In-Use Evaluation of Transit Buses Operated on Biodiesel Blends (B20) by St Louis Metro

Robb Barnitt
Mike Lammert, Robert McCormick
National Renewable Energy Laboratory (NREL)

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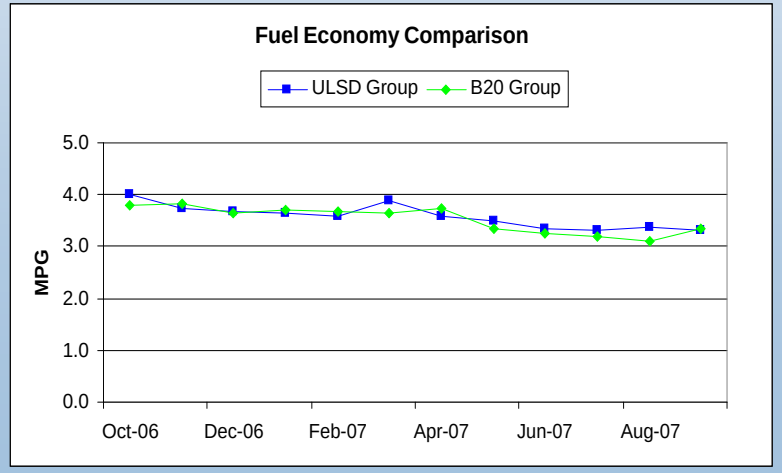
Agenda

- Project Objectives / Approach
- Implementation and usage
- On-road fuel economy
- Reliability
- Maintenance costs
- Fuel system durability
- Fuel analysis
- Lube oil analysis
- Conclusions

B20 Fleet Evaluation – Objectives

- Compare vehicles operating in the field on B20 and ULSD over 12 months:
  - Engine performance
  - Fuel economy
  - Vehicle maintenance cost
  - Fuel-induced variations in operation and maintenance
  - Lube oil performance



- Exhibit high degree of experimental control in vehicle selection and duty cycle
- Aid engine OEMs in exploring affects of B20 on engine durability
- Aid potential B20 users in understanding costs, benefits, and differences in operation

