025	525,821	54,796	3/26/2013	Catastrophic engine failure on road. No fuel in oil in prior samples, and no issues of fuel leaks or other fuel problems in work orders prior to failure.
2018	467,473	507,444	39,971	12/6/2013	Reported slow performance and DPF issues numerous times, high mileage engine and engine replaced to mitigate ongoing performance concerns.
2019	395,712	501,055	105,343	7/8/2011	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2020	470,967	503,116	32,149	3/4/2014	Engine replacement likely due to high mileage, no issues prior to engine replacement.

Table C1 – Biodiesel Engine Rebuild Information, Mileage and Likely Failure Mode

Petroleum Diesel Engine Rebuild Information, Table C2

PETRO DIESEL BUS NUMBER	ENGINE INSTALLED MILES	LIFE TO DATE MILES	ELAPSED ENGINE MILES	DATE ENGINE INSTALLED	NOTES ON WHY ENGINE WAS REPLACED
1047	103,061	607,688	504,627	Pre-2008	Early engine failure – likely due to manufacturers defect or unrelated cause. Cannot access records.
1048	567,529	568,567	1038	8/16/2013 1/22/2015	Initial replacement due to high mileage – second replacement likely due to fuel pump failure. Fuel dilution in engine oil in two prior oil samples. Engine did not have catastrophic damage, and was reported as running rough.
1049	275,566	574,078	298,512	11/17/2009	Cooling system failure at engine replacement at relatively low mileage.
1050	536,610	607,279	70,669	6/17/2013	Bus involved in accident – rear frame damage cracked outrigger, engine replaced at same time due to high mileage.
1051	377,921	607,394	229,473	12/17/2009	Multiple oil leaks in engine, necessitated engine rebuild to repair leaks.
1052	357,984	563,140	205,156	6/7/2010	Head gasket failure, glycol in engine oil, needed new engine, not related to fuel system failure or fuel type.
2040	583,670	637,232	53,562	1/24/2014	Multiple oil leaks, high mileage engine.
2041	443,245	610,547	167,302	6/10/2011	Transmission issue, transmission was replaced and engine had relatively high mileage – engine replaced at same time transmission was removed.
2042	587,894	625,339	37,445	4/16/2012 5/19/2014	Initial engine replacement due to internal engine failure. Oil analysis showed high aluminum, indicating internal engine wear and damage, but no fuel dilution. Second engine replacement due to engine knocking noises, high lead levels in engine indicating impending internal engine failure.
2043	484,238	597,879	113,641	5/29/2012	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2044	399,282	606,651	207,369	6/7/2010	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2045	524,369	591,849	67,480	10/17/2013	Oil leak at rear of engine block, rockers on #1 cylinder had issues, high mileage engine needed replacement.
2230	496,846	578,584	81,738	2/7/2013	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2231	514,767	591,515	76,748	1/30/2013	Engine replacement likely due to high mileage, no issues prior to engine replacement. Reported a few instances of hot engine lights and Cleaire issues but nothing major.
2232	587,174	602,829	15,655	9/26/2011 8/1/2014	Initial engine replacement likely due to high mileage, no issues prior to engine replacement. Second engine replacement due to no engine coolant, major oil leaks, and oil overfill, causing internal engine damage. Likely not related to fuel system issues.

2233	473,042	628,199	155,157	1/10/2012	Engine replacement likely due to high mileage, no issues prior to engine replacement.
2234	496,879	615,643	118,764	8/7/2012	Engine replacement likely due to high mileage, no issues prior to engine replacement. Other minor engine or performance issues reported, due to high miles engine was entirely replaced.

Table C2 – Petroleum Diesel Engine Rebuild Information, Mileage and Likely Failure Mode

Sample Oil Laboratory Analysis

The analysis below, for biodiesel0-fueled bus 2019, shows critical fuel dilution on the last oil sample.

C

N = Normal
A = Abnormal
C = Critical

ANA LABORATORIES, INC.
TEST REPORT
130-B Harding Ave, Bellmawr, New Jersey 08031-2409
(800) 648-2625 (856) 931-0011 Fax (856) 931-5205

Serving Customers Since 1973

VTA
NORTH
Attn: ETTA TYLER
1235 LA AVENIDA STREET
MOUNTAIN VIEW, CA 94043-125

UNIT INFO

YOUR COMPUTER NAME	VTANORTCA
YOUR COMPUTER UNIT I.D.	2019
TYPE	
MAKE	GILLIG
MODEL	20 LF
SUMP CAPACITY	
TYPE OF OPERATION	
OIL TYPE	Used

SYS INFO: ENG
TEST TYPE B1

LAB#	SAMPLE DATE	PROCESS DATE	HOURS/MILES SYS	HOURS/MILES OIL	OIL ADDED	OIL DRAINED	FLTR CHANGE FF	FLTR CHANGE BY	K	V	MO	* MG	ADDITIVES CA	BA	P	ZN
R13L019725	11/19/2013	11/22/2013	460.495	0	0	Yes	Yes	No	1	0	2	10	2313	0	1441	1263
R14A027280	01/27/2014	01/31/2014	467.124	0	0	Yes	Yes	No	0	1	3	8	2328	2	1016	1163
R14D011492	04/07/2014	04/11/2014	472.888	0	0	Yes	Yes	No	0	0	2	11	2893	0	1030	1130
R14F023309	06/19/2014	06/25/2014	479.028	0	0	Yes	Yes	No	0	1	3	11	2212	0	999	1128
R14H026363	08/25/2014	08/29/2014	484.519	0	0	Yes	Yes	No	0	0	2	5	2077	6	1170	1157

