Recent Research to Address Technical Barriers to Increased Use of Biodiesel

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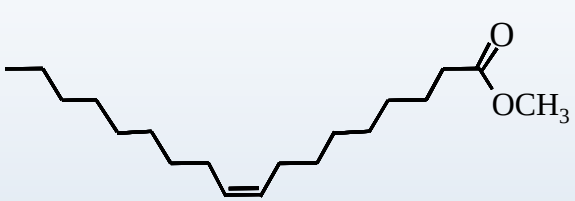
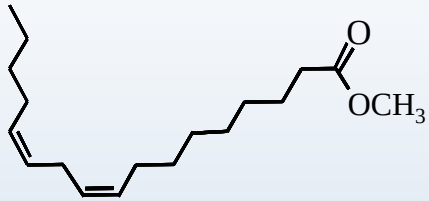
What is biodiesel?

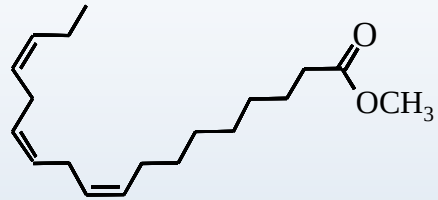
- Mono-alkyl esters of fatty acids (i.e. methyl or ethyl esters)



oleic acid



linoleic acid



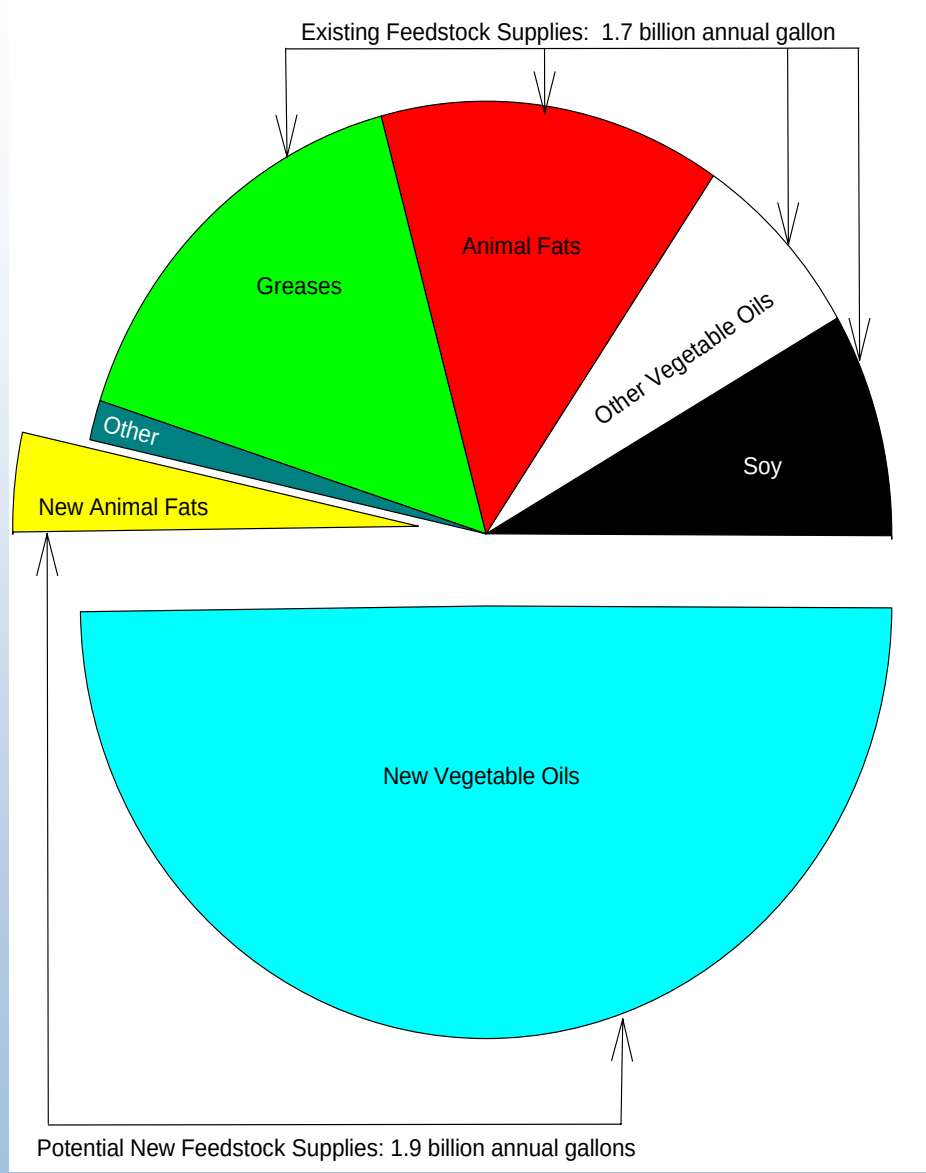
linolenic acid

100 lb triglyceride soy oil + 10 lb alcohol methanol = 10 lb glycerine (byproduct) + 100 lb Mono-alkyl ester Biodiesel

