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BIODIESEL INTERCITY PASSENGER RAIL REVENUE SERVICE TEST

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13. ABSTRACT (Maximum 200 words) Amtrak, with the support of the Federal Railroad Administration, operated a P-32 passenger locomotive in revenue service for a period of 12 months, on a blend of 20 percent pure biodiesel and 80 percent #2 ultra-low sulfur diesel (ULSD) fuel. The GE P-32 locomotive used in the biodiesel demonstration was a Tier 0 12-cyclinder engine built in 1991. The locomotive was operated on the Heartland Flyer route, providing passenger train service between Oklahoma City, OK, and Fort Worth, TX. Following the in-service trial, the locomotive underwent emissions testing at the GE Transportation's locomotive emissions test facility in Erie, PA. The locomotive was tested for emissions according to Federal Test Procedure outlined in 40 CFR Part 92. The test results showed that operating the P-32 passenger locomotive on B20 biodiesel blended fuel for 12 months did not adversely affect the emissions of the locomotive. In addition, tear-down inspection of four of the twelve engine power assemblies showed that B20 biodiesel fuel did not have any adverse effects on the engine components.				
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Executive Summary

The use of B20 (20 percent biodiesel blended with 80 percent diesel fuel) biodiesel fuel was successfully demonstrated in revenue passenger rail service for a period of 12 months in the locomotive of the Amtrak Heartland Flyer train. The Federal Railroad Administration (FRA) awarded a grant to Amtrak under agreement number DTFR53-09-G-00038 for the Biodiesel Passenger Rail Revenue Service Trial (revenue service trial) that tested 20 percent beef tallow biodiesel and 80 percent #2 ultra-low sulfur diesel (ULSD) fuel in a passenger locomotive. The Amtrak Heartland Flyer train provides passenger service from Oklahoma City, OK, to Fort Worth, TX. The train consists of one locomotive and three to four coach and baggage cars. The Heartland Flyer provides one daily roundtrip between the two cities, for a total of 412 miles.

Amtrak selected a 3200 horsepower General Electric P32-8 engine, manufactured in 1991 as the test locomotive, and designated it Engine #500. The engine is certified as a U.S. Environmental Protection Agency (EPA) Tier 0 engine. Three hundred and thirty one round trips totaling 136,372 route miles were made using B20 on Engine #500 during the revenue service trial. The biodiesel for the B20 blend was produced from Texas-native feedstock (beef tallow) by BQ9000-registered Direct Fuels of Euless, TX. Approximately 178,946 gallons of the mixed B20 fuel were delivered to Engine #500.

Prior to the commencement of the biodiesel trial, all fuels used were evaluated to ensure that they met their respective American Society for Testing and Materials (ASTM) specification before and after blending (i.e., the diesel fuel, the B100 biodiesel, and the B20 biodiesel were all tested). The B20 and ULSD fuels were tested monthly during the trial. Engine lubrication oil was also subjected to testing prior to the trial and routinely throughout the trial period. The analyses of the ULSD, B100, B20, and used engine oil were within applicable ASTM specifications.

The On Time Performance (OTP) values during the revenue service trial for fiscal year 2010 and 2011 were 81.4 percent and 86.9 percent, respectively. OTP metrics for the Heartland Flyer for the fiscal year prior to the trial was 83.8 percent. No adverse effects to OTP were attributed to the use of B20.

Upon completion of the revenue service trial, the locomotive was tested for emissions at the GE Transportation Locomotive Emissions Test Facility in Erie, PA. Engine emissions testing was performed, according to Code of Federal Regulations (CFR) 40 Part 92, for hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and particulate matter (PM) under line haul and switch duty cycles. The particulate and gaseous emissions were measured at low idle, idle, dynamic brake (DB), and notches 1 through 8. Duty cycle composite emission test results using both the EPA certification fuel (diesel fuel) and B20 were well below limits for HC, CO, NOx, and PM established by EPA for Tier 0 locomotive engines. An approximately 5 percent increase in NOx was identified in the use of B20 compared with diesel fuel. However, this increase in NOx was expected and was within the range identified by other biodiesel emission testing results that were published[1]. Moreover, the increase in NOx from the B20 use was below the EPA established limits for that category of engine.

[1] Fritz, S.G., “Evaluation of Biodiesel Fuel in an EMD GP38-2 Locomotive,” NREL/SR-510-33436 (May 2004)

Smoke opacity was also measured. Smoke opacity measurements using both the diesel fuel and the B20 were well below limits established by EPA for Tier 0 locomotive engines. In addition to the emissions testing, the fuel consumption of the engine was also recorded. The emissions test results indicated that it was possible to achieve full power using B20 biodiesel fuel. No loss in horsepower was observed at low idle, idle, DB, or notches 1 through 8.

Following the emissions testing, the engine was inspected. Engine #500 had two new power assemblies installed prior to the revenue service trial. The power assemblies were removed and inspected to determine engine wear and identify deposits that could be attributed to the alternative use of B20 fuel. The levels of piston deposits, surface sludge, ring and liner wear, as well as connecting rod bearing condition were inspected and evaluated. Chevron Oronite performed the tear-down inspections of the two power assemblies and concluded that there were no abnormal conditions related to engine deposits or engine wear as a result of the biodiesel use.

The revenue service trial, emissions testing, and engine inspection all demonstrate that it is feasible to operate a passenger locomotive engine on B20 biodiesel fuel and achieve full engine power, meet the established EPA standards for gaseous and particulate emissions, and not adversely impact the engine. Additional research is needed to determine performance in colder environments, availability and cost of B20 biodiesel fuel, possible long-term engine durability problems, and original equipment manufacturer (OEM) warranty issues with the use of such fuels.

Figure 1: Biodiesel Passenger Rail Revenue Service Trial Locomotive Engine #500 on the Heartland Flyer Service.

1. Introduction

The rising cost of diesel fuel and energy security highlighted the need for domestically produced and sustainable fuels, such as biofuels, for transportation. Biofuels are transportation fuels such as biodiesel or ethanol that are made from biomass materials and are usually blended with petroleum-based fuel. In 2008, the on-highway retail price for #2 diesel fuel was $4.70. This was the highest price for diesel fuel in decades. Figure 2 below shows the retail cost of diesel fuel during the past 4 years.

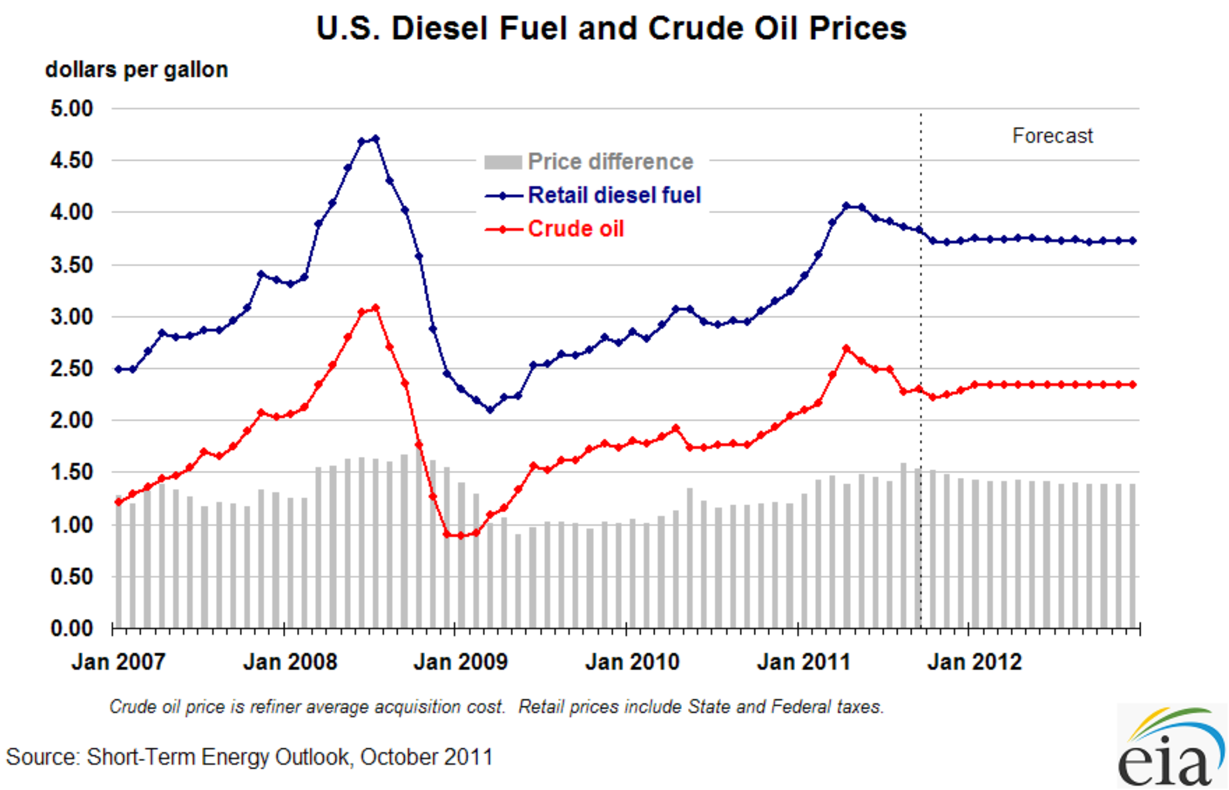

Figure 2: Retail Cost of #2 Diesel Fuel[2].