* ELEMENTAL ANALYSIS VALUES IN PPM BY WEIGHT — OIL QUALITY

Severity Code	Antimony	Titanium	Silver	Copper	Lead	Tin	Aluminum	Nickel	Iron	Chromium	Cadmium	Sodium	Boron	Silicon	Water % by vol *	%Soot *	Glycol *	Fuel	SAE/ISO Grade	TBN (mg/g) *	Vis @ 40C *	Vis @ 100C *
N	0	0	0	4	6	0	3	0	10	0	0	4	3	0	<.05	0.70	N	0.00	40W	5.81	NA	12.81
ANALYSIS INDICATES OVERALL SATISFACTORY CONDITIONS. RESAMPLE @ NEXT SCHEDULED INTERVAL.																						
N	0	0	0	4	6	0	2	0	10	1	0	3	5	1	<.05	0.40	N	0.00	40W	5.61	NA	13.20
ANALYSIS INDICATES OVERALL SATISFACTORY CONDITIONS. RESAMPLE @ NEXT SCHEDULED INTERVAL.																						
N	0	0	0	5	4	0	2	0	6	0	0	0	6	0	<.05	0.50	N	0.00	40W	5.84	NA	12.80
ANALYSIS INDICATES OVERALL SATISFACTORY CONDITIONS. RESAMPLE @ NEXT SCHEDULED INTERVAL.																						
N	0	0	0	4	7	0	3	0	7	0	0	3	3	4	<.05	0.50	N	0.00	40W	6.25	NA	12.99
ANALYSIS INDICATES OVERALL SATISFACTORY CONDITIONS. RESAMPLE @ NEXT SCHEDULED INTERVAL.																						
C	0	0	0	5	5	0	2	1	7	0	0	3	7	54	<.05	0.50	N	0.60	30W	4.48	NA	11.72
TRACE METAL(S) -NORMAL. LUBE CONTAMINANTS FUEL DILUTION, CHECK FOR LEAKING INJECTORS. SILICON CRITICAL & EXCESSIVE. , VISCOSITY LOW RECOMMEND DRAIN OIL IF NOT DRAINED. RECOMMEND CHANGE FILTER IF NOT CHANGED.																						

*Reporting is based on samples and information supplied by others and all corrective action, if any, is taken by others, no guarantees are expressed or implied. * These tests are accredited and meet the requirements of ISO 17025 verified by the ANSI-ASQ National Acceditation Board/ACLASS. Accreditation# AT-1471.*

Analyst: SD

APPENDIX D – ROAD CALL DETAILED INFORMATION

Biodiesel Road Call Information, Table D1

October 2008 through February 2015. Each road call listed below resulted from a fuel system or exhaust system problem, according to SAP work order history.

DATE	BUS No.	ROAD CALL CODE	ROAD CALL DESCRIPTION	PROBLEM
6/4/10	1012	FL LOFL	Low fuel gauge. Per D2 maint coach was fueled last night and took 40 gallons of fuel.	See below, fuel sender bad
8/1/10	1012	FL LOFL	Low fuel, front door has bent metal strip. Rq TC, Defect card	Replaced fuel sender
5/2/10	1013	EN LITE	Check engine light on constant, coach stalled 2 times. No visible leaks. bad fuel pump	Faulty accumulator sensor, no fuel to engine
3/18/14	1013	FL LKFU	Fuel leak. Wes 0717. SV Tow 0803. Wes/ D4/ 0806. Tow	#5 injector line, replaced all lines, etc.
7/23/09	1014	FL LKFU	Fuel leak not leaking bad with eng off (not near storm drain) Adv Gordy/1901. Fuel Injector line broken. Tow/Kerri/1900 - 10-99 @ 2020	#5 injector line, replaced
8/20/10	1014	FL LKFU	fuel leak - robert/2209 Adv Lynne/ Sunnyvale Tow/2308. Minimal spillage, approx a cup worth. None went into the stormdrain. Req Tow.	injector lines leaking, replaced
10/17/09	1015	EN MISC	Gas Leak . Maria/0925/D2 Adv/Sunnyvale Tow/Linda/1002 Tow - blew high pressure fuel line. 324 adv she left diapers to soak up spill	#5 fuel line broken, replaced lines
2/21/11	1044	EH MISC	Exhaust fumes, verified by Supervisor. - Ed/1439. Oper getting ill from fumes 10-19 @ 1438 - Vince NTM/1440	bad turbo connector but also same date replaced fuel accum drain
5/30/12	1045	EN HEAT	Loud screetching noise as coach accelerates and slow on take off. Op advise to turn power off and restart. Ray/D2/1813 UTR on road, coach is unsafe, very slow	boost pressure, possible fuel issue with accum temp sensor
8/11/09	1045	EN POWR	Check Engine Light Constant, coach began to jerk and hesitate, won't exceed 15-20 MPH. Adv Maria/1514 Adv Scott/ Customer Service/1515. Bad fuel pump	defective fuel pump, fuel leak
6/8/12	1045	EN POWR	Slow coach and Check engine light is on D2/Rat/1542	defective fuel pump
11/28/10	2011	EN POWR	Slow acceleration. Advised Wess/D-2/1000 Slow acceleration - 10-19	fuel press sensor, intermittent
1/24/11	2011	EN POWR	Slow coach. Request T/C.	low fuel press to Cleaire
11/18/08	2011	FL LKFU	Fuel leak. Nancy/D2/0905. UTR wrote work order for further repairs at the yard	fuel leaks