- Must meet the quality requirements of ASTM D6751
- Biodiesel is NOT unrefined vegetable oil or used cooking oil
- Typically used as blend with petrodiesel (up to 20%)
- Current U.S. average rack price $2.78/gal (versus $1.94 for No. 2 diesel)

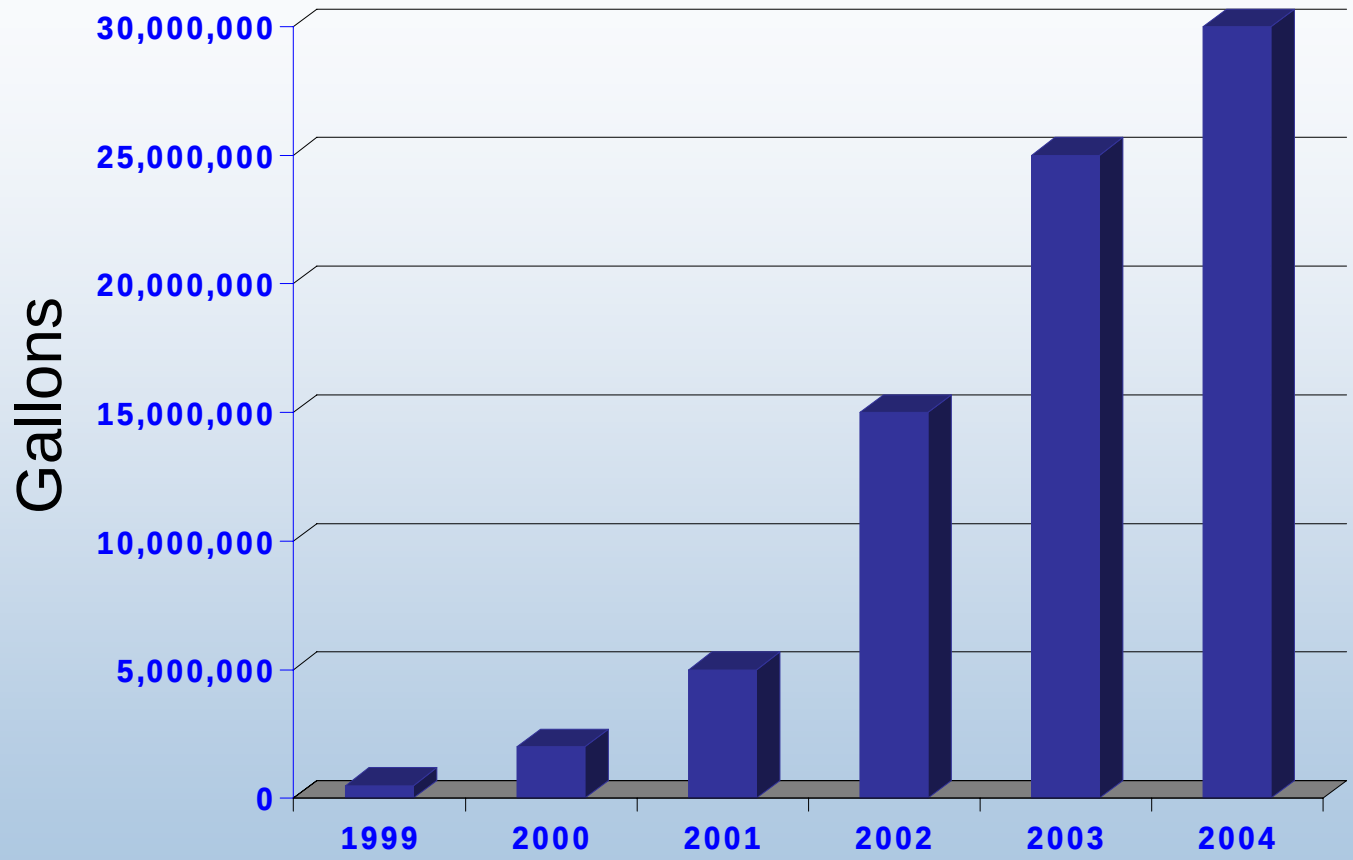
U.S. Biodiesel Feedstock Supply

- 1.7 billion annual gallon resource
- 3.6 billion annual gallons by 2015
- Long-Term Potential: 10 billion annual gallons by 2030
- US on-road market: 40 billion annual gallons



Feedstock analysis from NREL/TP-510-34796, June 2004

Biodiesel Production



Current capacity is more than 170 million annual gallons

Life Cycle Energy Cost

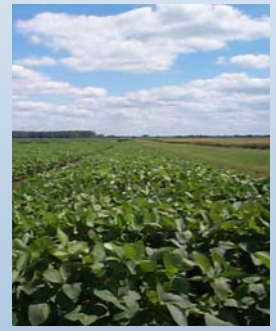
$$\text{Fossil Energy Ratio (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$

Petroleum diesel uses 1.1995 MJ of fossil energy to produce 1 MJ of fuel product energy.