As seen in the graph, the high cost of diesel in 2008, and current trend of the cost hovering just under $4/gallon, has prodded the transportation industry to find alternative options for fuel.

This project was funded by FRA to assess the feasibility of using B20 biodiesel fuel in a passenger locomotive in revenue service. For this test, the B20 biodiesel used was a blend of 20 percent pure biodiesel and 80 percent ULSD. The biodiesel revenue service trial was first proposed by the Oklahoma Department of Transportation (DOT) and initiated by the National Railroad Passenger Corporation (Amtrak) on February 27, 2010. Oklahoma DOT was successful in using B20 biodiesel fuel in its off-road vehicles and proposed that Amtrak try such fuels in the Heartland Flyer passenger locomotive. The Texas Department of Transportation also supported this revenue service trial.

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[2] http://www.eia.gov/emeu/steo/pub/gifs/Fig3.png. Energy Outlook Source Book 2011

The Biodiesel Passenger Rail Revenue Service Test fit well into Amtrak's environmental sustainability program and promoted research of alternative options for rail transportation fuel.

The revenue service portion of the trial was completed on May 15, 2011. This revenue service trial was designed to demonstrate the use of B20 beef-tallow-based biodiesel. This report outlines the 12-month revenue service trial of the Heartland Flyer train operating on B20 biodiesel, the associated engine emissions testing and the tear-down inspection of the locomotive engine power assemblies. The revenue service trial was intended to be a demonstration of biodiesel in a passenger locomotive in revenue service and not an evaluation of biodiesel as a locomotive fuel.

2. Background

Amtrak operates intercity passenger rail service across the United States. Amtrak operates the Heartland Flyer (Train numbers 821/822), under State-funded contracts with the Oklahoma and Texas Departments of Transportation, to provide daily service (7 days/week) with regularly scheduled station stops in Oklahoma City, Norman, Purcell, Pauls Valley, and Ardmore, OK, and Gainesville and Fort Worth, TX. The distance between Fort Worth and Oklahoma City is 412 miles round trip. The Heartland Flyer made 443 round trips during the revenue service trial. Three hundred and thirty one round trips totaling 136,372 route miles were made using B20 on Engine #500. Actual equipment mileage during this time period totaled 152,622 miles. Preventative maintenance, service and inspection, equipment modifications, or track outages took place on those days when Engine #500 was not in service on the Heartland Flyer route.

The biodiesel revenue service trial was initiated by a proposal Oklahoma DOT made to Amtrak regarding the use of B20 biodiesel in the Heartland Flyer train. Amtrak and FRA saw merit in the idea and formed a steering committee that included representatives from Amtrak, FRA, Oklahoma DOT, GE Transportation Services (GE), Electro-Motive Diesel, and biodiesel fuel suppliers. The steering committee met monthly via teleconference to develop the biodiesel revenue service test implementation plan. The test implementation plan called for fuel and oil analyses, emissions testing, and engine inspection along with the revenue service test. For this demonstration, Amtrak selected Engine #500. Engine #500 is a 3200 hp GE P32-8 manufactured in 1991. During the trial, a P42 locomotive was placed in the consist for service protection or to provide head end power if there were more than three coach cars in the train consist. The Heartland Flyer train consist is normally operated with one P42 4250 HP GE locomotive, one nonpower control unit, two bilevel coach cars, and one bilevel snack/coach car. Additional cars may be added to the train depending on ridership.

The biodiesel fuel used in Engine #500 was derived from animal fats, beef tallow in this case. Beef tallow is a byproduct of meat processing and is typically used in the production of some soaps. The beef tallow undergoes a transesterification process that yields biodiesel as an end product. In this process, the beef tallow is reacted with an alcohol, like methanol, in the presence of a catalyst to produce glycerin and fatty-acid methyl esters (FAME), also known as biodiesel[3]. The biodiesel source (B100) for the B20 blend was Texas-native feedstock (beef tallow) produced by BQ9000-registered Direct Fuels of Euless, TX, the same fuel supplier that provides the ULSD regularly used for other Amtrak locomotives fueled in Fort Worth, TX. Quick Fuel Fleet Services, arranged with the biodiesel fuel supplier to mix the proper allocation of B100 and red dyed ULSD for daily mobile refueling of Engine #500 in Fort Worth.

Prior to starting the in-service test, two new power assemblies, which would be inspected at the end of the trial, were installed on Engine #500. Being new, these two assemblies were the “baseline” to evaluate the engine wear from 12 months of biodiesel use. Biodiesel has solvent properties that may cause it to react adversely with a variety of materials (rubber, plastics, and metals) found in locomotive engines. GE performed emissions testing of Engine #500 using B20 biodiesel.

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[3] http://www.biodiesel.org/docs/ffs-production/production-fact-sheet.pdf?sfvrsn=4

GE's participation in the revenue service trial and performance of the emissions tests does not indicate approval for use of biodiesel blends in GE locomotives. Failure to adhere to the approved fuels cited in the locomotive manufacturer's operations and maintenance instructions may result in the engine warranty being voided, if fuel related failure occurs.

Figure 3: Fueling of Engine #500 in Fort Worth, TX.

3. Methodology

Amtrak operated the Heartland Flyer in normal passenger service while using B20 biodiesel fuel and maintaining normal operating and safety procedures and practices. The test locomotive was fueled in the "direct to train" (DTL) method by which the engine's fuel tank is filled via a fuel truck containing splash-blended biodiesel. Thus, there were no modifications required to the railroad facility infrastructure to accommodate use of the new fuel. Amtrak performed required maintenance and inspection on the locomotive during the test period in accordance with Amtrak's maintenance and inspection practices. During the revenue service trial, Engine #500 was subject to preventive maintenance inspections occurring every 92 days. This service inspection required the unit to be taken out of service and shipped to Chicago where this work was completed. Inspection of the locomotive was conducted very 92-days. Routine maintenance, unscheduled necessary repairs, equipment modifications, and infrequent track outages did result in Engine #500 being out of service for periods of time during the field trial and resulted in some difficulty in maintaining a working fuel and engine oil sampling schedule.

In addition to the regularly scheduled inspections, each locomotive unit was inspected daily in accordance with CFR Title 49 Parts 229.21 and 236.587, and a Maintenance Analysis Program Equipment Condition Report (MAP100) form was completed. The MAP100 form included any comments regarding equipment or failures en route observed by the train crew. Discussions with Amtrak mechanical department representatives and a review of the mechanical documentation determined that no mechanical repairs or maintenance have been required as a result of the alternative use of B20 biodiesel fuel during the trial.

The rest of this section of the report provides details on the fuel sampling, emissions testing, and engine tear-down inspection.

3.1 Fuel and Engine Oil Analyses

Prior to the commencement of the biodiesel trial, the fuels used—ULSD diesel fuel and B100 biodiesel fuel—were evaluated to ensure that they met their respective specifications, as determined by ASTM, before blending. Throughout the revenue service trial, the blended fuel was periodically tested to ensure that the blended product met the ASTM specification for B20. Any changes to the fuel supply required a new and complete evaluation of the new supply before use.

The ULSD diesel fuel used to produce the B20 biodiesel fuel blend was tested according to ASTM D975 fuel specifications (see Table 1).

Table 1: ASTM D-975, ULSD Diesel Fuel Specifications.

TEST	DESCRIPTION	ASTM	SPECIFICATION	UNITS
1	API Gravity	D-287	30 min	
2	Distillation	D-86		
	Initial Boiling Point		345 typical	°F
	10% Recovered Volume		420 typical	°F
	50% Recovered Volume		500 typical	°F
	90% Recovered Volume		540 min / 640 max	°F
	Final Boiling Point		670 typical	°F
	Total Recovered Volume		98.0 min	Volume %
3	Cetane Index	D-976	40 min	
4	Water and Sediment	D-1796	0.0500 max	Volume %
5	Sulfur Content	D-5453	15 max	ppm
6	Viscosity @ 40 ºC	D-445	1–9 min / 4.1 max	cSt
7	Cloud Point	D-2500	Report	°F
8	Flash Point	D-93	126 min	°F
9	Lubricity by HFRR	D-6079	520 max	microns

The B100 fuel was tested according to ASTM D6751 fuel specifications (see Table 2); certain parameters of the tested supply failed to meet those standards. A new batch of B100 was then tested and found to be in accordance with all criteria of ASTM D6751. This new batch was used for the blending of the B20 biodiesel fuel.

Table 2: ASTM D6751, B100 Biodiesel Fuel Specifications.

