Locomotive Biodiesel Fuel Update

LMOA - Fuel, Lube, and Environmental Committee

July 2011

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ABSTRACT

Biodiesel is "coming to a railroad near you." In fact, many railroads are likely already using biodiesel fuel blended into conventional diesel fuel, and may not even know it. One of the reasons for this is that in 2008, sufficient performance data became available to change the ASTM D975 diesel fuel specification to permit the blending of up to 5 percent biodiesel (B5) as a fungible, unlabeled component in the traditional diesel fuel pool. The neat biodiesel (B100) blend stock, however, must meet specifications in ASTM D6751 for pure biodiesel (B100) prior to blending, and the B5 blend must continue to meet all the parameters of D975. Other significant changes in the market, such as the adoption of Ultra Low Sulfur Diesel Fuel (ULSD) and new federal renewable fuel standards, are also driving increased incorporation of biodiesel into D975 diesel fuel by large petroleum refiners and blenders. This paper is intended to be an update to the 2005 biodiesel paper presented by the FL&E Committee [Bowen 2005], and will present information on government requirements for increased biodiesel production and use, included in the Energy Independence and Security Act of 2007 (EISA). This paper also covers the activities of the SAE Technical Committee 7 (Fuels) "Biodiesel in Railroad Applications" Subcommittee, and gives highlights of two studies looking at locomotive exhaust emissions when operating on biodiesel fuel blends.

2005 LMOA Paper

In 2005, the Locomotive Maintenance Officers Association (LMOA) Fuel, Lube, and Environment (FL&E) Committee presented a biodiesel paper that covered much of the background information on biodiesel and provides a high-level overview of the advantages and disadvantages of biodiesel fuel currently available in North America from a railroad perspective.

Topics covered included cold flow characteristics, compatibility with existing diesel fuel, volumetric energy content, stability, and microbial growth [Bowen 2005]. This 2011 update paper is intended to provide supplemental information to the 2005 LMOA paper.

Another source of biodiesel information related to the railroad industry is a 2008 Alternative Fuels report prepared by Southwest Research Institute® (SwRI®) for the Association of American Railroads (AAR) Research Committee [Majeweski 2008]. The biodiesel section of this report covered biodiesel properties and specifications, commercial and economic factors, environmental impacts, and engine performance. The AAR report highlighted the lack of significant data on locomotive engines.

Biodiesel Specifications

The ASTM Biodiesel Task Force began efforts to set biodiesel specifications in 1993. After 8 years of testing and data to address questions from the petroleum and engine manufacturing industries, ASTM D6751 Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels was approved by ASTM in 2001 for blending up to 20 percent biodiesel with No. 1 or No. 2 diesel fuels falling under ASTM D975. For No. 1 and No. 2 petrodiesel fuel, if No. 1 meets its grade requirements in D975 and the No. 2 meets its grade requirement in D975 the two may be blended together and used without re-analysis. There is no separate, individual specification for blends of No. 1 and No. 2 petrodiesel. ASTM D6751 was developed using that same thinking—if B100 meets D6751 and diesel fuel meets D975, then up to 20 percent biodiesel could be used and there was no separate specification for the finished blend of biodiesel with petrodiesel. The most important quality control functions were conducted at the parent fuel level, with downstream testing only needed to check for contamination or aging in storage or transport.

Engine companies and users, however, demanded ASTM specifications for the finished blended fuel since that is what the engine sees and that is what users purchase. The ASTM Biodiesel Task Force set out to develop the data needed to secure finished blended fuel specifications for up to B20. The same philosophy as No. 1 and No. 2 petrodiesel was maintained, i.e. if B100 meets D6751 and the diesel fuel meets D975 the two may be blended without the need for re-analysis and quality control was primarily performed at the parent fuel level. In order to secure passage of the finished blended fuel specification, and to maintain the philosophy that if the parent fuels met specification no additional analysis were needed on the finished blend, several important improvements were made to D6751 between 2001 and 2008:

- The acid number parameter was lowered from 0.8 to 0.5 mg KOH/gm maximum
- A stability parameter of 3 hours minimum induction period was added
- A cold soak filtration value of 360 seconds maximum was added (200 seconds maximum for cold weather applications)

In addition, a significant amount of additional in-use experience in on-highway and smaller nonroad diesel engines occurred and was better documented for technical aspects over longer periods of time, and additional engine emissions testing was performed. The improvements to D6751, and the additional experience from the field in a variety of applications, were necessary in order for a successful balloting to occur at ASTM for finished biodiesel blends. As with the current D975 specification, the biodiesel blended fuel specifications are based on the parameters necessary to ensure proper engine performance and are not based on the exact refinery feedstock or process utilized to get to those parameters.

In 2008, ASTM balloted and approved specifications for finished biodiesel blends covering blends up to B5 (ASTM D975) and blends containing between B6 and B20 (ASTM D7467) for both on and off road applications. In all cases, the B100 must meet the improved D6751 standard prior to blending.

With B100 meeting D6751 as a prerequisite, data showed blending of up to B5 did not substantially affect the finished properties of petrodiesel and no additional parameters were needed for blends of B5 and lower. The specification values for normal D975 petrodiesel could also be utilized for B5 and lower as a fungible component of petrodiesel without change, and are valid regardless of biodiesel content so long as the content remains at B5 or lower. Therefore, the D975 diesel fuel specification was revised to allow use of up to five volume percent biodiesel fuel (B5), without any special reporting or disclosure requirements. The neat biodiesel (B100) blend stock, however, <u>must</u> meet specifications in ASTM D6751.

For blends between 6 percent and 20 percent biodiesel, it was determined the T-90 specification should be raised by 5°C compared to D975, and that it would be useful to include two additional specifications (acid number of 0.3 mg KOH/gm maximum, stability induction period of 6 hours minimum) compared to ASTM D975. Similar to D975, the D7467 values were protective of engines as long as the biodiesel content remains between 6 percent and 20 percent and the exact level of biodiesel is not important to the engine—so long as it remains between 6 percent and 20 percent, the B100 met D6751, and the blended fuel meets D7467. ASTM D7467 was, therefore, also adopted in 2008 as a new specification covering diesel fuel with biodiesel blends between six percent (B6) and twenty percent (B20) for both on-highway and non-road use. For further information on biodiesel specifications and background, please see the 8th edition of Significance of Tests For Petroleum Products, ASTM International. (Salvatore 2010).

EISA Requirements

The Energy Independence and Security Act of 2007 (EISA 2007) expanded the Renewable Fuels Standard previously adopted in 2005 (RFS1) and for the first time specifically provided for a renewable fuel component with U.S. diesel fuel, and which is applicable to off-road applications such as locomotives. Congress tasked the U.S. EPA with adopting percentage-based renewable fuel standards, which resulted in the EISA 2007, or the Renewable Fuel Standard 2 (RFS2) program as it is now commonly called. Based on the EPA RFS2, each refiner, importer and non-oxygenate blender of gasoline and/or diesel is obligated to use a minimum volume of renewable fuel, and must ensure its use as a transportation fuel. The RFS greatly expands the total volume of all renewable fuels to be used in the market by up to 36 billion gallons per year in 2022.

