Current Status of Biodiesel in Railroads and Technical Issues Moving Forward

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Final Report To:

National Biodiesel Board

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Abbreviations and Acronyms

ASTM	ASTM International, formerly the American Society for Testing and Materials
B100	100% biodiesel
B20	20% biodiesel, 80% petroleum diesel
B5	5% biodiesel, 95% diesel fuel
BTU	British thermal unit
CARB	California Air Resources Board
CI	Compression ignition
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Analysis
DOE	United States Department of Energy
DOT	United States Department of Transportation
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EPA	United States Environmental Protection Agency
EPACT92	Energy Policy Act of 1992
GHG	Greenhouse Gas
HC	Hydrocarbon
LMOA	Locomotive Maintenance Officer's Association
NBB	National Biodiesel Board
NORA	National Oilheat Research Alliance
NO_X	Nitrogen Oxides
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
PM	Particulate Matter
ppm	Parts per million
RFS-2	Renewable Fuel Standard 2
RIN	Renewable Identification Number
SO_2	Sulfur dioxide
ULSD	Ultra Low Sulfur Diesel
VOC	Volatile organic compound

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Executive Summary

Background. The US railroad sector, including both freight and passenger divisions, is the third highest consumer of distillate fuel in the United States averaging over 3.2 billion gallons annually between 2000-2009 with projections of consumption expected to increase in future years. Recently, the US EPA certified biodiesel as an 'advanced biofuel' under the new Renewable Fuel Standard-2 (RFS-2) which requires obligated parties (i.e. petroleum refiners and importers) to incorporate traditional renewable fuel (i.e. ethanol) and increasing amounts of newer 'advanced biofuels' (biodiesel and cellulosic fuels) into fuel sold in the USA. 'Advanced biofuels' under RFS-2 are those fuels which provide a minimum life cycle carbon reduction of 50% compared to petroleum based gasoline or diesel fuel, including indirect land use effects.

The RFS-2 provides a required market in the USA for 1 billion gallons of biodiesel by 2012, and provides an opportunity for biodiesel to be utilized to meet the additional 4 billion gallons of advanced biofuels required by 2022. In 2008, biodiesel in concentrations up to 5% by volume was incorporated as a fungible component into the US diesel fuel specification, ASTM D975. The low capital and processing costs of biodiesel facilities versus other renewable alternatives makes biodiesel a low cost option for refiners to meet their RFS-2 obligations, but the RFS2 allows the refiner flexibility on where, when, and in what applications the renewable fuel is used. With the large volumes of fuel used by railroads, and the more simple infrastructure of railroads vs. other applications, it is likely biodiesel will be incorporated into the diesel fuel used by railroads in increasing amounts. A significant amount of research and development has gone into the use of biodiesel for other on-road and off-road applications, but less has been done with biodiesel in railroad applications.

With biodiesel use in railroads as a low cost option to meet RFS-2 requirements likely to increase, and limited practical experience with biodiesel blends in locomotives, the National Biodiesel Board members desired an assessment of the U.S. railroad system covering environmental, technical, and regulatory issues associated with implementation of biodiesel (B5 – B100) in the North American railroad system. Such an assessment could be used as a technically credible source document for the railroad industry, as well by the biodiesel and petrodiesel industries to set priorities for education efforts and future research. A special emphasis was placed on understanding technical questions or needs regarding the use of biodiesel and biodiesel blends in railroad applications that have not already been addressed through existing information or research, as well as summarizing the use that has occurred with biodiesel blends in railroads applications.

As this assessment was being conducted, SAE International (formerly the Society of Automotive Engineers) formed a 'Biodiesel in Railroad Applications' subcommittee within the SAE TC7 committee. In a separate effort, the Locomotive Maintenance Officers Association also began significant deliberations on biodiesel blends. The members of the LMOA and SAE TC7 railroad subcommittee represent the leading technical experts in locomotive engines and locomotive fuel. Input from both independent groups served as the guiding force for the information and data summarized here giving added technical credibility to the information contained in this report.

Results. The main outcomes of this effort can be separated into the two general areas: 1) existing experience using biodiesel blends in railroads, and 2) technical/regulatory information on biodiesel pertinent to railroads.

Regarding *existing experience*, much to the surprise of both the railroad and the biodiesel/petrodiesel community, a total of nineteen (19) cases of biodiesel use in revenue service railroad/locomotive applications were identified. This was a much higher number than expected. Some biodiesel cases were self-funded internally by an initiative to reduce emissions or by governmental grants. The diverse arena of applications with biodiesel usage included passenger, commuter/short haul, short line/switching, and line-haul that utilized biodiesel blends of 5 to 100% biodiesel (B5 to B100) over the past 15 years. The locomotive biodiesel use was computed and translated into locomotive-months to allow a better interpretation of the length of biodiesel use. Over thirty seven hundred (3,700) locomotive-months of biodiesel use was documented. While scientific data was not collected for most of this use, no major problems or issues were reported by the users. Engine parameters were monitored and documented in some cases, and data is still coming in from some efforts, but user experience was overall very positive. Operators reported observations of reduced diesel odor and black smoke due to biodiesel use but since most of these cases were simple revenue service (i.e. normal passenger or cargo service), additional testing and sample gathering were not conducted and much of this positive experience is considered anecdotal by the technical community. Some of the railroads ended their biodiesel usage due to the slightly higher cost of biodiesel, but they would begin usage again if the costs of biodiesel were offset by other factors (i.e. price vs. petrodiesel, or being the low cost compliance option to meet regulations).

In the *technical and regulatory* area, much of the work done for other on- and off-road markets (i.e. trucks, buses, construction equipment, farm tractors, etc.) also applies to railroads. The engines used in railroads, however, are generally much older, much larger, less sophisticated, and run at much lower speeds than the latest on-road engines. These differences led to some specific questions or data gaps for biodiesel blend use in locomotives, even though there is a tremendous amount of information on biodiesel use in other on-road and off-road applications. Based on the input and discussions from SAE TC7, the LMOA, and other discussions with industry members, the highest priority items identified in this report for follow-up are as follows:

- Input to the upcoming LMOA white paper on biodiesel use in railroads
- Gathering additional scientific data on existing experience in railroads
- More information on biodiesel emissions in railroads
- More information on biodiesel long term durability in railroads
- More information on material compatibility with higher blends (over B5 or B20)
- Sharing of existing technical information with railroads
- Work with the locomotive engine makers to more specifically outline technical needs or gaps in order for them to issue support for B20 to their customers.

The data and information in the report that follows represents and excellent source document for the railroad industry (railroad operators and locomotive manufacturers) as well as for the petroleum and biodiesel industry to guide education and technical efforts in the rail market moving forward.

Introduction

In 2009, U.S. Class I railroads spent almost six (6) billion dollars on diesel fuel and fuel costs account for nearly 20% of a railroads operating expense. The US railroad sector, including both freight and passenger divisions, is the third highest consumer of distillate fuel in the United States averaging over 3.2 billion gallons annually between 2000-2009 with projections of consumption expected to increase dramatically in future years. In addition, the US Environmental Protection Agency (EPA) has placed emission targets on locomotives which apply to all diesel line-haul, passenger, and switch locomotives including newly manufactured locomotives and remanufactured locomotives built after 1972.

Biodiesel is a domestically-produced, renewable fuel derived from vegetable oils, animal fats, and/or used cooking oils or greases which must meet the international fuel specification, ASTM D6751[1]. Biodiesel blends are currently being used in compression-ignition engines from below 5% to 100%. Biodiesel also provides many emissions-related benefits and reduces the carbon footprint when compared to petroleum. Biodiesel blends have been used or tested in some railroad applications, but areas of question exist within the railroad industry about large-scale implementation of biodiesel blends. Areas include: emissions, fuel system impacts, warranties, and internal working components of the locomotive engine and fueling system from pre-combustion through post-combustion. In addition, questions exist within the rail industry about large-scale implementation of biodiesel within their fueling infrastructure. These are all valid questions as railroads own and operate their own fueling infrastructure (terminals) and seventy percent (70%) of the fuel is delivered by pipeline. Some railroads have already begun to see biodiesel as petroleum marketers and distributors have started blending biodiesel to be in compliance with the Renewable Fuel Standard (RFS2).

The Renewable Fuel Standard (RFS-2) mandates 36 billion gallons of renewable biomass-based fuel be used by 2022 with at least one billion gallons of biomass-based diesel mandated for use by obligated parties beginning in 2012[2]. This carve out allows for use of biodiesel in off-road applications such as underground mining, road construction, and railroad transportation.

[1] http://www.biodiesel.org/pdf_files/fuelfactsheets/B100_Specification.pdf
[2] http://www.epa.gov/otaq/fuels/renewablefuels/index.htm

US and North American Railroad Profiles - Class I, II, and III railroads[3]

The US railroad industry is comprised of three separate classes of freight rail service; Class I railroads defined by annual (2008) revenue of $401.1 million or greater; Class II with between $32.1 million and 401.1 million in revenue; and Class III defined as those with less than $32.1 million in annual revenue with each threshold adjusted annually for inflation. There are seven (7) Class I railroads which account for the vast majority of freight movement in the US, with two-thirds of track movement, nearly 90% of rail employment, and 94% of freight railroad revenue[4]. The seven Class I railroads that operate in the United States are Burlington Northern Santa Fe (BNSF) Railway, Canadian National Railway (CN) – Grand Trunk Corporation, Canadian Pacific – Soo Line Railroad Company (CP), CSX Transportation (CSX), Kansas City Southern Railway (KCS), Norfolk Southern (NS,) and Union Pacific (UP). The two Canadian railroads, CN and CP, are technically not US Class I railroads, but the US portion of these rail lines/companies meet US regulatory criteria (revenue requirements) for US Class I railroads and as such are included here. Two Mexican railroads, Ferrocarril Mexicano and Kansas City Southern de México, would also be Class I railroads if they were U.S. railroads.

Class II railroads are referred to as Regional railroads and are, line-haul, freight railroads which operate at least 350 miles of track and/or earn at least $40 million in revenue. There were 33 Regional railroads in 2008. Local railroads include freight railroads which are not Class I or Regional and operate under 350 miles of track and earn less than $40 million annually. The Local railroad category can be further subdivided into local line-haul carriers and switching and terminal carriers. This latter category is composed of railroads which primarily provide switching and/or terminal services for other railroads and some of these are dedicated in urban areas where pollutant emissions such as particulate matter are of concern. In 2008 there were 525 local railroads, of which 326 were line-haul and 199 were switching and rail terminal. A listing of all Class I and Class II railroads is presented in Appendix A. Table 1 provides general information concerning certain aspects of all Class I, regional, and local railroads in the US as of 2008 (latest figures available).

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[3] www.aar.org

[4] www.aar.org/2009 Railroad Facts.pdf

Table 1. Summary statistics for the US Railroad Industry (2008)[2].

Type of Railroad	Number of Railroads	Miles of Road in the U.S.	Number of Employees	Freight Revenue (millions $)
U.S. Class I	7	94,082	164,439	$59,409
U.S. Regional	33	16,690	7,708	1,946
U.S. Local	525	28,554	11,596	2,059
Linehaul	326	22,058	5,423	1,269
Switching & Terminal	199	6,496	6,173	790
Total U.S. Railroads	565	139,326	183,743	$63,415

Transport and Financial Characteristics of Class I Railroads

Canadian Northern, CSX, and Norfolk Southern operate in the eastern United States while BNSF, CP, KCS, and UP operate in the Western US. These railroads combined had an average of 433,000 freight cars in service in 2008 and 2009, (between 25 and 30 million freight cars originated), and have over 24,000 locomotives in service. In 2009, the seven Class I railroads operated 86,203 miles of track in the eastern US and almost 110,000 miles in the west with 154 and 281 million total freight-miles in the east and west respectively. Line hauls in the western US were approximately twice the eastern US. Table 2 presents select data concerning infrastructure, financial, and operating characteristics of each Class I railroad.

The North American railroad system is comprised primarily of the seven Class I railroads and the two Mexico-based railroads, Ferrocarril Mexicano (Ferromex) and Kansas City Southern de Mexico. Figure 1 shows the major rail lines throughout North America for all Class I railroads.

Table 2. Select Characteristics about Class I Railroad operations (2009)[2].

	CSX	NS	CNGT	BNSF	KCS	SOO	UP
Total Miles of Track Operated	37,278	37,149	11,776	50,027	4,361	4,523	50,885
Total Carloads Originated	5,228,633	4,567,001	1,286,131	7,729,211	361,695	287,422	6,545,255
Grand Total Tons Originated	336,872,339	257,297,477	102,896,659	493,888,167	26,536,331	17,255,732	433,507,223
Average Haul (miles)	542	451	270	1,113	391	430	946
Diesel-Electric (number)	3,849	3,808	507	6,685	550	383	8,258
Diesel-Electric (aggregate HP)	13,715,700	13,009,250	1,377,200	24,950,913	1,805,296	1,328,930	30,316,556
Diesel-Electric (HP per unit)	3,563	3,416	2,716	3,732	3,282	3,470	3,671
Operating Revenue ($000)	10,219,153	10,661,340	2,400,269	18,132,372	1,029,503	865,125	17,934,844

In 2008, these nine (9) companies operated over 202,000 miles of track, have over 680,000 freight cars in service, and employ approximately 210,000 persons. For the five US-based railroads (BNSF, CSX, KCS, NS, and UP) and the two Canadian railroads operating in the US (CN and CP), they operate approximately 139,000 miles of track, have around 525,000 freight cars in service (US), and employ over 184,000 persons.

Commodities transported by Class I Railroads[2]

Type of commodities/freight hauled by US Class I railroads and their relative percentage contribution in both 2008 and 2009 is presented in table 3. Coal is by far the largest commodity hauled accounting for nearly one-half of all tonnage and nearly one-quarter of gross revenue. Railroads are responsible for 70 percent of coal deliveries. Table 4 presents data on certain categories of all seven Class I railroads for the past two years.

Figure 1. System/route map for Class I railroads operating in North America.

Table 3. Commodities transported by Class I railroads (2008 and 2009)[2].

