BIODIESEL QUALITY

IOWA CENTRAL FUEL TESTING LABORATORY

FORT DODGE, IOWA

PMCI CONVENTION 2011

Iowa Central Fuel Testing Laboratory

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Laboratory History

- 2006: An idea is born
- 2007: Bond referendum passed for college improvements
- 2008: Construction begins on new BHS building; temporary lab set up
- 2009: Lab moved to permanent new home; officially open for business June 2010

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Laboratory Scope

- Biodiesel Testing
  - ASTM D 6751
  - ASTM D 7467
- Diesel Testing
  - ASTM D 975
- Ethanol Testing
  - ASTM D 4806
  - ASTM D 5798
- Gasoline Testing
  - ASTM D 4814
- Additional Services
  - Mass Spectrometry
  - Research Support
  - Special Projects

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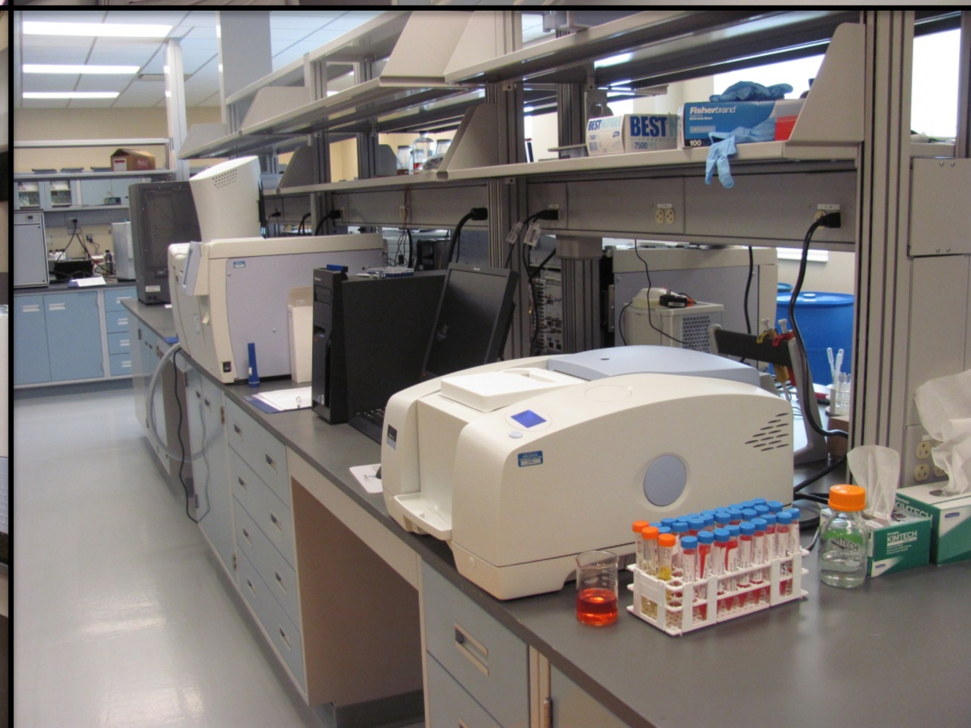
Accreditations

- National Biodiesel Accrediting Commission
  - BQ-9000
  - Completed June 2010
  - First in the nation
- International Organization for Standardization
  - ISO 17025
  - To be completed Fall 2011


FRAGILE


KIMTECH


Fisherbrand
BEST
KIMTECH

Renewable Fuel Quality

Significance of Specified Properties

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Ethanol

- Water Content: E 203
  - Gasoline hydrocarbons have limited solubility for water
  - Ethanol has higher solubility for water
  - Too much water may cause phase separation
- Solvent-washed Gum Content: D 381
  - Insoluble materials can form deposits on fuel system and engine components

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- Chloride Ion: D 7319
  - Chloride ions are corrosive to metals
- Copper: D 1688
  - Catalyst for low-temperature oxidation of hydrocarbons
  - Can increase the rate of gum formation
- Acidity: D 1613
  - Organic acids can be corrosive to metals

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- pHe: D 6423
  - If below 6.5, can cause film formation and wear in fuel pumps/injectors
  - If above 9.0, can cause plastic parts to fail
- Total Sulfate: D 7319
  - Plugging of fuel dispensing pump filters
  - Fuel injector sticking
- Sulfur: D 5453
  - Can contaminate catalytic converters reducing efficiency at removing hydrocarbons, CO and nitrogen oxides

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Biodiesel

- Flash Point: D 93
  - Set at 93° min. for non-hazardous designation
  - Also set at 130° min. for methanol content
- Viscosity: D 445
  - If too high, poor injector spray
  - If too low, power loss due to pump and injector leakage; also fuel dilution

- Sulfated Ash: D 874
  - Abrasive solids, metallic soaps, unremoved catalyst
  - Increased wear and deposits
  - Soaps contribute to filter plugging & deposits
- Sulfur: D 5453
  - Issues with emissions control
  - Engine wear and deposits depending on operating conditions
  - Biodiesel typically very low in sulfur

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- Copper Strip Corrosion: D 130
  - – Presence of acids or sulfur-containing compounds can contribute to metal corrosion
- Cetane number: D 613
  - – Ignition quality
  - – Typically not an issue with biodiesel
  - – Calculated index not valid for B100 or blends