In February 2010, EPA finalized the RFS2 program. This program set out specific volume requirements for various fuels that make up the 36 billion gallons required by 2022:

- Traditional Corn Based Ethanol: 15 billion
- Bio-mass based Diesel: 1 billion
- Advanced Biofuel, not differentiated: 4 billion
- Cellulosic Biofuel: 16 billion

Advanced Biofuel was defined as a fuel that reduces carbon emissions over 50 percent from a 2005 petrodiesel baseline, and the final RFS2 program certified biodiesel as an 'advanced biofuel' providing a minimum of 50% carbon reduction. Pertinent to the rail industry, the final RFS2 required the use of 1.150 billion gallons of Biomass-based Diesel for the combined two-year period of 2009 and 2010, increasing to 1 billion gallons each year starting in 2012. From 2012 through 2022, a minimum of 1 billion gallons per year must be used domestically, and the Administrator of the EPA is given authority to increase the minimum volume requirement. To qualify as Biomass-based Diesel, the fuel must also reduce greenhouse gas (GHG) emissions by at least 50 percent from a 2005 petroleum diesel baseline. Currently biodiesel is the only commercial fuel to meet the Advanced Biofuel requirement category, as well as fitting in the Biomass-based diesel requirement. The NBB anticipates 800 million gallons in 2011 and 1 billion plus for 2012 and beyond.

What this means for the railroad industry is that biodiesel (B5) is entering into railroad diesel fuel in increasing concentrations over the next few years. Concentrations of biodiesel are likely to be less than the 5 percent maximum limit permitted in ASTM D975 in these early years, but higher concentrations up to B5 are expected to be routine in future years.

Screening for Presence of Biodiesel in Railroad Diesel Fuel

A Mid Infrared Spectroscopy method can be used to quantify the amount of FAME (fatty acid methyl ester) biodiesel in diesel fuel, as specified in ASTM D7371 and EN 14078, for concentrations ranging from 1 to 20 volume percent. This FTIR (Fourier Transform Infrared) method uses a wave number of 1745 ± 5 cm^{-1} for quantification of the ester peak, and biodiesel content can be measured down to 0.05 volume percent. As a cautionary note, this absorbance relates to ester functionality, and non-biodiesel ester-based components found in some conventional diesel additive packages can also be contributors, although concentrations of traditional additive packages are usually 0.5 percent or lower.

One Western railroad began looking for the presence of biodiesel in their routine diesel fuel quality analyses starting in 2010. A commercially available analyzer was used that reportedly provides results comparable to the ASTM D7371 and EN 14078 methods, with a range of 0 to 20 percent FAME, an accuracy of ± 0.2 percent, and a repeatability of 0.1 percent. Approximately 145 samples were tested starting in June 2010, with most samples coming from the August to December, 2010 time period. The highest level of biodiesel tested was one sample from Iowa dated 9/26/2010, where the fuel sample tested at 1.6 percent biodiesel. Figure 1 summarizes the results of this survey, and shows that small concentrations of biodiesel were present in many of the samples. Although it is not known whether biodiesel was found in these samples due to its use to meet RFS2 or due to its naturally high lubricity (adding 2 percent biodiesel to even the poorest lubricity petrodiesel can bring a fuel back into lubricity specification compliance) or both, but biodiesel is making its way into the fuel used by railroads.

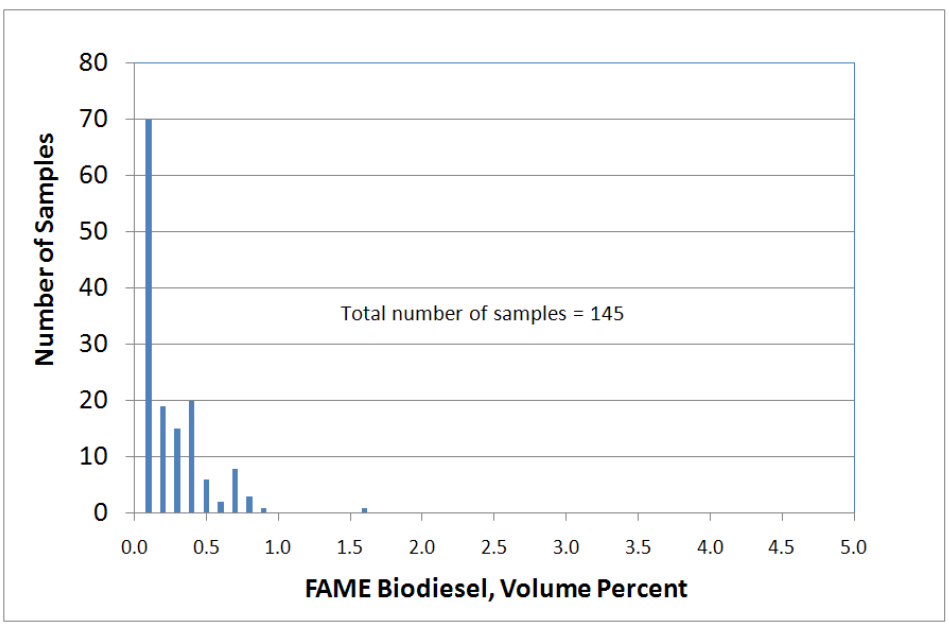

Figure 1. Western Railroad Survey of Biodiesel in Diesel Fuel Samples

EPA Diesel Fuel Regulations

Non-road diesel fuel was not regulated by EPA until June 2007, when the EPA Non-road diesel fuel regulations included provisions for locomotive and marine diesel fuel nationwide. Effective June 1, 2007, EPA limited the sulfur content of non-road diesel fuel to 500 ppm maximum. They also required the Cetane Number be greater than 40, and the volumetric aromatic content be less than 35 percent.

Effective June 1, 2010, non-road diesel fuel, except Locomotive and Marine, had a 15 ppm Sulfur maximum. Locomotive and marine diesel will be ULSD, 15 ppm max Sulfur starting June 1, 2012. This EPA fuel regulation did not address the issue of biodiesel although it has had the impact of encouraging biodiesel use. This is because biodiesel has naturally high cetane (over 47), zero aromatics, ultra-low sulfur (most biodiesel is already below 15 ppm sulfur), and ULSD will require the use of a lubricity additive or incorporation of low levels of biodiesel to meet the lubricity needs of existing and new diesel engines.

CARB Diesel Fuel Regulations

The California Air Resources Board (CARB) established regulations for intrastate locomotives and marine harbor craft effective January 1, 2007. The CARB regulations state all intrastate locomotives (i.e., those effectively captive within the State) must use CARB diesel fuel, which specifies less than 15 ppm maximum Sulfur, 10 percent maximum aromatics, a minimum lubricity standard, and meeting the ASTM D975 performance specification. Alternatively, refiners can certify diesel as a CARB fuel with aromatic levels higher than 10 percent if such a fuel has equivalent emissions using CARB specified testing protocols. Most commercial petrodiesel in California is currently of the ‘emissions equivalent’ variety as very little has less than 10 percent or less aromatics.