	2008				2009			
	Tons Originated		Gross Revenue		Tons Originated		Gross Revenue	
Commodity Group	(000)	% of Total	(millions)	% of Total	(000)	% of Total	(million $)	% of Total
Coal	878,569	45.40%	$14,200	23.50%	786,607	47.2	$12,052	25.1
Chemicals & allied prod.	176,108	9.1	7,717	12.8	162,691	9.8	6,831	14.2
Farm products	155,950	8.1	5,403	8.9	137,163	8.2	4,413	9.2
Non-metallic minerals	132,352	6.8	1,749	2.9	105,397	6.3	1,320	2.7
Misc. mixed shipments	120,278	6.2	8,184	13.5	102,707	6.2	6,240	13
Food & kindred products	105,071	5.4	4,610	7.6	100,695	6	4,261	8.9
Metallic ores	59,986	3.1	637	1.1	43,842	2.6	404	0.8
Petroleum & coke	44,690	2.3	1,867	4.4	38,139	2.3	1,540	3.2
Waste & scrap materials	48,848	2.5	1,415	2.3	36,866	2.2	1,022	2.1
Stone, clay & glass prod.	45,275	2.3	1,636	2.7	35,483	2.1	1,215	2.5
Metals & products	54,420	2.8	2,664	3.1	30,418	1.8	1,390	2.9
Pulp, paper & allied prod.	34,130	1.8	2,228	3.7	28,453	1.7	1,656	3.4
Lumber & wood products	30,856	1.6	1,684	2.8	21,736	1.3	1,095	2.3
Motor vehicles & equip.	24,791	1.3	3,623	6	16,754	1	2,397	5
All other commodities	22,442	1.2	2,895	4.8	21,304	1.3	2,205	4.6
Total	1,933,766		60,512		1,668,255		48,041	

Table 4 - General background data for all Class I railroads operating in the US[2].

	2008	2009
Tons originated	1,933,766,470	1,668,253,928
Carloads originated	30,624,773	26,005,348
Revenue ton-miles (000)	1,777,236,192	1,532,213,558
Miles of road operated	94,209	94,048
Number of locomotives in service	24,003	24,047
Number of freight cars in service	450,297	416,180
Capacity of locomotive fleet (horsepower)	86,425,213	86,503,845
Average freight train load (tons)	3,414	3,546
Average length of haul (miles)	919	918

Key 10-year trends in Class I railroads[2]

Table 5 shows 10-year trends in the number of carloads originated, tons originated, and revenue ton-miles for all seven Class I railroads. Each category shows an overall increase which is also expected to continue through 2035. Table 6 presents trend data on individual commodities hauled by the Class I railroads for 1999-2008. Overall there was a 13% increase over this time period with individual

Table 5. Data and trends for Class I railroads (freight and revenue) for 1999-2008[2].

Year	Carloads Originated (000)	Tons Originated (mil)	Revenue Ton-Miles (bil)
1999	27,096	1,717	1,433
2000	27,763	1,738	1,466
2001	27,205	1,742	1,495
2002	27,901	1,767	1,507
2003	28,870	1,799	1,551
2004	30,095	1,844	1,663
2005	31,142	1,899	1,696
2006	32,114	1,957	1,772
2007	31,459	1,940	1,771
2008	30,625	1,934	1,777
% change 1999-2008	13.02%	12.64%	24.01%

categories ranging from minus 41% to over 125%. Other key trends show average length of haul has increased 10% and over 26% since 1999 and 1990 respectively and average horsepower has risen from 2,665 in 1990 to over 3,600 in 2008.

Table 6. Trends in major commodities transported by Class I railroads (1999-2008)[2].

	Carloads by Major Commodity Group 000 carloads									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Farm Products	1,477	1,437	1,461	1,471	1,519	1,519	1,510	1,590	1,681	1,726
Metallic Ores	295	322	251	328	331	339	662	674	662	671
Coal	6,965	6,954	7,295	7,088	7,037	7,102	7,202	7,574	7,480	7,713
Nonmetallic Minerals	1,306	1,309	1,280	1,310	1,370	1,430	1,488	1,470	1,398	1,325
Food & Kindred Products	1,354	1,377	1,446	1,472	1,478	1,461	1,448	1,487	1,493	1,501
Lumber & Wood Products	673	648	603	619	612	616	611	548	456	392
Pulp, Paper & Allied Products	612	633	601	646	667	669	679	671	652	666
Chemicals & Allied Products	1,814	1,820	1,777	1,866	1,913	1,981	1,937	1,943	2,050	2,040
Petroleum & Coal Products	543	565	547	533	606	651	689	689	691	578
Stone, Clay & Glass Products	538	541	528	559	581	594	603	570	513	467
Primary Metal Products	682	723	642	656	648	701	680	728	666	634
Transportation Equipment	1,896	1,984	1,777	1,831	1,811	1,849	1,923	1,871	1,810	1,521
Waste & Scrap Material	624	619	591	617	651	725	706	701	726	729
Misc. Mixed Shipments	6,451	6,796	6,231	6,650	7,145	7,791	8,153	8,536	8,465	8,078
All Other	1,866	2,036	2,177	2,255	2,500	2,666	2,850	3,065	2,717	2,584
Total	27,096	27,764	27,207	27,901	28,869	30,094	31,141	32,117	31,460	30,625

Annual energy consumption by US railroads[2]

The US railroad system (Class I, Regional, local, and passenger) consumed slightly greater than 2.4 billion gallons of diesel fuel in calendar year 2009 which was down significantly from the previous nine years (2000-2008). Table 7 presents US total distillate consumption (000 gallons) for 2000-2009 as well as distillate used in the transportation sector (on-highway, vessel bunkering, and railroad), and railroad consumption alone with the percentage of total and transportation. Between 2000 and 2009, the railroad sector used an average of slightly greater than 6.9 percent of the total energy consumed in the US transportation as a whole. Table 8 presents 10-year trends of distillate consumption by the rail sector by state for 2000-2009. The 10 largest railroad fuel consumption states are Texas, Oklahoma, California, Ohio, Kentucky, Pennsylvania, Georgia, Wyoming, Illinois, and Kansas.

Table 7. US Distillate Consumption (2000-2009) by Transportation Category[5].

Year	U.S. Total Distillate Adj Sales/Deliveries Total to End Users (Thousand Gallons)	U.S. Total Distillate Adj Sales/Deliveries Transportation Total (Thousand Gallons)	U.S. Residual Fuel Oil Adj Sales/Deliveries Transportation Total (Thousand Gallons)	U.S. Total Distillate Adj Sales/Deliveries to Railroad Consumers (Thousand Gallons)	Railroad Fuel Consumption (% of Total Transportation Fuel Consumption)	Railroad Fuel Consumption (% of Total Distillate Fuel Consumption)
2000	57,217,230	38,197,244	6,192,294	3,026,147	6.8%	5.3%
2001	58,971,486	38,273,146	4,345,284	2,958,815	6.9%	5.0%
2002	57,884,652	39,426,630	4,783,956	3,061,280	6.9%	5.3%
2003	60,201,666	42,053,104	3,801,425	3,086,390	6.7%	5.1%
2004	62,383,608	42,740,897	4,886,978	3,302,209	6.9%	5.3%
2005	63,129,150	43,848,085	5,533,552	3,679,575	7.5%	5.8%
2006	63,912,660	45,448,186	6,000,434	4,123,195	8.0%	6.5%
2007	64,323,294	45,895,115	6,773,950	3,934,440	7.5%	6.1%
2008	60,649,008	42,416,211	6,230,994	3,069,997	6.3%	5.1%
2009	55,665,540	38,116,093	5,607,263	2,481,484	5.7%	4.5%
10-year Average	60,433,829	41,641,471	5,415,613	3,272,353		
10-year Std. Dev.	2,983,597	2,980,944	938,999	498,162		

Since 1990 the amount energy consumed per ton-mile (expressed as Btu per ton-mile or energy intensity) has dropped over 27% and for the period of 1999 to 2008 it dropped 16%. Table 9 shows the energy efficiency of Class I railroads expressed as energy intensity for the period of 1999-2008 and data on number of locomotives, tons originated, length of haul, revenue miles, etc. Table 10 presents data for each of the Class I railroads concerning their fuel consumption for both line haul and switching operations as well as total diesel fuel cost for each from 2005-2009.

[5] http://www.eia.gov/dnav/pet/pet_cons_821usea_a_EPD0_VAL_Mgal_a.htm

Table 8. State-level Distillate Consumption (2000-2009) by all railroads (000 gallons)[4].

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
AL	46,951	55,951	59,156	53,081	70,717	61,094	82,443	81,618	57,991	54,222	62,322
AK	3,868	4,367	4,801	1,720	6,357	7,233	6,723	6,256	5,791	5,093	5,221
AZ	3,769	5,029	12,642	4,687	14,983	13,672	15,037	11,637	6,461	7,079	9,500
AR	44,493	99,176	126,920	120,526	97,256	53,641	29,835	27,596	20,881	13,230	63,355
CA	183,196	184,232	243,861	74,218	284,154	326,174	344,459	309,249	248,184	190,404	238,813
CO	49,110	39,800	35,922	48,733	42,374	15,351	3,465	2,820	3,947	52,506	29,403
CT	10,286	5,533	4,763	3,358	3,189	3,727	3,385	4,304	3,185	2,332	4,406
DE	175	234	833	1,141	729	240	1,034	1,357	1,105	1,163	801
FL	107,113	107,290	72,596	81,481	63,506	63,895	71,382	71,962	62,761	36,428	73,841
GA	68,411	70,674	113,719	100,718	105,963	107,280	115,406	76,332	67,979	66,211	89,269
HI	0	0	0	0	0	0	0	3	6	4	1
ID	46,647	23,985	22,817	17,507	24,059	21,364	16,199	14,805	13,146	10,626	21,116
IL	106,462	74,416	104,587	201,714	67,903	62,959	44,626	44,125	59,125	72,282	83,820
IN	74,455	24,559	78,884	94,519	98,211	127,857	101,845	72,399	60,070	51,563	78,436
IA	25,487	15,538	19,836	37,415	50,949	54,942	47,894	64,501	28,426	23,517	36,851
KS	53,134	36,037	64,248	76,553	56,660	140,067	119,252	101,550	97,520	92,600	83,762
KY	101,162	99,969	90,029	88,669	98,437	123,613	137,753	187,037	104,275	66,167	109,711
LA	44,319	61,188	52,183	53,903	46,325	35,762	58,176	59,812	30,769	19,613	46,205
ME	2,901	466	334	1,016	65	46	45	122	1,673	7,700	1,437
MD	5,216	3,534	1,243	16,749	2,332	15,950	16,581	11,166	2,830	576	7,618
MA	17,826	20,612	11,862	17,882	43,475	60,409	66,155	61,795	31,689	19,969	35,167
MI	43,549	10,429	23,866	13,806	23,600	24,015	39,379	54,478	12,676	10,770	25,657
MN	62,095	53,881	52,164	54,540	68,011	84,524	82,976	135,723	90,225	51,484	73,562
MS	21,236	24,889	18,805	41,679	37,279	15,628	44,214	63,723	31,138	28,038	32,663
MO	29,687	23,686	20,000	49,063	54,271	50,458	40,687	30,212	13,606	25,257	33,693
MT	78,847	59,763	54,636	20,972	44,392	62,480	61,008	75,681	7,476	6,153	47,141
NE	70,182	2,519	2,479	37,965	46,731	55,132	49,793	14,005	14,505	4,487	29,780
NV	6,801	6,066	7,494	1,465	5,700	5,394	7,898	6,700	6,315	9,946	6,378
NH	2	30	91	188	161	130	119	115	125	791	175
NJ	15,200	13,557	29,570	18,779	17,033	16,182	15,627	15,102	14,866	8,771	16,469
NM	5,840	18,134	9,987	15,769	14,531	13,103	22,196	8,390	2,528	344	11,082
NY	41,902	25,962	18,876	80,032	66,367	70,519	80,554	61,147	42,374	37,886	52,562
NC	59,358	77,911	82,253	59,429	53,084	77,308	40,905	46,282	28,121	71,205	59,586
ND	38,228	46,907	46,122	45,564	62,326	70,909	72,389	137,309	69,395	3,888	59,304
OH	148,030	168,220	165,601	184,296	255,809	228,343	306,162	366,358	153,700	172,179	214,870
OK	328,657	354,919	305,676	263,653	169,630	338,463	440,689	383,697	464,753	199,094	324,923
OR	72,930	53,312	62,985	21,234	53,898	75,377	82,909	80,280	90,187	78,824	67,194
PA	101,249	90,247	94,167	64,773	48,750	90,665	104,965	114,769	112,261	96,985	91,883
RI	0	43	0	0	0	0	128	13	71	4	26
SC	15,189	15,967	11,759	5,267	11,910	8,842	8,965	10,949	14,443	3,106	10,640
SD	4,109	5,073	4,271	4,059	5,547	5,535	6,451	9,429	7,066	7,898	5,944
TN	81,620	91,508	80,755	70,242	75,115	92,778	91,493	84,357	40,442	41,832	75,014
TX	509,347	626,684	581,101	698,802	675,846	656,384	917,178	713,255	623,485	564,782	656,686
UT	33,356	24,222	29,089	30,154	38,690	25,136	26,034	31,422	21,922	21,852	28,188
VT	938	1,089	22	26	60	311	680	656	2,068	9,281	1,513
VA	34,143	61,272	52,357	48,328	47,138	58,347	64,357	70,224	77,598	68,753	58,252
WA	26,368	36,072	50,707	24,523	71,754	123,936	101,543	102,514	74,395	54,756	66,657
WV	9,863	8,803	9,849	9,325	12,039	13,275	13,759	15,247	14,896	1,749	10,881
WI	53,317	45,954	35,828	33,368	37,235	37,381	31,955	32,142	56,524	36,435	40,014
WY	135,525	74,965	85,183	84,885	117,786	79,567	85,310	59,815	75,023	71,648	86,971
US	3,026,147	2,958,815	3,061,280	3,086,390	3,302,209	3,679,575	4,123,195	3,934,440	3,069,997	2,481,484	3,272,353

Table 9. Total locomotives, freight cars transported, train miles, tons, and energy intensity of Class I Railroads – 10-year period[2].

Year	Number of locomotives in service	Number of freight cars (thousands)	Train-miles (millions)	Car-miles (millions)	Tons originated (millions)	Average length of haul (miles)	Revenue ton-miles (millions)	Energy intensity (Btu/ton-mile)	Energy use (trillion Btu)
1999	20,256	579	490	33,851	1,717	835	1,433,461	363	520.0
2000	20,028	560	504	34,590	1,738	843	1,465,960	352	516.0
2001	19,745	500	500	34,243	1,742	859	1,495,472	346	517.3
2002	20,506	478	500	34,680	1,767	853	1,507,011	345	520.3
2003	20,774	467	516	35,555	1,799	862	1,551,438	344	533.9
2004	22,015	474	535	37,071	1,844	902	1,662,598	341	566.2
2005	22,779	475	548	37,712	1,899	894	1,696,425	337	571.4
2006	23,732	475	563	38,995	1,957	906	1,771,897	330	584.5
2007	24,143	460	543	38,186	1,940	913	1,770,545	320	566.9
2008	24,003	450	524	37,226	1,934	919	1,777,236	305	542.5

Locomotives

In 2009 (latest data available), 24,040 locomotives were in service in the US as this number has increased steadily since 2000. In addition, the average horsepower per unit locomotive has increased as well as total in-fleet horsepower. Table 11 presents trends in each of these since 2000 and table 12 shows the relative age of locomotives in service from 1985 until the present. Almost 85% of the locomotives in service today were manufactured before 2004 which may be significant as future emission regulations are imposed on the rail sector by the EPA. Table 13 contains data on the number of locomotive units purchased new, leased new, and rebuilt for Class I and the total railroad industry.