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- Cloud Point: D 2500
  - Low temperature operability
- Carbon Residue: D 4530
  - Carbon matter left after combustion
  - Indirect measure of deposit formation
- Acid Number: D 664
  - Measure of free fatty acids/degradation products
  - Increased corrosion; increased fuel system deposits

- Free & Total Glycerin: D 6584
  - Free: just glycerin
  - Total: glycerin and mono-, di- and triglycerides
  - Injector deposits, filter plugging, sediment in storage tanks
- Phosphorus: D 4951
  - Can damage catalytic converters
  - Biodiesel typically very low in phosphorus

- Vacuum Distillation: D 1160
  - More of a boiling point vs. distillation curve
  - Ensure that fuel has not been adulterated
- Metals: EN 14538
  - Ca, Mg, Na, K
  - Contribute to Ash value
  - Metallic soaps can cause filter plugging

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- Oxidation Stability: EN 15751
  - Oxidation products can form organic acids and polymers
  - Can lead to filter plugging

A Survey of Biodiesel Quality

- Compilation of over 1000 individual tests
- Which tests fail most often
- Compare quality vs. size of facility
- Compare quality vs. BQ-9000 status

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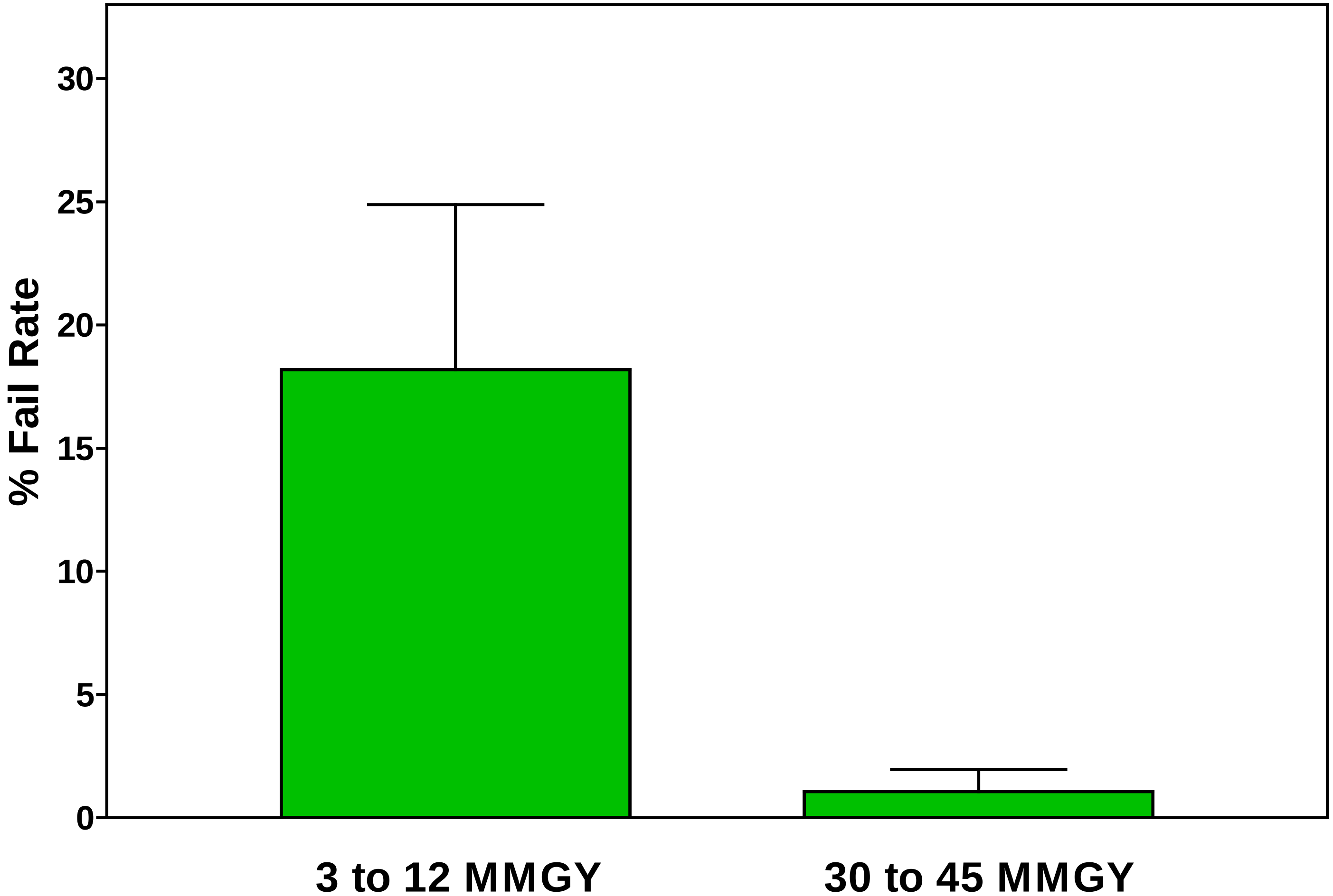
Tests with the Highest Fail Rate

Test	% Fail
Cold Soak	33.8
Oxidation Stability	20.7
Methanol	10.5
Total Acid	10.0
Free Glycerin	7.7
Distillation	5.2
Total Glycerin	4.8
Sulfur	4.1
Sodium and Potassium	3.7
Flash Point	3.1
Calcium and Magnesium	1.4