Biodiesel is naturally zero aromatic, ultra low sulfur, and high lubricity, so B20 and lower blends are also legal in California if the finished blends meet their ASTM performance specifications (D975 for blends of B5 and lower, D7467 for blends between B6 and B20, B100 must meet

D6751 prior to blending). Higher levels do not currently have an approved ASTM performance specifications, and are considered legal if used under the waiver program of the California Division of Weights and Measures for fuels that do not have approved ASTM specifications.

CARB is in the process of evaluating emission impact on all new diesel fuels, including biodiesel, and determining if there is a need for additional testing or certification for biodiesel blends in California for on/off road diesel fuel. It is assumed any changes needed for California for on/off road diesel engines will also apply equally to railroad applications, but this needs to be confirmed, possibly through the SAE committee discussed below.

SAE Technical Committee 7 (Fuels) Biodiesel in Railroad Applications Subcommittee

A forum titled “Biodiesel in Railroad Applications” was held at the SAE International World Congress in April 2010, in Detroit, Michigan. The subject of forum was to consider the impact of renewable fuel mandates on railroad applications. Presentations covered topics such as EPA exhaust emission standards for locomotives, regulations and mandates, railroad fuel logistics, railroad concerns, OEM statements, low temperature operability, fuel stability, emissions lessons from automotive experience and current and past demonstration programs. One of the outcomes of this forum was to establish a Subcommittee under the SAE umbrella of SAE Technical Committee 7 (Fuels). The Charter of the Subcommittee is to “Identify issues of concern to the railroads, engine and equipment manufacturers, and fuel suppliers upon introduction of biodiesel blends in the diesel pool in North America. Formulate and propose a practical path forward.”

The subcommittee voted to concentrate on three major focus areas:

- Exhaust Emissions
- Engine Durability
- Fuel Handling and Material Compatibility

The Subcommittee held a workshop in January 2011 in Richmond, California. Highlights from that meeting included:

- There was general agreement that, based on experience in other applications and the advent of B5 incorporation into the ASTM D975 specification, use of up to 5 percent biodiesel in regular diesel as specified by ASTM D975 using biodiesel blend stock meeting ASTM D6751 is acceptable and unavoidable in most cases. However, continued monitoring of potential long term impacts specific to railroads are warranted.

- Many performance issues common to other diesel engine applications have been addressed through the ASTM process but that information has not been provided to the railroad/locomotive community. The National Biodiesel Board (NBB) is working toward having a practical information package prepared and will provide it to the members of the Subcommittee. The NBB is also assembling data from existing locomotive biodiesel test programs for subcommittee members' consideration, knowing that in many cases such programs have produced limited information.

- The LMOA Fuel, Lube, and Environment Committee was to make recommendations for the scope of any future locomotive biodiesel testing to ensure that durability is addressed, and that the number of units and test duration are sufficient.

One of the major issues for railroads regarding the use of biodiesel fuels is uncertainty about the impact on exhaust emissions. One significant concern for railroads involves changes in the exhaust emissions of a locomotive due to the use of biodiesel blends that could result in the locomotive being noncompliant with applicable EPA regulations. At issue is an increase in NO_X emissions that has been observed in some instances with use of biodiesel fuel. A definitive answer to this question may require significant additional testing since changes in NOx with low biodiesel blends can fall within normal test to test variability of petrodiesel alone, but the general consensus is B5 is a legal fuel, and can be used in locomotives without concerns as to EPA compliance. The point is made that any in-use exhaust emissions compliance testing will be done with EPA certification diesel fuel, which does not include biodiesel.

Another NO_X-related issue involving biodiesel has to do with calculating railroad NO_X inventories, and the impact on fleet average agreements. As an example, Union Pacific Railroad and BNSF Railway have entered into a voluntary Memorandum of Understanding (MOU) with the California Air Resources Board to limit NO_X emissions from locomotives operating in the SCAQMD (South Coast Air Quality Management District) to an average of 5.5 g/hp-hr (Tier 2) starting in 2010 (often referred to as the South Coast Fleet Average Agreement) [MOU - 1998]. At issue is whether the current specification efforts by CARB for other on/off road uses will allow the continued use of current emissions values for biodiesel blends, or whether railroads will need to adjust the NO_X emission factors used to calculate their fleet-average NO_X emissions by some yet-to-be-determined factor due to the use of biodiesel fuel. At this time, this remains an open issue.

Concerns over potential NO_X increases are a particular concern for Canadian Railroads that operate under a MOU that caps NO_X emissions. Estimated NO_X emissions are near the capped limit and increases cannot be tolerated [Dunn 2003].

Biodiesel Effects on Locomotive Exhaust Emissions

The impact of biodiesel fuel in relatively small-bore, high-speed on-highway diesel truck engines has been extensively studied over the last 15 years, and the effects are well documented [EPA 2002]. Figure 2 shows some average trends on emissions for pre-1998 high-speed diesel engines from an EPA survey for different blend levels of biodiesel. On average, PM, CO and THC emissions decrease while NO_X emissions increased in proportion to biodiesel in the fuel, although there were relatively few data points below B20.

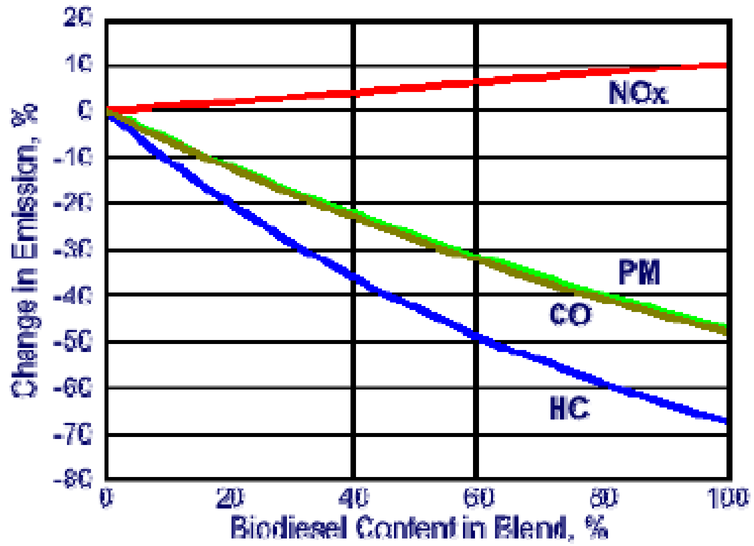

Figure 2. Average Impact of Biodiesel on Emissions for High-Speed On-Highway Diesel Engines

Very limited data exists on biodiesel effects in larger-bore, medium-speed locomotive engines, and results from smaller, newer engines using different EPA testing protocols may not apply to locomotive engines. One area of concern raised by the SAE Subcommittee was some of the locomotive biodiesel studies that have been performed recently or are currently underway include exhaust emissions testing not performed using EPA's Federal Test Procedure (FTP) for locomotives, as specified in Title 40 of the US Code of Federal Regulations (CFR), Part 92. Inspection of test reports from some of these studies indicates clear deviation from EPA FTP requirements. This can result in confusion over biodiesel fuel effects in locomotives, especially for reported PM and visible smoke emissions, due to the fact that PM results are highly dependent on sampling methodology and engine technology. In EPA on-road testing, biodiesel reduced the solid carbon fraction of particulate matter (this is the portion of particulate most visible to the naked eye) but does not affect the lubricating oil contribution to particulate. If the carbon portion of the total particulate matter is small, which is the case for many older locomotives, there may be a visible smoke reduction but not a corresponding reduction in measured particulate matter. Members of the SAE Subcommittee stressed any future locomotive biodiesel studies that include exhaust emissions testing be performed "by the book" using the EPA FTP for locomotives.