Diesel Fuel Requirements for Locomotives

As with on-road diesel fuel, locomotive diesel fuel quality in the US is regulated to meet two general needs—the technical aspects needed by the users and the engine/vehicle to insure the fuel is 'fit for purpose' and will work in the engine or application, and societal needs/desires for reduced air pollution from the burning of fuels for power. The technical needs are addressed by the diesel fuel specifications developed through ASTM International, ASTM D975. The societal needs/desires for reduced air pollution are addressed through registration of fuels with EPA under the Fuels/Fuel Additive clauses of the Clean Air Act Amendments of 1990 (i.e. Section 211), and though the certification of engine emissions and durability by the engine manufacturer when the engine was first sold or

Table 10. Annual diesel fuel consumption and costs by line haul and switching operations for each Class I railroad (2005-2009)[2].

	Diesel Fuel Consumption by Operation									
	2005		2006		2007		2008		2009	
Railroad	Freight	Yard Switching	Freight	Yard Switching	Freight	Yard Switching	Freight	Yard Switching	Freight	Yard Switching
BNSF	1,353,264,855	49,082,145	1,430,909,216	47,302,784	1,392,717,201	48,869,799	1,362,517,943	52,497,057	1,158,509,396	41,697,604
CSX	536,832,973	58,655,625	538,830,555	58,873,887	512,821,994	56,032,131	491,639,423	53,717,674	402,970,429	44,029,492
GTC (CN)	94,163,298	16,580,811	92,991,911	15,150,477	93,630,286	13,540,833	88,188,373	12,290,022	69,213,918	8,762,070
KCS	70,908,035	3,075,608	66,976,604	2,192,354	68,658,414	1,766,661	62,132,949	1,816,759	59,101,809	1,459,973
NS	476,339,572	37,059,937	484,634,302	34,148,907	460,497,004	37,126,610	450,237,811	32,317,375	365,986,143	26,554,906
SOO (CP)	45,340,000	3,967,000	43,569,000	4,309,000	44,635,000	4,040,000	44,082,000	4,383,000	32,253,000	3,886,000
UP	1,203,866,777	148,727,928	1,219,382,622	153,098,221	1,177,581,256	150,109,893	1,086,893,081	143,470,336	869,619,570	110,310,898

	Cost of Locomotive Fuel by Operation (000 dollars)									
	2005		2006		2007		2008		2009	
Railroad	Freight	Yard Switching	Freight	Yard Switching	Freight	Yard Switching	Freight	Yard Switching	Freight	Yard Switching
BNSF	$1,891,297	$68,598	$2,647,084	$87,507	$3,095,099	$102,318	$4,301,493	$165,734	$2,184,047	$78,745
CSX	$706,076	$77,519	$1,001,812	$109,470	$1,091,095	$119,218	$1,531,822	$167,370	$701,545	$76,652
GTC (CN)	$120,039	$21,137	$164,938	$26,872	$204,856	$29,626	$268,185	$37,374	$116,216	$14,716
KCS	$118,943	$4,829	$131,268	$9,520	$147,190	$3,904	$297,526	$4,558	$98,103	$4,380
NS	$674,712	$52,494	$912,277	$64,282	$966,398	$77,916	$1,389,825	$99,761	$601,636	$42,654
SOO (CP)	$84,826	$7,234	$95,012	$9,088	$99,351	$8,678	$137,822	$13,633	$62,584	$6,790
UP	$2,137,310	$251,661	$2,507,294	$306,531	$2,627,384	$323,819	$3,582,878	$264,783	$1,506,249	$188,402

Table 11. 10-year trend of Locomotives in Service and Average and Aggregate Horsepower[2].

Year	Total Units in Service	Average Horsepower Per Unit	Aggregate Horsepower (millions)
1999	20,256	3,200	64.8
2000	20,028	3,261	65.3
2001	19,745	3,275	64.7
2002	20,506	3,378	69.3
2003	20,774	3,415	70.9
2004	22,015	3,458	76.1
2005	22,779	3,467	79
2006	23,732	3,485	82.7
2007	24,143	3,518	84.9
2008	24,003	3,601	86.4

Table 12. Date of Manufacture for Class I Railroad Locomotives[2].

Date Built	Units in Age Bracket	Percent Of Total
Jan. 1, 2008 - Dec. 31, 2008	757	3.20%
Jan. 1, 2007 - Dec. 31, 2007	907	3.8
Jan. 1, 2006 - Dec. 31, 2006	1,145	4.8
Jan. 1, 2005 - Dec. 31, 2005	876	3.6
Jan. 1, 2000 - Dec. 31, 2004	4,777	19.9
Jan. 1, 1995 - Dec. 31, 1999	4,146	17.3
Jan. 1, 1990 - Dec. 31, 1994	2,494	10.4
Jan. 1, 1985 - Dec. 31, 1989	1,604	6.7
Before 1985	7,297	30.4

Table 13. Type of Locomotive in Service (10-year trend) – Class I and Total Rail Industry[2].

	Locomotives (Class I Only)					All Locomotive Units	
Year	Purchased New	Leased New	Total New	Rebuilt	Grand Total	New	Rebuilt
1999	437	272	709	156	865	709	156
2000	174	466	640	81	721	640	81
2001	290	420	710	45	755	710	45
2002	224	521	745	33	778	745	33
2003	464	123	587	34	621	587	34
2004	379	742	1,121	5	1,126	1,121	5
2005	220	607	827	84	911	827	84
2006	280	642	922	158	1,080	922	158
2007	471	431	902	167	1,069	902	167
2008	649	170	819	129	948	819	129

remanufactured. These regulations or requirements were set up so the user of fuel does not need to concern themselves with fuel quality or emissions—those are handled by the fuel company and the engine company before the user touches or uses the fuel.

Locomotive diesel fuel technical specifications

ASTM International, previously the American Society for Testing and Materials, is the industry consensus body utilized in the USA for setting fuel specifications. ASTM is open to all who care to participate, and is comprised of experts from engine, vehicle and fuel system companies, refiners and alternative fuel companies, users, and third party experts and government regulators. ASTM uses a rigorous balloting process where one negative vote can defeat a proposed specification or change. ASTM fuel specifications are the most well respected specifications in the world, in large part due to the fact so many experts vote and are active in its very rigorous, open process. Over the years, ASTM has developed a fuel specification for traditional diesel fuel used in on-road and off-road diesel applications. This specification, ASTM D975 "*Standard Specification for Diesel Fuel Oils*", was first published in 1948 and it is the specification largely utilized by the railroad industry for the purchase of locomotive fuel[6]. Railroad engine companies design their engines for fuels meeting ASTM D975, and fuel sellers and buyers use ASTM D975 as the basis for commercial trade of locomotive diesel fuel.

ASTM 975 is a performance specification that was developed to provide a fit for purpose fuel for use in diesel engines produced from traditional petroleum refining of crude petroleum oils. As a performance specification, D975 contains the physical and chemical properties needed for diesel engine operation, but is not dependent on the particular refinery process or crude oil feedstock used. This allows maximum flexibility for refiners to meet the performance needs of engines and users at the lowest possible cost. There are some properties related to and important for diesel engine operation, however, not specified in early versions of D975. Some examples are BTU content, density, surface tension, lubricity, and compressibility. These values are not specified in D975 because they're largely consistent and pre-determined through the crude oils and existing processing techniques used to produce petroleum-based diesel. This may become a bigger factor in the future, as new alternative fuels and new processing techniques may not bring these inherent properties to the table, or may need controls for other minor compounds not found in traditional petrodiesel.

In general, the properties of ASTM D975 diesel fuel have remained the same since its initial passage in 1948. While the D975 does not specifically address emissions, only engine and performance

[6] http://www.astm.org/Standards/D975.htm

issues, over the years EPA requirements for cetane number, sulfur and aromatics have been added to D975 since they are legal requirements in the US. In 2006, EPA mandated an ultra low sulfur grade of diesel containing no more than 15 ppm sulfur for on-road fuels which became the S15 grade in D975 (S15 grade is not needed for rail operations yet—see below for more information). Subsequently, D975 was changed to add lubricity requirements as the de-sulfurization process had the effect of reducing fuel lubricity and most ULSD today requires a lubricity additive to provide fuels that meet D975.

Biodiesel began setting ASTM specifications in 1993 as the lead mechanism to secure the support of the engine, vehicle, and fuel system companies. Most engine companies said they would not support their engine warranty—or recommend the use of biodiesel—to their customers until the biodiesel industry had secured an approved specification through ASTM. After over $60 million in testing and demonstrations and eight years, the first B100 blend stock specification was approved by ASTM in 2001, ASTM D6751 "Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels". Biodiesel is inherently ultra low in sulfur and aromatics and high in cetane number. Different than ultra low sulfur petrodiesel, biodiesel is naturally high in lubricity due to the oxygen contained in biodiesel. In fact, because biodiesel lubricity is more than adequate ASTM didn't see a need to incorporate a lubricity specification for B100 blend stock. ASTM D6751 covers biodiesel intended for blending into diesel fuel in levels up to 20% in a similar way to how No. 1 and No. 2 diesel fuels were blended. If the two parent fuels meet their specifications they can be blended and used in conventional diesel engines and there is no need for additional testing after blending. For use of levels higher than 20% biodiesel, the engine manufacturer should be consulted, since the specifications were designed for blends up to B20.

The D6751 B100 blend stock standard provided a specification path for the industry to develop, but engine companies, users, and fuel regulators desired finished blended fuel specifications for the biodiesel blend. This would facilitate engine design (since the engine sees the finished blend, not the parent fuels), fuel purchase (specifying one standard rather than both parent fuels), and fuel quality enforcement in the field (for which the parent fuel values were not known). In 2008, after more testing and making several important improvements to the B100 specification (lower acid number, addition of new fuel stability and cold soak filtration specifications), ASTM adopted finished fuel specifications for biodiesel blends up to B20.

Blends of biodiesel of 5% or less with petrodiesel, made with D6751 grade B100, are now included in ASTM D975 and must meet the exact same properties as petrodiesel containing no biodiesel.

A blend of B5 is now considered a fungible, seamless part of normal diesel fuel covered by D975. Blends between B6 and B20 were also approved in 2008 under a new ASTM specification, ASTM D7467[7]. D7467 contains the same exact parameters as No. 1/No. 2 petrodiesel but adds parameters for acid number (0.3 mg KOH/gm maximum) and stability (6 hour minimum induction period) that are not found in D975.

US Environmental Protection Agency Registration

As stated earlier, the societal needs/desires for reduced air pollution are addressed in locomotives through EPA registration of the fuels used in the USA and through certification of engine emissions by the engine/locomotive manufacturer. All fuels must be registered with EPA under the Fuels and Fuel Additives requirements (Section 211) of the Clean Air Act Amendments of 1990 before being placed into legal commerce. There are significant fines (i.e. over $30,000 per day) that can be levied by EPA if fuels are not legally registered with EPA and sold into commerce in the USA.

As part of EPA requirements, fuel manufacturers must register diesel fuels with EPA under one of three categories: Baseline, Non Baseline, or Atypical. Baseline fuel is defined by EPA as diesel manufactured from traditional petroleum or shale that is comprised only of Carbon, Hydrogen, Oxygen, Nitrogen and Sulfur (CHONS) and that meets ASTM D975 and EPA requirements for sulfur, cetane index and aromatics. Non Baseline fuel can be manufactured from sources other than traditional petroleum or shale, must meet D975 and EPA requirements for sulfur, cetane index and aromatics, and contain no more than 1% oxygen. Atypical fuel is fuel that does not meet ASTM D975 (i.e. needs a different specification) and/or contains more than 1% oxygen or contains elements other than CHONS. In addition, new fuels must not harm emissions controls devices. Each fuel manufacturer must provide EPA with an emissions profile of the fuel for CO, HC, PM, and NOx including fully speciated hydrocarbon emissions, as well as results of a 90 day subchronic inhalation emissions study on white rats or be part of a consortium that has already provided the data to EPA.

Biodiesel is considered an 'atypical' fuel because it has more than 1% oxygen and it has its own ASTM blend stock specification, D6751. The National Biodiesel Board submitted both the speciated emissions profile and the 90 day subchronic inhalation results to EPA in 2000. Biodiesel is therefore registered as a fully legal fuel and fuel additive with the EPA. In fact, biodiesel is the only fuel beside

[7] http://www.biodiesel.org/pdf_files/fuelfactsheets/B20_Specification.pdf

petrodiesel and traditional gasoline to supply EPA with 90 day subchronic inhalation results, which showed biodiesel emissions to be much less likely to cause health issues than petrodiesel.

The EPA has issued a very useful document, "Guidance for Biodiesel Producers and Biodiesel Blenders/Users" EPA 420-B-07-019 November, 2007, which covers the topic in more detail[8]. One of the key aspects of the EPA registration of biodiesel is meeting the D6751 standard.

In addition to the EPA registration requirements, EPA has also recently set additional specifications to dramatically reduce the sulfur content of diesel fuel. This ultra low sulfur level, 15 parts per million maximum, enables the use of diesel exhaust catalyst systems sensitive to 500 ppm sulfur but that can reduce particulate and NOx emissions by over 90% compared to 2004 levels. Locomotive diesel fuel was not specially regulated until EPA released non-road diesel engine emissions standards in 2004[9]. The standards apply to all non-road sectors (e.g., construction, underground mining, marine). The standards began to take effect in 2007 and all non-road diesel fuel will be a level not exceeding 15 ppm by 2014. One drawback to un-additized ULSD is the documented loss of lubricity. Since most vegetable oils and animal fats are inherently low in sulfur, biodiesel is also inherently low in sulfur. In addition, biodiesel has been shown to restore all lost lubricity in un-additized ULSD, even at very low blends[10]. Table 14 provides the "phase-in" of ULSD into each non-road market between the present and 2014.

Table 14. ULSD implementation into the Non-road, Locomotive, and Marine markets.

Diesel Producer	Covered Fuel Sector	2011	2012	2013	2014
Large Refiners & Importers	Non-Road	15 ppm	15 ppm	15 ppm	15 ppm
Large Refiners & Importers	Locomotive & Non-Road	500 ppm	15 ppm	15 ppm	15 ppm
Small Refiners & Other Exceptions	Non-Road, Locomotive and Marine	500 ppm	500 ppm	500 ppm	15 ppm

Locomotive Emissions Regulations

Locomotive exhaust emissions have been regulated by the U.S. Environmental Protection Agency (EPA) since 2000. These regulations cover Carbon Monoxide (CO), Hydrocarbon (HC), Nitrogen Oxides (NO_X), Particulate Matter (PM), and Smoke Opacity for new locomotives, and overhauled

[8] http://www.epa.gov/oms/renewablefuels/420b07019.pdf
[9] http://www.epa.gov/oms/standards/fuels/diesel-sulfur.htm
[10] http://www.biodiesel.org/docs/ffs-performace_usage/lubricity-benefits.pdf?sfvrsn=4

locomotive engines originally manufactured in 1973 and later. One key aspect of the EPA locomotive regulations is Federal Preemption against any State or local air district regulations. For example, this precludes the California Air Resources Board (CARB) from directly regulating locomotive emissions.