Test Fail Rate: Large vs. Small Producer



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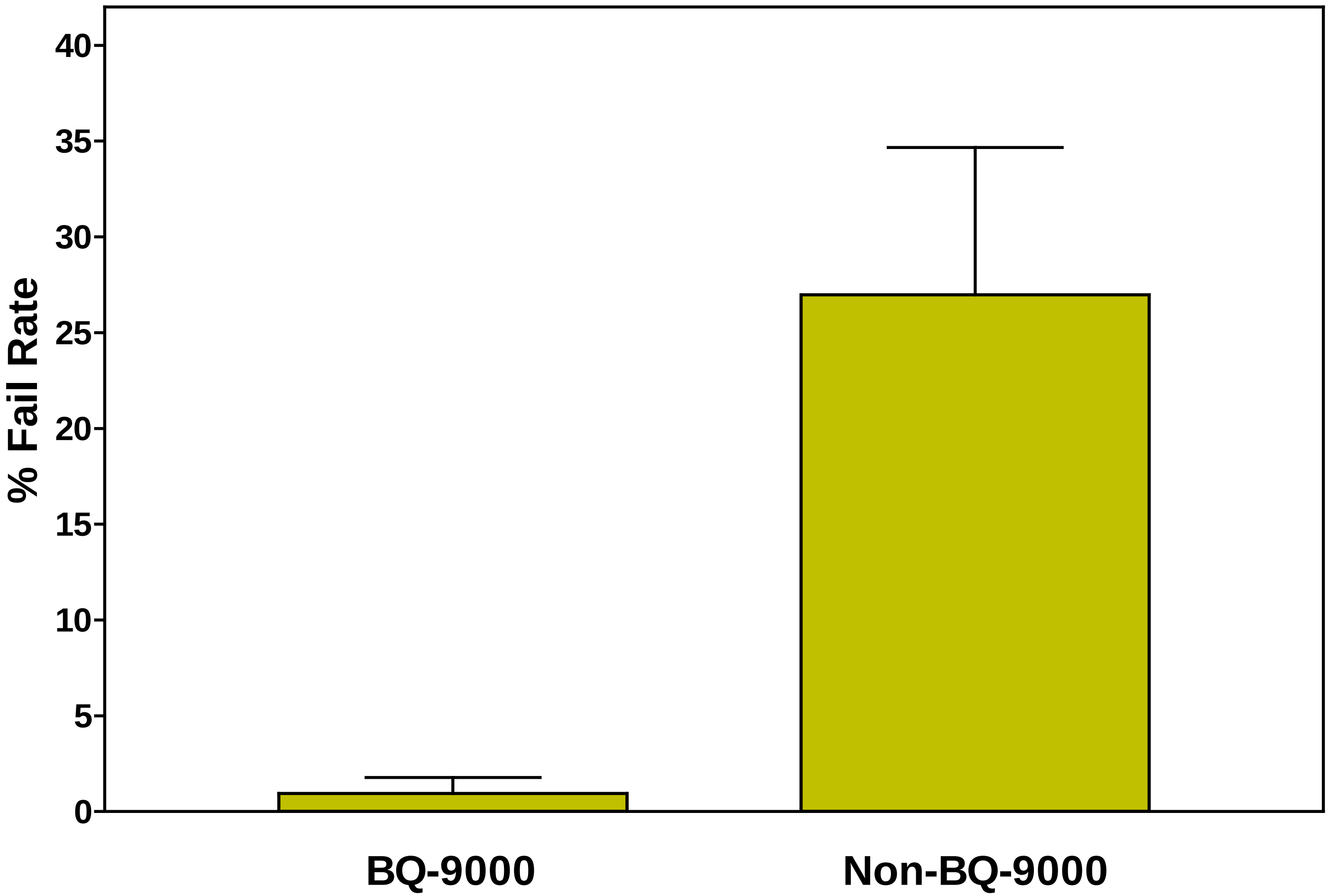
Test Fail Rate: BQ-9000 vs. Non-BQ-9000



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Fail Rate for BQ-9000 Producers

Size of Facility (MMGY)	Number of Tests	Number of Fails	% Fail Rate
37.5	26	0	0
40	52	0	0
30	5	0	0
30	37	0	0
30	186	0	0
45	12	1	8.3
30	16	0	0
12	25	0	0
30	39	0	0
30	82	1	1.2
4	12	0	0

Fail Rate for Non-BQ-9000 Producers

Size of Facility (MMGY)	Number of Tests	Number of Fails	% Fail Rate
3	164	13	7.9
3.6	36	15	41.7
6	35	18	51.4
5	90	18	20.0
?	8	5	62.5
5	63	6	9.5
?	64	5	7.8
10	20	3	15.0