There are two known locomotive biodiesel research studies in the literature where EPA FTP testing was used. Both were performed by SwRI. One study performed in 2002 for the US Department of Energy's National Renewable Energy Laboratory (NREL) investigated biodiesel in a 2,000 HP EMD GP38 locomotive [Fritz 2002]. In this study, fuel consumption and exhaust emission tests were performed on a pre-Tier 0 EMD GP38-2 locomotive when operating on four different fuels; a 2-D diesel fuel meeting U.S. EPA locomotive certification test specifications, a diesel fuel meeting the requirements of the California Air Resources Board (CARB), a blend of 20 percent bio-fuel into the EPA locomotive certification fuel (B20), and a second blend of 20 percent bio-fuel with the CARB diesel (C20). Regulated emission measurements of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), particulate (PM), and smoke opacity were made using U.S. EPA locomotive test procedures specified in 40 CFR Part 92. Test results from this study are summarized in Table 1 and showed a 5 to 6 percent increase in average NO_X emissions with B20 fuel compared to EPA locomotive certification diesel. A lack of measured PM response with any of the test fuels was attributed to the fact that PM emissions from this two-stroke EMD engine are largely lubricating-oil derived. Long term durability and reliability associated with the routine use of biodiesel were not addressed in this study.

Table 1. Pre-Tier 0 EMD GP38 Biodiesel Test Results Summary

Fuel	HC	CO	NO_x	PM
EPA Line-Haul Duty-Cycle Weighted Emissions, g/hp-hr [a]				
EPA Loco. Cert. Diesel	0.64	5.4	12.4	0.46
CARB diesel	0.64	4.3	12.3	0.46
B20	0.64	4.5	13.1	0.50
C20	0.64	4.0	12.8	0.48
EPA Switch Duty-Cycle Weighted Emissions, g/hp-hr [a]				
EPA Loco. Cert. Diesel	0.82	2.2	12.8	0.38
CARB diesel	0.76	1.8	12.5	0.34
B20	0.78	2.0	13.5	0.37
C20	0.73	1.8	13.1	0.37

[a] Average of three runs on each fuel.

In 2010, GE published results of a biodiesel study performed in cooperation with BNSF Railway for a Tier 2, 4,400 HP, GE ES44DC locomotive [Osborne 2011]. Low Sulfur Diesel (LSD) with sulfur concentration of 391 ppm was used for baseline testing and also as the base fuel for fuel blends of 2 percent, 10 percent, and 20 percent biodiesel by volume. Neat biodiesel for this program was supplied by Cargill, and was derived from soybean. B2, B10, B20, and B100 refer to the fuel blends that contain 2 percent, 10 percent, 20 percent, and 100 percent biodiesel by volume, respectively. The blending of these test fuels was completed at SwRI. A summary of the final fuel properties from this test program is presented in Table 2.

Table 2. GE ES44DC Biodiesel Study Test Fuel Properties

Determinations	ASTM Test Method	LSD	B2	B10	B20	B100
API Gravity @ 15.6 °C Specific gravity Density (kg/m^3)	D4052	35.9 0.845 842.6	35.8 0.846 843.1	35.2 0.849 846.3	34.4 0.853 850.3	28.3 0.886 883.0
Viscosity @ 40°C (cSt)	D445	2.4	2.4	2.5	2.7	4.2
Sulfur (Wt%)	D2622	0.0391	ND	ND	ND	ND
Sulfur (ppm)	D5453	ND	372.9	336.4	298.5	0.8
Cetane Index	D4737	45.2	45.9	46.6	46.8	52.8
Cetane Number	D613	43.3	42.7	44.1	45.0	52.3
Heat of Combustion Gross (kJ/kg) Net (kJ/kg) Gross (kJ/L) Net (kJ/L)	D4809	 45,666 42,842 38,477 36,097	 45,568 42,770 38,417 36,057	 44,952 42,168 38,041 35,685	 44,324 41,571 37,690 35,350	 39,877 37,344 35,213 32,976
wt% Carbon wt% Hydrogen wt% Oxygen by difference Hydrogen/Carbon Oxygen/Carbon	D5291	86.67 13.31 0.02 1.83 0.00	85.84 13.19 0.97 1.83 0.01	85.10 13.12 1.78 1.84 0.02	83.92 12.97 3.11 1.84 0.03	76.76 11.94 11.30 1.85 0.11
Cloud Point (°C)	D2500	-20	-17	-17	-14	1
Hydrocarbon Type Aromatics (%) Olefins (%) Saturates (%)	D1319	 24.9 1.9 73.2	 26.8 2.9 70.3	 29.0 4.4 66.6	 36.7 3.3 60	 ND ND ND
Flash Point (°C)	D93-80	61	54	55	58	163
Free Glycerin (wt%) Total Glycerin (wt%) Monoglyceride (wt%) Diglyceride (wt%) Triglyceride (wt%)	D6584	ND	ND	ND	ND	<0.002 0.153 0.515 0.098 0.042
Distillation	D1160 % Recovered IBP 10 50 90 FBP	Temp. °C 188 211 263 331 374	Temp. °C 182 206 256 332 364	Temp. °C 173 200 262 342 362	Temp. °C 179 207 290 358 371	Temp. °C 326 345 348 351 371
Notes: ND – not determined						

Gaseous and particulate emissions were sampled using the EPA locomotive FTP, per 40 CFR Part 92. Regulated brake-specific gaseous emissions weighted over the EPA Line-Haul and

Switch Locomotive Duty Cycles are summarized in Figure 3 for the Line-Haul Cycle, and in Figure 4 for Switch Cycle. The change in NOx duty cycle composite values for B2, B10, and B20 as compared to the LSD base fuel was not greater than one standard deviation of the triplicate certification diesel fuel tests, and was likely within the range of normal test to test variation. However, B100 NOx increases of 15 percent over the Line-Haul Cycle and 11 percent over the Switch Cycle were well outside expected test to test variation.

Changes in HC emissions relative to the base fuel were within normal test measurement variation except for B100, where HC was reduced by 21 percent and 24 percent over the Line-Haul and Switch cycles, respectively. B20 and B100 showed significant CO reductions of 17 percent and 34 percent, respectively, over the Line-Haul cycle, and 11 percent and 35 percent over the Switch cycle. CO changes for B2 and B10 were within the expected test measurement variability. These test results suggest biodiesel induced HC and CO reductions are substantially smaller for this Tier 2 four-cycle medium speed GE locomotive engine than for high speed heavy duty highway engines, in which extensive testing has shown on average much greater HC and CO reductions than what is observed in the current work.