US Environmental Protection Agency Regulations

The EPA standards that have been adopted are referred to as original (1998) emission regulations (Tier 0, 1, and 2) and the newer (2008) emission regulations which include remanufactured tier 0,1, and 2 (0+, 1+, and 2+), 3, and 4 and are defined as follows[11]:

- Original (1998) emission regulations (Tier 0, 1, and 2): Adopted December 1997 and became effective from 2000, applies to locomotives originally manufactured from 1973 and anytime they are manufactured or remanufactured. Tier 0-2 standards are met though engine design methods, without the use of exhaust gas after-treatment.

- Newer (2008) emission regulations: Adopted March 2008 with more stringent emission requirements. Tier 3 standards, to be met by engine design methods, become effective from 2011 for switch locomotives and 2012 for line-haul. Tier 4 standards, which are expected to require exhaust gas after-treatment technologies, become effective from 2015. The 2008 regulation also includes more stringent emission standards for remanufactured Tier 0-2 locomotives.

    - Tier 0+ — Applies (effective 2010) to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time they are manufactured or remanufactured.
    - Tier 1+ — Apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines are required to meet the Tier 1+ standards at the time of the manufacture and each subsequent remanufacture.
    - Tier 2+ — Applies to locomotives and locomotive engines originally manufactured in 2005 and later. Tier 2 locomotives and locomotive engines are required to meet the

[11] http://edocket.access.gpo.gov/2008/pdf/R8-7999.pdf

applicable standards at the time of original manufacture and each subsequent remanufacture.

- Tier 3 standards—Near-term engine-out emission standards for newly-built and remanufactured locomotives. Tier 3 standards are likely to be met using engine technology.
- Tier 4 standards—Longer-term standards for newly-built and remanufactured locomotives. Tier 4 standards are expected to require the use of exhaust gas after treatment technologies, such as particulate filters for PM control, and either EGR or urea-SCR (selective catalytic reduction) for NOx emission control.

The limit values are summarized below in Table 15 for Line-Haul Locomotives (> 2,300 HP) and for Switcher locomotives (< 2,300 HP) respectively[12]. Note that Line-Haul locomotives need to meet both the Line-Haul and Switch cycle standards, except for Tier 4, which only have to meet line-haul.

Table 15. Federal Emission Requirements for Line-haul and Switching Locomotives and Applicable Dates of Implementation.

LINE-HAUL LOCOMOTIVE EMISSION STANDARDS [g/bhp-hr]

Standards apply to:	Take effect in year:	PM	NO_X	HC
Remanufactured Tier 0 without separate loop in-take air cooling	2008 as Available, 2010 Required	0.22	8	1
Remanufactured Tier 0 with separate loop intake air cooling	2008 as Available, 2010 Required	0.22	7.4	0.55
Remanufactured Tier 1	2008 as Available, 2010 Required	0.22	7.4	0.55
Remanufactured Tier 2	2008 as Available, 2013 Required	0.1	5.5	0.3
New Tier 3	2012	0.1	5.5	0.3
New Tier 4	2015	0.03	1.3	0.14

SWITCH LOCOMOTIVE EMISSION STANDARDS [g/bhp-hr]

Switch locomotive standards apply to:	Take effect in year	PM	NO_X	HC
Remanufactured Tier 0 (0+)	2008 as available, 2010 required	0.26	11.8	2.1
Remanufactured Tier 1 (1+)	2008 as available, 2010 required	0.26	11	1.2
Remanufactured Tier 2 (2+)	2008 as available, 2013 required	0.13	8.1	0.6
Tier 3	2011	0.1	5	0.6
Tier 4	2015	0.03	1.3	0.14

It is the responsibility of the engine manufacturer (or re-manufacturer) to conduct the testing required to certify each engine and provide this information to EPA. When conducting this testing, the EPA requires the use of a special EPA emissions reference fuel that has been specially designed to

[12] http://www.epa.gov/fedrgstr/EPA-AIR/2008/June/Day-30/a7999a.pdf

represent an average petrodiesel in the market, knowing that the emissions values of real fuels in the market can vary by as much as 15% from batch to batch.

While burning biodiesel blends in a locomotive engine may provide different emissions levels than those the engine was certified on with EPA reference diesel fuel, engine companies and users generally do not need to certify or report emissions for engines when using biodiesel or biodiesel blends in the field since EPA has already approved biodiesel as a legal fuel and fuel additive for use in the US. The following statement from the Caterpillar owner's manual is instructive:

"*Engines that are manufactured by Caterpillar are certified by use of the prescribed U.S. Environmental Protection Agency (EPA) and European Certification fuels. Caterpillar does not certify diesel engines on any other fuel*." "*Note: The owner and the operator of the engine has the responsibility of using the correct fuel that is recommended by the manufacturer and allowed by the U.S. EPA and, as appropriate, other regulatory agencies*."

Major Emission Studies related to Biodiesel and Biodiesel Blends in Locomotives

Although biodiesel is a legal fuel and fuel additive for use in locomotives, and users do not in general have to report in-use emissions (emissions inventories are traditionally done using the values from the EPA engine certification levels with EPA reference diesel fuel), some users are interested in the emissions reductions and health benefits that could be derived through the use of biodiesel or biodiesel blends. There is a substantial amount of data on the emissions of biodiesel in conventional on road / non-railroad diesel fuel. However, engines used on locomotives utilize different technology (generally older, less sophisticated) than on-road engines and the emissions impacts of using biodiesel may be different for locomotives than that generally accepted for on-road engines. There are relatively few emissions evaluations on biodiesel use in locomotives which have used the official EPA Federal Test Procedures.

Two major research projects, both conducted at Southwest Research Institute in San Antonio, Texas, have investigated select emissions resulting from the use of biodiesel and biodiesel blends in Class I locomotives however. Both studies followed the federal testing protocol for emissions and following are highlights of each of these projects[13].

[13] Part 92 CFR Title 40.

Evaluation of Biodiesel Fuel in an EMD GP38-2 Locomotive[14]

May 2004 Principal investigator: Steve Fritz, Southwest Research Institute (SWRI)

- Tests run on a two-stroke EMD GP38-2 Locomotive with a 2000 HP 16-645E diesel engine under both line-haul and switch duty-cycles.
- Four separate fuels were tested for HC, PM, and NOx emissions: EPA locomotive certification test specifications, on a CARB diesel fuel, with a blend of 20% biodiesel into the EPA locomotive certification fuel (B20), and a second blend of 20 percent biodiesel with the CARB diesel (C20).
- No operational problems were observed.
- PM emissions for this locomotive engine were generally unresponsive to all fuel types which is attributed to the fact that most of the PM emissions from this mode of two-stroke EMD engine are lubricating-oil derived.
- NO_X emissions with B20 fuel compared to EPA locomotive certification diesel increased five to six percent, but were within the variation of B20 tests performed in other engine test programs with B20 tests at that time (2000).

The Effects of Biodiesel Fuel Blends on Exhaust Emissions from a General Electric Tier 2 Line-Haul Locomotive[15]

September 2010 Principal Investigators: Dustin Osborne and Steve Fritz, Southwest Research Institute and Doug Glenn, GE Transportation

Summary of Key Points:

- 2005 Tier 2 General Electric ES44DC line-haul locomotive with a GE GEVO-V12 four-stroke engine tested in EPA Locomotive Line-Haul and Switch Duty Cycles.
- Fuel containing a sulfur concentration of approximately 400 ppm, and fuel blends containing 2%, 10%, 20%, and 100% soybean derived biodiesel (B2, B10, B20, B100).
- Relative to the 2004 study, the Tier 2 four-cycle locomotive in this study consumes a fraction of the lubricating oil and emits far less PM. Particulate matter (PM) was reduced 7% to 23% over each biodiesel blend tested compared to the base fuel with the lowest results at B10 and the highest reduction in Switch Cycle.
- The change in NOx duty cycle composite values for B2, B10, and B20 as compared to the ULSD base fuel was not greater than one standard deviation of the triplicate CERT tests, and was likely within the range of normal test to test variation.
- Hydrocarbon (HC) emissions over the duty cycles were within normal test measurement variation except for neat biodiesel, where HC was reduced by 21% and 24% over the Line-Haul and Switch Cycles.
- Carbon monoxide (CO) reductions were 17% and 24% (at B20 and B100 respectively) over the Line-Haul cycle as compared to the base fuel.

[14] http://www.nrel.gov/docs/fy04osti/33436.pdf

[15] Dustin Osborne, Fritz, Steve, and Glenn, Doug. 2010. The Effects of Biodiesel Fuel Blends on Exhaust Emissions from a general Electric Tier 2 Line-Haul Locomotive. Proceedings of the ASME internal Combustion Engine Division 2010 Fall Conference ICEF2010. September 12-15, 2010, San Antonio, Texas.

South Coast Memorandum of Mutual Understanding (MOU) (1998) – California Air Resources Board[16]

In 1994, The California Air Resources Board (CARB) developed and adopted M14 into their State Implementation Plan (SIP) focused exclusively on the South Coast Ozone Nonattainment area. As a result of measure M14, ARB staff developed a MOU with the California Railroads and the U.S. EPA that was signed in July 1998. The MOU includes provisions for early introduction of clean units, with requirements for a fleet average in the SCAB equivalent to U.S. EPA's Tier 2 locomotive standard by 2010. The overall purpose of the Memorandum is to reduce emissions from railroad operations in the South Coast Nonattainment Area consistent with Measure M14 through implementation of a locomotive fleet average emission standard. The memorandum has been entered into by the CARB, and the Burlington Northern and Santa Fe Railway Company and Union Pacific Railroad Company, which are the Class I freight Railroads operating within the boundaries of the South Coast Nonattainment Area. Measure M14 of the 1994 SIP anticipates that locomotive fleets operating in the South Coast Nonattainment Area in 2010 and later will emit on average no more than the 5.5 grams per brake horsepower-hour ("g/bhp-hr"), which is equivalent to Tier 2 (2005 and later) new locomotive NO_x emission standard included in the Final EPA National Locomotive Rule.

California is in the process of determining whether it will require different specifications for biodiesel like it is has done for conventional petrodiesel used in California (i.e. CARB diesel). All locomotives in California must use CARB diesel. At present, blends up to B20 have been deemed acceptable in California, so long as the finished blends meet the ASTM D975 or D7467 standards, and blends over B20 can be utilized under a variance program of the California Department of Food and Agriculture (CDFA) who enforces diesel fuel quality specifications in California. It is generally thought that biodiesel meeting CARB and/or CDFA requirements can be used in locomotives under this MOU, however this may need to be further clarified.

Biodiesel Background

Biodiesel is a domestically-produced, renewable fuel produced from vegetable oils, animal fats, and/or used cooking oils or greases that can be used in compression-ignition engines. The ASTM definition of biodiesel is: *fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats which meets ASTM D6751.* This tight definition was needed in order to secure vehicle, engine, and fuel injection equipment company support for biodiesel, as thus consensus

[16] http://www.arb.ca.gov/msprog/offroad/loco_flt.pdf

on the ASTM specifications. The definition of D6751 biodiesel eliminates raw vegetable oils and fats, non-esterified oils, partially esterified oils, and coal slurries—all of which have been in-appropriately referred to as 'biodiesel' in older, published literature. Today, the only legal biodiesel is that which meets the stringent requirements of ASTM D6751 and is registered with the US Environmental Protection Agency. Biodiesel meeting D6751 has the following beneficial properties and attributes:

- Blends with petroleum-based diesel in any percentage – once it is blended it does not separate
- Higher Cetane Number – generally high 40's to over 50 versus average USA petroleum-based diesel of 42-44. Higher cetane contributes to a smoother, more complete burn
- High Flash Point – non hazardous shipping (over 200° F)
- Virtually Zero Sulfur – meets ULSD limits of 15 ppm or less
- Zero Aromatics–reduces toxicity
- Superior Lubricity–2% biodiesel restores the lubricity of the poorest un-additized ULSD
- Contains 11% oxygen, which reduces black smoke (particulates)
- Reduced life cycle carbon emissions of over 50% compared to 2005 petrodiesel life-cycle

Renewable Fuel Standard 2 –applicability to biodiesel

In December 2007, the Energy Independence and Security Act (EISA) or Renewable Fuel Standard 2 (RFS2) was signed into law that mandates 36 billion gallons of renewable fuel per year by 2022 with "ramp ups" from the present until then[17]. Specifically RFS2 contains four (4) "nested" volume mandates: Renewable Fuel, Advanced Biofuel, Biomass-Based Diesel, Cellulosic Biofuel. RFS2 also puts in place a renewable identification number (RIN) system for compliance and trading. The biomass-based diesel category includes diesel fuel and non-road uses (except ocean-going vessels) such as underground mining, railroads, and off-road construction and allow for renewable fuel in jet fuel and home heating oil. In addition, certain lifecycle greenhouse gas (GHG) emissions reductions compared to a 2005 baseline petroleum equivalent must be met for each of the four categories. Of the four categories in the RFS2, biodiesel can qualify for biomass-based diesel as well as an advanced biofuel. Both must meet a 50% reduction in total life-cycle greenhouse gas emissions and presently, biodiesel is the only commercially available biofuel that qualifies as an advanced fuel. Figure 2 presents a graphic display of the RFS-2 and its increasing volumes of renewable fuel from the present to 2022.