2/20/09	2011	FL LKFU	Fuel Leak Adv Jerilyn/D2/1740. Adv Carrie/Sunnyvale Tow/ 1820 Temp repairs. Supv will transport oper.	fuel leaks
10/26/10	2011	FL LKFU	Fuel leak. Adv Maria/D2/1452. UTR-Sunnyvale/Lynn 1518	#6 injector line leak at seal
1/6/09	2011	FL LOFL	Low Fuel light intermittent, Adv D2/Freddie/1423. Adv Op to note on defect card & if the light comes on contant. Freddie Adv 40 gal on 01/05/09.	fuel sender bad
4/6/09	2011	FL LOFL	Gauge is reading empty. Oper stated that fuel gauge is now ready 3/4 fuel.	Possible bad gauge, fuel leak a few days later
5/7/09	2011	FL LOFL	Fuel gauge reading empty. Maint/D2/1625 will fuel coach on layover.	fuel sender bad
5/14/09	2011	FL LOFL	Low Fuel, on empty. Rely/1100 says it took 40 gallons this coach should be ok.	fuel sender bad
5/26/09	2011	FL LOFL	Low fuel. Called D2 Freddy/1302 13 gallons last night. Will need more fuel, added fuel has a bad guage	fuel sender bad
11/9/12	2012	FL LKFU	Fuel leak. D2/maint/adv/1239. 10-19	two days later Cleaire fuel pump bad
5/6/12	2013	EN POWR	slow coach, check engine light on constant. Plugged exhaust	DPF clogged
12/26/12	2013	EN STAL	Bus stalled out - will not re-start. 10-19 UTR. Adv/D2/Maria/1705. 97@1733 D2	fuel press sensor faulty
5/5/14	2013	FL LKFU	The operator stated the coach has a fuel leak. Adv D2/Wes/1516. 10-19 Fuel leak at top of fuel pump.	accum leaking at fuel pump
1/4/10	2014	EH SMOK	Exhaust fumes, diesel fumes D2/Regina/1046 10-19	DPF clogged
2/26/09	2014	EN LITE	Check engine light on steady fuel center valve code- sch 10-8 running fine at this time.	DPF issue
3/22/12	2014	EN POWR	Slow coach UTM DS 2035, Defect card.	low fuel pressure, DPF backpressure, sensor issue
11/7/08	2014	EN STAL	stalling North Maint. is 10-14 back to the yard.	fuel filter changed, DPF issue reported day before
9/3/10	2014	EN STAL	stalled out will not re-start Fred/1840/Adv Coach Ran out of gas/ Gas Gauge reads full	Fuel sender bad
5/8/12	2015	EN MISC	Slow coach, using streets to 10-19 instead of pull in route. Note issue on defect card utm DDS 1748	DPF clogged
8/25/09	2015	EN POWR	Slow coach. DS 2204 Noted on defect card. UTR on road	small fuel leak, boost issues

12/17/09	2015	EN POWR	Coach will not accelerate over 40 mph and takes overpasses at 10 mph, Adv Gordy/1455, Adv Customer Service/Pat/1455.	DPF clogged
10/26/08	2015	FL LKFU	Massive fuel leak. Tow called @ 2136 UTR. Per Linda from sunnyvale tow the driver will do clean-up.	fuel line fitting leaks
1/5/15	2016	EN LITE	Chk eng. lite intermittently and jerking Oper. adv. after troubleshooting lite and jerking has stopped.	fuel issues, accumulator issue
12/28/14	2016	EN MISC	Coach is sluggish and jerking 10-22 per op	see above, fuel issues and accum issue
12/31/14	2016	EN POWR	slow coach. Adv oper eng is still cold might need a couple of trips to correct issue.	See above, fuel issue and accum issue
3/21/14	2016	EN STAL	Bus stalled out - wont re-start Advised Maria @ North Yard / 1747 Oper returned 1904. Not pumping Fuel	bad fuel pump
1/21/10	2016	FL MISC	Oper adv fuel gauge reads full, but low fuel light is on. Called D2 maint./Dennis/1538 adv coach took 3 gallons last night, recommended TC. TC requested.	fuel sender bad
9/9/09	2017	EN LITE	check eng lite on. 10-19 from Stanford Shoping Center. Active Code UTR	fuel pump bad
3/18/10	2017	EN POWR	slow acceleration SM EXHAUST excel- OK 10-8	See below, multiple road calls, DPF on 4/9/10 fixed issues
3/18/10	2017	EN POWR	Slow coach. Adv Fred/Dd2/1202 Sched was already met by a mech. Req T/C. 10-19 UTR	See below, multiple road calls, DPF on 4/9/10 fixed issues
3/31/10	2017	EN POWR	Slow coach. Adv/D2/Disp/Jerlyn/1335 10-19	Trans position sensor, see below, multiple road calls, DPF on 4/9/10 fixed issues
4/2/10	2017	EN POWR	slow acceleration. adv-d2/d5	trans fluid, see below, multiple road calls, DPF on 4/9/10 fixed issues
4/9/10	2017	EN POWR	Very slow coach, won't go over 20 MPH UTR on road.	DPF replaced, road calls went away, see above
12/29/11	2017	EN POWR	No Power, Coach won't go over 20 MPH, DS @ 1842/1901 - Exch on road & 10-19	bad DPF
5/21/12	2018	EN LITE	had a check eng lite right after he pulled out of the yard. Per Freddy coach was checked out and sent back out. Sch went reg rte late.	injector control valve faulty
5/22/13	2018	EN LITE	Check egine light, coach is slow to accelerate.	Cleaire system issues
8/2/10	2018	EN MISC	slow coach coach exchange	See below, fuel injectors replaced
8/7/10	2018	EN MISC	Op is hearing knocking noise coming from the engine. UTR	fuel injectors replaced