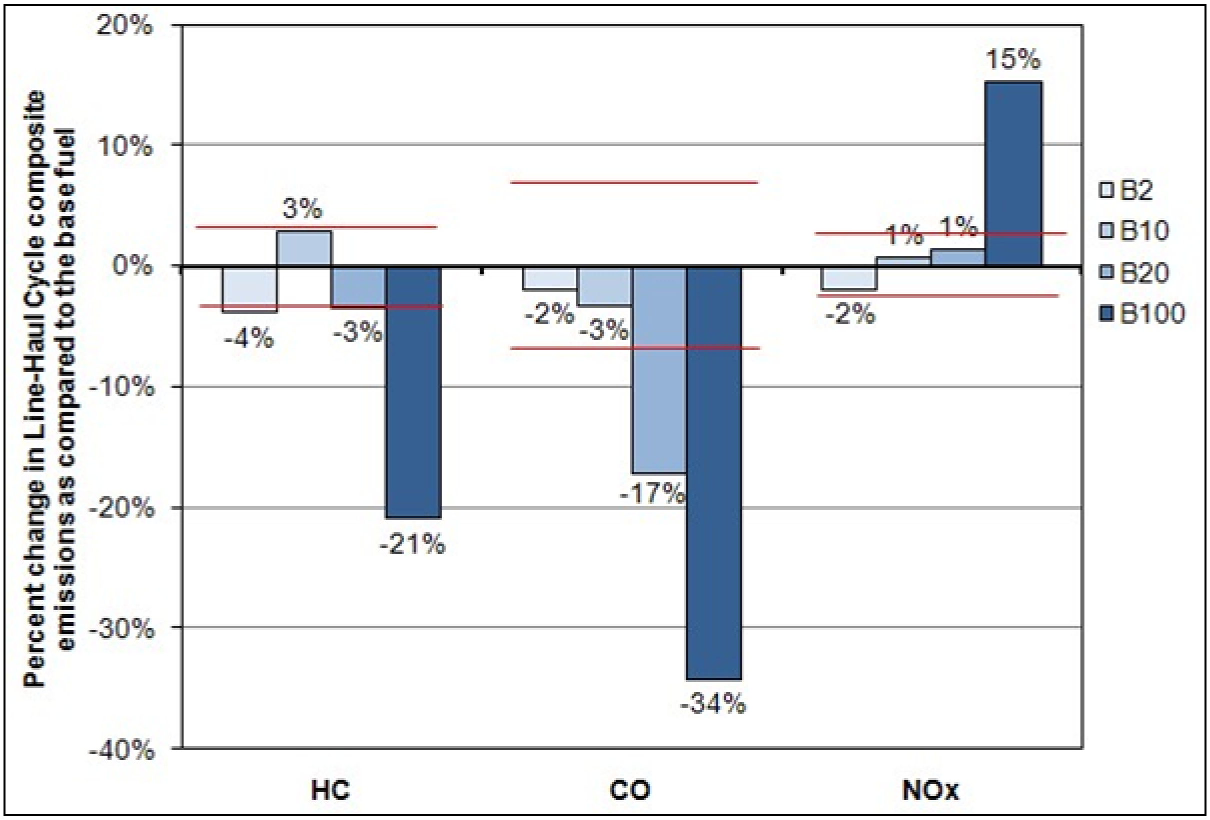

Figure 3. Percent change in GE ES44DC Line-Haul Cycle composite gaseous emissions for each biodiesel blend as compared to LSD base fuel. The horizontal lines indicate hypothetical change in emissions associated with ±1Stdev of the Line-Haul Cycle composite results from triplicate tests with EPA certification fuel.

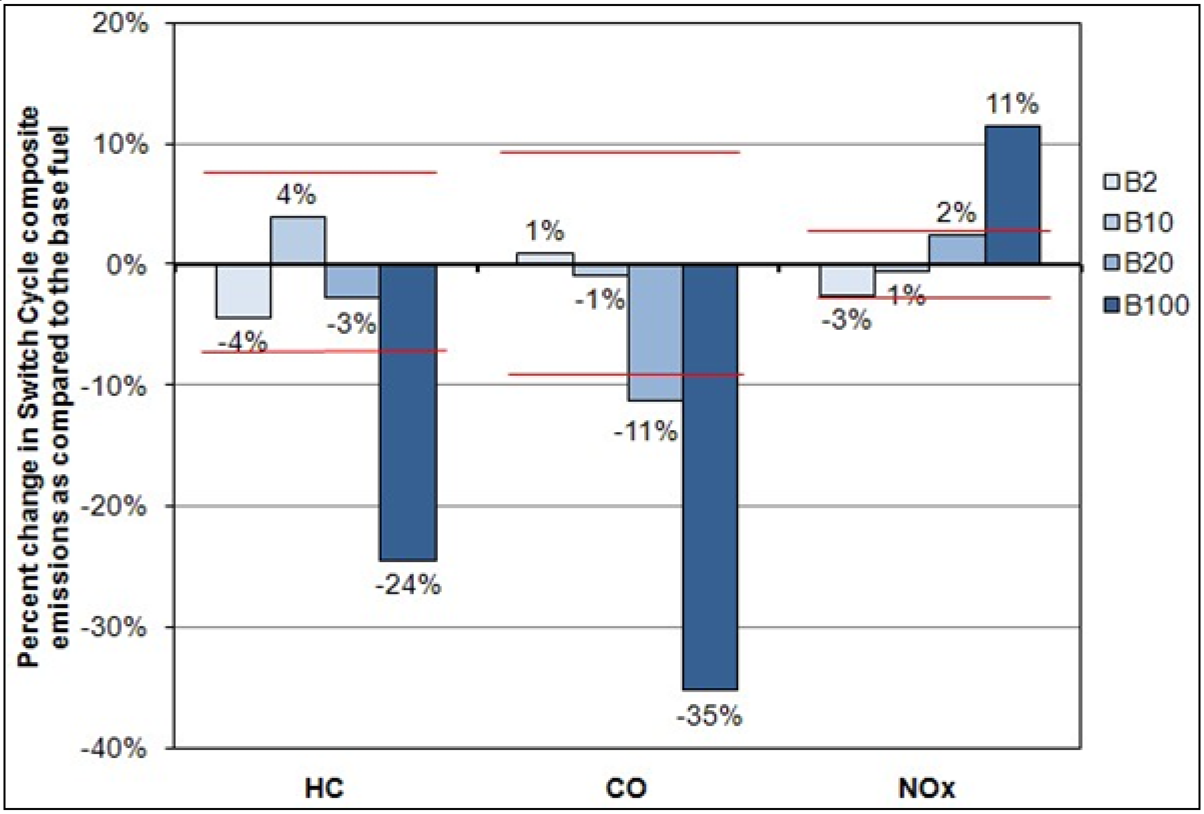

Figure 4. Percent change in GE ES44DC Switch Cycle composite gaseous emissions for each biodiesel blend as compared to LSD base Fuel. The horizontal lines indicate hypothetical change in emissions associated with ±1Stdev of the Switch Cycle composite results from triplicate tests with EPA certification fuel.