TEST	DESCRIPTION	ASTM	SPECIFICATION	UNITS
1	Flash Point	D-93	130 min	°C
2	Water and Sediment	D-2709	0.0500 max	Volume %
3	Kinematic Viscosity @ 40 ºC	D-445	1.9–6.0	cSt
4	Sulfated Ash	D-874	0.020 max	Weight %
5	Sulfur	D-5453	15 max	ppm
6	Copper Strip Corrosion	D-130	No. 3 max	Rating
7	Cetane Index	D-976	47 min	
8	Cloud Point	D-2500	Report	°C
9	Carbon Residue	D-4530	0.0050 max	Weight %
10	Acid Number	D-664	0.50 max	Mg KOH/g
11	Free Glycerin	D-6584	0.020 max	Volume %
12	Total Glycerin	D-6584	0.240 max	Volume %
13	Phosphorous	D-4951	0.0010 max	Weight %
14	Distillation Temperature	D-1160	360 max	°C
15	Calcium and Magnesium	EN14538	5 max	ppm
16	Sodium and Potassium	EN14538	5 max	ppm
17	Oxidation Stability	EN14112	3 min	Hours

Once blended, the B20 fuel was tested according to ASTM D7467 specifications (see Table 3). As with the B100, certain parameters of the initial B20 sample did not meet ASTM D7467 specifications. Anomalies in the test results of the B100 and B20 biodiesel fuel initial samples are discussed further in the Results section of this report.

Table 3: ASTM D7476, B20 Biodiesel Fuel Specifications.

TEST	DESCRIPTION	ASTM	SPECIFICATION	UNITS
1	Flash Point	D-93	52 minimum	°C
2	Water and Sediment	D-2709	0.0500 maximum	Volume %
3	Kinematic Viscosity @ 40 ºC	D-445	1.9–4.1	cSt
4	Ash Content	D-482	0.01 maximum	Weight %
5	Sulfur	D-5453	15 maximum	ppm
6	Copper Strip Corrosion	D-130	No. 3 maximum	Rating
7	Centane Index	D-976	40 minimum	
8	Cloud Point	D-2500	Report	°C
9	Carbon Residue 10%	D-524	0.3500	Weight %
10	Aromaticity	D-1319	35 maximum	Volume %
11	Acid Number	D-664	0.3 maximum	Mg/KOH
12	Free Glycerin	D-6584	Report	Volume %
13	Total Glycerin	D-6584	Report	Volume %
14	Distillation Temperature 90%	D-86	343 maximum	°C
15	Biodiesel Content	D-7371	6–20	Volume %
16	Oxidation Stability	EN14112	6 minimum	Hours
17	Lubricity	D-6070	520 maximum	microns

A new batch of the B100 and B20 biodiesel fuel were sampled, retested, and determined to be within tolerance of all applicable ASTM specifications prior to the commencement of the revenue service trial (see Section 4).

During the field trial, Direct Fuels tested the B100 fuel supply weekly and certificates of analysis were made available to the fuel driver with every load delivered to Amtrak. The ULSD fuel was also tested. All ULSD samples, with the exception of one sample collected near the end of the trial, were within relevant testing specifications. The analytical testing of the B20 blend was conducted on a monthly basis by ANA Laboratories, per ASTM D7467; the blend was determined to be within the limits of specification.

Engine lubrication oil was subjected to testing prior to commencement of the field trial and during the trial. Engine used oil was tested for metals, fuel and water, oxidation, nitration, soot, and sulfate by ANA Laboratory. In addition to the aforementioned tests, the used oil samples were tested by Chevron Oronite for base number (ASTM D4739), acid number (ASTM D664), pentane insolubles using the Locomotive Maintenance Officer Association (LMOA) method (ASTM D7317), viscosity increase (ASTM D445), oxidation, wear metals (ASTM D5185), fuel dilution (ASTM D3524) and biodiesel dilution using Chevron Oronite proprietary methods. The engine oil was changed every 92 days during scheduled PM servicing.

3.2 Locomotive Exhaust Emissions Testing

The locomotive exhaust emissions were analyzed following the commencement of the revenue service test. The exhaust emissions testing were done in accordance with the Federal Test Procedures outlined in 40 CFR Part 92, "Emission Standards for Locomotives and Locomotive Engines." The B20 revenue service test locomotive was taken to the GE Locomotive Emissions Testing Facility in Erie, PA, for the emissions testing. Once at GE, the locomotive was inspected and loaded to determine its powering cycle. Engine #500's fuel supply system was disconnected and a system capable of measuring the net rate at which fuel is supplied to the engine was connected. The engine was operated for a period of time in all its powering modes (low idle, idle, DB, and notches 1–8), simulating in-service load conditions. Engine #500 power output produced by the alternator/generator at each throttle setting was recorded as measurements of current flow through the electrical resistance bank.

Following the loading tests, the engine exhaust was sampled and tested for various gaseous and particulate emissions. The emissions were measured over two steady-state test cycles, simulating line haul and switch engine duty cycle of the locomotive. The duty cycle simulations for the emissions testing consisted of operating Engine #500 at different power levels, from low idle to notch 8. Switch engine operations were simulated by operating the engine in steady-state conditions much of the time in low idle, idle, and low power notches. Line haul operations were simulated by operating the engine in steady-state condition in the high power notches, particularly notch 8.

Two sets of emissions tests were completed on the locomotive, one using the B20 fuel available in the onboard fuel tank, and the other using EPA locomotive certification petroleum diesel fuel stored at the facility. ULSD fuel normally used in service on the Heartland Flyer route was not used as the conventional fuel for the emissions test. The locomotive emissions testing facility at GE does not normally have a supply of ULSD on site, and the fuel storage logistics and environmental, health, and safety concerns related to temporary storage of ULSD at the GE testing facility for this particular test prevented its use during testing. Samples of B20 and the certification diesel fuels were collected for analysis at the GE testing facility. Gaseous emission and particulate matter sampling, as well as smoke opacity and fuel consumption testing were performed as part of the test protocol.

The gaseous emissions were sampled and measured continuously throughout the test; whereas, the particulate emission was sampled beginning 10 seconds after the start of the engine throttle setting (e.g., idle, notch 1, etc.) and ended 6 minutes after the start of the throttle setting. To analyze the emissions, raw exhaust is sampled, via probes, directly from the exhaust stream during each engine throttle setting (see Figure 3). The probes are connected to gas analyzers that measure the amount of gaseous emissions in the probe. This information is fed to data analyzer systems and recorded. A portion of the exhaust stream is channeled through a special section for the particulate matter analyses and diluted with ambient air. Particulates from the exhaust stream were collected on pre-measured and pre-conditioned filters following dilution with ambient air of the raw exhaust sample. The filters were measured to determine the amount of particulate emitted with each throttle setting of the engine by comparing its weight after the test with its initial pre-measured weight.

During the emissions test, the fuel flow rate for each throttle setting was measured continuously. Also, the smoke opacity was measured continuously as each throttle setting was engaged. The smoke opacity measurements were taken at steady-state, 30-second peak, and 3-second peak intervals. Results of the emission testing using the B20 biodiesel fuel and EPA certification fuel were compared against one another and against EPA emission limits for Tier 0 locomotive engines. Results of the certification fuel and the B20 testing are discussed further in the Results section of this report.

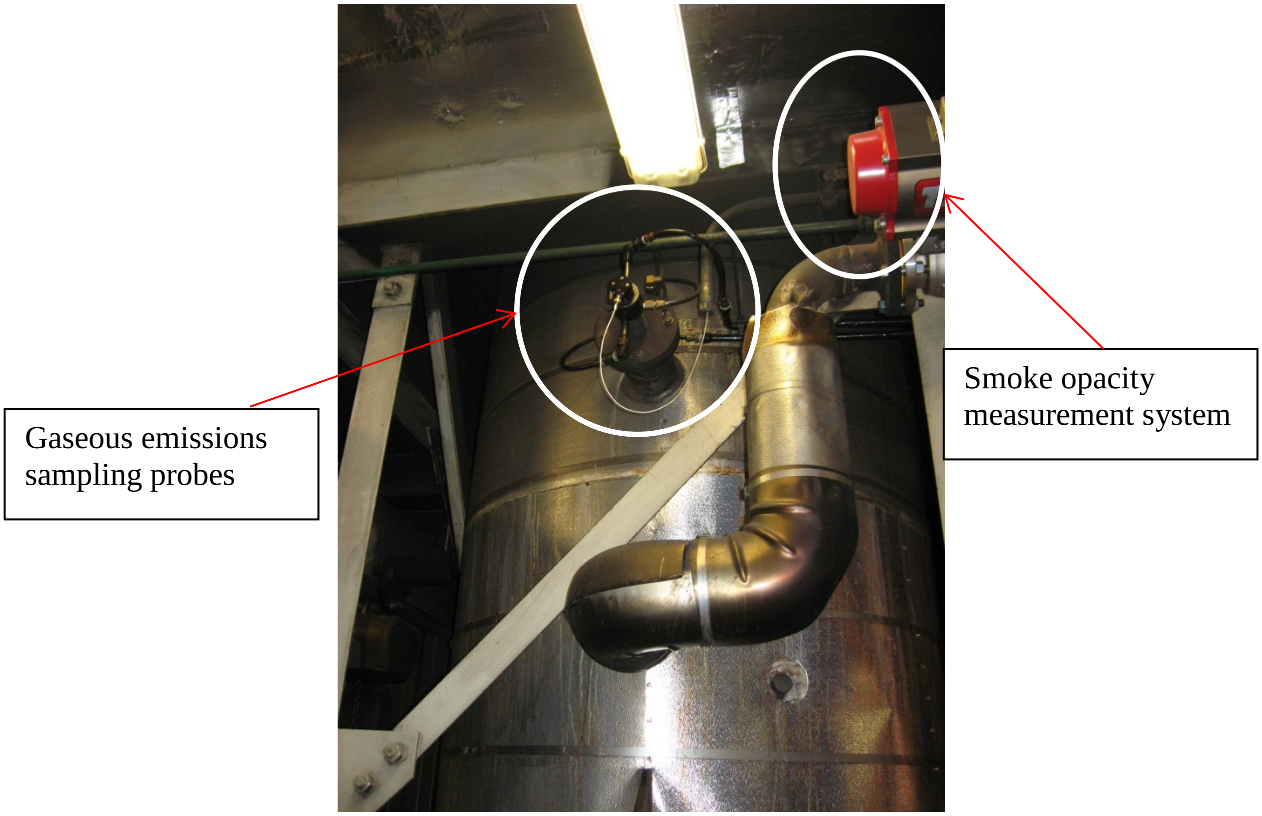

Figure 4: Gaseous Emissions Sampling Probes.