8/29/11	2018	EN POWR	Slow Coach, Adv D2 Maint/Dennis/1307. UTR slow coach. Mechanic advises that the coach is slow but OK for service.	DPF, not changed but had to run hard to unplug
5/23/13	2018	EN POWR	Slow coach. Rq TC	Cleaire system issues
9/22/10	2019	EH LKEX	Exhaust fumes REQ TC, When op pulled into D2, Dispatch had this coach waiting.	DPF replaced
10/31/11	2019	EH LKEX	Exhaust fumes inside coach DS @ 0831	fuel leak
9/15/10	2019	EH SMOK	Fumes inside coach, Op adv he is able to proceed until he gets back to div at 1222-1242. Adv Abel/1131. UTR on the road	flex pipe, but see DPF replacement above
1/17/10	2019	EN LITE	Check engine light is on and strong odor of burn. Adv Ed/D2/0912. 10-19 for new coach.	accumulator module faulty
12/11/08	2019	EN MISC	strong smell coming from the eng. area. Could be somekind of leak. Oper adv of possible fuel . Blk 5541 adv for transfer of paxs. Adv Fred/1517. Fuel Leak, Sm Drip	fuel leak
11/23/09	2019	EN POWR	Loss of power. D2/Reli/ instructed to 10-19. Paul/0553. 10-19	DPF replaced
12/14/14	2020	EH MISC	Exhaust and smoke in coach. Ed\1049 clear air injector to filter came loose. Temp repairs. disconnect injector.	flex pipe, also Cleaire injector faulty
10/1/09	2020	EN POWR	Coach looses acceleration intermittently UTM	Cleaire system issues

Table D1 – Fuel System Failure Road Calls for Biodiesel Buses, Oct 2008 through Feb 2015

Petroleum Diesel Road Call Information, Table D2

October 2008 through February 2015. Each road call listed below resulted from a fuel system or exhaust system problem, according to SAP work order history

DATE	BUS No.	ROAD CALL CODE	ROAD CALL DESCRIPTION	PROBLEM
1/13/12	1047	EN LITE	check eng light, alarm is activated . op was advised to shut the coach off and recycle the battery switch. Vance/1132 U T R - Mech will drive bus back to yard - Op. will drive mech. truck	fuel accumulator faulty
11/2/11	1047	EN MISC	Coach is vibrating, Adv Ron/0645. Road tested, running rough	See below, injectors replaced
11/21/11	1047	EN MISC	Operator is complaining coach smells like smoke. Gordy/D5/1452. 10-19	replaced injectors, old engine though
11/19/08	1047	EN POWR	Slow coach, 15-20 mph, req TC	accumulator temp sensor faulty
10/30/13	1047	EN POWR	loss of power, engine wheezing, unusual grinding noise. Fresh soot over engine compartment. Tow-Adv/Sunnyvale Tow/1203. Fuel leak.	fuel leaks
1/3/15	1047	FL MISC	Strong smell of fuel inside bus. TC req	injector line #2 fuel leaks
12/8/09	1048	EN LITE	Check engine/stop engine, low oil light/buzzer. D5/1957. U T R	fuel pump bad
12/27/09	1048	EN LITE	Stop engine, check engine and low coolant light is on. Adv/D5/Kathy/1214. Replaced belt tensioner.	fuel sys issues, see below
12/27/09	1048	EN LITE	Check engine light constant. 10-8 wrote work order for repair in yard.	fuel sys issue
12/22/14	1048	EN LITE	chk eng/stop eng eng fluid lights/buzzers and coach stalls and wont stay running on restarts. UTR - mobile following to Div.	fuel pump bad
6/1/10	1048	EN POWR	Slow coach. Defect card. UTR on road. Op 10-22 @ 0920	Fuel system problems
6/10/10	1048	EN POWR	Very slow acceleration. Adv Ron/D5/0725 10-19 for new coach.	Fuel system problems
12/20/14	1048	EN STAL	Stalling with a low oil light and low coolant light. Adv D5/Wes/1552. Added tran fluid and eng oil. Replaced water pump.	12/22 replaced fuel pump
5/13/10	1048	FL LKFU	Fuel leak. Adv Ron/D5/1300. Made repairs. Reattched the fuel line. 10-8	fuel leak
8/6/14	1048	FL LKFU	Fuel leak, not near storn drains. Adv/D5/ Ron/0956/Ron/1016. Busted Fuel line	fuel leak
2/2/12	1049	EN LITE	Check eng lite on - goes off & on again checked out ok	Accumulator faulty
1/27/12	1049	EN POWR	No acceleration. ADv/D5/Disp/Cathy/2149 acitve fuel pressure delivery code	related to 2/2/12 accumulator fuel sys failure