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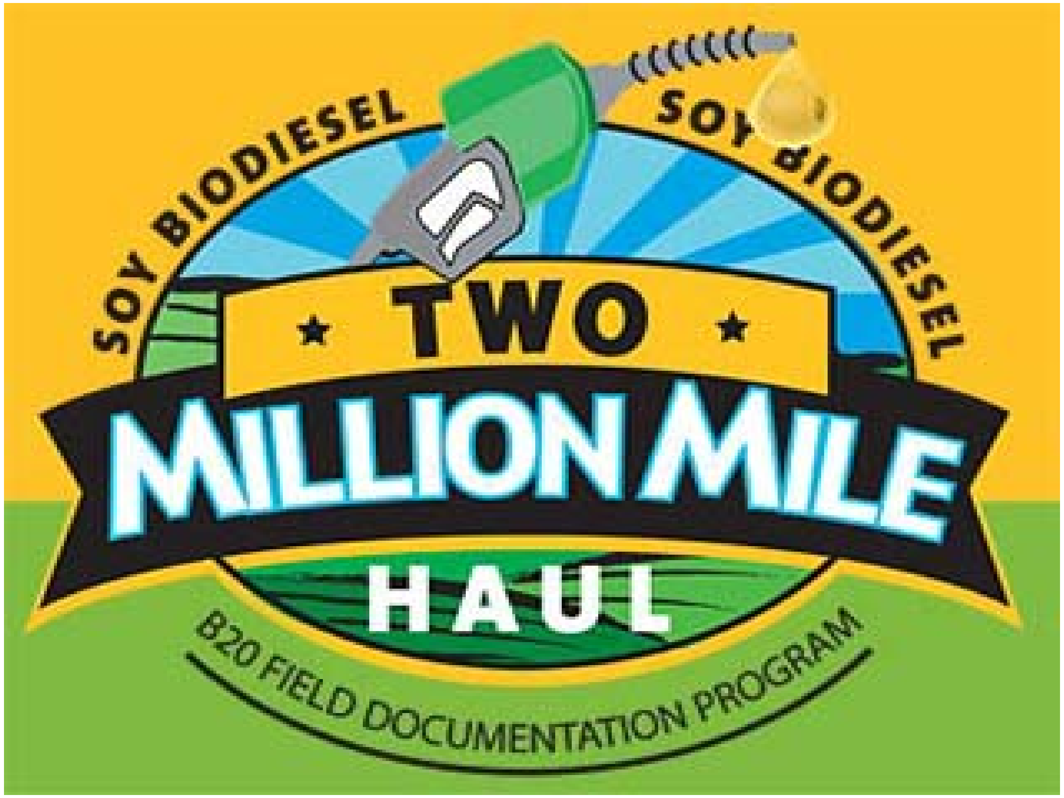
The Two Million Mile Haul



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Partners

Decker Truck Line, Inc. (DTL)

National Biodiesel Board (NBB)

Renewable Energy Group, Inc. (REG)

Iowa Soybean Association (ISA)

Caterpillar Engine Company (CAT)

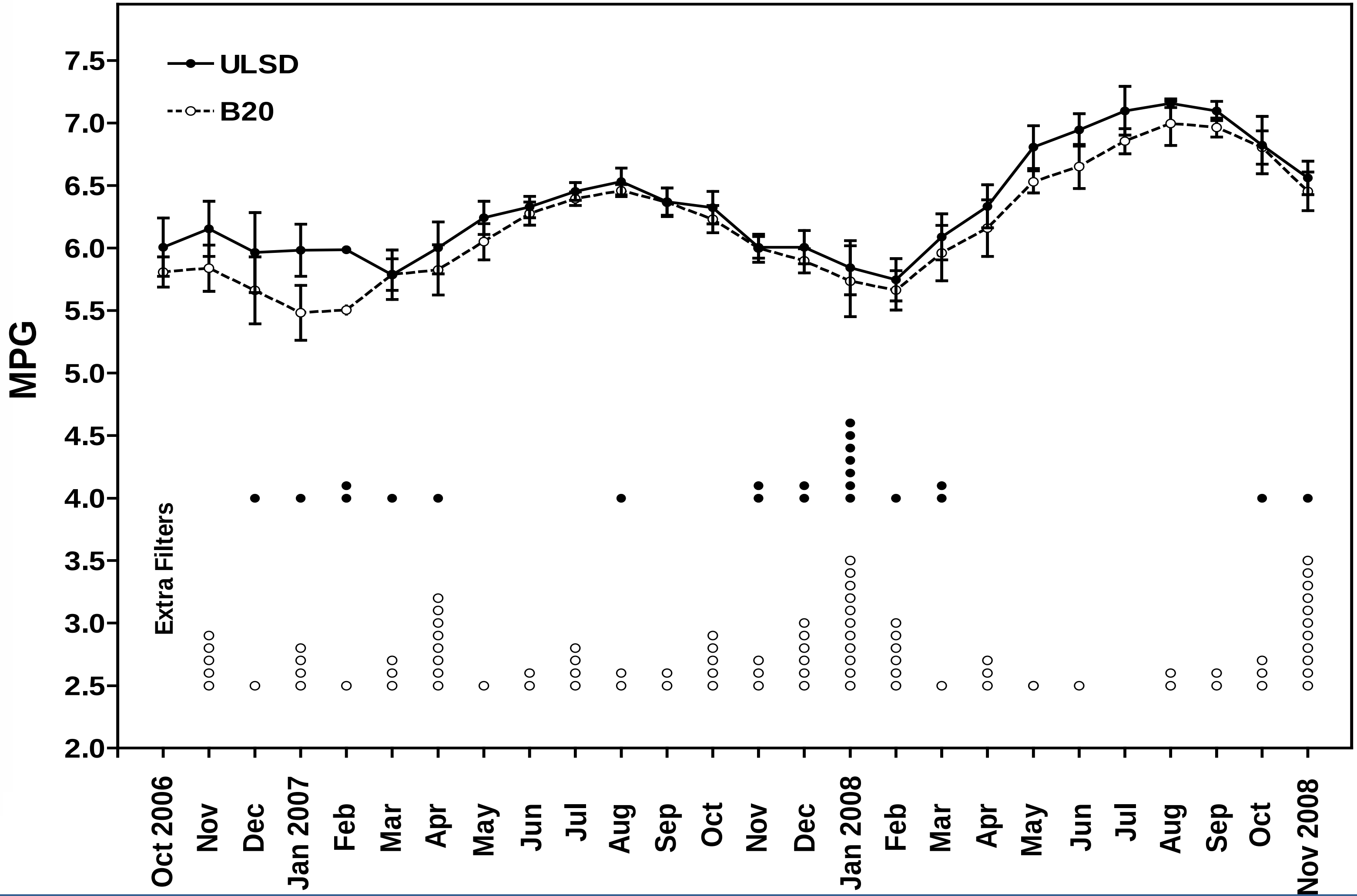
Iowa Central Community College (ICCC)