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3.3 Engine Power Assembly Mechanical Tear-Down and Inspection

Amtrak removed two power assemblies from Engine #500 and replaced them with two new units (baseline units). These two new power assemblies were the baseline units to assess the effects of biodiesel on the engine after 12 months of using B20 fuel. They were installed in position 2 of the engine on the right and left side, 2R and 2L. Following the revenue service trial and the engine exhaust emissions testing, the two baseline units were removed and inspected. The inspections were conducted to identify any adverse effects of the B20 fuel on engine components such as the connecting rods, bearing, pistons, and piston rings, to name a few that were expected to be directly or indirectly impacted. General engine condition—engine cleanliness (rocker box and crankcase)—was evaluated; a visual inspection of the locomotive was made, and a review of operational history was conducted. The power assemblies were photographed during the post-revenue service inspection.

Figure 5: Amtrak personnel removing the 2R power assembly for inspection.

Amtrak maintenance facility personnel removed the baseline units, and Chevron Oronite, who also conducted analyses at their laboratory, inspected them. Additionally, 5R and 5L power assemblies were removed. These power assemblies were not newly installed but were removed and inspected to better assess the wear of baseline power assemblies, 2R and 2L.

Figure 6: 2R Power assembly cylinder with piston removed.

Figure 7: Chevron Oronite personnel measuring the surface area of 2R power assembly cylinder liner to categorize wear.

4. Results

The Amtrak Heartland Flyer passenger train was tested in revenue service using B20 blend of biodiesel fuel for a period of 12 months. During that period, fuel consumption data was recorded. Following the revenue service trial of B20 biodiesel, the engine underwent emissions testing, and four of its power assemblies were put through tear down inspections.

4.1 Revenue Service Trial Results

At the end of the revenue service trial, 178,946 gallons of B20 fuel had been delivered to locomotive Engine #500. The cost variance comparing the price of biodiesel to regular ULSD #2 during the trial period totaled $21,175. During the revenue service trial, the cost of B20 ranged from $0.00 to $0.31/ gallon more than ULSD #2. On average, this was a $0.13/gallon price difference for biodiesel versus the cost of #2 ULSD diesel fuel. Documentation supporting fuel delivery dates, quantity of fuel delivered, cost of fuel, etc. can be found in Appendix A.

Daily inspections of Engine #500 while in revenue service were documented on the MAP100. The 92-day preventative maintenance inspection scope of work performed on this locomotive is outlined in a 12-page form completed and maintained by Amtrak titled “P32 92-Day PM Inspection WMS Template ID: 58537.” Copies of both of these forms are appended to this report. Based on review of this documentation and interview with Amtrak Mechanical personnel, no adverse mechanical impacts attributable to alternative fuel use were identified during the trial period. Samples of the 92-Day Inspection and MAP100 forms are included in Appendix B and C, respectively.

OTP during the revenue service trial for FY10 and FY11 were 81.4 percent and 86.9 percent, respectively. OTP metrics for the Heartland Flyer for the fiscal year prior to the trial was 83.8 percent. Therefore, using biodiesel to power Engine #500 did not impact its service performance.

Discussion of the results for tests conducted during and after the revenue service trial is outlined in the following subsections.

4.2 Fuel and Engine Oil Analyses Results

Each of the fuels (i.e., diesel fuel and biodiesel fuel) used to develop B20 biodiesel fuel was evaluated before blending to ensure that it met its individual ASTM specification. Once blended, the B20 fuel was subject to periodic testing to ensure that the blended product met the ASTM biodiesel specification.

During the field trial, Direct Fuels tested the B100 fuel supply weekly, per ASTM D6751 specifications, and certificates of analysis were made available to Amtrak. Samples of the certificates provided by Direct Fuels to Amtrak are found in Appendix D. The ULSD fuel was also tested, per ASTM D975 specifications. Results from those tests are provided in Appendix E. All ULSD samples were within testing specifications with the exception of one sample collected near the end of the trial. This sample identified a slightly higher lubricity value; however, the follow up sample was within tolerance.

Initial samples of B100 and B20, collected and analyzed before the start of the revenue service trial, did not conform to their respective ASTM standards (D6751 and D7467). The initial baseline B100 samples contained unacceptable concentrations of free and total glycerin (see Table 4). The test results indicated that the samples had a 0.230 percent volume of free glycerin and 0.250 percent volume of total glycerin, which is above the allowed maximum of 0.020 and 0.240 percent volume for free and total glycerin, respectively, per ASTM D6584 specifications for determining glycerin content. The presence of high levels of glycerin in the final product of B100 can result in fuel separation, material incompatibility, and/or fuel injector carbon buildup[4].

Table 4: ANA Laboratory Test Results for B100 Biodiesel Fuel Initial Sample.

	Description	ASTM	Spec.	Results	Units
1)	Flash Point	D-93	130 min	165	°C
2)	Water and Sediment	D-2709	0.0500 max	<0.0150	Vol %
3)	Kinematic Viscosity @ 40 ºC	D-445	1.9–6.0	4.62	cSt
4)	Sulfated Ash	D-482	0.020 max	0.001	wt %
5)	Sulfur	D-5453	15 max	0.0005	ppm
6)	Copper Strip Corrosion	D-130	No. 3 max	1a	Rating
7)	Cetane Index	D-976	47 min	60.3	
8)	Cloud Point	D-2500	Report	17	°C
9)	Carbon Residue	D-524	0.0050 max	0.0031	wt %
11)	Acid Number	D-664	0.50 max	0.30	mg KOH/g
12)	Free Glycerin	D-6584	0.020 max	0.23	Vol %
13)	Total Glycerin	D-6584	0.240 max	0.250	Vol %
14)	Phosphorous	D-4951	0.0010 max	<0.0001	wt %
14)	Distillation Temp 90%	D-86	343 max	341	°C
15)	Calcium and Magnesium	EN14538	5 max	<1	ppm
16)	Sodium and Potassium	EN14538	5 max	<1	ppm
17)	Oxidations and Stability	EN14112	3 min	>10	Hours

[4]Mike Beauchaine, *Measuring Water, Methanol and total Glycerin in B100 Samples, http://www.biodieselmagazine.com/articles/1663/measuring-water-methanol-and-total-glycerin-in-b100-samples/* (May 25, 2007).

As outlined in Table 5, new B100 samples were determined to be within tolerance of all ASTM specifications prior to the commencement of the trial. The testing was done by ANA Laboratories.

Table 5: ANA Laboratory B100 Baseline Sample Second Test Results.

Test	Description	ASTM	Spec.	Results	Units
1)	Flash Point	D-93	130 min	146	°C
2)	Water and Sediment	D-2709	0.0500 max	0.0100	Vol %
3)	Kinematic Viscosity @ 40 ºC	D-445	1.9–6.0	4.67	cSt
4)	Sulfated Ash	D-482	0.020 max	0.001	wt %
5)	Sulfur	D-5453	15 max	0.0007	ppm
6)	Copper Strip Corrosion	D-130	No. 3 max	1a	Rating
7)	Cetane Index	D-976	47 min	59.1	
8)	Cloud Point	D-2500	Report	17	°C
9)	Carbon Residue	D-524	0.0050 max	0.049	wt %
11)	Acid Number	D-664	0.50 max	0.28	mg KOH/g
12)	Free Glycerin	D-6584	0.020 max	0.00	Vol %
13)	Total Glycerin	D-6584	0.240 max	0.00	Vol %
14)	Phosphorous	D-4951	0.0010 max	<0.0001	wt %
14)	Distillation Temperature 90%	D-86	360 max	331	°C
15)	Calcium and Magnesium	EN14538	5 max	<1	ppm
16)	Sodium and Potassium	EN14538	5 max	<1	ppm
17)	Oxidations and Stability	EN14112	3 min	>10	Hours

The initial baseline B20 sample was found to be unacceptable for aromaticity (see Table 6 below). High levels of aromatics in the fuel can impact the emissions of the locomotive. Therefore, it was imperative that the B20 samples meet the ASTM standards during and after the revenue service trial. The aromatic content was measured at 46.6 percent volume of the fuel, whereas the ASTM specification for B20 fuel required a maximum of 35 percent aromatic content by volume of the fuel.

Table 6: ANA Laboratory B20 Baseline Sample Test Results.