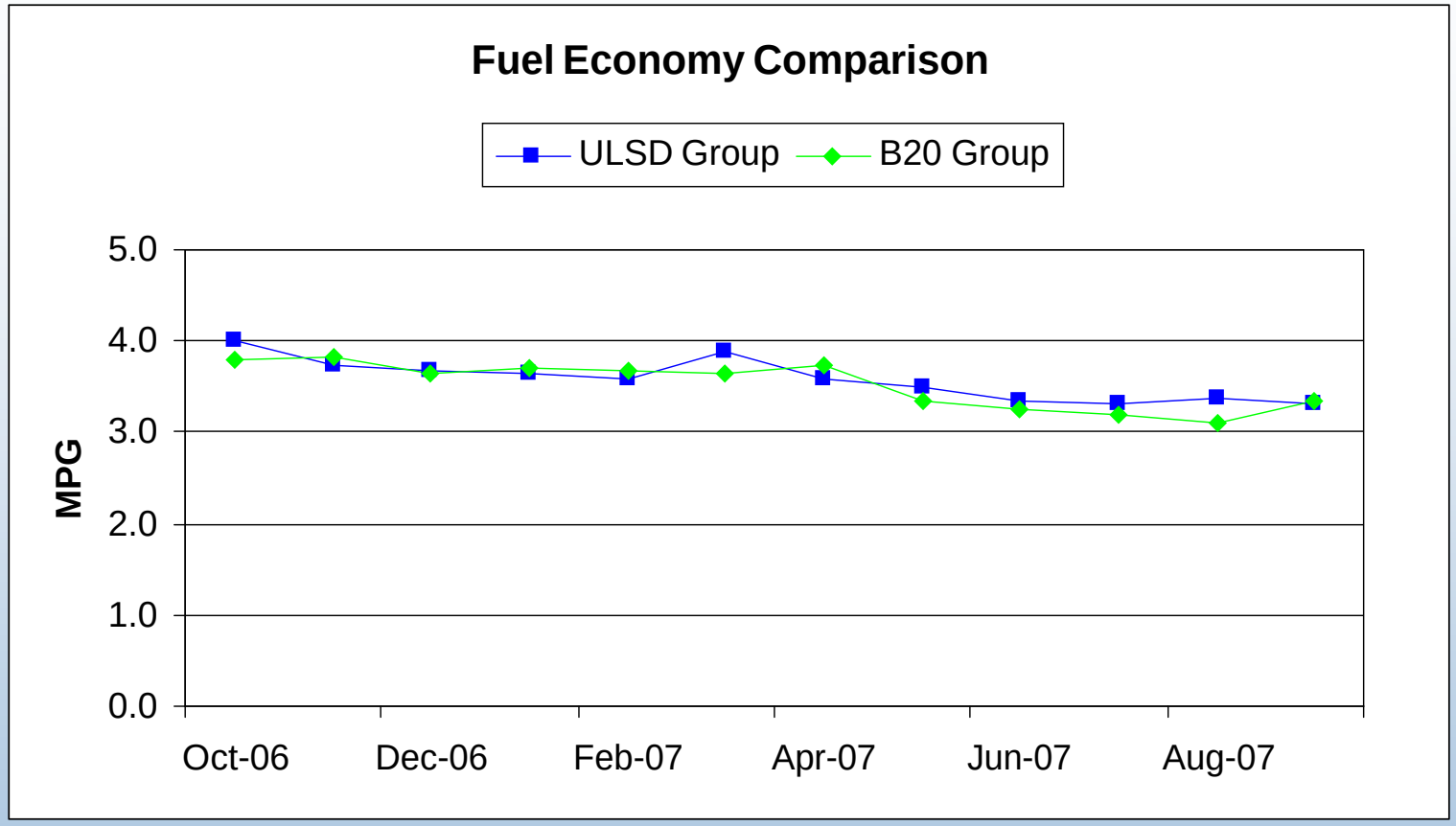
B20 Fleet Evaluation – Approach

- 15 mechanically identical Metro transit buses:
  - 2002 Gillig Phantom
  - 2002 Cummins ISM (2004 cert with EGR)
  - 8 operated on B20, 7 on ULSD
- B20 and ULSD buses housed in different garages, but have been assigned to similar routes for duty cycle parity
  - 13.75 and 14.57 mph average speeds
  - Metro submits data electronically from their internal database
  - Fuel, Labor, Parts
- Fuel sample collection and analysis - partnership with HWRT (B20 supplier)
- Lube oil sampling and analysis program with Cummins
  - Oil sampled at ~2,000-mile intervals

Implementation and Usage

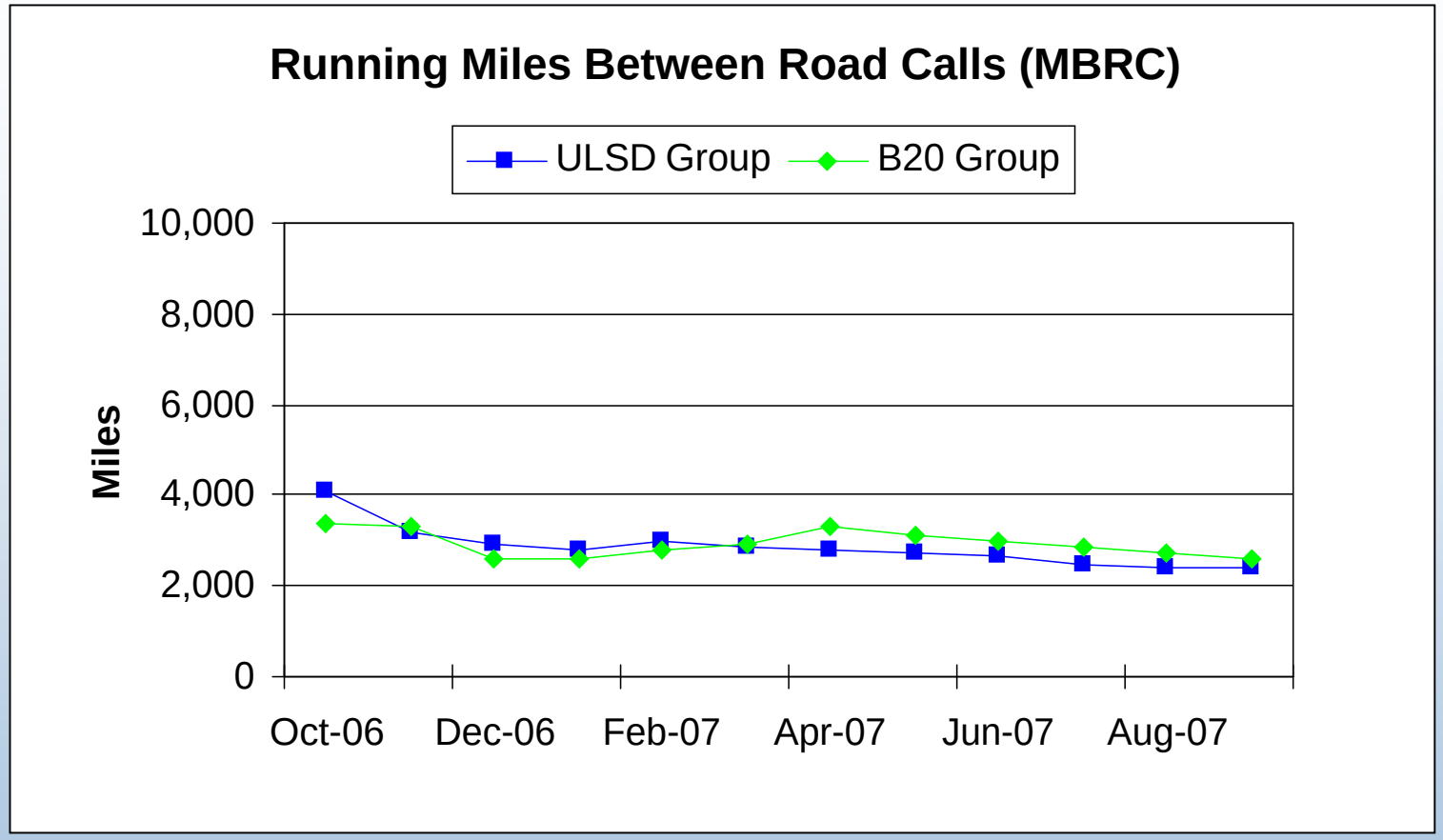
- Metro reports fairly seamless transition to biodiesel/ULSD B20 blend
  - UST fuel storage, B20 added to residual fuel until B0 → B20
  - Instituted a 2000 mile fuel filter replacement schedule during transition (normally 6000 mile)
  - First experience with ULSD, phased in simultaneously with B20 (10/06)
- Based upon 12 months (10/06 – 9/07) of operational data
  - 394,116 miles driven by B20 buses (49,267 per bus average)
  - 90,983 gallons B20 consumed