[17] http://www.epa.gov/otaq/fuels/renewablefuels/index.htm

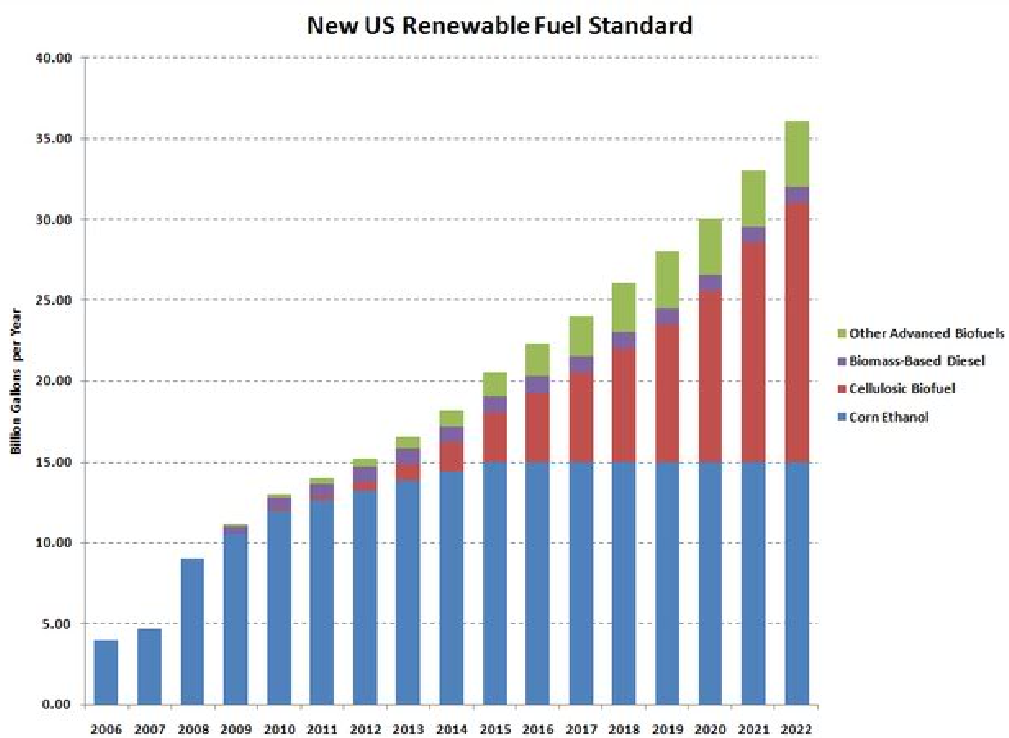

Figure 2. Renewable Fuel Standard 2 (RFS-2) with Specific Renewable Fuel "carve outs".

The specific definition of biomass-based diesel is as follows:

- A renewable fuel with lifecycle GHG emissions at least 50% less than baseline diesel and
  - o is a transportation fuel (motor vehicle, <u>nonroad, locomotive, marine</u>), transportation fuel additive, heating oil, or jet fuel,
  - o is biodiesel (mono-alkyl ester that meets ASTM D6751) or non-ester renewable diesel,
  - o is registered as a motor vehicle fuel or fuel additive under 40 C.F.R. Part 79 if intended for use in a motor vehicle, and
  - o DOES NOT include renewable fuel where renewable biomass is "simultaneously" co-processed with petroleum.

Presently (2012), biodiesel is also the only renewable fuel for distillate blending with approved ASTM specifications:

- D6751: B100 prior to blending
- D975: On/off road blends up to 5% biodiesel
- D7467: On/off road blends B6 to B20
- D396: Home heating oil up to 5% biodiesel

Based on EIA consumption values for the railroad sector for 2000 to 2009, biodiesel consumption (gallons) at a B5 and B20 would equate to an average of 163 and 654 million gallons per year respectively with a low of 125 and a high of 825 million gallons per year for B5 and B20 respectively.

Current OEM positions on Biodiesel use in Railroads

At the time of this report, both EMD and GE have issued various documents indicating the use of blends up to B5 meeting ASTM D975 can be used in their railroad locomotives. The position of other locomotive engine makers or re-manufactures was not investigated. At present, neither company supports the use of blends higher than B5, but both companies are aware that higher blends are being used in their equipment. Both companies continue to study the use of biodiesel blends, and intend on updating their position statements as more information becomes known.

Biodiesel Use in Locomotives in US and Canada

A literature search of materials and information available in the public domain and a telephone survey was conducted as part of this project to better understand biodiesel use within the railroad sector as a whole. The information obtained in this survey shows varied experiences with biodiesel by different types of railroads and the survey conducted was informal, anecdotal in nature, and for the most part, certainly not a rigorous analysis. Most of the cases utilized legacy equipment and had very little or no real relevance to line-haul freight. In all, twenty (20) railroad/locomotive trials, demonstrations, and revenue service projects involving biodiesel were identified. These projects were divided into the following categories and number of tests analyzed: Passenger Train/ Commuter (6); Line Haul Freight Trains (5); Short Line/Switching (7); and Specialty Locomotives (2). A total of ninety-one (91) engines were operated on biodiesel with the following blend levels: thirty-four (B5-B10), fifty (B20-B30), one on B50, and six (B100). Forty-seven locomotives were pre –emissions; thirty-two, Tier 0; ten Tier 1, and two Tier 2.

Table 16 provides brief summary of all 20 demonstrations/trials surveyed in this project. More detailed summaries of the 20 individual biodiesel locomotive demonstrations and emission test surveys are presented in Appendix B.

Table 16. Summaries of the twenty (20) Biodiesel in Railroads Demonstrations/Trials.

Railroad	Location	Months	Blend	# , HP	Engine	Tier
Passenger Train/Commuter						
Amtrak Heartland Flyer	Oklahoma - Texas	12	B20	1 3200	GE P32-8	1
New Jersey Transit	New Jersey	19	B20	2	645E3B 710GB	0 2
South Florida Tri-Rail	Miami/WPB, FL	96	B20	16 2000 2800	EMD 645 Cat. 3412 Detroit 3406	0
Santa Fe Southern	Santa Fe, NM	54	B20	2 1500	EMD GP-7 1952-1953	pre-emissions
NM Rail Runner	New Mexico	12	B20	5 3600	EMD Rblt.	1
Indiana State Fair RR	Indiana	0.5	B10	2 1500	EMD-6P7 EMD-6P9	pre-emissions
Line Haul Freight						
Iowa Interstate RR	Council Bluffs, IA	6	B20	1 2000	GM EMD GP38-645E	0
Canadian Pacific	Calgary to Edmonton	5	B5	4 4400	GE AC 4400	1
Eastern Washington Gateway RR	Washington	3	B25	1 3600	GE EMD	pre-emissions
Genesee Wyoming	Provo-Ogden, UT	3	B20	1 3000	GM EMD 16-645E3	0
MN Prairie Line RR	St. Paul, MN	42	B5	2	Caterpillar GP20 and GP15	pre-emissions

Table 16 (cont). Summaries of the twenty (20) Biodiesel in Railroads Demonstrations/Trials.

Railroad	Location	Months	Blend	# , HP	Engine	Tier
Short Line / Switching						
Alabama State Port Authority RR Yard	Mobile, AL	3	B20	8	Older switching	0
BNSF Railway / Montana State University	Montana	9	B20	1	SD-40-2	0
GWI	Kingsboro, TN	48	B20	5	GM EMD	1
				1500		
				1800		
US NAVY Crane Naval Base	Crane, IN	60	B20	7	EMD-1200	pre-emissions
					Rblt QSK19	
US Steel Switching Yard	Gary, IN	48	B10	22	EMD's reblt.	pre-emissions
					1950's era	
San Francisco Bay LB Rrailroad	San Francisco, CA	36	B50	1	Alco S-2	pre-emissions
				1000		
Richmond Pacific Switching Yard	Richmond, CA	12	B5	3	EMD-1200	pre-emissions
				1200		
Specialty Locomotives						
Sierra Railroad	Davis, CA	6	B100	6	GE-B30-7A	pre-emissions
PowerTrain				3000		
Electricity Generation						
Mt. Washington Cog Railway	Conway NH	12	B10	1	J. Deere 6125H	2
Summer tourist train				600		

Given what was found in this survey, this compendium should be viewed in the context of a learning experience concerning what additional information future locomotive biodiesel demonstrations need to include as far as data collection so others can directly benefit from their experience. A possible list would need at a minimum:

- The actual number of gallons of B100 (neat or blend) consumed.
- Was the biodiesel from a BQ-9000 producer and did it meet the ASTM D6751 specification upon use?
- How was fuel delivered to the locomotives – DTL (direct truck to locomotive) or wayside fueling and if so, were there any wayside fueling issues?
- What was the frequency of delivery (e.g., daily, weekly, monthly), how was the fuel stored between deliveries, and how was the fuel blended and by whom?

Survey Data Analysis: Railroads in the US/Canada and Locomotive Engines

Twenty (20) railroad/locomotive trials, demonstrations, and revenue service projects involving biodiesel were identified and were divided into the following categories with the number analyzed:

- Passenger Train/ Commuter (6)
- Line Haul Freight Trains (5)
- Short Line/Switching (7)
- Specialty Locomotives (2)

Benefits using biodiesel were improved air quality, reduced smoke and soot, but these were mainly subjective and no analytical proof was offered. Four railroads cited improved engine performance with B20 while two other railroads cited improved fuel efficiency with blends of B20 and B50, but no data was available to substantiate this claim. One railroad cited problems with their use of biodiesel (B20) that appear to be storage and handling related. The survey does not take into account any experiences railroads had with biodiesel a part of the diesel fuel at blends of 5% by volume or less. Eleven railroads discontinued use due to challenges of finding a cost effective, consistent, high quality supply of biodiesel. In the survey, a total of ninety-one (91) engines were operated on biodiesel of which eighty-five (85) ran on biodiesel blends while in revenue service. The biodiesel blend levels used among all locomotive engines were as follows: thirty-four (B5-B10), fifty (B20-B30), one on B50, and six (B100). A significant number of engines were non-regulated or pre-Tier.

Survey Data Analysis: Railroads in the US/Canada and Locomotive Engines

Twenty (20) railroad/locomotive trials, demonstrations, and revenue service projects involving biodiesel were identified and for the purpose of this report were divided into the following categories with the number analyzed:

- Passenger Train/ Commuter (6)
- Line Haul Freight Trains (5)
- Short Line/Switching (7)
- Specialty Locomotives (2)

Benefits found of using biodiesel were improved air quality, reduced smoke and soot, but these were mainly subjective and no analytical proof was offered. Four railroads cited improved engine performance with B20 while two other railroads cited improved fuel efficiency with blends of B20 and B50, but no data was available to substantiate this claim. One railroad cited problems with their use of biodiesel (B20) that appear to be storage and handling related. In addition, the survey does not take into account any experiences, pro or con, railroads or locomotives had with biodiesel being a part of the normal diesel fuel pool at blends of 5% by volume or less.

Eight (8) railroads continued to use biodiesel (B5-B20-B50) as of 2011. Eleven railroads discontinued use due to challenges of finding a cost effective, consistent, high quality supply of biodiesel. In the survey, a total of ninety-one (91) engines were operated on biodiesel of which eighty-five (85) ran on biodiesel blends while in revenue service. The biodiesel blend levels used among all locomotive engines were as follows: thirty-four (B5-B10), fifty (B20-B30), one on B50, and six (B100). A significant number of engines were non-regulated or pre-Tier.

Fuel Handling, Storage, and Distribution Issues with Biodiesel and Railroads

Fuel delivery to the locomotives can be accomplished by a number of methods and is dependent upon location, sources and volume demand. Delivery of the diesel fuel can come by truck, railcar, barge and/or pipeline and the storage tanks can be small (<50,000 gallons) to well over one million gallons. Railroads do periodic testing of all diesel fuel they use to assure it meets the current ASTM D 975 specifications. Fuel samples are generally taken with every batch of diesel fuel delivered.

Dispensing of the fuel on-site can occur through a service tracks and/or direct-to- locomotive via a truck or railcar (DTL). Figure 4 shows a DTL operation with a semi tank truck and figure 5 shows a service track operation. With the DTL, the diesel fuel is placed in the truck either off-site (e.g., a terminal) or the truck is filled on-site from a storage tank and driven to the locomotive. Fueling from a railcar is essentially the same except fuel is pulled from the top of the car. Service track operations involve diesel fuel being drawn from a storage tank and directly piped to the service track and dispensed directly into the locomotive. All fuel dispensed into a locomotive is filtered.

Figure 3. Example of Direct Truck-Locomotive (DTL) fueling operation for a locomotive.

Figure 4. Service Track Fueling operation.

Fueling Locomotives with Biodiesel

An interview with a major Class I railroad indicated for blends of biodiesel at the 5% level or less, (≤ B5) that may run in a pipeline, there should not be any difficulty transporting it as it will mirror the same delivery mechanism as conventional diesel fuel either to a transport truck, rail car, or direct to a service track fueling operation. However, they indicated blends of B6 and greater that would not come directly to their facility via pipeline would need to be blended in a separate operation either on-site by the railway or off-site and placed in a dedicated tank. For a DTL operation in which the truck were to fill up off-site this could be accomplished in much the same manner as that of a normal biodiesel delivery truck to a point of end use with a biodiesel blend, but fueling would need to be seamless to the railroad fueling operation. If a rail tank car were to provide a biodiesel blend directly to the locomotive, it too would need to be blended in the same manner as a tank truck.

For operations involving diesel fuel directly placed into main storage tanks (> 1 million gallons) and delivered to the service track this would require a dedicated B100 storage tank in close proximity to the diesel fuel storage tank and have the biodiesel metered in to the pipeline that transports diesel to the service track fueling platform. This approach will be dependent upon the quantity of biodiesel needed on a daily, weekly, or monthly basis which will directly affect the storage tank size and area required for storage and the capital and operating costs of the biodiesel storage and delivery mechanism for correct blending/metering to the service track. It was suggested by an OEM that railroad companies would consider implementing blending infrastructure for biodiesel if government incentives existed.

Society of Automotive Engineers (SAE) International – TC 7 – Biodiesel in Railroad Applications

While there is considerably more field experience with biodiesel blends in railroads than initially understood, very little scientifically controlled testing and use of biodiesel (B100) or biodiesel blends such as B20 has occurred within the rail sector as compared with other diesel applications. This has been due largely the increased cost of biodiesel compared to petroleum-based diesel in the past and the lack of regulations on railroads that allowed users to re-coup the benefits of using a renewable, domestically produced, low carbon, cleaner burning fuel like biodiesel. Railroads who haven't tried biodiesel have expressed questions regarding the use of biodiesel blends in their individual operations in the areas of emissions, fueling logistics, infrastructure, warranties, and internal working components from pre-combustion through post-combustion.

In April 2010, a forum was held by the SAE in Detroit as part of the SAE World Congress. More than fifty (50) experts from the railroad industry, national trade organizations, federal government, petroleum companies, biodiesel industry, and others met to address issues related to the environmental, technical/engineering, and regulatory needs related to railroad and locomotive manufacturers acceptance and approval of biodiesel and biodiesel blends in the US and North American railroad sector. Subsequent to the forum, SAE formed a "Biodiesel in Railroad Applications" subcommittee within SAE TC 7. The subcommittee contains over 30 members and includes most major railroads and locomotive and engine manufacturers. Specifically, this group adopted the following charter: "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."

Three working groups (Emissions, Engine Durability, and Fuel Handling and Material Compatibility) were formed with the basic goal of each working group to address potential issues and questions by the railroad sector.

In addition to activity with the SAE TC7 Biodiesel in Railroad Applications Subcommittee, during this same time period the topic of biodiesel was also taken up by the Locomotive Maintenance Officers Association (LMOA) Fuels, Lubricants, and Environment (FL&E) committee. The LMOA FL&E committee decided to update the 2005 biodiesel paper presented by the FL&E Committee to cover present information on government requirements for increased biodiesel production and use included in the Energy Independence and Security Act of 2007 (EISA). This paper was presented at the Railway Exchange 2011 conference in Minneapolis September 18-21.