Test	Description	ASTM	Spec.	Results	Units
1)	Flash Point	D-93	52 min	72	°C
2)	Water and Sediment	D-2709	0.0500 max	<0.0010	Vol %
3)	Kinematic Viscosity @ 40 °C	D-445	1.9–4.1	3.19	cSt
4)	Ash Content	D-482	0.01 max	0.003	wt %
5)	Sulfur	D-5453	15 max	9	ppm
6)	Copper Strip Corrosion	D-130	No. 3 max	1a	Rating
7)	Cetane Index	D-976	40 min	45.6	
8)	Cloud Point	D-2500	Report	-6	°C
9)	Carbon Residue 10%	D-524	0.3500 max	0.1010	wt %
10)	Aromaticity	D-1319	35 max	46.6	Vol %
11)	Acid Number	D-664	0.3 max	0.12	mg KOH/g
12)	Free Glycerin	D-6584	Report	0.07	Vol %
13)	Total Glycerin	D-6584	Report	0.07	Vol %
14)	Distillation Temperature 90%	D-86	343 max	336	°C
15)	Biodiesel Content	D-7371	6–20	17.4	Vol %
16)	Oxidation Stability	EN14112	6 min	>10	Hours
17)	Lubricity	D-6079	520 max	207	microns

Testing of subsequent batches of B20 fuel showed conformance with the ASTM standards, as can be seen in Table 7 below.

Table 7: ANA Laboratory B20 Baseline 2nd Sample Test Results.

Test	Description	ASTM	Spec.	Results	Units
1)	Flash Point	D-93	52 min	74	°C
2)	Water and Sediment	D-2709	0.0500 max	<0.0010	Vol %
3)	Kinematic Viscosity @ 40 °C	D-445	1.9–4.1	3.14	cSt
4)	Ash Content	D-482	0.01 max	0.003	wt %
5)	Sulfur	D-5453	15 max	9	ppm
6)	Copper Strip Corrosion	D-130	No. 3 max	1a	Rating
7)	Cetane Index	D-976	40 min	53.3	
8)	Cloud Point	D-2500	Report	-7	°C
9)	Carbon Residue 10%	D-524	0.3500 max	0.040	wt %
10)	Aromaticity	D-1319	35 max	31	Vol %
11)	Acid Number	D-664	0.3 max	0.19	mg KOH/g
12)	Free Glycerin	D-6584	Report	0.0	Vol %
13)	Total Glycerin	D-6584	Report	0.0	Vol %
14)	Distillation Temperature 90%	D-86	343 max	331	°C
15)	Biodiesel Content	D-7371	6–20	20	Vol %
16)	Oxidation Stability	EN14112	6 min	>10	Hours
17)	Lubricity	D-6079	520 max	195	microns

All revenue service B100 test results appear to be within specification, and copies of B100 sampling results can be found in Appendix F. Copies of the B20 analytical results can be found in Appendix G; all samples conformed to the applicable ASTM testing standards.

Samples of used oil from the engine were collected and analyzed. ANA Laboratory tested the engine used oil for metals, fuel and water, oxidation, nitration, soot, and sulfate. Baseline and follow up sampling results from ANA Laboratory are contained in Appendix H. In addition to the aforementioned tests, the used oil samples were tested by Chevron Oronite for base number (BN) (ASTM D4739), acid number (AN) (ASTM D664), pentane insolubles by LMOA method (ASTM D7317), viscosity increase (ASTM D445), oxidation, wear metals (ASTM D5185), fuel dilution (ASTM D3524), and biodiesel dilution by proprietary methods used by Chevron Oronite. The oil used in Engine #500 was 20W-40 multigrade generation 5 locomotive oil. Used oil samples were collected approximately every 15 days.

Tests for the acidic and basic content of the used oil can indicate whether the engine oil underwent degradation while in service. According to the Chevron Oronite report contained in Appendix I, the BN retention was good, dropping to a low of 7.37 mmKOH/g[5]. AN rose slightly over this same time period to 4.18 mm KOH/g before dropping. The change in acid number could be attributed to a change in the oil, though this could not be confirmed. The ASTM D7317 and ASTM D445 specifications determined the pentane insolubles in the used oil and kinematic viscosity of the used oil, respectively. Analyses of the used oil showed that coagulated insolubles by the LMOA method remained low with a maximum of 2.6 percent weight, whereas the analyses of the viscosity of the engine used oil showed no significant increase in its viscosity.

Oxidation of the engine oil was measured by infrared method. Oxidation was under control and remained low for the duration of the test. Wear metals (iron, copper, and lead) were measured using the inductively coupled plasma method. For all three, the levels were very low and well within the condemning limits. Fuel dilution (total) and biodiesel dilution were also monitored. As an acidic material, biodiesel dilution in the oil may be problematic because it can be corrosive to metallic surfaces. For the duration of the test, both total fuel dilution and biodiesel dilution were very low and, in many observations, were below measurement limit[6]. Results from Chevron Oronite analyses are contained in Appendix I.

In summary, all samples of used oil collected and analyzed during the trial were routinely within tolerance of ASTM specifications and/or recommended values and are contained within Appendices D and J. These results indicate that in this revenue service trial, the biodiesel did not adversely affect the operations of the engine.

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[5] Van Slyke, P. and Anderson, D., FR-861 Amtrak General Electric Transportation Evaluation of a B-20 Biodiesel in a General Electric P-32 Locomotive, March 2010-June 2011. Chevron Oronite Company LLC, Richmond CA.

[6] Van Slyke, P. and Anderson, D., FR-861 Amtrak General Electric Transportation Evaluation of a B-20 Biodiesel in a General Electric P-32 Locomotive, March 2010-June 2011. Chevron Oronite Company LLC, Richmond CA.

4.3 Locomotive Exhaust Emissions Test Results

Engine Exhaust Emissions testing was performed for HC, CO, NOx, and PM under line haul and switch duty cycles, according to 40 CFR Part 92. The particulate and gaseous emissions were measured at low idle, idle, DB, and notches 1–8. Smoke opacity measurements were also taken according to 40 CFR Part 92, using both the EPA certification fuel and the B20 biodiesel.

4.3.1 Gaseous and Particulate Emission Test Results

Duty cycle composite emission test results using both the EPA certification fuel and B20 were well below limits established by EPA for Tier 0 engines for the gaseous emissions: HC, CO, NOx, and PM. There was an approximately 5 percent increase in NOx emissions observed in the use of B20 compared with the EPA diesel certification fuel. However, this increase in NOx was expected and was within the range identified by other published emission test results of B20 fuel use[7].

There were no significant differences identified in the emission results when comparing the certification fuel with B20 for PM, HC, and CO, except at low idle. Results for PM, HC, and CO at low idle showed an increase in emissions using B20 in comparison to EPA diesel certification fuel. Fuel consumption values also showed an increase at low idle with B20 compared with the diesel fuel. However, the disparity in the results between the B20 and certification fuel for the gaseous and particulate emissions, as well as the fuel consumption values, were not replicated at idle, DB, or notches 1–8. There was no clear explanation for this anomaly. GE, who performed the emissions testing on Engine #500, suggested that the disparity could have been caused as much by an engine operating issue as by the fuel difference. No loss in horse power was observed at low idle, idle, dynamic brake, or notches 1–8. The following graphs in Figures 7, 8, 9, 10, 11, and 12, and Tables 8 and 9 show the results from the gaseous, particulate matter, and smoke opacity emissions testing, as well as the results of fuel consumption and engine performance assessments.

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

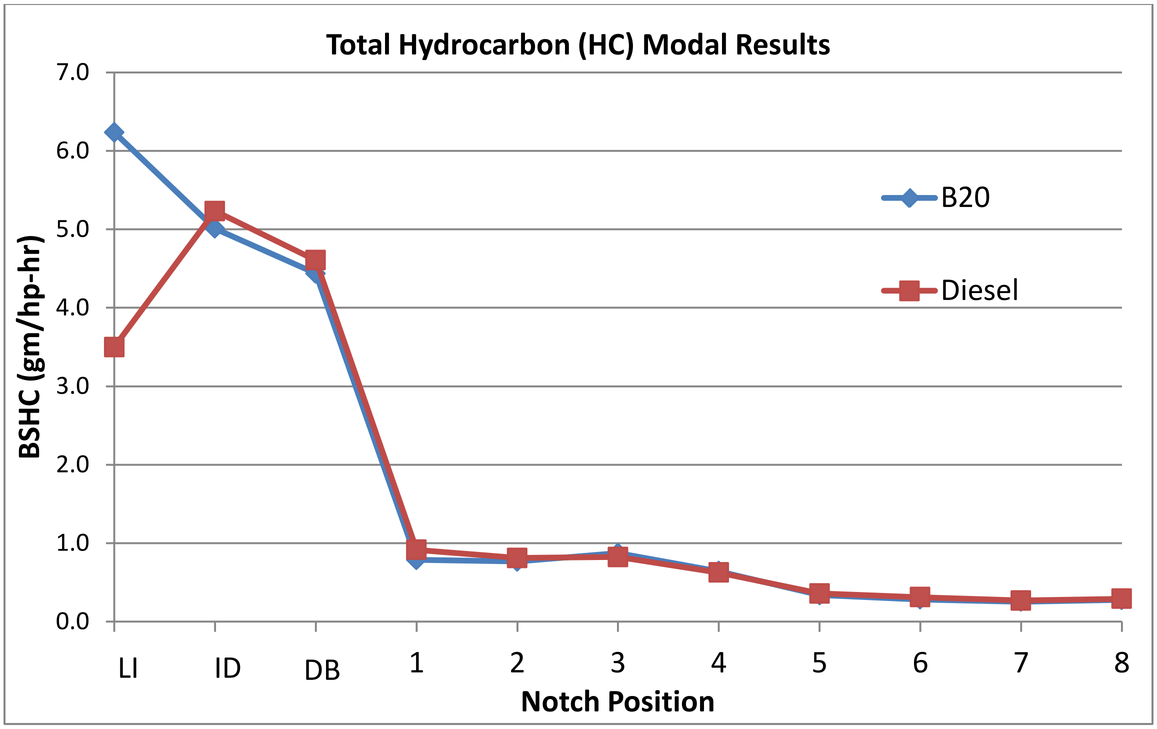

Figure 8: Total Hydrocarbon (HC) Emissions Test Results.