6/6/14	1049	EN POWR	No charge light on / low engine oil / no power. Advised Wes @ Chaboya / 1851 Added on gal. of engine oil - bus still needs to be towed - U T R Sunnyvale tow called 1926	lots of problems including fuel system replacement, $36,000 repair
3/6/13	1049	FL LKFU	Anti-freeze leaking from coach. No storm drains near by. Ron/D5/1153 Operator later advised may be a fuel leak. Tow--Broken fuel line, Adv/Sunnyvale Tow/1217. Oper will stay with coach , CBT.	injector line leak
9/25/14	1050	EN LITE	Check engine light on / Intermittenly U T R - exchange requested	bad fuel pressure sensor
2/8/11	1050	EN MISC	slow coach and also shaking, fuel leak, no drains nearby. Ron/0650. Operator is requesting medical for inhaling fumes, AMR 652, SJFD E2 Transported Op to Kaiser Hospital SJ. fuel leak, broken injector line. SV tow/0719	fuel leak
5/16/09	1050	EN POWR	PWR Loss. TC	fault in fuel sensor circuit, see below
6/8/09	1050	EN POWR	Slow coach. UTR on road. Noted on defect card. DS 2318	fault in fuel sensor circuit, see below
8/15/09	1050	EN POWR	Slow coach. Checked fluids and turned on fan enabled switch OK for service.	fault in fuel sensor circuit, see below
9/13/09	1050	EN POWR	Loss of acceleration. Adv Kathy/D5/1125 10-19	accumulator fuel temp sensor wiring issue
11/9/09	1050	EN POWR	Slow Coach	fuel sensorm, possible bad wires? Sensor replaced
9/9/14	1050	EN POWR	Op. states that the coach is slow. One wheelchair restraint will not operate properly. Request TC	see above 9/25/14, fuel press sensor replaced a few days later
8/29/13	1050	EN STAL	Stalled out. Advised Wes @ Chaboya / 1600. Bad fuel control vaulve and power supply. 10-19. adv/358 that the coach is unattended.	no fuel to engine, fuel system problems
10/6/13	1051	EN LITE	Check Engine light intermittent.Active code #94 for fuel injector, coach will need TC	fuel temp sensor faulty
10/24/13	1051	EN LITE	Check engine light on constant. Coach operating normal at this time. Adv/D5/ Vance/1504. 10-19 Fuel delivery pressure code.	fuel issues, fuel delivery code in ECM
10/26/13	1051	EO MISC	Low oil light and alarm intermittent. Adv/D5/Wes/1454. Fuel pressure Delivery code	fuel sys code
12/10/12	1052	FL LKFU	Fuel leak. No storm drains nearby. Ron 0938. minor leak. Ok to drive	nothing in sap, fuel leak repaired by road call mech
9/30/14	1052	FL LKFU	some type of leak. Thinks it might be diesel Adv Sunnyvale Tow/2059 330 to transport oper to D5. Wes/D5/2020. Fuel leak, UTR on the road.	Fuel leak
11/19/10	2040	EH LKEX	Exhuast leak in coach. Adv/D4/Alex/1348 UTM	DPF issues

10/27/10	2040	EH MISC	Coach is leaking fuel Adv D4/Pito/1740 UTR Tow Sunnyvale Tow\Linda\1807 - 10-99 @ 1922	Fuel leak
10/18/13	2040	EN LITE	Check Engine light, Low Coolant light & Alarm, Coach shuts itself off everytime oper opens door. D4/Alex/1251 10-19 Fuel pump issues, 903 will 10-14 with coach.	Accumulator faulty, also Cleaire system issues
1/15/10	2040	EN MISC	Slow coach, gauges reading fine UTR on road. Op willing to keep coach for rest of the day. No coach exchange	DPF, fuel accum faulty
11/24/10	2040	EN POWR	Slow coach. D4/Alex/0601. 10-19	turbo, fueling issues
10/29/11	2040	EN POWR	Coach is very slow. Jerliyn\0725. 10-19	DPF fuel inj clogged
11/5/11	2040	EN POWR	Power loss after exiting freeway. Adv/D4/Jerilyn/0650. 10-19 UTR	DPF issue, accum faulty
4/17/13	2040	EN POWR	Slow aceleration. Op advised to throttle and clear out exhaust, and cut main power for at least 3 mins. Op will advise, D4/1322/Jerlyn. Noted on defect card. Coach will not exceed no more then 8MPH	DPF issue a few days later
5/10/13	2040	EN POWR	Slow coach. Jerilyn/1855. U T M	Cleaire system problem
8/8/13	2040	EN POWR	Slow coach. The particulate filter is clogged. Needs to be serviced in the yard. 10-8 reg route.	DPF clogged
8/10/13	2040	EN POWR	Power loss and slow coach. 10-19	DPF clogged
10/25/11	2040	EN STAL	Coach Stalled, coach will start but not move, Not CBT, B/O Radio. Adv Steve/0610. UTD, shut down coach, restarted, 10-8	fuel leak
11/16/10	2040	FL LKFU	Fuel leak, D4/Alex/0648, 317 is transporting Op back to div. fuel leak coming from injector but unable to confirm, TOW/Carrie/0725	fuel leak
10/8/11	2040	FL LKFU	Fuel leak. Pito\1607. Broken fuel line. Lynne\Sunnyvale Tow\1606. 99@1835	inj pump leak
10/25/11	2040	FL LKFU	Fuel leak, constant drip. Adv/D4/ Jerilyn/1632. Carrie/Sunnyvale Tow/1713 Leaking fuel line unable to repair, repairs needed at division. 99/1930	inj line leak
1/11/09	2041	EH LKEX	Exhaust leak inside coach. Adv Robert/D4/1057. UTR Excessive exhaust inside coach.	Fuel leaks in addition to exhaust leaks
12/23/08	2041	EH MISC	Oper adv when heater is on there is excessive exhaust in coach. Req TC. No personell for TC	exhaust flex pipe, see above fuel leak on 1/11/09
10/7/11	2041	EN LITE	check engine light int. sluggish on take offs heater hose broken	injection line leaking