The sulfate portion of diesel PM is derived from sulfur contained in the fuel and lubricant. The amount of sulfur present in the fuel can affect PM significantly. Biodiesel inherently does not have significant amounts of sulfur and blending increased amounts of biodiesel with a fuel that contains higher levels of sulfur results in a downward trend in-fuel sulfur concentration. To isolate the effects of biodiesel on PM from the effects of fuel sulfur concentration, non-sulfate PM values were determined for each test and are shown along with the total PM in Figure 5 for the Line-Haul Cycle and in Figure 6 for the Switch Cycle. Sulfate measurements from the LSD test were linearly applied to PM results from each of the other fuel blends based on the sulfur concentration of each blend. From the non-sulfate PM results it can be observed that PM reduction over the line-haul cycle did not increase with increasing amounts of biodiesel beyond the B10 fuel blend. However, Switch Cycle PM reduction increased for each step in biodiesel fuel blend concentration. In both cases the bulk of the PM reduction benefit was realized at the B10 level, followed by diminished returns in PM reduction with increasing levels of biodiesel. PM reduction benefits were observed even for B2, where PM reductions relative to LSD of 7% and 10% over the Line-Haul and Switch Cycle occurred.

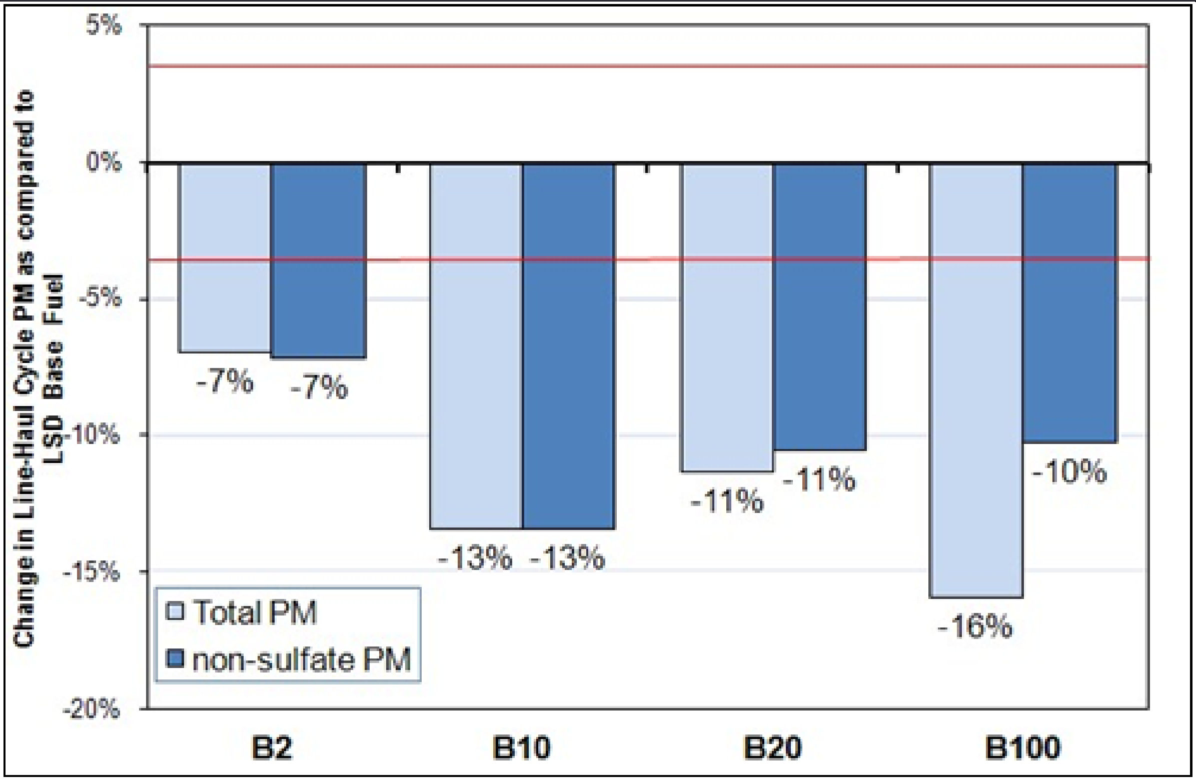

Figure 5. Percent change in Line-Haul Cycle total PM and non-sulfate PM emissions for each biodiesel blend as compared to LSD Base Fuel. The horizontal lines indicate hypothetical change in emissions associated with ±1Stdev of Line-Haul Cycle composite PM results from triplicate control tests with EPA certification fuel.