On-road Fuel Economy



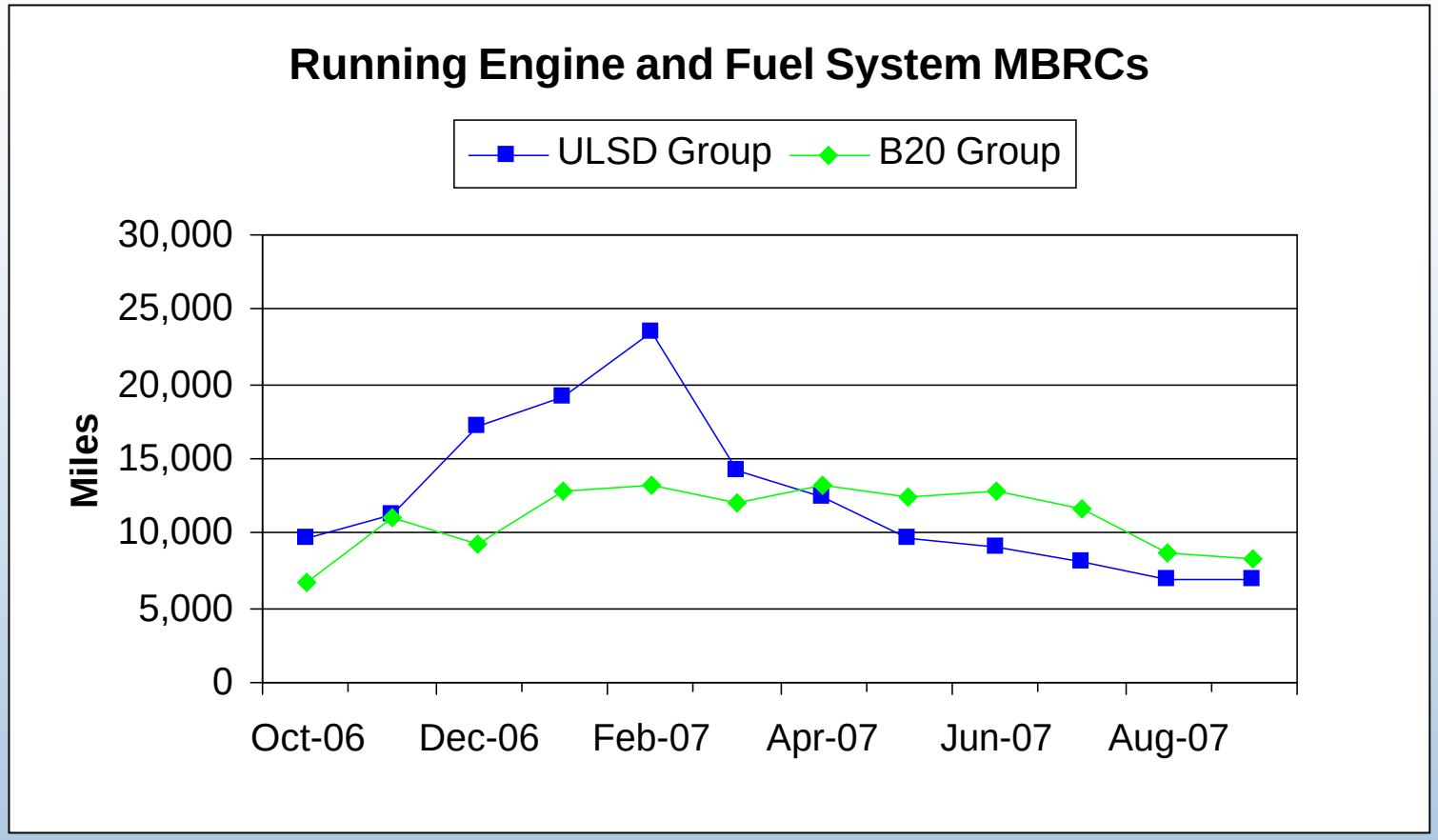
- 3.58 mpg ULSD, 3.52 mpg B20 (-1.71%)
- Difference not statistically significant