U.S. Dept. of Agriculture (USDA)

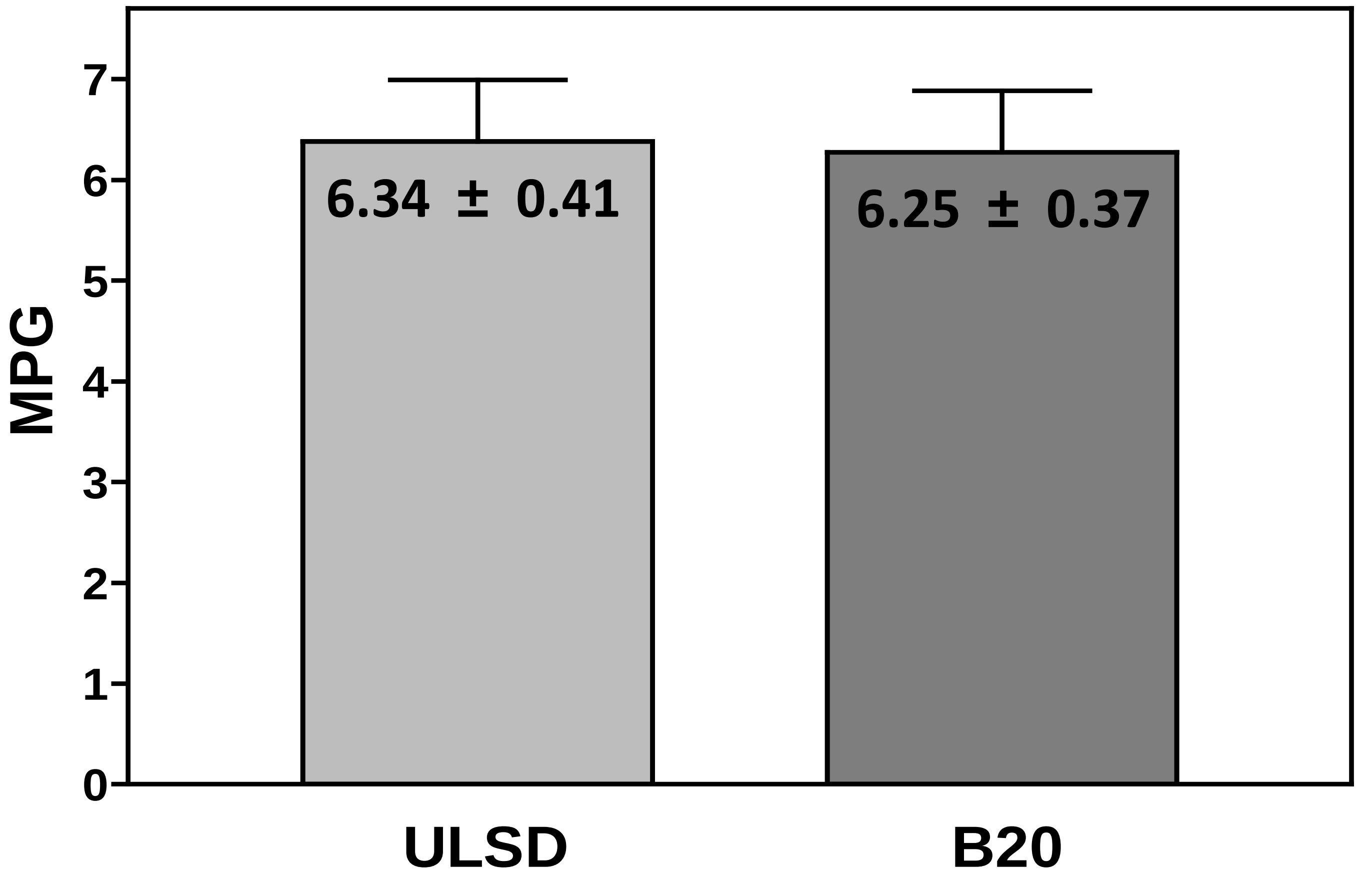
- Study design
  - Many fleet studies done, but little publicly available information exists regarding long-term over-the-road use
  - 10 control units and 10 matched test units, factory fresh
  - Control used 100% #2 diesel, test used 20% blend of soy biodiesel with #2 petroleum diesel (B20)
  - Monitored the following:
    - Fuel economy
    - Maintenance costs
    - Engine oil properties
  - Did limited engine tear-down for wear analysis
  - Test ran for two years, or approximately 2 million miles per group (Oct. ‘06 thru Nov. ’08)