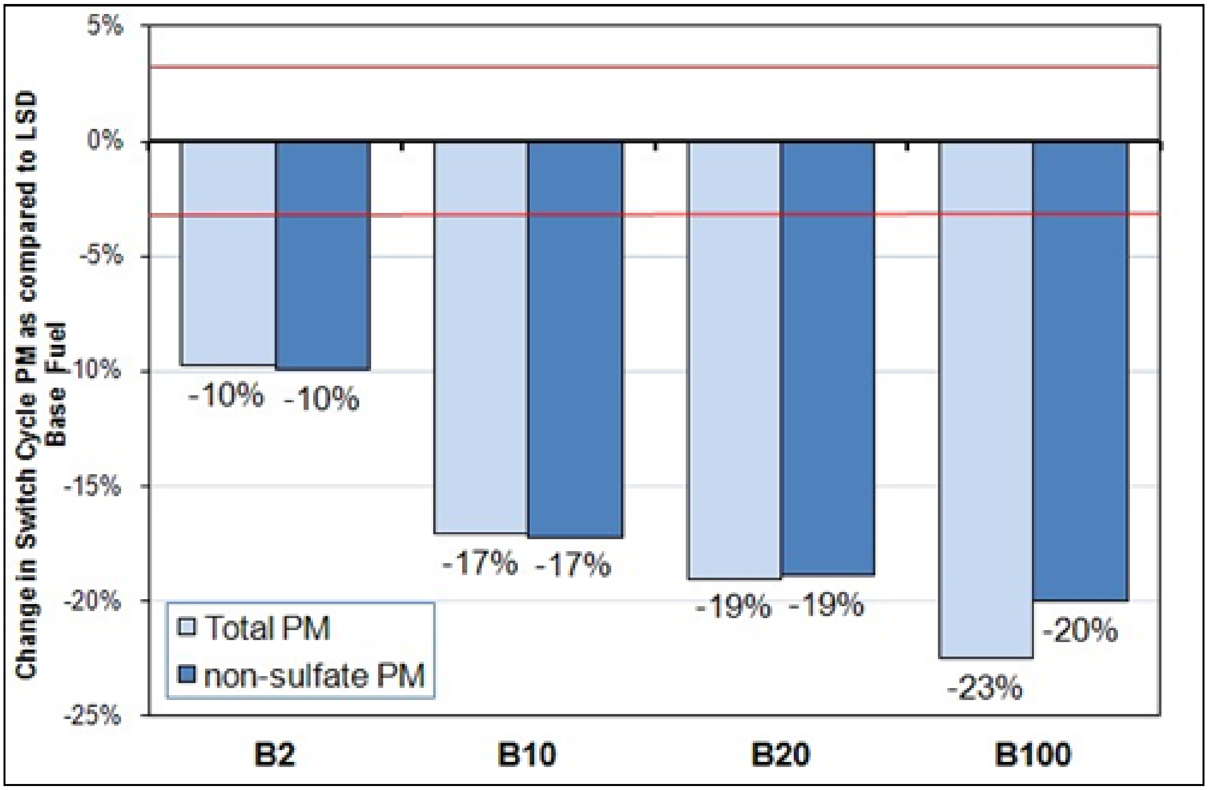

Figure 6. Percent change in Switch Cycle total PM and non-sulfate PM emissions for each biodiesel blend as compared to LSD Base Fuel. The horizontal lines indicate hypothetical change in emissions associated with ±1Stdev of Switch Cycle composite PM results from triplicate control tests with EPA certification fuel.

Smoke test results for each test fuel are shown in Figure 7. Under FTP regulations, PM is measured gravimetrically, and smoke measured optically. Although changes in smoke opacity do not necessarily correlate to gravimetrically determined PM, especially as it pertains to fine and ultrafine PM, smoke opacity can be an indicator for soot PM. As such, the downward trend in smoke opacity with increasing amounts of biodiesel may be another indication of the lower soot levels associated with biodiesel in this testing.

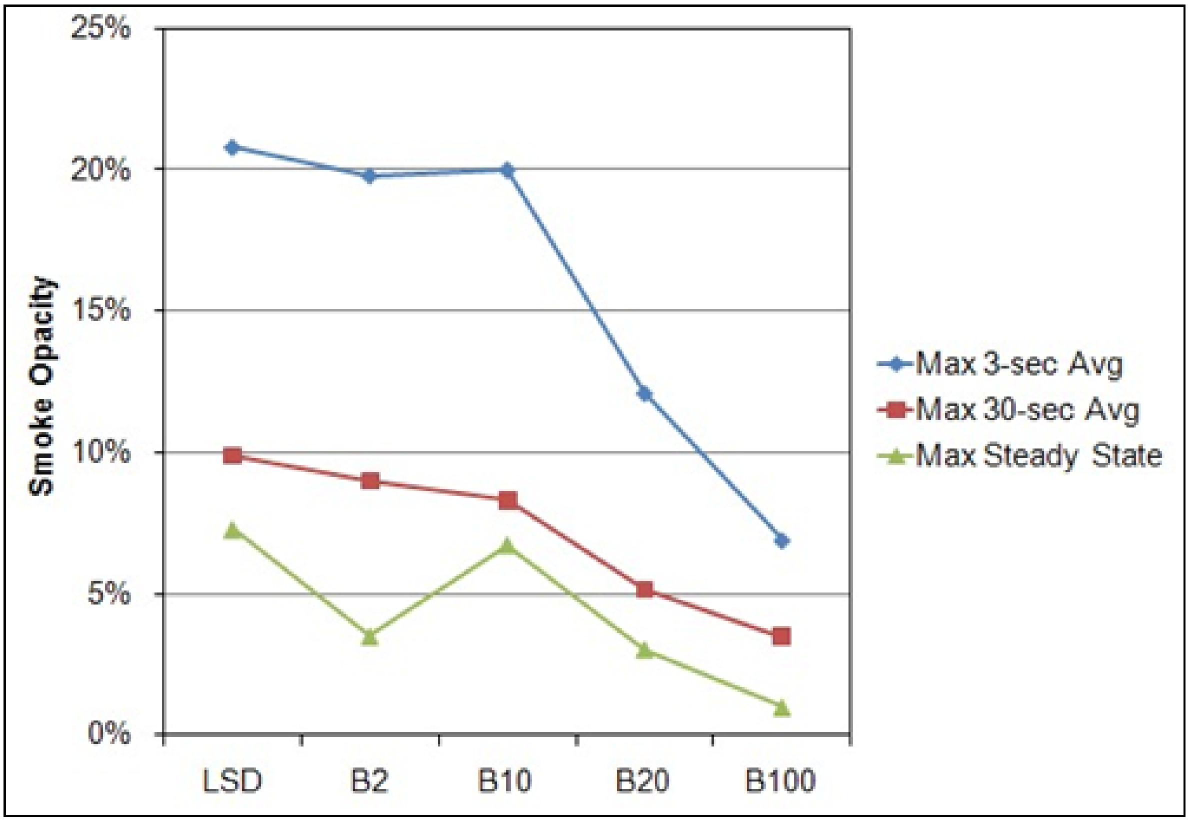

Figure 7. GE ES44DC Smoke Test Results

The change in brake specific volumetric fuel consumption for each biodiesel blend as compared to the LSD base fuel is shown in Figure 8. Volumetric fuel consumption increased about 1 percent for B2 and B10 over the Line-Haul cycle, and increased 2 percent and 7 percent for B20 and B100, respectively. The fuel energy density penalty associated with biodiesel has negative implications for locomotives, such as the need for more frequent fueling and possibly reduced maximum power. In this study, the ES44DC locomotive controls were able to compensate for the lower energy density test fuels, hitting target power during all of the fuels testing except at Notch 8 during B100 testing, where fuel injection became volume limited and the resulting brake power was approximately 2 percent below target.