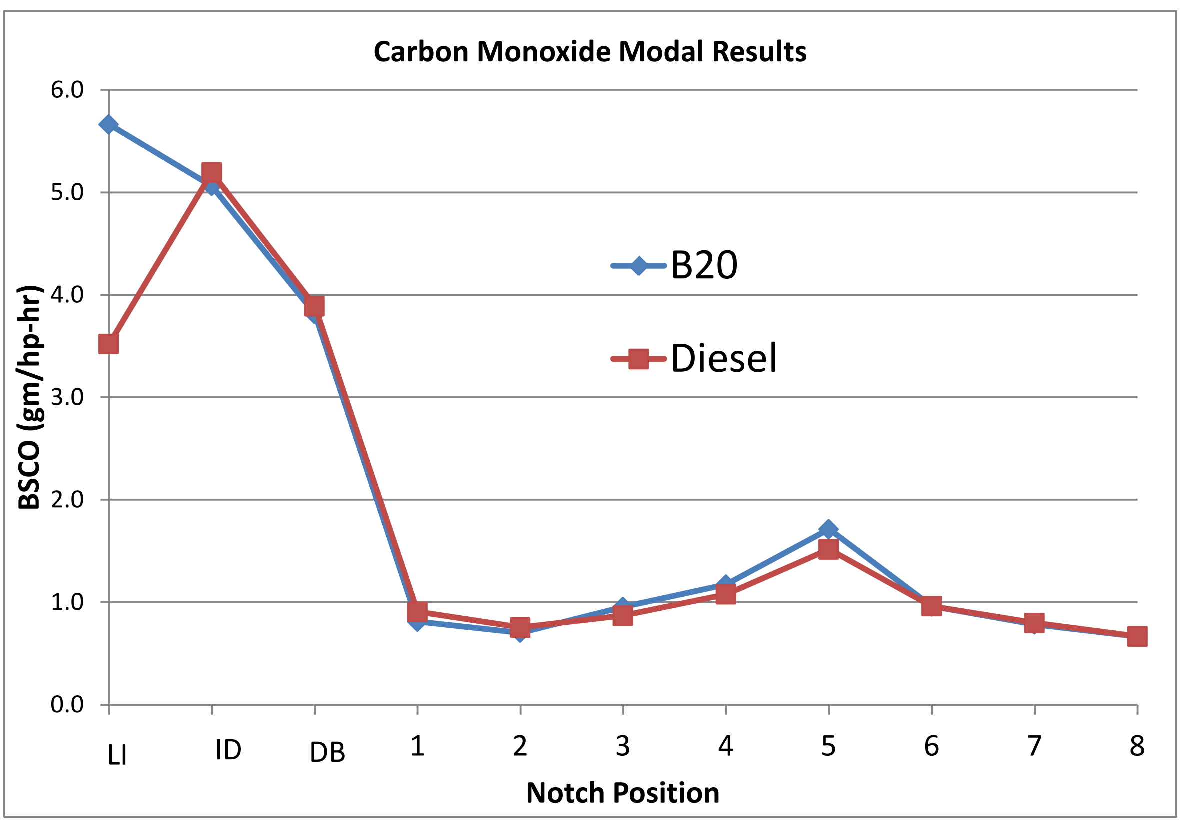

Figure 9: Carbon Monoxide (CO) Emissions Test Results.

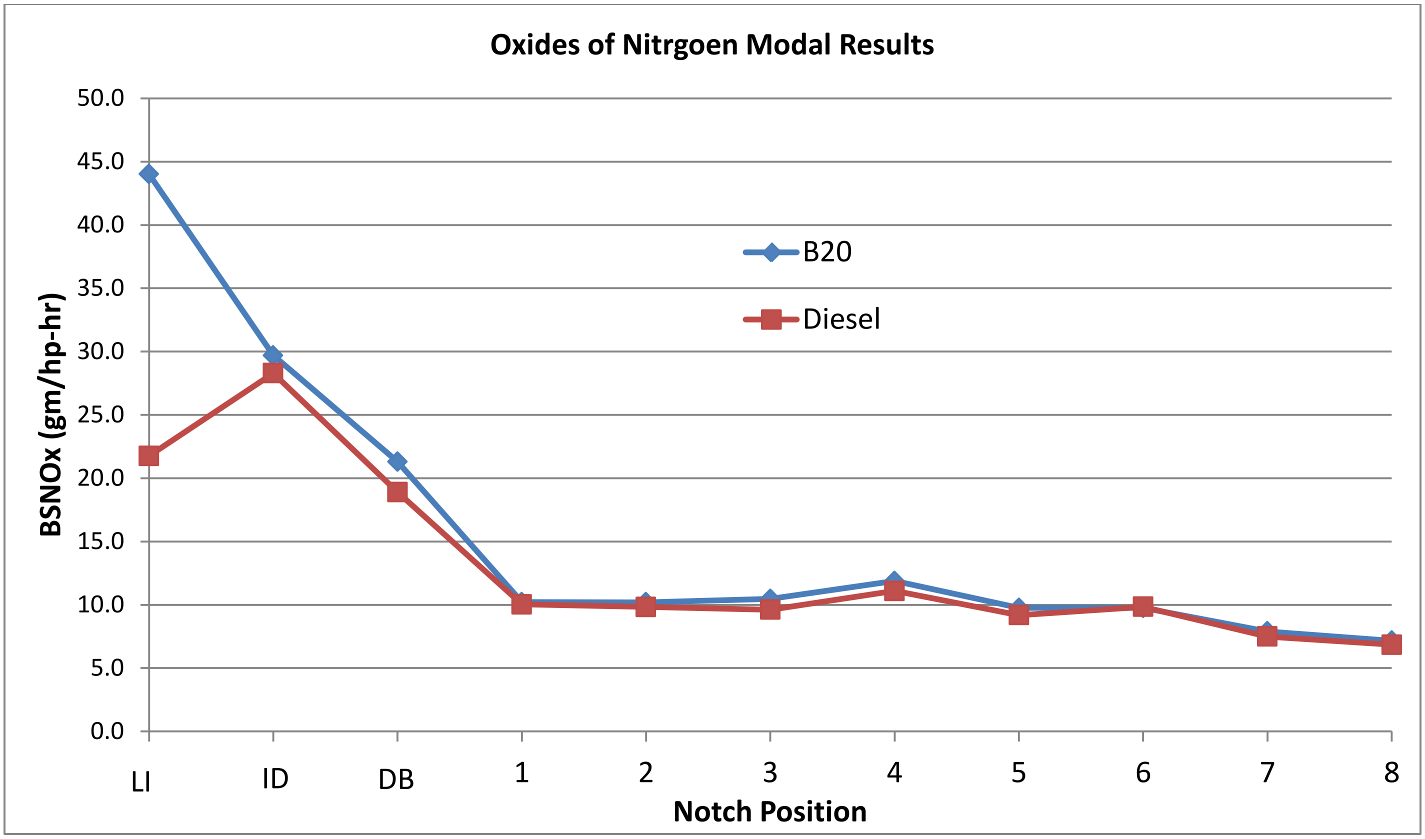

Figure 10: Oxides of Nitrogen (NOx) Emissions Test Results.