FUEL ECONOMY

Average Fuel Economy by Month



Average Fuel Economy



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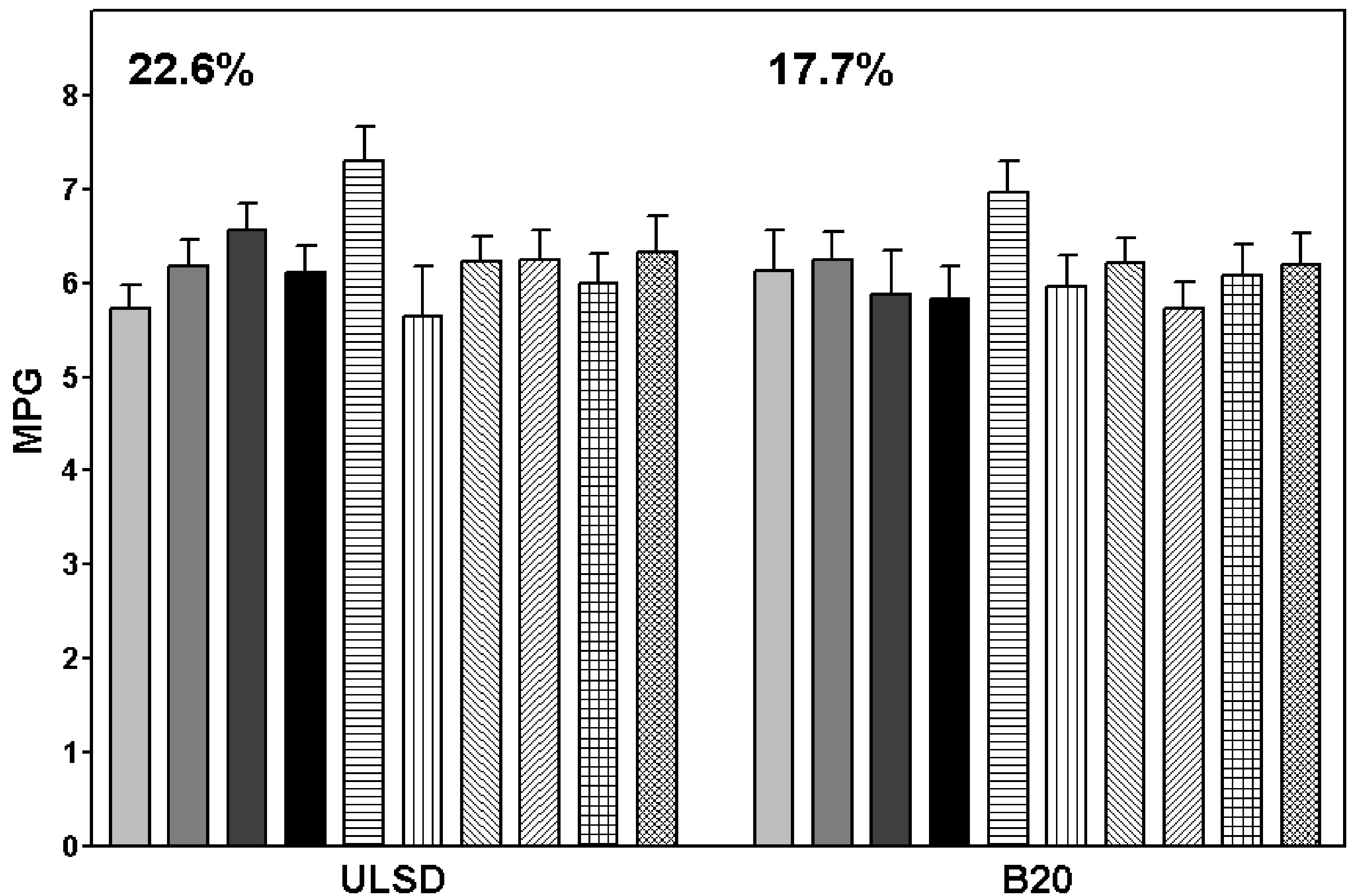
Driver Variability in Fuel Economy



MAINTENANCE

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Total Maintenance and Repair Costs Expressed in Cents per Mile:

Group	Miles	PM Costs (¢ per mi.)	Engine Costs; Fuel Related (¢ per mi.)	Engine Costs; Non-fuel Related (¢ per mi.)	Tires, Axles, etc. (¢ per mi.)	Miscell. Costs (¢ per mi.)	Accident costs (¢ per mi.)	Total Maintenance & Repair Costs (¢ per mi.)
ULSD	2,003,330	0.893	0.051	0.060	1.015	0.499	1.565	4.082
B20	2,035,970	1.075	0.092	0.045	0.978	0.682	0.432	3.304

Total Preventive Maintenance (PM) Costs Expressed in Cents per Mile:

Group	Miles	PM-A Cost (¢ per mi.)	Cost of Additional Fuel Filters (¢ per mi.)	Total PM-A Cost (¢ per mi.)	Total PM-B Cost (¢ per mi.)	Cost of Fouled Fuel Filters (¢ per mi.)	Total PM Costs (¢ per mi.)
ULSD	2,003,330	0.091	0.008	0.100	0.761	0.032	0.893
B20	2,035,970	0.095	0.028	0.123	0.856	0.096	1.075