Road Calls



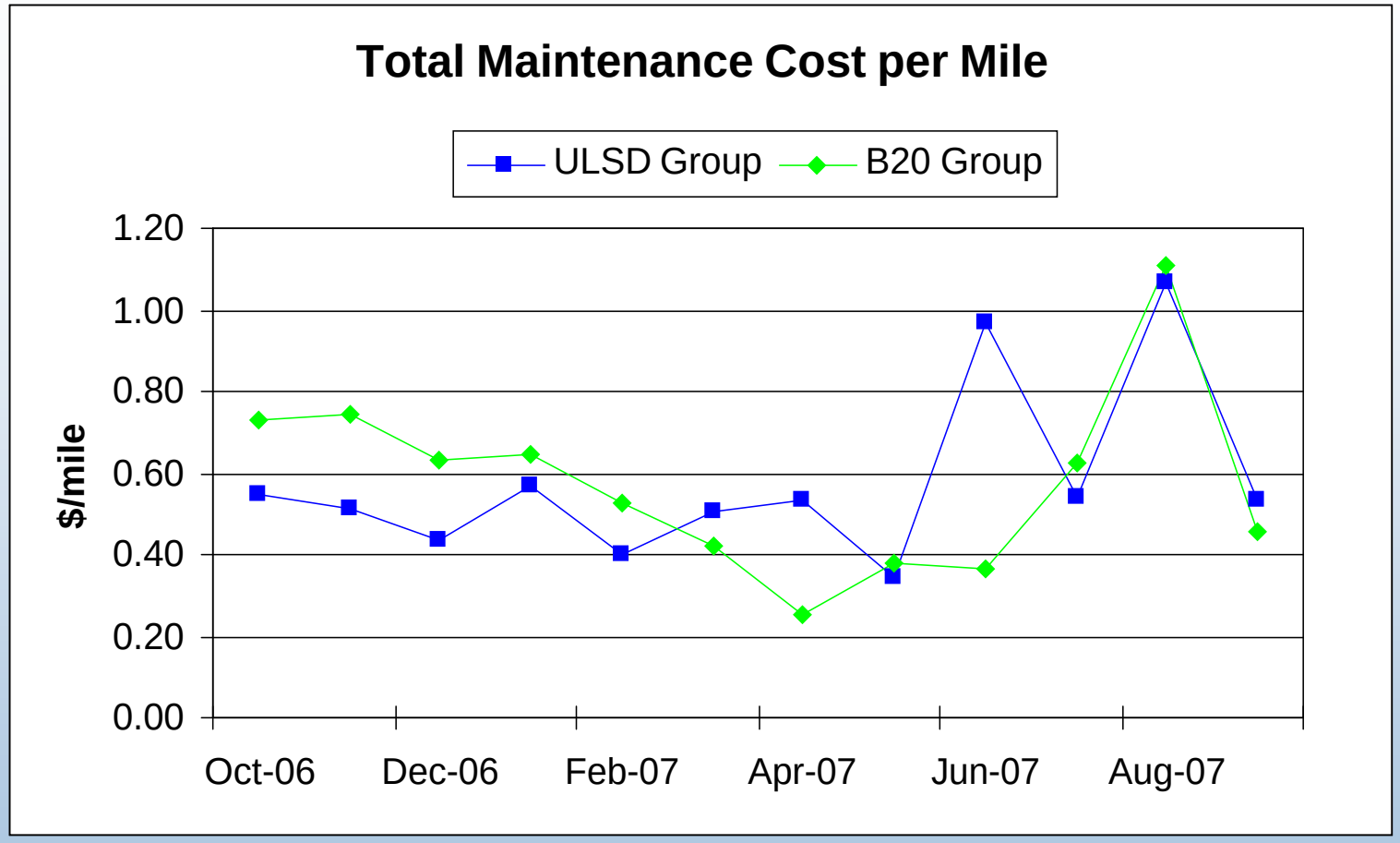
- Average Total MBRCs comparable
  - 2,375 ULSD, 2,627 B20

Engine, Fuel System Road Calls



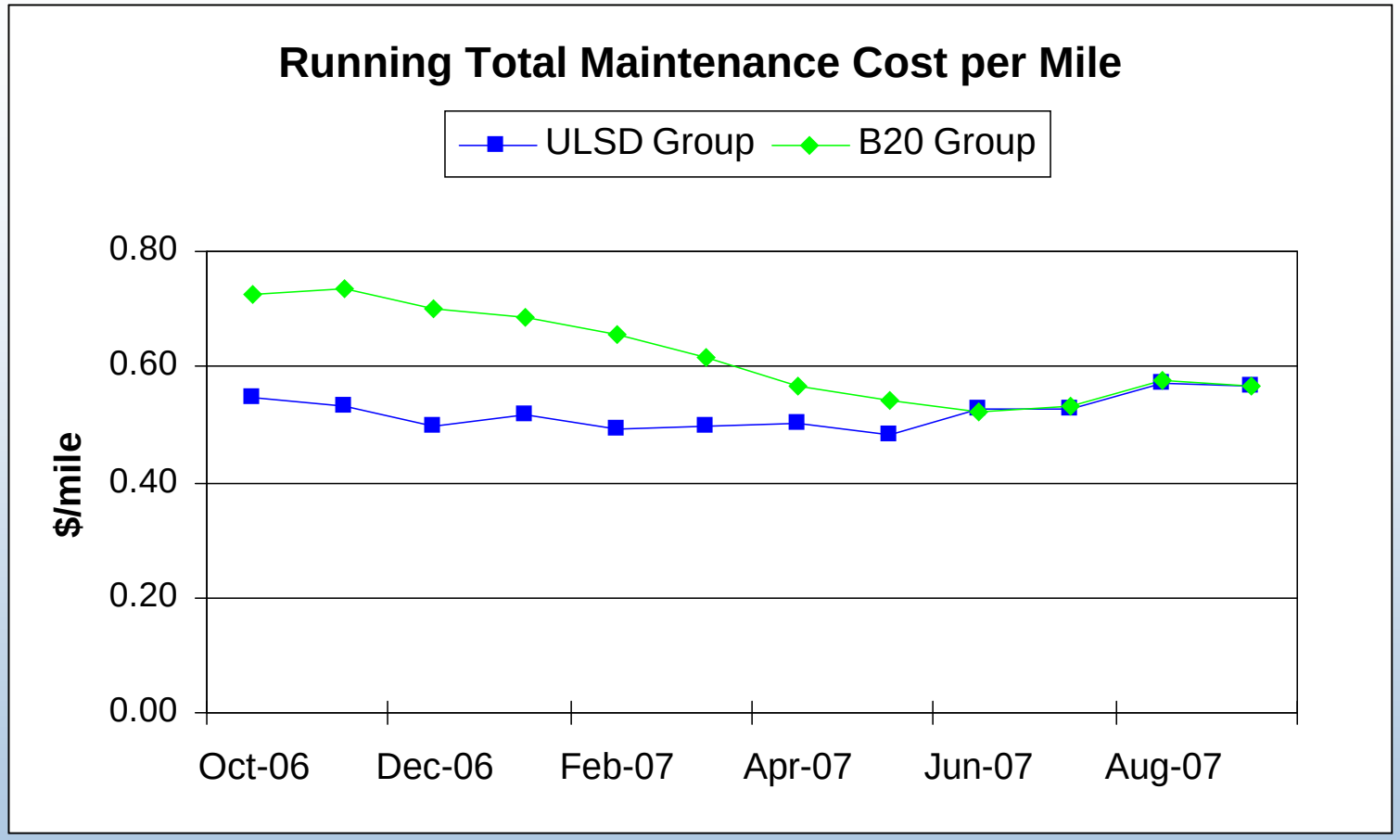
- Average engine/fuel system MBRCs comparable
  - 6,924 ULSD, 8,211 B20