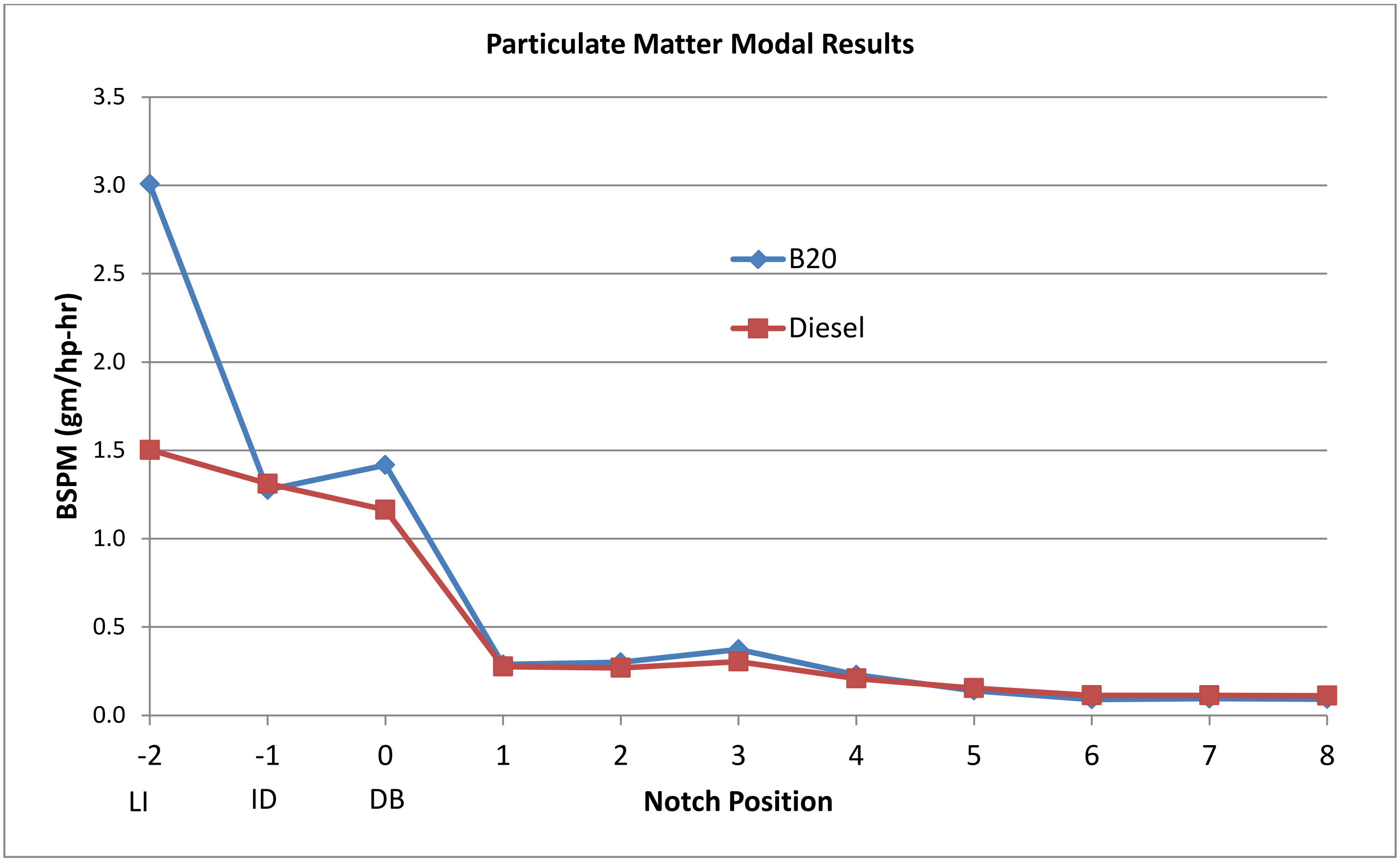

Figure 11: Particulate Matter Emissions Test Results.

As can be seen in the preceding graphs (Figures 8–11) and Table 8 below, the emissions of Engine #500 using B20 biodiesel fuel compares favorably with the certification diesel fuel. The gaseous and particulate emissions from Engine #500 were significantly lower than the EPA emissions limits for a Tier 0 engine, specifically for HC, CO, and PM. The measured NOx emission of the engine on B20 was slightly higher than the measured NOx emission of the engine on certification diesel fuel, but ultimately did not exceed the EPA limits.

Table 8: Modal Emissions Results.

Line Haul Duty Cycle Results				
	BSHC	BSCO	BSNOx	BSPM
	(gm/hp-hr)			
B20 Fuel	0.38	0.90	8.3	0.13
EPA Certification (Diesel) Fuel	0.39	0.80	7.9	0.14
Tier 0 Limit	1.00	5.00	9.5	0.60
Switch Duty Cycle Results				
	BSHC	BSCO	BSNOx	BSPM
	(gm/hp-hr)			
B20 Fuel	0.68	1.2	10.7	0.26
EPA Certification (Diesel) Fuel	0.68	1.2	10.0	0.24
Tier 0 Limit	2.10	8.00	14.0	0.72

Also measured was the smoke opacity of the engine on B20 and certification fuel. As mentioned previously, high aromaticity in the B20 fuel can affect the emissions of the engine by increasing the smoke opacity. Table 9 below shows the smoke opacity results. The percent opacity was measured at various time intervals. For each notch position of the engine, the opacity of the emitted smoke was recorded at 3 seconds peak interval, 30 seconds peak interval, and steady state. Data was again collected for the B20 biodiesel and certification diesel fuel. The test results show that the B20 fuel performed comparably with the diesel fuel, and below the EPA limit for Tier 0 engines.

Table 9: Smoke Opacity Emissions Test Results.

Smoke Opacity Test Results			
	Steady-State	**30-Second Peak**	**3-Second Peak**
	% Opacity		
B20 Fuel	12	16	35
Diesel Fuel	11	15	34
Tier 0 Limit	30	40	50

Notwithstanding the disparity in emissions and fuel consumption observed at low idle between the B20 and diesel fuel test results, Engine #500 performed well. The fuel consumption and engine performance results indicated that Engine #500 performed as well on the B20 biodiesel as it did on the diesel fuel. Engine #500 was able to make full horsepower using B20 biodiesel as it did using diesel fuel (see Figure 12).

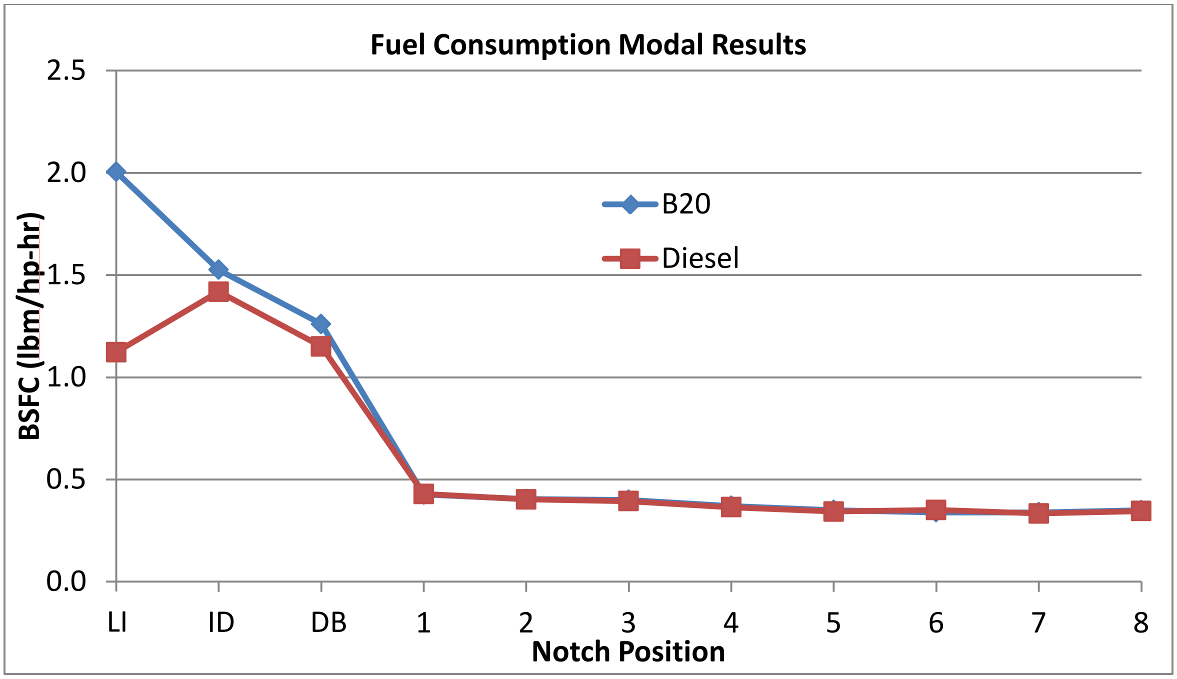

Figure 12: Fuel Consumption of Engine #500.

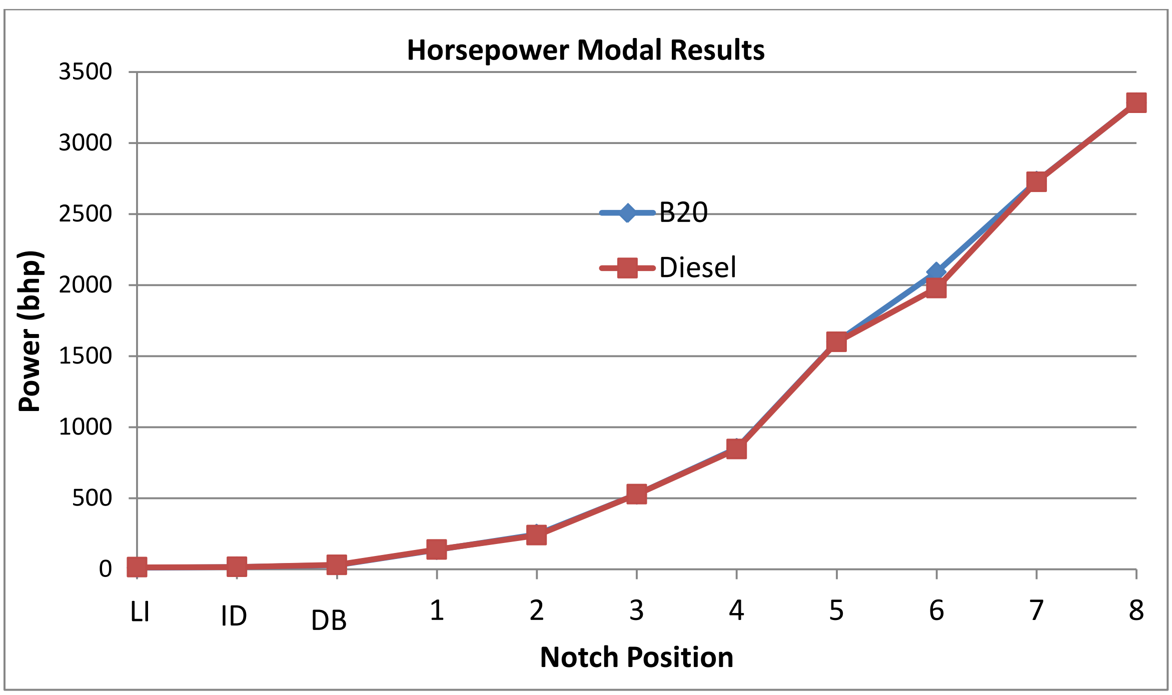

Figure 13: Engine #500 Powering Performance.