Technical Needs for Biodiesel Blends in Railroads Moving Forward

Based on the input and discussions from SAE TC7, the LMOA, and other discussions with industry members, the highest priority technical items identified in this report for follow-up are as follows:

- Input to the upcoming LMOA white paper on biodiesel use in railroads
- Gathering additional scientific data on existing experience in railroads
- More information on biodiesel emissions in railroads
- More information on biodiesel long term durability in railroads
- More information on material compatibility with higher blends (over B5 or B20)
- Sharing of existing technical information with railroads
- Work with the locomotive engine makers to more specifically outline technical needs or gaps in order for them to issue support for B20 to their customers.

Conclusions

The US railroad sector, including both freight and passenger divisions, is the third highest consumer of distillate fuel in the United States averaging over 3.2 billion gallons annually between 2000-2009 with projections of consumption expected to increase in future years. The recently enacted Renewable Fuel Standard in the USA (RFS-2) mandates at least one billion gallons of "advanced" biomass-based diesel be used in 2012 through 2022. Biodiesel is a low cost option which qualifies as an "advanced" biofuel under RFS2 and it is the only "advanced" biofuel available in the US in volumes high enough to meet the billion gallon RFS2 requirements. The high volumes of fuel used in rail sector, combined with the relatively simple infrastructure and ability to incorporate large amounts of biodiesel with relative ease and low cost, leads to the conclusion biodiesel will likely be incorporated by large refiners subject to RFS2 regulations into the diesel fuel railroads use in increasing amounts.

Biodiesel is a domestically-produced, clean burning, renewable, low carbon fuel made from vegetable oils and animal fats. Oils and fats are minor by-products of producing high protein meal, such as soybean meal, or from the production of high quality meats (i.e. cattle, pork, poultry). As such, biodiesel made from oils and fats reduces life cycle carbon emissions over 50% compared to petroleum based fuels while encouraging—not sacrificing—food production. Biodiesel is manufactured to the stringent international fuel specification, ASTM D6751. Blends of biodiesel up to 5% have been incorporated as a fungible component in the petrodiesel specification, ASTM D975, and finished blends between B6 and B20 are covered by ASTM D7467. Biodiesel has seen increasing use in other on/off road sectors as a low cost means to achieve various societal and emissions goals or policies. With the lack of similar policies for fuel used in railroads, and the higher cost of biodiesel vs. petrodiesel in the past, most railroads have little experience with biodiesel.

The RFS2 may drive large refiners to incorporate biodiesel into the fuel railroads use. Thus, the purpose of this report was to provide a summary of the actual experience of biodiesel in railroad applications—as well as a summary of technical needs of biodiesel blends in railroads—in order to facilitate the use of biodiesel in railroads in the future.

More biodiesel has been used in railroads than previously thought. Over thirty seven hundred (3,700) locomotive-months have been documented with biodiesel blends of 5% to 100% in passenger, commuter/short haul, short line/switching, and line-haul applications over the past 15 years. While much of the use was not done with scientific data collection in mind, overall user experience has been very positive. Operators reported observations of reduced diesel odor and black smoke due to biodiesel use, but since most of these cases were simple revenue service (i.e. normal passenger or cargo service), additional testing and sample gathering were not conducted.

In order to get a better technical understanding of biodiesel use in rail applications, both SAE International (previously the Society of Automotive Engineers) and Locomotive Maintenance Officers Association (LMOA) have begun efforts on biodiesel to help address issues related to the environmental, technical/engineering, and regulatory needs related to railroad and locomotive manufacturers acceptance and approval of biodiesel and blends in the US and North American railroad sector. The major rail engine makers, GM/EMD and GE, both support blends up to B5 at present and the additional technical information to encourage locomotive and railroad engine manufacturers support of B20 was identified.

Appendix A

Class I and Regional Railroads

Class I Railroads

BNSF Railway Company

CSX Transportation

Grand Trunk Corporation (owned by Canadian Northern)

Kansas City Southern Railway Company

Norfolk Southern

Soo Line Railroad Company (owned by Canadian Pacific)

Union Pacific Railroad Company

Regional Railroads

Alabama & Gulf Coast Railway

Alaska Railroad Corp.

Buffalo & Pittsburgh Railroad, Inc.

Central Oregon & Pacific Railroad

Dakota, Minnesota & Eastern Railroad1

Dakota, Missouri Valley, & Western

Elgin, Joliet & Eastern Railway

Florida East Coast Railway

Great Lakes Central Railroad

Indiana & Ohio Railway, The

Indiana Rail Road, The

Iowa Interstate Railroad, Ltd.

Iowa, Chicago & Eastern Railroad

Kansas & Oklahoma Railroad, Inc.

Kyle Railroad

Missouri & Northern Arkansas Railroad

Montana Rail Link

Montreal, Maine & Atlantic Railway Ltd.

Nebraska Kansas Colorado Railway, Inc.

New York, Susquehanna & Western Rwy., The

Northern Plains Railroad, Inc.

Paducah & Louisville Railway

Pan Am Railways

Portland & Western Railroad, Inc.

Providence and Worcester Railroad Company

Red River Valley & Western Railroad Co.

San Joaquin Valley Railroad Co.

South Kansas & Oklahoma Railroad

Texas Northeastern Railroad

Texas Pacifico Transportation Ltd.

Utah Railway Co.

Wheeling & Lake Erie Railway Co.

Wisconsin & Southern Railroad

Appendix B

Biodiesel Use in Railroad Applications

Passenger / Commuter Trains

Railroad: **Amtrak Heartland Flyer AHF 2010-2011**
Category: Passenger

Fuel Supplier and Blend Level:

This revenue service trial used B20 procured from Direct Fuels of Euless, Texas.

Funding Source(s):

Amtrak received a grant from the Federal Railroad Administration for $274,000, in partnership with Texas DOT and Oklahoma DOT.

Engines:

The Amtrak locomotive #500 is a GE P32-8 rated at 3200 HP (Tier 1). This engine was originally manufactured in 1991 in Erie, Pennsylvania, but new power assemblies were installed for the B20 trial.

Project Duration and Geographic Location:

The Oklahoma and Texas trial began in late April of 2010 and concluded its 12 month run in April of 2011.

Data Monitored or Collected:

At the end of the 12 month trial GE Transportation and Chevron-Oronite performed engine analysis and materials compatibility evaluations at the Chicago Amtrak facility. In addition Amtrak monitored fuel consumption and engine oil dilution every 10 days.

Results:

Amtrak stated the demonstration went well with no operational problems or fuel related failures. Amtrak hopes to expand the use of biodiesel in their locomotives.

GE considers the project as a demonstration project. Though no fuel related issues were reported, GE could not make any conclusion about the suitability of biodiesel in locomotive application from running just one locomotive on B20. Also, GE considers one year a very short period of time to assess the effect of B20 on elastomers and other engine components.

Railroad: **New Jersey Transit Rail Operations**
Category: Passenger Train / Commuter

Fuel Supplier and Blend Level:
Sprague Energy was the fuel supplier. The blend level was B20.

Funding Source(s):
New Jersey Department of Environmental Protection (NJ DEP).

Engines: (2)
EMD 16 – 645E3B Engine (GP40FH-2 Locomotive)
EMD 16 – 710GB Engine (PL42AC Locomotive)

Project Duration and Geographic Location:
Duration = 19 months
All testing was conducted at NJ Transit's Meadows Maintenance Complex in Kearny, NJ.

Data Monitored or Collected:
Engine power output, fuel consumption, CO_2, NO_x, HC, CO, Smoke Opacity
Note: All power and emissions testing was not compliant with Federal Test Protocol (FTP) as per 40 CFR Part 92

For eight different fuel blends: No. 2 Summer, ULSD Summer, B20 Summer, ULSD B20 Summer, No. 2 Winter, ULSD Winter, B20 Winter, ULSD B20 Winter

Results:
GP40FH-2 Locomotive
All B20 blends resulted in comparable horsepower, decreased exhaust opacity and decreased greenhouse gas CO_2 emissions with respect to pure petroleum diesel.
Summer B20 blends exhibited NO_x and HC increases of up to 15% and CO decreases of up to 43%.
The winter B20 blends exhibited decreases in NO_x of up to 10% along with HC increases of up to 5%. CO emissions varied widely for the winter blends, with B20/No. 2 exhibiting a decrease in CO of 13% and B20/ULSD showing increases in CO of 40%.

PL42AC Locomotive
All B20 blends also resulted in comparable horsepower, decreased exhaust opacity and decreased greenhouse gas CO_2 emissions with respect to pure petroleum diesel.
Summer B20 blends exhibited NO_x decreases of up to 15.5%, HC decreases of 6.8% and CO decreases of 27.3%.
The winter B20 blends exhibited decreases in NO_x of up to 17.8% and decreased CO of 50.9%, but showed an increase in HC of up to 29%.

Railroad: **South Florida RTA Tri-Rail 2002-2010**
Category: Commuter train

Fuel Supplier and Blend Level:

The South Florida RTA (SFRTA) used B100 for the first 3 months procured from TransMontaigne. The high cloud B100 they were using was not suitable for the winter months so SFRTA began to use B20. SFRTA continued using B20 in their older locomotives until July 2010. After July 2010 pricing became an issue and SFRTA had stopped using biodiesel.

Funding Source(s):

SFRTA self-funded their use of biodiesel.

Engines:

The 16 locomotives used biodiesel in three pre-Tier 0 engine types: 2800 HP 12-645-F3B (traction) and Caterpillar 3412 and 3406 (head end power). [Note locomotive TRCX817 was equipped with a DDC-MTU 8V2000 HEP engine]

Project Duration and Geographic Location:

Biodiesel use in Florida began in 2002 with 3 months on B100 and 8 years on B20.

Data Monitored or Collected:

SFRTA measured fuel economy at 2.4 miles per gallon and also performed routine engine inspection. FTP (Federal Test Procedure) emissions performed on one F49PH locomotive.

Result:

Overall perception of biodiesel use was positive, however some low temperature problems were experienced with the particularly high cloud nature of the B100 used. SFRTA is interested in using biodiesel again in their locomotive fleet if the slightly higher cost was reduced.

Railroad: **Santa Fe Southern RR 2006-present**

Category: Passenger

Fuel Supplier and Blend Level:

The B20 fuel was procured from Honstein Oil in Santa Fe, New Mexico.

Funding Source(s):

The biodiesel usage was privately funded from some resources derived from the tourism business of the Historic Community of Santa Fe.

Engines:

The engines used were GM EMD GP-7 567B, 16 cylinder engine rated at 1,500 HP from the early 1950's (pre Tier emissions).

Project Duration and Geographic Location:

The New Mexico B20 usage has continued since 2006.

Data Monitored or Collected:

Data is not available for this usage.

Results:

The staff of Santa Fe Southern RR had a positive perception of their use of B20.

Railroad: **New Mexico Rail Runner 2009**
Category: Commuter Line

Fuel Supplier and Blend Level:

The B20 fuel in this trial was procured from Blue Sun LLC.

Funding Source(s):

This trial was self-funded by New Mexico Rail Runner (NMRR) with some state grant support to offset some costs.

Engines:

The locomotives in this trial were powered by refurbished EMD 3600 HP (Tier 1) engines.

Project Duration and Geographic Location:

This New Mexico trial occurred for one full year in 2009.

Data Monitored or Collected:

The operators noted the locomotives ran cleaner when operating on B20, but no data or definition was provided.

Results:

The transition to B20 was seamless and the NMRR would return to using B20 again with no objections except for the slightly higher cost of the fuel.

Railroad: **Indiana State Fair Railroad 2005-06**
Category: Passenger

Fuel Supplier and Blend Level:

The B10 fuel was procured from Jackson Oil during the summers of 2005 and 2006.

Funding Source(s):

Jackson Oil Company donated the biodiesel fuel for the project as a public relations promotion. The project was staffed by volunteers of the State Fair Season.

Engines:

The engines used were 1500 HP EMD GP-7 and GP-9 (pre emissions) manufactured in the early 1950's. In addition the Indiana State Fair Train also operated 275 HP generators on B10 for air conditioning and lighting in the railcars.

Project Duration and Geographic Location:

The State Fair Train operated in the month of August when the fair was open for 12 days with 10 round trips per day.

Data Monitored or Collected:

No parameters were measured other than routine engine maintenance and inspection.

Results:

The overall experience with biodiesel was positive. The Director of Operations would consider biodiesel use in the future if the cost differential was subsidized. This railroad only operated in August for 12 days when the State Fair was open.

Line Haul Freight Trains

Railroad: **Iowa Interstate Railroad 2010**
Category: Line Haul Freight

Fuel Supplier and Blend Level:

Renewable Energy Group (REG) supplied B20 blends of fuel for this trial.

Funding Source(s):

This trial was conducted under a grant from the U.S. Department of Transportation between REG and the University of Kansas Transportation Research Institute.

Engines:

The locomotive was powered by an EMD GP38 645E 2,000 HP Tier 0 engine, which had been rebuilt from a 1966 block.

Project Duration and Geographic Location:

The Midwestern project was performed as two 3-month trials occurring from June 2009 to January 2010.

Data Monitored or Collected:

Emission testing performed at the beginning and end of each 90-day trial. The emissions testing were not with the FTP protocol. Emissions were measured with a Sensors Inc. SEMTECH-DS portable test system that measured real-time emissions of CO, CO_2, NO, NO_2, THC. An auxiliary electrochemical sensor measured oxygen simultaneously. Soot was measured with a 415S G002 Variable Sampling Smoke Meter (AVL). Static load testing and operational tests were performed at the Iowa Interstate rail yard in Council Bluffs, Iowa.

Results:

The results of this study were presented at the 90^{th} Annual Meeting of the Transportation Research Board, Washington, DC. In the report, a reduction in partially combusted hydrocarbons was observed with a slight increase in NO_X emissions. At the B20 level a 35% reduction in soot emissions was also observed. No significant performance or maintenance issues were observed during the 90-day trials, and neither the engine nor its operation was modified. The conclusion of the study suggested that biodiesel blends are a viable “drop in” substitute for petroleum diesel in railroad switching yards from both a performance and air quality standpoint.

Railroad: **Canadian Pacific RR 2009-10**
Category: Line Haul Freight

Fuel Supplier and Blend Level:

Canadian Pacific used B5 procured from suppliers in the U.S. and Canada.

Funding Sources:

Canadian National Renewable Diesel Demonstration Initiative was the primary funding of this trial.

Engines:

The four locomotives using B5 were the GE AC 4400 Tier 1.

Project Duration and Geographic Location:

This study occurred during November 2009 to March 2010 between Calgary and Edmonton on 110 miles of mainline track.

Data Monitored or Collected:

The cold flow performance was monitored as the study was conducted during the winter months. General Electric (GE) used a boroscope before and after the study to monitor various engine components including the cam section, rollers, liners, rocker box and injector nozzle. GE also performed oil sampling per their method and downloaded fault and failure logs from the engine database. During this study emissions were not monitored.