Maintenance Costs - Total



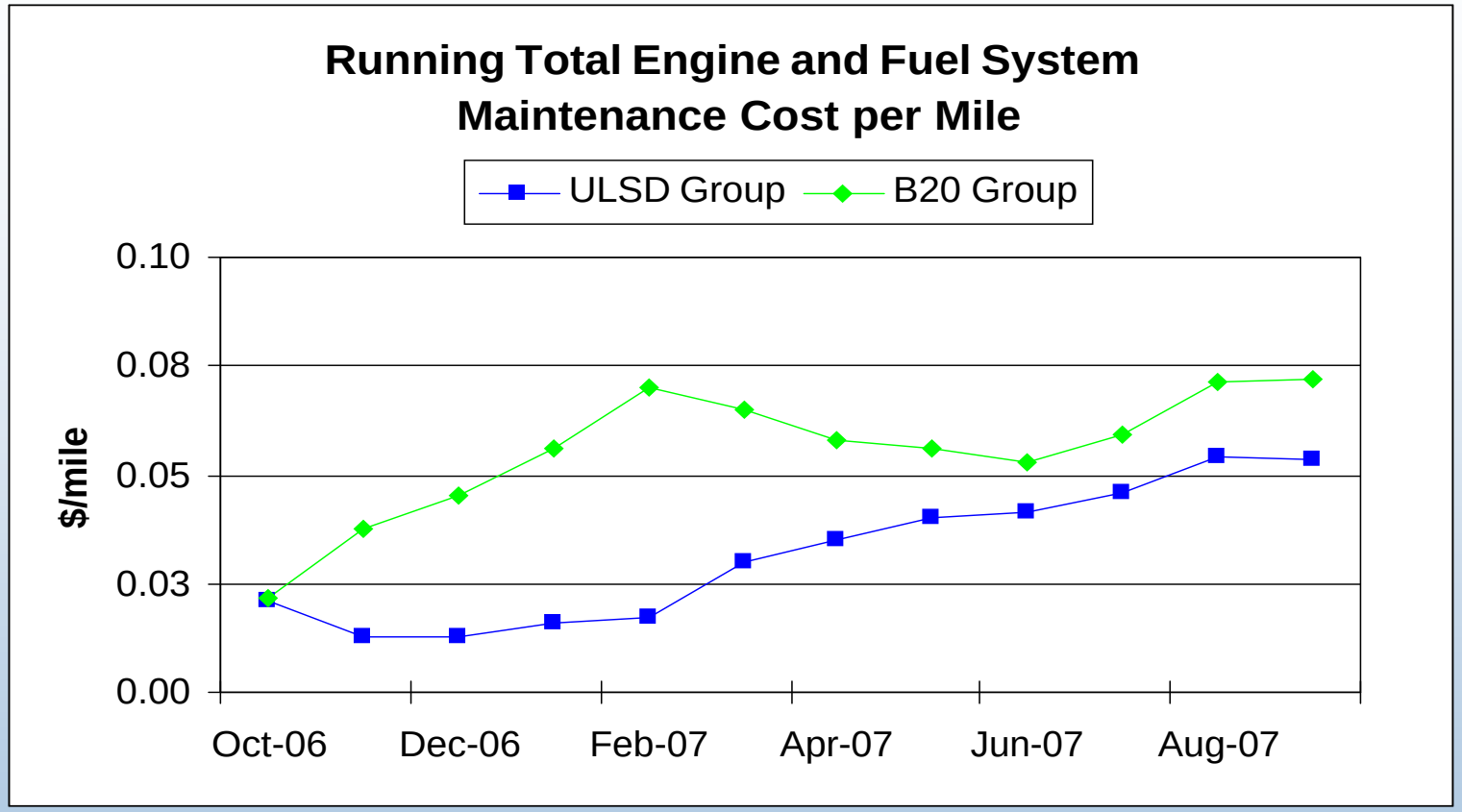
- June and August 2007 spikes driven by scheduled (brakes and radiator) maintenance, and other non-engine or fuel system repairs

Maintenance Costs - Total



- 12-month average maintenance costs:
  - $0.566/mile ULSD, $0.568/mile B20
  - Merged after 9 months
  - Not a statistically significant difference

Maintenance Costs – Engine, Fuel System



- 12-month average engine and fuel system maintenance costs:
  - $0.053/mile ULSD, $0.072/mile B20