2/13/13	2041	FL LKFU	fuel leak -small drip, no storm drain, can smell it in the coach also Crystal/Sunnyvale Tow/1752. UTR on the road per 906	Fuel leak
6/23/10	2042	EN LITE	Check engine light. one inactive code, 10-8	fuel accum sensor faulty
12/23/14	2042	EN MISC	High back pressure light on in engine area. Write up on defect card, unless effects engine performance per Cerone Maint/1250	DPF clogged
5/4/09	2042	FL LKFU	SJPD adv leak coming from 61 line. Oper adv he has a leak, possibly fuel. Adv/D4/ Bob/2141. U T R- Fuel line	Fuel leak
9/30/10	2042	FL LKFU	Fuel leak. Adv/D4/Disp/Pieto/1752. UTM	fuel tank press relief valve faulty
5/28/09	2043	EN LITE	Check engine light intermittent, loss of power. Turbo leak, fuel pump code failure	fuel accum sensor faulty
11/21/09	2043	EN POWR	Slow coach. Adv/D4/Robert/1716 10-19 UTR	DPF clogged
8/21/11	2043	EN POWR	Coach barely moves - Peter/0714 - Aranda/0716. 10-19 @ 0714	DPF clogged
3/30/12	2043	EN POWR	Slow Coach. UTR 10-19	High exhaust backpressure, DPF clogged
2/16/14	2043	EN POWR	Coach delays acceleration engine misfire, aber light is on, exhaust filter clogged	low fuel press to exhaust aftertreatment system
3/5/09	2043	FL LKFU	eng. fuel leak/coming out rapidly. d4 adv/donnita-1014am. Leak at pump. SVL Tow called @ 10:46. 99@1204	fuel leaks at pressure sensor
10/8/09	2043	FL LKFU	Fuel leak Adv Sunnyvale Tow/1957 Peto/1934. Tow	Fuel leak
6/6/09	2044	EN LITE	Check engine light interm. U T M dead schedule @ 1906 - defect card	DPF clogged 2 days later
4/26/12	2044	EN LITE	Check engine light. UTR, no codes, request TC. DS @ 2036/2103	lift pump failure
1/28/15	2044	FL LKFU	Fuel leak. Jerilyn. 10-19	fuel leak
6/17/13	2045	EH LKEX	Exhaust smell inside coach. Adv Alex/ 0706. 908 checked, ok for coach to 10-19, using surface streets. All windows & roof hatches were opened.	exh leaks, also DPF clogged
1/17/13	2045	EH SMOK	Coach is emitting excessive white smoke. Coach was check and UTD the issue. 10-8 regular route.	fuel leaks on 1/21/13
11/6/11	2045	EN LITE	Check engine light and transmission shifting rough. Adv/D4/Aranda/0855 10-19 UTR	inj control valve faulty
3/29/12	2045	EN LITE	Check engine light on constant. Fuel delivery pressure code unable to clear, will need TC and further at division	Cleaire sys issues
12/17/08	2045	EN NOST	Coach stalled out & won't restart front or rear - Adv Jerilyn @ 1910. UTR added 6qt oil, pushed coach back to yard	bad fuel pump
2/24/11	2045	EN NOST	Problem starting coach Const "Eng Oil" light on - Maria/1940 - No answ D4 maint/1939 & 1943 - Tried calling SV Tow	fuel transfer pump faulty

			unable to finally get them until 1950 - Finally advised John Palomo/2001 904 10-98 @ 1935 Bad Fuel Pump	
12/22/08	2045	EN POWR	No power to accelarator. Blew out exhaust.	DPF clogged
12/24/08	2045	EN POWR	Slow coach loss of power. Blew out exhaust.	DPF clogged
12/29/08	2045	EN POWR	Slow coach Adv Customer Service/Tony/0611. UTM.	DPF clogged
12/29/08	2045	EN POWR	Slow acceleration. TC requested. Very slow coach UTR on the road.	fuel press switch faulty
6/28/10	2045	EN POWR	Slow Coach amber light is on constantly T/C	DPF clogged
1/21/13	2045	EN POWR	Slow accelrelation. Alex\0626. 10-19	fuel leaks on 1/21/13
7/10/11	2045	EN STAL	Coach keeps stalling out (once on Fwy & 3 times more) Peter/D4 Maint/0825 - John/0526. 10-19 on surface streets @ 0822	fuel return check valve issue
12/27/08	2045	FL LKFU	Fuel Leak, Adv Jerilyn/0912. Fuel leak, 10-19	fuel leak
11/16/09	2045	FL LKFU	Fluid leaking from coach, oper smelled fuel. Not near storm drain. Adv/D4/ Jerilyn/1824 - Sunnyvale Tow@ 1916 Linda Broken fuel line - Oper transprtd back to yard & will sit out time there - Relay to finish out run - SV Tow `10-99 @ 2041	fuel leak
11/21/12	2045	FL MISC	fuel fumes in coach. Aranda/0825 broken fuel line. Tow/0823. Sup is transporting op. 10-99/1030	fuel leak
6/9/11	2230	EN LITE	Check Engine light is on constant. UTR active codes. 10-19	Fuel primer pump faulty
11/8/08	2230	EN POWR	Delayed take off, Op stated it is very slow Req TC	DPF clogged
10/9/10	2230	EN POWR	Slow coach. Adv Jerilyn/D4/0615. 10-19 for new coach,.	lift pump connector leaking and fueling issues
10/10/10	2230	EN POWR	Slow Coach. Adv Abel/D4/0621. 10-19 for a new coach.	accum fuel pressure
11/22/10	2230	EN POWR	Slow coach. Op advised throttle not repsonding. Delay. D4/Bill/0611 blew out exhaust from cleaire system	low fuel press, DPF clogged
11/25/10	2230	EN POWR	Slow acceleration. Request T/C. Oper decided to hold at Sierra and Piedmont. When adv to 10-19, he refused.	accum fuel pressure
12/15/10	2230	EN POWR	Slow coach, power loss. Rq TC UTR on road. Op already reset comp and throttle blow out.	fuel pump replaced, DPF clogged
1/27/11	2230	EN POWR	slow acceleration, picks up/down 10-22 per op	fuel pump sensor faulty
3/18/11	2230	EN POWR	Slow coach. 10-22 Per OP	See below on 3/22/11