The test result presented in Figure 13 reinforces the locomotive engineers' assertion that they were able to achieve the full power at notch 8 during the revenue service trial. GE's report to Amtrak on the emissions testing is contained in Appendix J.

4.4 Engine Power Assembly Mechanical Tear-Down and Inspection Results

Following the emissions testing of Engine #500, a mechanical inspection to evaluate the engine for deposits and wear was performed by Chevron Oronite personnel. According to Chevron Oronite, the results of the testing showed no abnormal conditions related to engine deposits or engine wear. The condition of the parts was deemed comparable to normal conditions as experienced on passenger and freight locomotive operations. The engine parts inspected showed normal piston deposits. The liner wear was minimal. Piston rings also showed low wear and were in serviceable condition. The engine bearings showed normal wear and even loading with no evidence of corrosion. Even though the inspection of the 2R and 2L connecting rod bearings showed normal wear, there was some evidence of small pitting which was determined not to be caused by corrosion; further investigation was deemed necessary.

Inspection of Engine #500 after 12 months of B20 biodiesel use showed that the two new power assemblies had moderate piston deposits and a very clean engine surface lacking any sludge or deposit depth. A close up of the interior of the power assembly cylinder can be seen in the figures below.

Figure 24: Interior views of power assembly cylinder showing buildup.

The buildup seen was categorized as normal buildup from engine combustion. See Figure 14 above. The connecting rod of the power assembly can be seen in Figures 15(a) and 15(b) below. The striation marks observed in Figure 15(b) on the right has been classified as uniform wear.

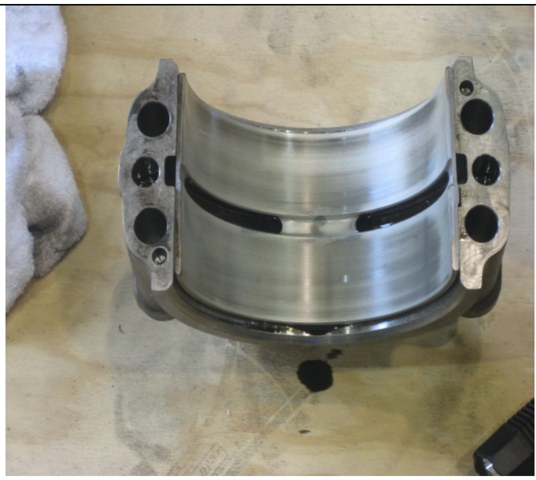

Figure 15(a): 2R Power assembly connecting rod.

Figure 15(b): Close up of 2R connecting rod.

Appendix I contains the report submitted to Amtrak by Chevron Oronite. The report addresses the following conclusions:

- Used oil analysis exhibited good viscosity control.
- Used oil analysis exhibited good base retention and acid control.
- Used oil analysis exhibited good oxidation control.
- Used oil exhibited very low wear metals (Pb, Cu, Fe) indicating low wear.

5. Conclusion

The Amtrak revenue service trial of B20 biodiesel was listed as number 23 on Time Magazine's Top 50 Inventions of 2010 list. At the end of the revenue service trial, 35,789 gallons, or 20 percent, of the total fuel volume used during this test was produced from a nonpetroleum, renewable, and sustainable source of fuel. For the biodiesel revenue service trial, the test locomotive was provided, through DTL fueling methods, a total of 178,946 gallons of B20 biodiesel fuel that reliably met ASTM specifications for biodiesel. Existing infrastructure and vehicles were used for the trial. No engine modifications were required or performed on locomotive Engine #500, and no capital improvements were required to accommodate delivery of fuel. For these reasons, DTL fueling method may be the preferred fueling method when considering further use of B20 biodiesel fuel.

No adverse impact related to B20 fuel use was observed on OTP during 331 roundtrips from Oklahoma City, OK, to Fort Worth, TX (a total of 136,372 route miles). A total of 152,622 equipment miles was logged during this period using B20. No additional maintenance performed on Engine #500 was attributed to alternative use of B20 fuel.

During the course of the trial, the cost of B20 biodiesel ranged from $2.16/gallon to $3.70/gallon compared with ULSD #2, which ranged from $2.14/gallon to $3.52/gallon. The cost variance of B20 in comparison to ULSD ranged from $0.00/gallon to $0.31/gallon. On average, this was a $0.13/gallon price difference between biodiesel and ULSD diesel fuel. This market fluctuation may have been partially caused by changes in State law related to tax exemption of B20 that resulted in changes to supply and demand.

Emissions testing was performed for HC, CO, NOx, and PM under line haul and switch duty cycles. The particulate and gaseous emissions were measured at low idle, idle, DB, and notches 1–8 and were found to be below the limits set by the EPA for a Tier 0 class of locomotive engines. Similarly, smoke opacity measurements using both the EPA certification fuel and the B20 biodiesel fuel were below limits established by EPA for Tier 0 locomotive engines. An approximately 5 percent increase in NOx was identified in the use of B20 compared with diesel fuel. However, this increase in NOx was expected and was within the range identified by other emissions testing results published using B20 fuel. While some previous engine emissions testing of B20 biodiesel has shown (according to published reports) HC, CO, and PM reductions, the emissions testing conducted for this research effort did not indicate reductions using B20 in comparison to conventional petroleum diesel fuel for this particular locomotive. However, the emission testing did demonstrate that the alternative fuel tested well below EPA Tier 0 emission limits for locomotive engines. Moreover, test results indicated that it was possible to achieve full power using B20. Inspection of the baseline power assembly units and engine oil analyses showed that 12 months of B20 biodiesel use by Engine #500 resulted in normal wear of the baseline units.

Additional research is needed to determine performance in colder environments, availability and cost of B20 biodiesel fuel, long-term engine durability issues, and OEM warranty issues with the use of such fuels. An increase in domestic production of biofuels such as biodiesel could result in biodiesel fuel cost reduction, which may be an incentive to adopt B20 biodiesel as an alternative fuel for rail transportation.

6. References

1. Beauchaine, M., “Measuring Water, Methanol and total Glycerin in B100 Samples,” http://www.biodieselmagazine.com/articles/1663/measuring-water-methanol-and-total-glycerin-in-b100-samples/ (May 25, 2007).
2. *Biodiesel Production*. National Biodiesel Board. http://www.biodiesel.org/docs/ffs-production/production-fact-sheet.pdf?sfvrsn=4
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4. Glenn, Doug, “Emission Testing of Amtrak Unit #500.” GE Transportation (May 25, 2011).
5. Van Slyke, P., Anderson, D., “FR-861 Amtrak General Electric Transportation Evaluation of a B20 Biodiesel in a General Electric P-32 Locomotive - March 2010 – June 2011.” Chevron Oronite Company LLC, Industrial Engine Oils, Richmond, California.

Appendix A—Fuel Delivery Summary, Quantities, Cost

Appendix B—92-Day Scope of Work

Appendix C—Map 100 Forms

Appendix D—Biofuel Certificates of Analysis (Direct Fuels)

Appendix E—Ultra-Low Sulfur Diesel (ULSD) Sampling Results

Appendix F—B100 Sampling Results

Appendix G—B20 Biodiesel Sampling Results

Appendix H—Used Oil Sampling Results

Appendix I—Chevron Oronite Tear-Down Inspection of Engine #500 Power Assemblies

Appendix J—Emissions Testing of Amtrak Unit #500 (GE Report)

Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
B100	100% Biodiesel
B20	20% Biodiesel and 80% ULSD
BQ9000	National Biodiesel Accreditation Program
CFR	Code of Federal Regulations
CO	Carbon Monoxide
cSt	CentiStokes
Cu	Copper
DOT	Department of Transportation
DB	Dynamic Brake
E500	Engine #500
EHS	Environmental Health and Safety
EPA	U.S. Environmental Protection Agency
Fe	Iron
FRA COTR	Federal Railroad Administration/Contracting Officer's Technical Representative
FTP	Federal Test Procedures
FY	Fiscal Year
GE	General Electric
HCS	Hydrocarbons
HP	Horsepower
MAP100	Maintenance Analysis Program Equipment Condition Report
mg/KOH	Milligrams/Potassium Hydroxide
NOx	Oxides of Nitrogen
OTP	On Time Performance
P32-8	GE 3200 HP Diesel Locomotive
Pb	Lead
ULSD	Ultra Low Sulfur Diesel