Fuel System Part Replacements

Fuel	Part Replaced	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Total
ULSD	Fuel Filter		2	1	1		1	1	2	3	1		1	13
	Fuel Injector					2						1		3
	Fuel Pump													0
	Fuel Sys Flush				2									2
B20	Fuel Filter	7	5		1	10	1	3			1			28
	Fuel Injector		1	1	2	3			1	1	2	2	2	15
	Fuel Pump													0
	Fuel Sys Flush			1	2		1							4

- Fuel filters (28 to 13)
  - Weighted in first 2 months (2000 mile change interval to account for the solvent effect)
  - Feb-07 – likely due to unseasonably cold temps dropping below the cloud point of the fuel
  - Cloud Point stable
  - Fuel injector replacement higher with B20 than ULSD (15 to 3)
  - Evidence of operability issues led to injector replacement

Fuel Injector Replacements

Unit No	Fuel	Evaluation Start Mileage	B20 Miles Before failure	Injectors Replaced	Unit No	Fuel	Evaluation Start Mileage	ULSD Miles (Before Failure)	Injectors Replaced
3408	B20	127,467	55,355	2	3401	ULSD	110,990	45,072	1
3409	B20	125,630	47,270	1	3402	ULSD	98,042	45,786	0
3410	B20	127,825	3,865	1	3403	ULSD	113,496	44,019	0
3410	B20	127,825	18,635	2	3404	ULSD	87,056	19,101	1
3411	B20	123,374	10,364	1	3405	ULSD	110,583	14,128	1
3411	B20	123,374	12,332	1	3406	ULSD	103,929	48,874	0
3412	B20	131,582	13,180	1	3407	ULSD	129,510	48,851	0
3412	B20	131,582	33,403	1					
3412	B20	131,582	40,406	1					
3413	B20	128,805	35,542	1					
3413	B20	128,805	40,444	1					
3414	B20	124,923	20,950	1					
3415	B20	129,530	38,204	1					
Average Miles		127,392	28,458				107,658	26,100	
Standard Deviation		2,664	16,104				13,305	16,617	

- Failures on bus order group as early as 100k miles
- B20 buses had higher mileage at start of evaluation
- No pattern in B20 miles before failure
- No red flags with fuel quality (free/total glycerin)
- Cummins warranting injectors on bus order group

Fuel Analysis

- 15 B100, 30 B20 samples collected and analyzed
- Focused analytical approach led by NREL with assistance from SwRI
- Covered Feb-July 2007 (6 of 12 months)

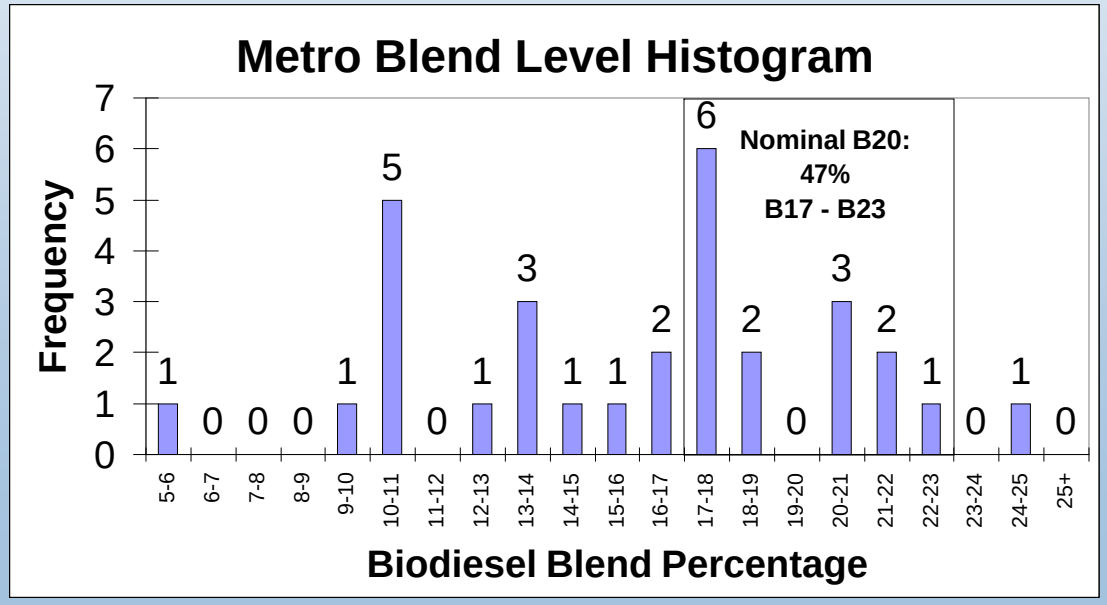
B100 Results

- Free/total glycerin within spec
- Na+K, Ca+Mg, P within spec
- Flashpoint 14/15 met spec
- Bottom line - B100 met specs tested for