Results:

There were no operational problems observed during this study. Canadian Pacific (CP) is pleased with the cold weather test results but challenges remain for availability and sourcing. CP would like to consider higher blends.

The conclusion of the CP trial by Natural Resources Canada is summarized below:

The Canadian Pacific Biodiesel Demonstration Project successfully demonstrated the viability of B5 biodiesel use in cold weather freight rail service. Using a blend of ULSD and B100 conforming to ASTM D6751, Canadian Pacific successfully operated four GE AC4400CW locomotives in significant cold weather conditions. Despite temperatures below -40°C, CP experienced no temperature-related interruption of service. GE's engine inspections further demonstrated no negative mechanical effects from the use of B5 biodiesel. Following the completion of the demonstration project, GE approved the use of up to B5 biodiesel in their family of locomotives powered by FDL and Evolution engines. This approval requires the fuel to be compliant with the ASTM standard. The test successfully demonstrated the viability of B5 biodiesel use in cold weather freight rail service.

Railroad: **Eastern Washington Gateway RR 2008**
Category: Line Haul Freight

Fuel Supplier and Blend Level:

B25 fuel was procured from Columbia BioEnergy of Vancouver, Canada.

Funding Source(s):

The biodiesel usage was self-funded by the Eastern Washington Gateway Railroad.

Engines:

Power was supplied by an EMD 3600 HP engine built in 1968 (pre emissions).

Project Duration and Geographic Location:

The locomotives used biodiesel for 3 months starting in June 2008

Data Monitored or Collected:

Only routine engine checks were performed.

Results:

The operators had a positive impression about biodiesel and noticed less visual smoke and reduced diesel odor. The only complaint was that the fuel was not readily accessible to procure. The Eastern Washington Gateway RR stated that they would consider using biodiesel in the future if a readily available supply were available.

Railroad: **GWI Genesee Wyoming 2008**
Category: Line Haul Freight

Fuel Supplier and Blend Level:

The B10 and B20 fuel was procured from a local fuel supplier.

Funding Source(s):

The biodiesel usage was self-funded by the Genesee Wyoming Railroad.

Engines:

The locomotive was equipped with an EMD 16-645E3 3000 HP Tier 0 engine.

Project Duration and Geographic Location:

The biodiesel usage was conducted over a three month time frame in Utah between Provo and Ogden.

Data Monitored or Collected:

The filters and cylinders were visually inspected every five to ten days, but no data is available on what was examined or outcomes.

Results:

The overall perception of biodiesel was positive as there were no engine problems. The cost was the determining factor and why the test lasted three months. The railroad indicated they would consider using biodiesel in the future if the fuel was price comparable with conventional diesel.

Railroad: **Minnesota Prairie Line 2006-09**
Category: Short Line Freight

Fuel Supplier and Blend Level:

The B2 and B5 fuel was procured from Central Bi-Products out of North Redwood Falls, MN. Initially the trial began with B2 in the summer of 2006 then switched to B5.

Funding Source(s):

The biodiesel usage was self-funded by Minnesota Prairie Line which is owned by Twin Cities and Western Railroad.

Engines:

The locomotives, EMD GP15C and GP20C were powered by Caterpillar Generation II engines (pre emissions), with approximately 1,500 and 2,000 HP. These engines were originally built in the 1970's and were repowered in the 1990's.

Project Duration and Geographic Location:

The locomotives operate 5 days a week along 229 miles of track in Minnesota where it hauls agricultural products, timber, and cannery products.

Data Monitored or Collected:

There were no records of emissions or other parameters measured.

Results:

The Minnesota Prairie Line (MPL) had a positive perception of biodiesel use as the price of the B2 and B5 was consistent with the cost of ULSD. The MPL would have continued to use the biodiesel blend, but the fuel became higher in cost and returned to using ULSD with no biodiesel.

Short Line / Switching Yard Locomotives

Railroad: **Alabama State Port Authority 2007**
Category: Switching Yard

Fuel Supplier and Blend Level:

The B20 fuel in this trial was supplied from a local distributor.

Funding Source(s):

This trial was self-funded by the Alabama State Port in 2007.

Engines:

The engine types in all eight locomotives are unknown, except they are classified as Tier 0.

Project Duration and Geographic Location:

The 3-month B20 usage occurred in 2007 along the gulf coast of Alabama.

Data Monitored or Collected:

Routine engine oil checks and engine checks were performed.

Results:

The Alabama Port Authority (APA) had a positive experience using biodiesel. The operators observed less diesel smell and reduced black smoke. The APA also reported the fuel was "drop in" as no engine modification was needed. The only problem was the inability to locate a regional supplier who could be cost competitive with the supply. The APA is seeking to reduce greenhouse gas emissions at the public seaport terminals and chose to test biodiesel to fulfill this task.

Railroad: BNSF Railway / **Montana State University July 2010 – July 2011**
Category: Switching Yard & Local

Fuel Supplier and Blend Level:

The B20 fuel was procured from Earl Fisher Biofuels in Chester, Montana.

Funding Source(s):

This trial was jointly funded by BNSF Railway in collaboration with Montana State University, College of Technical Sciences and Montana Department of Environmental Quality (DEQ). Testing was conducted with two BNSF locomotives at the Havre, MT rail yard.

Engines:

BNSF 1928 was powered by an EMD 16-654E3 engine which developed 3000HP on B20 biodiesel blend derived from Camelina seed oil. The engine was rebuilt in 2008 to meet Tier 0 emission standards. BNSF 1945 was a duplicate engine running on standard #2 petroleum diesel (B0) as a control.

Project Duration and Geographic Location:

The trial occurred over 12 months and ended in July 2011.

Data Monitored or Collected:

BNSF monitored various parameters.

Results:

On board filter plugging shortly after B20 was introduced to the fuel system for the first time. This was attributed to B20 biodiesel having different solvency properties compared to straight petroleum diesel. Material which had accumulated in the petroleum diesel fuel system over the years was dissolved by the B20 blend and plugged the fuel filters.

With as little as 3 months in storage, significant biological attack occurred and damaged the B20 injector rendering it unusable. Pairs of injectors were removed from both locomotives at regular intervals during the year-long study. One injector of each pair was examined immediately where slight differences in wear patterns on critical components were noted between the B20 and petroleum diesel injectors. The second injector of each pair was placed in storage for a period of time to simulate locomotive ‘lay-up’.

Railroad: **GWI 2007- present**
Category: Switching Yard & Fleet

Fuel Supplier and Blend Level:

Fuel blends of B10, B20, and B30 were procured from Tri-Cities Petroleum in Virginia.

Funding Source(s):

The Eastman Chemical Company (ECC) was offered incentives from the state of Tennessee and also received subsidies and discounts from their fuel supplier for this trial.

Engines:

The five locomotives using biodiesel are owned by Rail Link, a subsidiary of Genesee & Wyoming, Inc. ECC in Kingsport, TN uses EMD 1500 and 1800 HP pre emissions locomotives to distribute over 1,000 railcars at their facilities.

Project Duration and Geographic Location:

ECC began using various blends of biodiesel (B10-B30) in 2007 in Tennessee.

Data Monitored or Collected:

The Fleet Manager did not have specifics on testing or parameters measured during the trial.

Results:

The Fleet Manager noted biodiesel use had reduced exhaust emissions for their workers (visual) and the community of Kingsport. ECC had issues with locating suppliers who were price competitive.

Railroad: **NAVY Base, Crane Indiana 2006-present**
Category: Switching Yard

Fuel Supplier and Blend Level:

The B20 fuel used was procured from Country Mark in Indiana.

Funding Source(s):

The Navy has a working capital fund for transportation operations.

Engines:

Six of the seven locomotives were equipped with EMD-1200 pre-emissions engines.

Project Duration and Geographic Location:

The Midwest Naval switching yard conducted a 3-month operational trial under normal duty cycles in 2006. There was a control diesel engine that ran during the same period. No problems were reported and they have continued running on B20 since 2006.

Data Monitored or Collected:

Periodic testing of the crankcase oil was performed with no oil dilution problems observed. Routine engine checks and maintenance was performed with no need to increase the frequency of fuel filter changes. Since the biodiesel use began in 2006 there have been no emission studies to date.

Results:

The Naval Base Transportation Division Manager has been very pleased with the performance of B20 in all seven locomotives. The Division Manager is also pleased about biodiesel making a difference in air quality for the Naval Base, but his assessment was subjective in nature. The Navy is making an effort to reduce greenhouse gases and improve air quality on base. The Navy would like to decrease the carbon footprint and reliance on foreign oil. Locomotives running on B20 seem to burn cleaner in their opinion. They reported a decrease in visible black smoke and they indicate the stack exhaust has reduced odor.

Railroad: **US Steel switching yard 2007-present**
Category: Switching Yard

Fuel Supplier and Blend Level:

Biodiesel blends of B2, B5 and B10 were procured from a local distributor.

Funding Source(s):

US Steel does not receive any federal funding or support from other sources for biodiesel use.

Engines:

All twenty two (22) EMD locomotives were equipped with 1950's rebuilt engines (pre emissions).

Project Duration and Geographic Location:

The use of biodiesel took place in Gary, Indiana initially with B2 in 2007. Three months later the yard switched to using B5 in the winter and B10 in the summer months.

Data Monitored or Collected:

Engine oil was measured and monitored every 90 days, but no information is available on the results of these measurements. There were no emissions or opacity measurements taken despite the enthusiasm to improve air quality.

Results:

US Steel has positive experience with biodiesel as they have been consuming over two million gallons of biodiesel blends as B5 and B10 each year. The operators reported the engines run more efficiently and it has been perceived in the community as beneficial to the environment in Indiana. The company is encouraging use of biodiesel in other states where they have facilities.

Railroad: **San Francisco Bay Railroad SFB 2008-present**

Category: Switching Yard/Short Haul

Fuel Supplier and Blend Level:

The B50 and B100 fuel used in this trial was procured from San Francisco Biofuel Coop.

Funding Source(s):

The San Francisco Department of Environment, Bay Area Air Quality Management, and Green Depot have provided funding for the biodiesel usage.

Engines:

The locomotive using biodiesel was equipped with a 1,000 HP six cylinder engine manufactured in the mid 1940's (pre-emissions).

Project Duration and Geographic Location:

Biodiesel use began in 2008 within the City of San Francisco.

Data Monitored or Collected:

The San Francisco Bay Railroad conducted a biodiesel test study with the California Air Resources Board (CARB) Mobile Source Operations Division in September 2008. The emissions testing was performed with a mobile Sensors Inc. SEMTECH unit on one switching locomotive hauling 4 loaded cars containing 130 tons of soil. Three fuels were tested: B0 (pure CA ULSD), B50 and B100. Emission measurements included CO, CO_2, NO, NO_2, and opacity. Results indicated slightly increased NO_X emissions but dramatic reductions in opacity.

Results:

No adverse issues have been observed with biodiesel use. The operators have noticed improvements in reduced visual smoke, soot and odor. Emissions data were averaged for each test run, then the median value of these averages were compared with the three fuels used. The test data was analyzed and showed that runs in the uphill direction were more stable and had more consistent results than those in the downhill direction. These observations were consistent with results of other studies using remote sensing devices.

Railroad: **Richmond Pacific RR California 2007**
Category: Switching Yard

Fuel Supplier and Blend Level:

The B5 fuel was procured from L.C. Biofuels, LLC.

Funding Source(s):

The state of California provided grant funds for the biodiesel usage for one year.

Engines:

The locomotives were powered with EMD SW-1200 non-regulated engines from the 1950's and 1960's.

Project Duration and Geographic Location:

This West Coast usage took place in 2007 for a year.

Data Monitored or Collected:

There were no parameters measured in this usage.

Results:

The engines used are part of a Carl Moyer program for reducing emissions and biodiesel blends were not in the set of fuels tested under Carl Moyer. Richmond Pacific RR had to switch back to only fuel tested under Carl Moyer, in this case petroleum diesel containing no biodiesel. The Richmond Pacific RR would like to use biodiesel blends again if its use is found acceptable by CARB in conjunction with engines covered under Carl Moyer. The operators had a positive perception while they were using the biodiesel blends and noted that it performed the same as diesel fuel, but no data was available to support this claim. The operators also noticed the engine seemed to emit less black smoke.

Specialty Locomotives

Railroad: **Sierra Railroad / PowerTrain 2001-02**
Category: Specialty – Power Generation

Fuel Supplier and Blend Level:

B100 fuel was obtained from various suppliers in the area.

Funding Source(s):

This trial was funded privately by the Sierra RR with additional grants from CARB. The objective of this trial was to study the use of locomotives as portable backup utility power for municipal power generation. Between 2001 and 2002, 48 locomotives were purchased and retrofitted to become regional temporary power generation units.

Engines:

The locomotives using biodiesel were GE B30-7A, with 3000 HP non-regulated engines.

Forty-eight individual locomotives in total were purchased and retrofitted to become B100 regional temporary stationary power generation plants in CA in 2001-2002.

Project Duration and Geographic Location:

The locomotives were operated on B100 for 6 months in Davis, California.

Data Monitored or Collected:

Emissions data was collected in 2002, but six months into the project the funding had collapsed. The emissions data collected is in the custody of Sierra Railroad. The engine oil was monitored periodically (parameters unknown) and the fuel was monitored for microbial growth.

Results:

Fuel stabilizers were used for the B100 in this trial. The operators did not experience any problems with the use of B100. More testing would have been performed if the grant would not have fell through.

Railroad: **Mount Washington Cog Railway, NH 2007-present (Summer Months)**
Category: Specialty Tourist RR

Fuel Supplier and Blend Level:

The COG Railway started using B5 and gradually moved up to B20. The fuel for this usage was procured from Reliable Biodiesel in Conway, New Hampshire.

Funding Source(s):

The biodiesel usage is funded internally by the owners of COG Railway.

Engines:

The locomotive is powered with a John Deere 12.5 liter 6125H 600 HP EPA non-road Tier 2 engine.

Project Duration and Geographic Location:

The COG Railway has continued to use B20 when in operation every summer since 2007.

Data Monitored or Collected:

The engine oil is tested every 250 hours and routine maintenance logs were kept.

Results:

The operators have noticed the engine emits less black smoke than with conventional diesel fuel.

Appendix C

National Railroad Organizations and Agencies

Following are several major United States-based trade organizations, government agencies, etc. that are actively involved with energy, environmental, economic/financial, technical/engineering, and regulatory issues associated with the rail system. These bodies have an interest or need to be involved as biodiesel implementation moves forward.

- American Railway Engineering and Maintenance-of-Way Association (AREMWA) – AREMWA is responsible for development and advancement of both technical and practical knowledge and recommended practices pertaining to the design, construction and maintenance of railway infrastructure. http://www.arema.org/.

- American Short Line and Regional Railroad Association (ASLRRA) – a non-profit trade association that represents the interests of its short line and regional railroad members in legislative and regulatory matters. http://www.aslrra.org.