3/22/11	2230	EN POWR	Slow coach, very slow to start, Op having trouble going over overpasses and going through intersections.... 10-22 per op. coach is running good. DS @ 2333/2353	fuel leak 3/25, replaced fuel pump
3/29/11	2230	EN POWR	power loss. inactive codes, road tested, 10-8	See below on 4/22/11
4/22/11	2230	EN POWR	Coach very slow barely makes it through an intersection Aranda/0549. 10-19 for new coach @ 0552	Fuel leak in ecm connectors
4/26/11	2230	EN POWR	Slow Coach, Op request TC. DS @ 2020/2033	Fuel leak in connectors, caused multiple issues
9/20/14	2230	FL MISC	Fuel, engine smell, oper will check for leaks. Adv/D4/Gregory/1024. 10-19 Mech was unable to verify smell, 904 will drive coach back to the yard, oper will drive truck.	fuel leaks and DPF clogged
11/13/08	2231	EN LITE	Check Engine light is on. Restarted but light came back on. 2 codes are on. 1 active code. Req TC at Great Mall @ 1656 if none avail then 10-19 from that 10-20.	fuel sys issues
1/13/10	2231	EN POWR	Slow coach. DS 2128 Rq TC, Defect card	serviced Cleaire
7/26/13	2231	FL LKFU	Fuel leak. No storm drains nearby, but oper advised to get absorbent material to contain leak. Adv/D4/Abel/1237. U T R - Tow - Sunnyvale tow called @ 1306	Fuel leaks
1/23/10	2233	EN LITE	Check engine light is on. All fluids ok and codes ok. Check engine light is now off.	possible DPF, wo for oil but DPF changed a few days later
7/13/09	2233	EN MISC	Very slow bus. Needs coach exchange.	fuel press faulty
3/2/10	2233	EN NOST	co. stalled out, no start d4/pam adv-tow adv pam-0906.fuel control valve gone-tow	injec contr valve faulty
7/5/09	2233	EN POWR	Slow Coach will not exceed 35 miles per hour. 10-19	low fuel press, DPF clogged
1/26/10	2233	EN POWR	Loss of power and slow coach. Request TC- will exchange with 9871	DPF clogged, see above
8/29/11	2234	EH MISC	Slow Coach Amber light is on. 10-19	No work order, DPF clogged on a later w/o
11/24/09	2234	EN POWR	Slow coach. Adv/D4/Vance/1145. 10-19 bad turbo	fuel press, DPF clogged
9/15/10	2234	EN POWR	Slow coach. ReqT/C	DPF clogged
2/4/11	2234	EN POWR	Loss of power and slow acceleration.	DPF clogged and high backpressure
6/10/11	2234	EN POWR	Loss of power. Unable to repair	fuel leaks, DPF clogged
12/25/10	2234	EN STAL	Coach Stalled. Fuel pump going out. 10-19	fuel pump faulty
8/21/09	2234	FL LKFU	fuel leak. 10-19 to d-5	fuel sys leaks

Table D2 – Fuel System Failure Road Calls for Petroleum Diesel Control Group, Oct 2008 through Feb 2015

APPENDIX E – UNDERGROUND SAMPLING TEST RESULTS

Figures E1 through E4 – Sample Laboratory Analyses for B5 and B20

Herguth Laboratories, Inc.

Certificate of Analysis
Lab Number V7000918

Ray Franklin
Valley Transportation
3331 N First Street
Bldg B
San Jose CA 95134-1906

05/14/10

Page 1

Client Code : SCTRXX   Sample Date : 04/21/10   P.O. Number : 4604413
Herguth ID : LABV7000918
Description : North Oxner, B5 Biodiesel straight from Pump #5
Oil Type : Biodiesel Fuel Blend (GN_131)
Unit Type : Biodiesel Diesel Fuel (GN_DF003)

Test Performed	Proc-Rev	Result
Biodiesel Blend as FAME by FTIR HL-1141A	1141A-1.1	4.45 vol. %

Result appears acceptable.
Fourier Transform Infrared Analysis (FTIR) of the fuel sample submitted shows the percent of Fatty Acid Methyl Ester (FAME) component in the ~1750 cm-1 wavenumber region. FAME is the major indicator for Biodiesel. The FTIR was calibrated based on standards prepared by blending Diesel with B100 Soy Biodiesel.

Respectfully Submitted,
Herguth Laboratories, Inc.

Bobby R Licu, Senior Evaluator

cc: Ray Franklin

These results are submitted pursuant to our current Terms, Conditions and Limitations and Laboratory Pricing Policy.
No responsibility or liability is assumed for the manner in which these results are used or interpreted.
*101 Corporate Place, Vallejo, CA 94590-6968 * Toll-Free Phone 1-800-645-5227 * Fax 1-707-554-0109 * www.herguth.com*
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Figure E1 – B5 fuel sample from fuel lane nozzle, 4/21/2010, 4.45% biodiesel

Herguth Laboratories, Inc.