Fuel Analysis

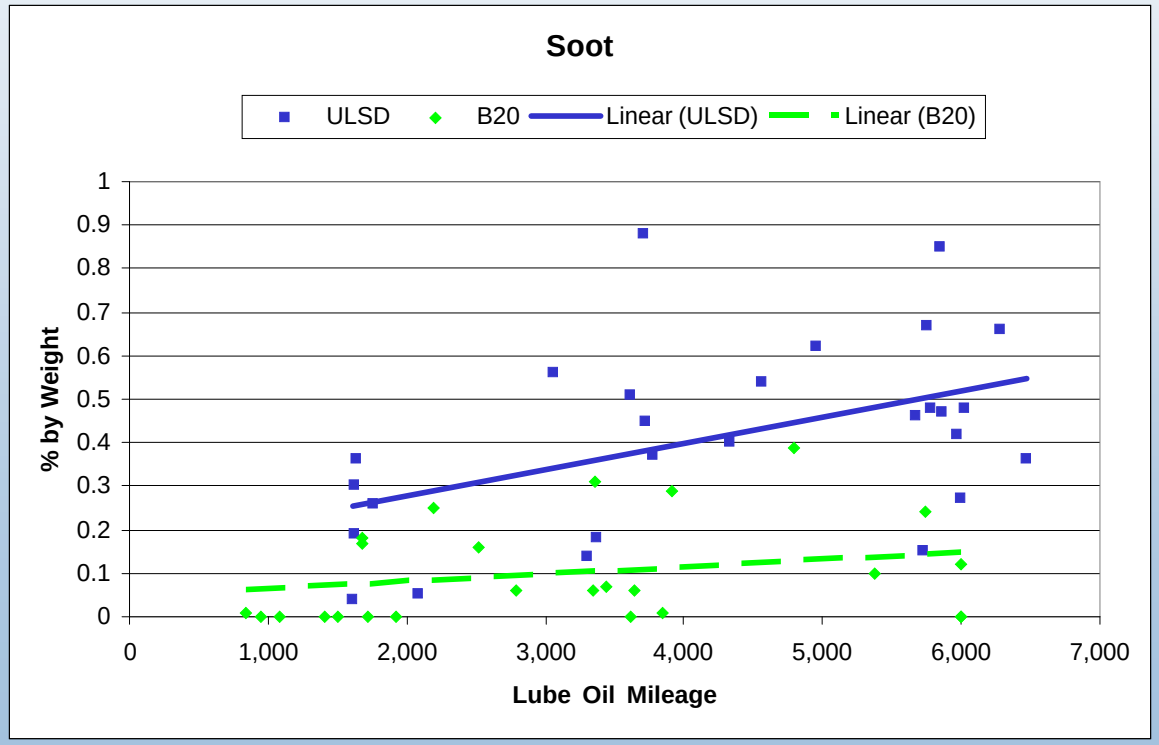
B20 Results

- Cloud Points ranged -10C to -15C
  - No seasonal variation, within Metro spec
- B20 samples analyzed for blend content
  - The blend level of the samples was determined using ASTM D7371 with an accuracy of +/- 2%
  - 47% Nominal B20 (B17-23); 14/30 samples



Lube Oil Analysis

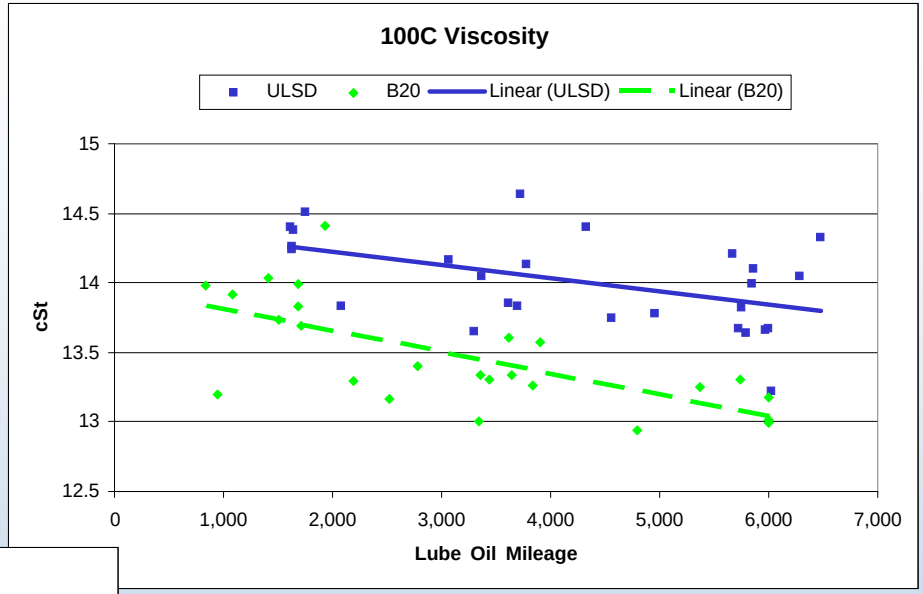
- 64 oil samples analyzed by Cummins
  - 833–6477 oil miles
  - 6000 miles change interval
- Despite apparent scatter, tight dataset for lube oil data