Preventive Maintenance Intervals:

Group	Average Miles per Unit	Average A-Service per Unit	A-Service Interval (mi.)	Average B-Service per Unit	B-Service Interval (mi.)
ULSD	200,333	8.2	24,431	10.1	19,835
B20	203,597	8.8	23,136	10.7	18,852

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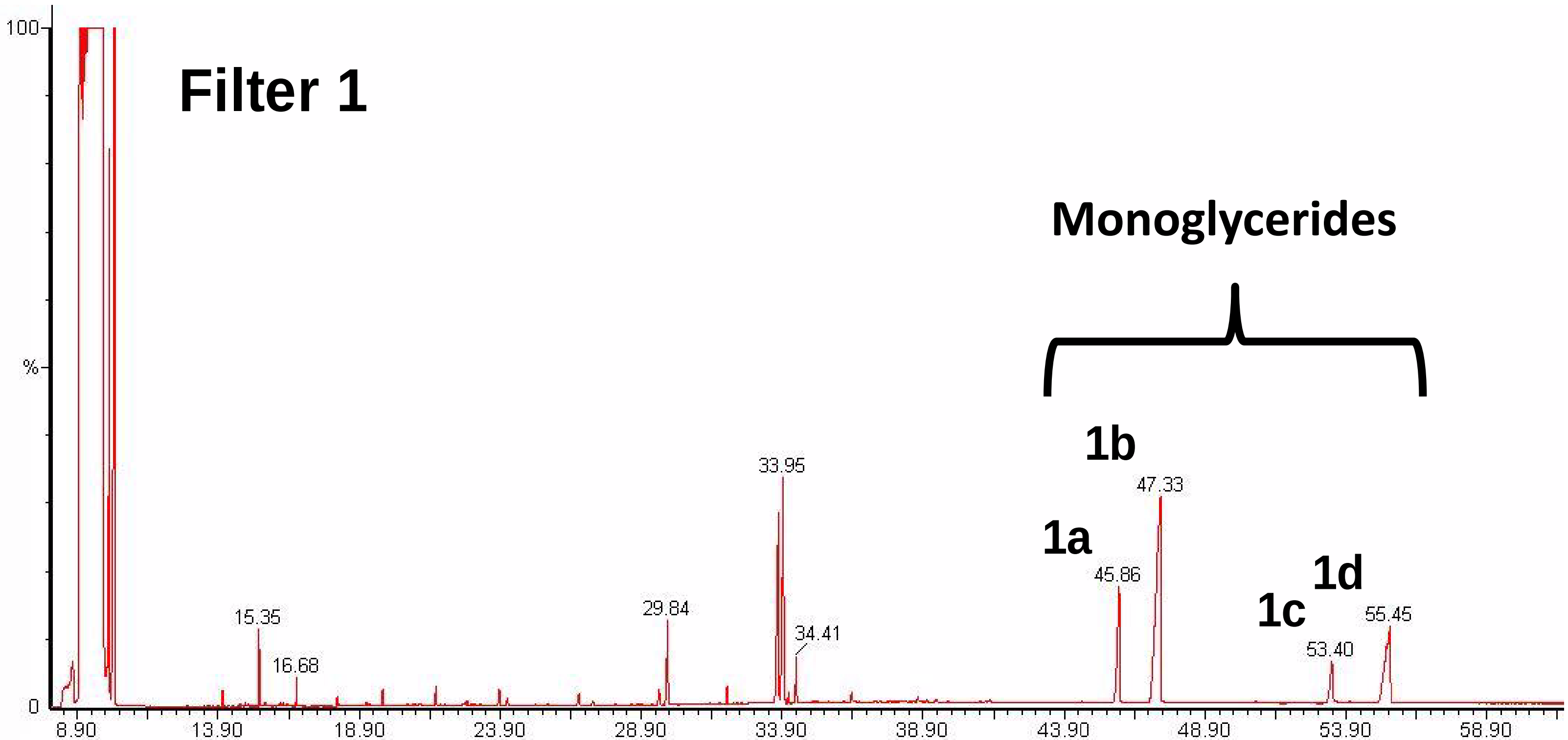
ULSD Fuel Filters Minneapolis			
Unit #	**Fouled**	**Preventive**	**Total**
1320	0	4	4
1334	0	3	3
1349	2	1	3
1376	1	1	2
1377	1	1	2
TOTALS	**4**	**10**	**14**

B20 Fuel Filters Minneapolis			
Unit #	**Fouled**	**Preventive**	**Total**
1325	9	7	16
1335	4	10	14
1346	5	6	11
1336	2	7	9
1375	6	7	13
TOTALS	**26**	**37**	**63**

ULSD Fuel Filters Chicago			
Unit #	**Fouled**	**Preventive**	**Total**
1321	0	1	1
1322	0	2	2
1340	0	1	1
1347	2	0	2
1379	0	3	3
TOTALS	**2**	**7**	**9**

B20 Fuel Filters Chicago			
Unit #	**Fouled**	**Preventive**	**Total**
1323	8	7	15
1324	9	1	10
1341	2	1	3
1348	2	0	2
1378	3	1	4
TOTALS	**24**	**10**	**34**

Representative Material on Fouled Filters:



- Summary of preventive maintenance cost factors:
  - Slightly reduced maintenance intervals for B20 group
  - Increased preventive filter replacements for B20 group
  - Increased costs associated with fouled filters for B20 group