Certificate of Analysis
Lab Number V7002465

Ray Franklin
Valley Transportation
3331 N First Street
Bldg B
San Jose CA 95134-1906

10/21/10

Page 1

Client Code : SCTRXX   Sample Date : 10/12/10   P.O. Number : 4606668
Herguth ID : LABV7002465
Description : Division: North, Bio diesel (Bottom)
Oil Type : Biodiesel Fuel Blend (GN_131)
Unit Type : Biodiesel Diesel Fuel (GN_DF003)

Test Performed	Proc-Rev	Result
Biodiesel Blend as FAME by FTIR HL-1141A	1141A-1.1	28.00 vol. %

Biodiesel level is higher than specified (20%).
Fourier Transform Infrared Analysis (FTIR) of the fuel sample submitted shows the percent of Fatty Acid Methyl Ester (FAME) component in the ~1750 cm-1 wavenumber region. FAME is the major indicator for Biodiesel. The FTIR was calibrated based on standards prepared by blending Diesel with B100 Soy Biodiesel.

Respectfully Submitted,
Herguth Laboratories, Inc.

Bobby R Licu, Senior Evaluator

cc: Ray Franklin

*101 Corporate Place, Vallejo, CA 94590-6968 * Toll-Free Phone 1-800-645-5227 * Fax 1-707-554-0109 * www.herguth.com*
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Figure E2 – Bottom of tank sample, B20, 10/12/2010, 28.00% biodiesel

Herguth Laboratories, Inc.

People and Data You Can Count On

Certificate of Analysis
Lab Number V7002466

Ray Franklin
Valley Transportation
3331 N First Street
Bldg B
San Jose CA 95134-1906

10/21/10

Page 1

Client Code : SCTRXX   Sample Date : 10/12/10   P.O. Number : 4606668
Herguth ID : LABV7002466
Description : Division: North, Bio diesel (Middle)
Oil Type : Biodiesel Fuel Blend (GN_131)
Unit Type : Biodiesel Diesel Fuel (GN_DF003)

Test Performed	Proc-Rev	Result
Biodiesel Blend as FAME by FTIR HL-1141A	1141A-1.1	16.42 vol. %

Result(s) appear acceptable.
Fourier Transform Infrared Analysis (FTIR) of the fuel sample submitted shows the percent of Fatty Acid Methyl Ester (FAME) component in the ~1750 cm-1 wavenumber region. FAME is the major indicator for Biodiesel. The FTIR was calibrated based on standards prepared by blending Diesel with B100 Soy Biodiesel.

Respectfully Submitted,
Herguth Laboratories, Inc.

cc: Ray Franklin

Bobby R Licu, Senior Evaluator

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Figure E3 – Middle of tank sample, B20, 10/12/2010, 16.42% biodiesel

Herguth Laboratories, Inc.

Certificate of Analysis
Lab Number V7002464

Ray Franklin
Valley Transportation
3331 N First Street
Bldg B
San Jose CA 95134-1906

10/21/10

Page 1

Client Code : SCTRXX   Sample Date : 10/12/10   P.O. Number : 4606668
Herguth ID : LABV7002464
Description : Division: North, Bio diesel (Top)
Oil Type : Biodiesel Fuel Blend (GN_131)
Unit Type : Biodiesel Diesel Fuel (GN_DF003)

Test Performed	Proc-Rev	Result
Biodiesel Blend as FAME by FTIR HL-1141A	1141A-1.1	17.76 vol. %

Result(s) appear acceptable.
Fourier Transform Infrared Analysis (FTIR) of the fuel sample submitted shows the percent of Fatty Acid Methyl Ester (FAME) component in the ~1750 cm-1 wavenumber region. FAME is the major indicator for Biodiesel. The FTIR was calibrated based on standards prepared by blending Diesel with B100 Soy Biodiesel.

Respectfully Submitted,
Herguth Laboratories, Inc.

cc: Ray Franklin

Bobby R Licu, Senior Evaluator

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Figure E4 – Top of tank sample, B20, 10/12/2010, 17.76% biodiesel

APPENDIX F – BIODIESEL COST INFORMATION

Below is a synopsis of the miles travelled by sub fleet and by fuel type. Also shown is the fuel cost synopsis based on price per gallon per month and miles travelled each month. These numbers are used elsewhere in calculations for parts used per mile, etc.

BIODIESEL MILES TRAVELLED BY FUEL TYPE

- B5 SME, October 2008 through September 2010 – 1,348,772 miles
- B20 SME, October 2010 through September 2014 – 2,007,435 miles
- B20 Canola, October 2014 through February 2015 – 212,663 miles
- TOTAL BIODIESEL MILES FOR ALL 17 VEHICLES – **3,568,870 miles**

PETROLEUM CONTROL GROUP MILES TRAVLLED

- TOTAL PETRO MILES FOR ALL 17 VEHICLES **– 4,791,802 miles**

2002 Model Year Miles Travelled – Buses equipped with Cleaire Exhaust Aftertreatment systems

- BIODIESEL MILES TRAVELLED FOR 10 VEHICLES – **2,146,099 miles**
- PETROLEUM MILES TRAVELLED FOR 11 VEHICLES – **3,186,837 miles**

BIODIESEL COSTS FOR ALL BIODIESEL FUEL TYPES, 17 Vehicles - **$2,537,950.80**

COST IF BIODIESEL BUSES FUELED WITH REGULAR DIESEL, 17 Vehicles - **$2,165,125.64**

SAVINGS IF FUELED WITH PETRO INSTEAD OF BIODIESEL, 6 years 4 months - **$372,825.16**

PETROLEUM COSTS, 17 vehicles in control group - **$3,065,706.33**