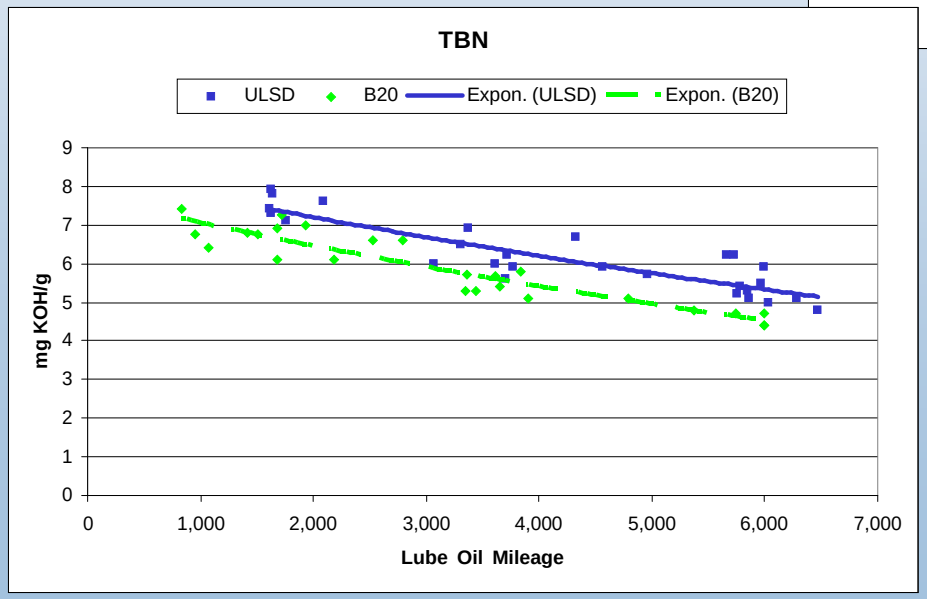


- Soot loading lower with B20 than ULSD, but both quite low

Lube Oil Analysis

- Viscosity as indicator of fuel dilution
  - Viscosity appears lower with B20, but B20 and ULSD samples “in-grade” throughout drain period

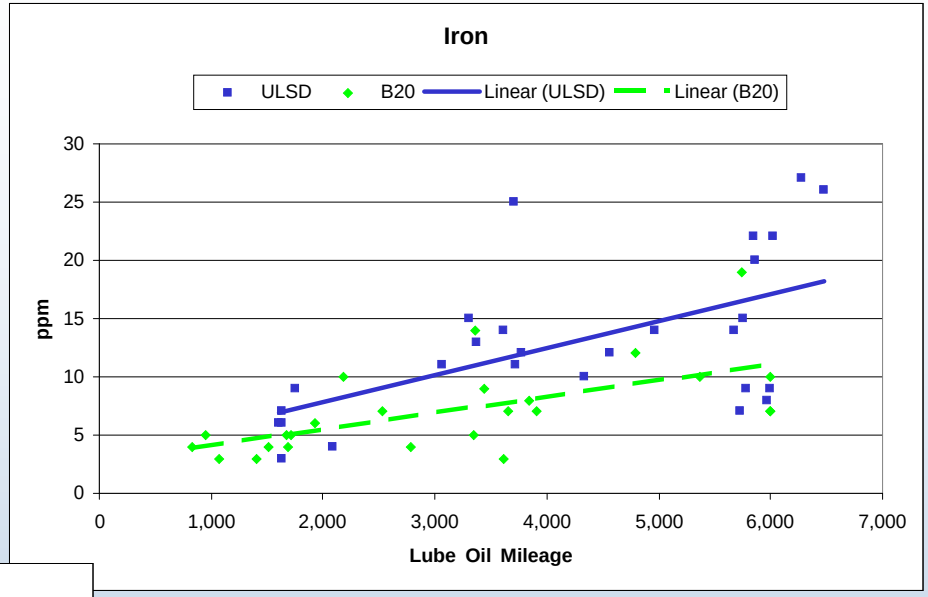


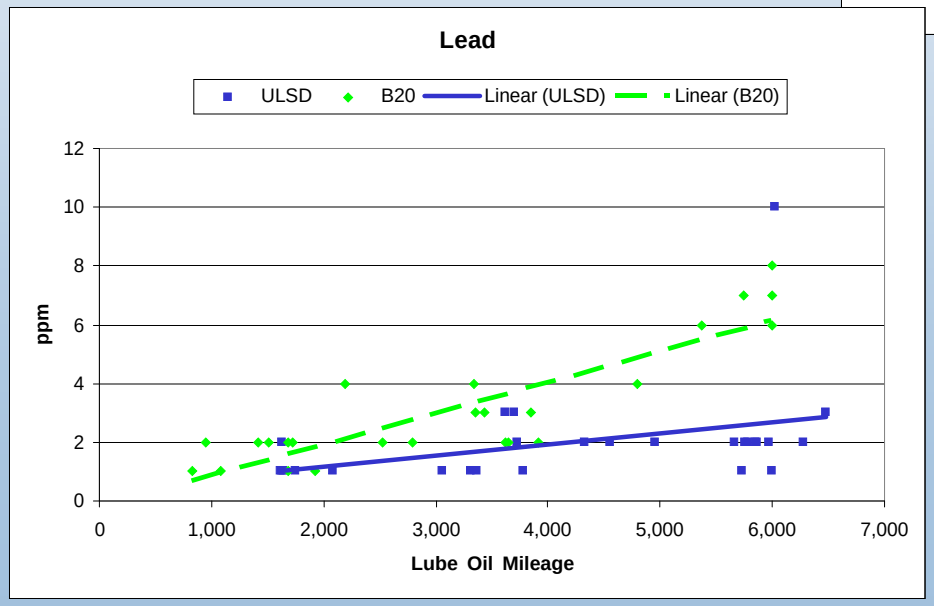


- TBN slightly lower with B20, but both B20 and ULSD show sufficient TBN retention at end of drain

Lube Oil Analysis

- Iron as indicator of wear
  - Slightly Lower with B20, especially with high mileage





- Lead as indicator of corrosion
  - Slightly Higher with B20, especially with high mileage

Conclusions

- No statistically significant difference between buses running on B20 and ULSD
  - On-road fuel economy
  - Reliability (Road Calls)
  - Total maintenance costs
- Difference in Fuel System and Engine maint. costs driven by fuel injector replacements
  - Skewed toward B20 buses; failure mode unknown
- No other observed fuel system durability issues
  - Biodiesel blend variability (<B20)
  - Lube oil data suggests no harm with B20 use
  - TBN decrease, fuel dilution increase (but still “in-grade”)
  - Some potential benefits (soot, wear metals)

Special Thanks

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