- Association of American Railroads (AAR) – The mission of the AAR is to work with elected officials and leaders in Washington, D.C. on critical rail transportation issues to ensure that the railroads meet America's transportation needs today and in the future. In addition, the primary focus of the AAR is the interoperability of rolling stock, including locomotives, and their components. www.aar.org.

- Federal Railroad Administration (FRA) – was created by the Department of Transportation Act in 1966. FRA promulgates and enforces rail safety regulations; administers railroad assistance programs; conducts research and development in support of improved railroad safety and national rail transportation policy; provides for rehabilitation of Northeast Corridor rail passenger service; and consolidates government support of rail transportation activities. The FRA is one of ten agencies within the U.S. Department of Transportation concerned with intermodal transportation and operates through seven divisions. http://www.fra.dot.gov.

- Railway Engineering-Maintenance Suppliers Association (REMSA) – The mission of REMSA is to provide global business development opportunities to members; transfer knowledge about markets, products and the industry to members and their customers, and to support government initiatives that advance the North American railroad industry. http://www.remsa.org/.

- Surface Transportation Board (STB) – The Surface Transportation Board (STB) was created in the ICC Termination Act of 1995 and is the successor agency to the Interstate Commerce Commission. The STB is an economic regulatory agency that Congress charged with resolving railroad rate, service disputes, and reviewing proposed railroad mergers. The STB is independent, although administratively affiliated with the Department of Transportation. The STB serves as both an adjudicatory and a regulatory body. The agency has jurisdiction over railroad rate, service issues, and rail restructuring transactions (mergers, line sales, line construction, and line abandonments); certain trucking company, moving van, and non-contiguous ocean shipping company rate matters; certain intercity passenger bus company structure, financial, and operational matters; and rates and services of certain pipelines not regulated by the Federal Energy Regulatory Commission. http://www.stb.dot.gov.

- Transportation Technology Center, Inc. (TTCI) – A wholly owned subsidiary of the Association of American Railroads. TTCI is a world-class transportation research and testing organization, providing emerging technology solutions for the railway industry throughout North America and the world. www.aar.org.

Appendix D

Locomotive Maintenance Officers Association – Test Protocol

LOCOMOTIVE MAINTENANCE OFFICERS ASSOC.

ENGINE LUBRICATING OIL EVALUATION FIELD TEST PROCEDURE

DIESEL ENGINE LUBRICATING OIL EVALUATION

FIELD TEST PROCEDURE

PREPARED BY

FUELS AND LUBRICANTS COMMITTEE

OF THE

LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION September 2000

This is the revised 1976 procedure. The committee's updates were the study group of Mr. Dennis Campbell (EMD), Mr. Robert Dittmeier (Ethyl), and Dennis McAndrew (GE) December 9, 1999

This field-test protocol only addresses how to run a field test, it noes not address what additional requirements may be required by either the Original Equipment Manufacturer (OEM), the railroads, or from other power generation applications.

This procedure recommended by the Locomotive Maintenance Officers Association (LMOA) represents its judgment given with due consideration of the necessary limitations of a practical operation and in accordance with the aims and objectives of LMOA. LMOA assumes no responsibility for the affect of its reports, recommended procedures and practices and standards, or for the observance or non-observance by federal, state or local government agencies, or by manufacturers, of its standards, practices or procedures. It should be noted that findings and recommendations of LMOA in any case represent only its independent opinion arrived in accordance with its aims and purposes. LMOA does not warrant or guarantee the correctness of its opinion, or that its opinion will be accepted or recognized by any other person, organization or governmental agency. The recommended procedures of LMOA are in no way binding on its membership.

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COMPANY REPRESENTATION

FUELS & LUBRICANTS COMMITTEE

DURING 1974, 1975 and 1976

ALCO ENGINE CO.
AMOCO OIL CO.
ATCHISON, TOPEKA & SANTA FE RWY.
ATLANATIC RICHFIELD RESEARCH
BESSEMER LAKE ERIE RR
BURLINGTON NORTHERN INC.
CHESSIE SYSTEM
CHEVRON CHEMICAL CO.
CHICAGO, ROCK ISLAND & PACIFIC RR
CONTINENTAL OIL CO.
EXXON CO.
GENERAL ELECTRIC CO.
GENERAL MOTORS CORP.
GULF RESEARCH & DEVELOPMENT CO.
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LOUISVILLE & NASHVILLE RR
MISSOURI PACIFIC RR
MOBIL OIL CO.
NORFOLK & WESTERN RR
PENN CENTRAL TRANS. CO.
READING COMPANY
SAINT LOUIS SAN FRANCISCO RWY.
SHELL OIL CO.
SOUTHERN RAILWAY
SOUTHERN PACIFIC RR
STANDARD OIL CO. OF CALIF.
TEXACO INC.

The above list is retained to highlight those that were involved with creating the original document.

LMOA DIESEL ENGINE CRANKCASE LUBRICATING OIL FIELD EVALUATION PROCEDURE

Purpose and Scope

The purpose of this procedure is to provide a uniform method for conduct of and reporting of field evaluation tests. The rational is to determine if a new crankcase lubricating oil possesses the necessary characteristics to enable it to satisfactorily lubricate main power plant diesel engines, which are incorporated in railroad locomotives. It is intended that this procedure be used for the evaluation of proposed lubricating oils containing a new additive formulation not yet in commercial service. This testing may also include proven additives incorporated into base oil formulations of significantly different characteristics, e.g., Viscosity Index Improves, Group 1 or Group 2 base stocks. It may be used for products containing an additive formulation already in commercial service and under this condition, it would seem appropriate that the procedure be modified.

A successful lubricating oil field evaluation test requires the close cooperation of: the railroad or company supplying the test equipment, the oil and/or additive company and the OEM. This cooperation should begin before the test is started, recognizing that a field evaluation of a new product always entails some risk.

The OEM's have historically screened new lubricating oils by the use of bench tests and/or stationary engine tests. It is expected that the engine builders will continue this process and will formally notify the appropriate oil and/or additive company that its candidate lubricant is, in their view, worthy of field test.

All the participants ultimately benefit from a new product, but it is appropriate that it be their responsibility of the oil and/or additive companies to arrange for a location to perform the test. All parties involved benefit from this testing by being able to evaluate the latest technology. The normal rules of warranty administration apply during the conduct of a test.

Performance Parameters

The lubricating oil under test is to be evaluated for its ability to provide:

1. Oil chemistry that is non-corrosive to engine bearing materials including silver, copper-lead, and aluminum.
2. Adequate film strength to satisfactorily lubricate all internal engine components.
3. Deposit control in critical areas such as piston cooling cavities and piston ring groves and lands.
4. Protection against corrosive wear within the power assembly.
5. Sufficient dispersancy and detergency to maintain open oil passages, provide satisfactory oil filter life and control oil related deposits.
6. A lubricant that will limit ash, carbon, sludge, or varnish deposits from developing on engine parts to any degree which would interfere with the engine performance.
7. Stability against oxidation; loss of alkalinity, dispersancy and detergency while providing reasonably long effective oil life.

Test Team

At the beginning of testing technical representatives of the railroad or the company supplying the test equipment, the oil and/or additive company and the OEM having field test responsibility shall be designated. Those designated should be present at the mid-term and the final inspections of the engines involved in the test. A competing oil and/or additive company shall not be allowed to inspect engine parts or allowed to inspect engine parts or obtain used oil performance except by written agreement of the oil and/or additive company conducting the testing. The same requirements apply to engine builders with respect to each other's equipment.

Operating Conditions

The following service conditions are known to affect lubricating oil performance in an engine and therefore are to be reported in the final evaluation of results:

1. Altitude
2. Tunnels
3. Ambient temperature
4. Fuel quality
5. Duty cycle
6. Maintenance practices including parts replacement, incidents of fuel or water contamination.
7. Airborne contaminants – air filter c/o record
8. Oil change schedule – oil filter c/o record

9. Lubricating oil consumption

10. Interchange of locomotives

Bracketed items would be considered as increased severity and would also need to be documented. [Altitude 5,000 ft. or above.] [Ambient temperatures in excess of 115°F.] (Artificially created by tunnels) [Fuel sulfur content of 0.5% or above]

Fuel usage is a measure of duty cycle. During the course of the evaluation, the MWHr (megawatt hours) data from one of the units used the test should be recorded.

Duration of Test

A standard test shall require the accumulation a minimum of 100,000 miles and minimum of 12 consecutive months so as to incorporate all seasonal climatic conditions. The test will be terminated at a shorter period if the test team agrees that the oil has failed. It may be run longer at the discretion of the test team. If for some reason beyond the control of the test team and aside from failure of the test oil, the test must be terminated before reaching minimum timeframe, it shall be declared void.

Selection of Locomotives

A complete evaluation should include both EMD and GE locomotives. The evaluations may occur on different railroads. The locomotives selected should ideally be those of highest commercial Brake Mean Effective Pressure (BMEP) ratings available from each OEM. A variation from this desirable goal requires a statement of the OEM that the evaluation in the substitute locomotive will adequately predict performance in the highest rated unit. In addition Electro-Motive Division of GM includes the requirement of evaluating a minimum of two of their locomotives containing silver wrist pin bearings.

Each test oil should be evaluated in four to six locomotives manufactured by each OEM. Ten locomotives would be considered a maximum to operate on a test oil. All parties should be involved in decisions to operate a larger number of locomotives on the test oil. Two of the same class locomotives operating on the railroad's fleet oil are recommended as control units and treated in the same manner as those which are used for the test oil.

Parts Evaluated for Each Engine as Appropriate to Engine Type

Air Box

Bearings (connecting rod only)

Cams lobes and camshaft

Top deck or rocker box covers

Crankcase

Crankcase Covers

Heads (combustion face)

Cylinder liners

Valve and valve train

Piston and articulated pins

Piston pin inserts

Piston pin and articulated pin bushing

Pistons ring grove and lands, crowns and undercrowns

Inlet ports

Piston rings

Intake and exhaust valves

Thrust washers

Test Inauguration

The engines used for test and control locomotives should be new or have been newly overhauled. The lubricating oil system external to the engine such as filters, cooler and the radiator system must be cleaned and inspected prior to start of test. A minimum of four pre-measured power assemblies on each engine shall be new or rebuilt to factory standards. Two of these power assemblies are to be applied to each bank of the engine. Two of these power assembles are to be applied to each bank of the engine. All piston ring side clearances on EMD are to be recorded.

Test Procedure

Locomotives should be load tested prior to the start of test to assure normal operation. A schedule of inspections shall be established for each test and include, as a minimum, six-month and end of test inspection. Under normal conditions it is not necessary to remove parts from the engines at the six-month inspection point.

Crankcase deposit ratings as well as top deck deposit ratings should be made in at least two cylinder locations at the six-month point.

At the six-month inspection, cylinders of GE engines are to be borescoped for evidence of piston ring sticking or cylinder scoring. This same evaluation is to be performed on EMD engines by "air box inspection". On EMD units, top ring side clearances are to be determined and recorded at this inspection.

Oil changes are to be made based on laboratory analysis or to the maximum OEM's requirements. The limits are to be those published by the engine manufacturer for this purpose unless agreed to by all parties prior to the test. A record of all lubricating oil changes is to be included in the final report.

Oil changes are to be made based on laboratory analysis or according to each OEM's condemning limits. The limits are to be those published by the engine manufacturer for this purpose unless agrees to be all parties prior to the test. A record of all lubricating oil changes is to be included in the final report.

A lubricating oil sample is to be obtained weekly if possible and analyzed by the oil and/or additive company. The analysis should consist of the following determinations as a minimum: viscosity at 40° C and 100°C, LMOA pentane insolubles, pH, Total Base Number (D4739), Total Acid Number (D664), and wear metals by an appropriate spectrometer.

Every effort should be made to prevent mixing of the test lubricant with other lubricants. If at all possible, a supply tank complete with pump, hose and nozzle should be available at the major service point to facilitate proper oil addition. Where possible an onboard lubricating oil supply tank should be installed to allow test oil addition when away from main terminal. Decisions on these points should be reached prior to the beginning of test. The oil and/or additive company involved should procure and analyze sufficient samples of the candidate lubricating test oil to establish if there is the degree of crankcase oil mixing. An organic or inorganic marker could be useful in tracking any contamination from the fleet oil.

A sample of diesel fuel oil from the onboard fuel tank should be obtained and analyzed at the start of test, the mid point and at the end of test. Tests should include gravity, cetane index, sulfur and distillation; and these analyses should form a part of the final report.

A complete record of all parts removed and all service performed on each test engine and each control engine during the course of the evaluation shall form a part of the final report.

At the end of the evaluation, the four "test" power assemblies shall be removed from each engine and completely evaluated as detailed in the appendix.

Rating Methods

In general the methods used for rating engine parts will be those developed by the Coordinating Research Council, Inc. These methods are covered in "CRC Manual No. 18 (for deposits) and Manual No. 12 (for sludge). It is not necessary to rate all of the engine parts in as much detail as covered in the CRC Manual. In general there are three types of ratings: Condition, Deposits and Measurement. The most complex of these rating techniques is that associated with deposits. Considerable experience is required to obtain consistent results. Rating Symposiums are conducted periodically under the auspices of the Coordinating Research Council. The oil and/or additive companies normally employ a number of individuals who are thoroughly experienced in judging the degree of deposits and who regularly participate in these programs. It is recommended that a qualified person, either from the oil and/or additive company perform the end of test ratings.

The following defines the type of rating believed necessary for the conduct of an oil evaluation test. At the discretion of the test team, additional type ratings may be made.

Deposit Only

Air box, covers-top deck or rocker box, crankcase, crankcase covers, heads (combustion face) and ports-inlet.

Condition Only

Bearings, bushings, cam lobes, camshafts, valve mechanisms and pins.

Deposit, Condition and Measurement

Cylinder liners-cylinder, piston and piston rings

Intake and exhaust valves and piston thrust washers

Appendix A lists appropriate extractions from CRC Manual No. 18 and No. 12.

Final Report

The oil and/or additive company involved will present a written report to the participating railroad and participating OEM. The railroad technical department and/or the OEM may cooperate in preparation of the report, but their participation shall not constitute an endorsement of the product.

The final report shall include tabulated wear and deposit ratings, illustrative photographs, lubricating oil analysis data and maintenance records as defined elsewhere. The following photographs representing typical conditions are to be included. In addition any abnormal condition should be documented by photograph where appropriate.

Photographs

Connecting rod bearings

Bearing surface and back

General

Air box – left bank front and rear

Top deck or rocker box, their covers and valve gear

Crankcase main frame

Head

Full fire face with valves in place

Close up of two valve seats

Piston

Side view close up full piston with rings

Close up of ring belt without rings

Top view of crown

Undercrown

Rings – Detail

Silver insert bearing

Valves

Close up of entire set after removal showing faces and stem up to weld joint

This document is the proposed procedure for field testing crankcase engine oil formulations. It does not address what is acceptable to the end user or OEMs.