ENGINE OIL
and
ENGINE TEAR-DOWN

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Metals Analysis

Metal	ULSD (values in ppm)	B20 (values in ppm)
Iron	42.4 ± 20.8	39.3 ± 14.0
Chromium	1.48 ± 0.64	1.56 ± 0.67
Copper	114 ± 206	100 ± 164
Lead	10.8 ± 12.2	8.88 ± 5.38
Calcium	3990 ± 390	4110 ± 510
Magnesium	19.2 ± 18.9	18.4 ± 6.9
Phosphorus	1330 ± 150	1360 ± 210
Zinc	1590 ± 110	1600 ± 180
Aluminum	2.00 ± 1.03	2.06 ± 1.18
Boron	4.82 ± 5.48	4.21 ± 4.52
Silicon	11.4 ± 15.9	11.0 ± 11.4
Silver	0.55 ± 1.03	0.34 ± 0.57
Sodium	5.55 ± 3.04	5.14 ± 2.41
TAN (mg KOH/g)	ND	4.78 ± 1.14 (*n* = 54)
TBN (mg KOH/g)	ND	6.99 ± 1.17 (*n* = 54)

Other Data

Viscosity: 14.9 cm/s^2 (ULSD)
14.7 cm/s^2 (B20)

Glycol: None detected

Residual water: Less than 0.1 %

Soot: Approx. 0.25 %

Engines Submitted for Tear-down and Analysis:

Serial No. and Unit No.	**KCB89646, #1375**	**KCB89927, #1377**	**LEE04770, #1348**
Engine	2004 EPA Cert.	2004 EPA Cert.	2007 EPA Cert.
Group	B20	ULSD	B20
Hours	4559	4512	2630
Mileage	221,800	225,400	131,200
Average Load (%)	50	51	35
Destination	Minneapolis	Minneapolis	Chicago

- Hoses
  - Several fuel hose assemblies analyzed
  - No adverse effects
  - Some heat hardening but not significant
- Exhaust and intake valves
  - Valves analyzed from one B20 unit
  - Some soot but no impact on wear
  - Valve wear comparable to that of valves from ULSD engine

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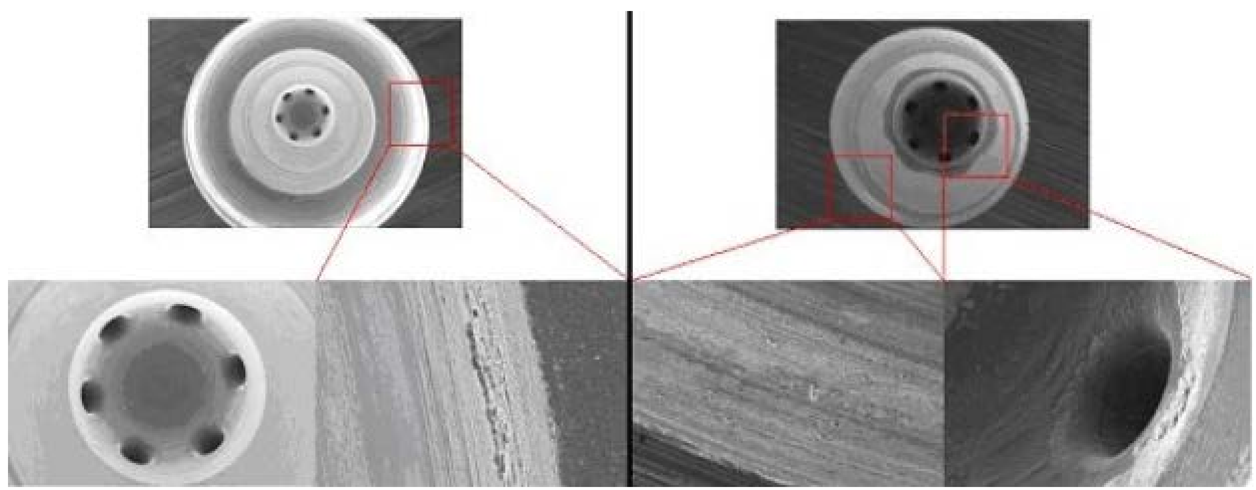
- Pistons, rings and liners (PRL)
  - Piston rings from both engine types showed similar wear patterns
  - Piston deposits were 20% higher in top groove but 40% lower in intermediate groove in the B20 unit
  - Liners appeared similar
  - Should be noted that only two engines were analyzed

- Injectors
  - 2 sets of 6 injectors from each unit
  - Minimal wear for mileage
  - No varnish or deposits found except for minor combustion product buildup on B20 injectors; no effect on performance
  - Bench performance tests were similar and showed expected values at this mileage



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Summary

- Iowa Central Fuel Testing Laboratory
  - Low cost/rapid turnaround
  - Personalized service
  - Routine testing/occasional requests
- Fuel Quality
  - Larger producers more consistent
  - BQ-9000 producers more consistent
  - Cold soak and oxidation stability fail most often

- Two Million Mile Haul
  - Very modest difference in fuel economy overall
  - Much greater variation in driver-to-driver fuel economy
  - Slightly higher maintenance costs in B20 group due mainly to filter plugging and shortened PM intervals
  - No discernable variations regarding engine wear

THANKS!

QUESTIONS?