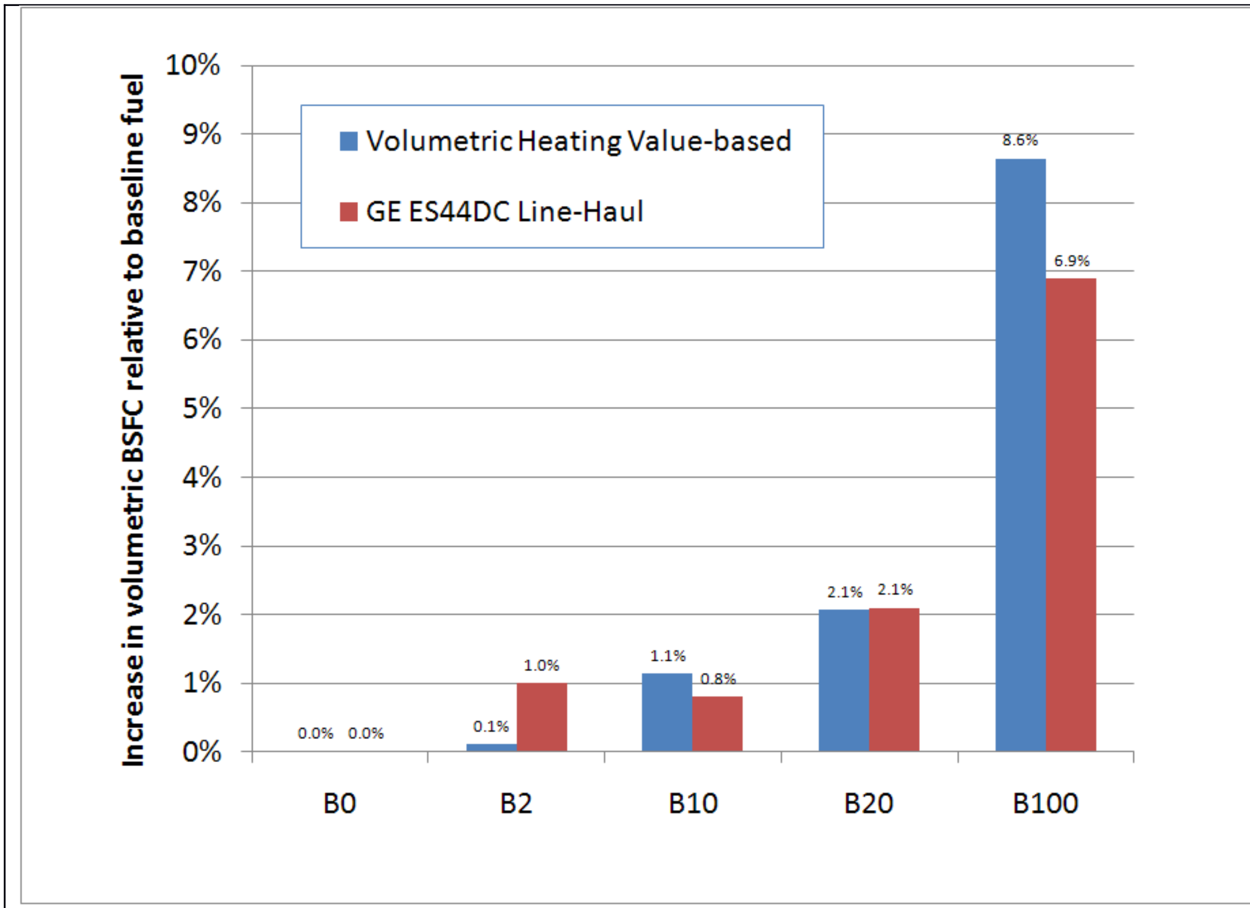

Figure 8. Increase in observed volumetric BSFC relative to the LSD base fuel for each biodiesel blend over the EPA Line-Haul Cycle.

Conclusions

Due to the EISA 2007 (RFS2) requirements, biodiesel “is coming to a railroad near you.” Over the next few years, B5 is expected to be routinely found in locomotive fuel throughout the country.

Next Steps

As diesel fuel prices and required RFS2 volumes continue to increase, there will likely be pressure to increase the biodiesel blend concentration beyond the current ASTM D975 limit of 5 percent. The SAE Technical Committee 7 (Fuels) Biodiesel in Railroad Applications Subcommittee is expected to follow developments in this area, and participate in planning research programs investigating durability, fuel handling, and exhaust emissions for the railroad industry. The LMOA FL&E Committee has several representatives on the SAE Subcommittee, and will provide future updates to the LMOA membership.

References:

Bowen, G., L. Haley, and D. McAndrew, “Biodiesel – A Potential Fuel Source for Locomotives,” LMOA – Locomotive Maintenance Officers Association, 67th Annual Meeting Proceedings, pp. 236-257, September 19-20, 2005.

Dunn, R., 2003. “Biodiesel as a locomotive fuel in Canada”, Transport Canada Report TP 14106E, http://www.tc.gc.ca/eng/innovation/tdc-summary-14100-14106e-666.htm

Energy Independence and Security Act (EISA). 2007. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

EPA, 2002. "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions," U.S. Environmental Protection Agency, Draft Technical Report EPA420-P-02-001, October 2002, http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf, also available at http://www.epa.gov/oms/models/analysis/biodsl/p02001.pdf

Fritz, S., “Evaluation of Biodiesel Fuel in an EMD GP38-2 Locomotive.” National Renewable Energy Laboratory (NREL) Report No. NREL/SR-510-33436, May 2004.

Majewski, A., Jääskeläinen, H., and Fritz, S., “Alternative Fuels Availability, Make-Up, and Potential Impact On Locomotive Engines,” SwRI Final Report No. 03.14052 to Transportation Technology Center, Inc. for the AAR Research Committee, December 2008.

“MOU - Memorandum of Mutual Understandings and Agreements: South Coast Locomotive Fleet Average Emissions Program,” July 2, 1998.

Nikanjam; M., J. Rutherford, D. Byrne, E. Lyford-Pike; and Y. Bartoli, “Performance and Emissions of Diesel and Alternative Fuels in a Modern Heavy-Duty Vehicle,” SAE Paper No. 2009-01-2649, November 2009.

Nikanjam; M., J. Rutherford, and K. Spreen, “Performance and Emissions of Diesel and Alternative Fuels in a Heavy-Duty Industry-Standard Older Engine,” SAE Paper No. 2010-01-2281, October 2010.

Osborne, D. and S. Fritz, “Exhaust Emissions and Fuel Consumption from an EMD GP49-3 Passenger Locomotive Operating on Neat Biodiesel,” SwRI Report 03-12781, November 2006.

Osborne, D., S. Fritz, and D. Glenn, “The Effects of Biodiesel Fuel Blends on Exhaust Emissions from a General Electric Tier 2 Line-Haul Locomotive,” ASME Paper No. ICEF2010-35024, September 2010, and published in the Journal of Engineering for Gas Turbines and Power, Volume 133, Issue 10, May 2011.

Salkvatore, J.R., "Significance of Tests for Petroleum Products: 8th Edition," ASTM Press, ISBN13: 978-0-8031-7001-8, 350 pages, 2010.

List of Abbreviations

AAR Association of American Railroads

ASTM ASTM International (formerly American Society for Testing and Materials)

BNSF	BNSF Railway Company
B*x*	B5, B20, etc. Biodiesel blended at *x* percent into diesel fuel
C20	CARB diesel fuel blended with 20 volume percent biodiesel
CARB	California Air Resources Board
CFR	U.S. Code of Federal Regulations
CO	Carbon Monoxide
EMD	Electro Motive Diesel
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
FAME	fatty acid methyl ester
FL&E	Fuel, Lube, and Environment Committee
FTIR	Fourier Transform Infrared (spectroscopy)
FTP	Federal Test Procedure
GE	General Electric Company
GHG	greenhouse gas
HC	hydrocarbons
HP	horsepower
LMOA	Locomotive Maintenance Officers Association
LSD	low sulfur diesel (< 500 ppm S)
MOU	Memorandum of Understanding
NBB	National Biodiesel Board

NO_X	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
PM	particulate matter
RFS	Renewable Fuel Standard, created under the Energy Policy Act of 2005
RFS2	2007 expansion of the Revised Renewable Fuel Standard in 2007 by EISA
SAE	SAE International (formerly the Society of Automotive Engineers)
SCAQMD	South Coast Air Quality Management District
SwRI®	Southwest Research Institute®
THC	total hydrocarbons
ULSD	ultra low sulfur diesel (< 15 ppm S)