Fossil energy ratio = 0.8337

Biodiesel uses 0.3110 MJ of fossil energy to produce 1 MJ of fuel product energy

B100 Fossil energy ratio = 3.2



B20 reduces life cycle petroleum consumption by 19%
B20 reduces life cycle CO_2 emissions by 16%

Analysis from NREL/TP-580-24772, May 1998

Biodiesel Blenders Tax Credit

- American Jobs Creation Act 2004
- 1¢ per percentage of biodiesel blended
  - Vegetable oils and animal fats
  - B20 = 20 ¢, B2 = 2 ¢
- 1/2 ¢ for recycled oils
- Must meet ASTM D6751
- Highway Trust Fund is not impacted
- Effective January 1, 2005
- Expires December 31, 2008 (extended in 2005 Energy Policy Act)

Biodiesel Market Penetration Issues

Fuel Quality and Quality Standards

- ***ASTM Specification for Blends***
- ***Fuel Stability***

NO_x Emissions

Impact on Engine/Emission Control Systems Durability

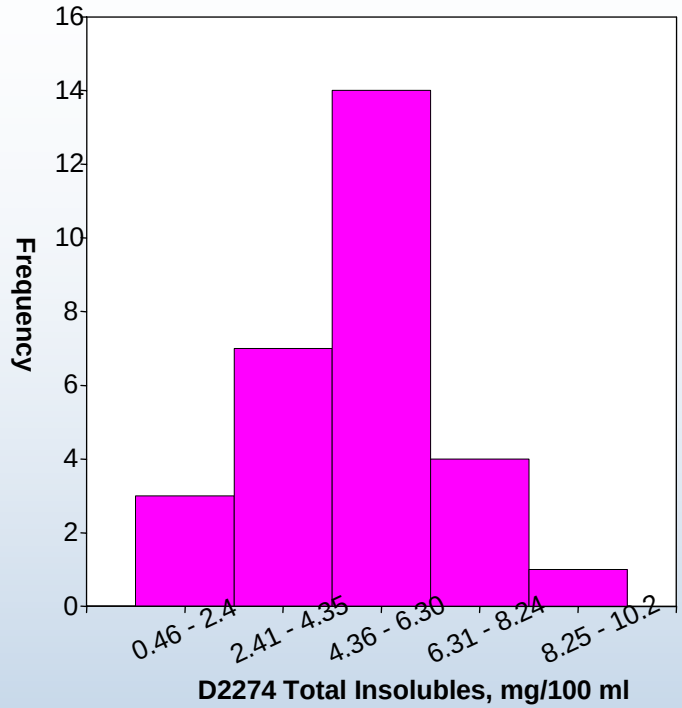
- ***In-Use Experience and Operating Costs***
- ***Testing in Post-2006 Engines***

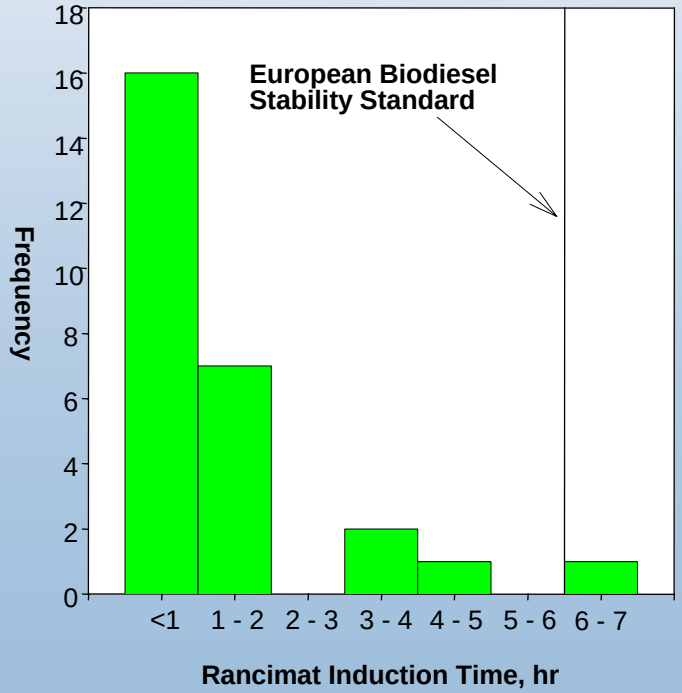
ASTM Specifications

- ASTM D6751 Specification for B100 for Blending
  - Currently being modified to:
    - Generally tighten the specification and improve quality
    - Address stability concerns of OEMs
    - Ensure compatibility with 2007/2010 diesel technology
- B20 finished fuel specification in progress
  - Users, OEMs want B20 specification ASAP
  - Recently balloted at ASTM - failed on lack of oxidation stability specification for B20
- Incorporation of B5 into D975 (petrodiesel specification)
  - Recently balloted at ASTM - failed on lack of oxidation stability specification in D6751

B100 Quality Survey Stability Results

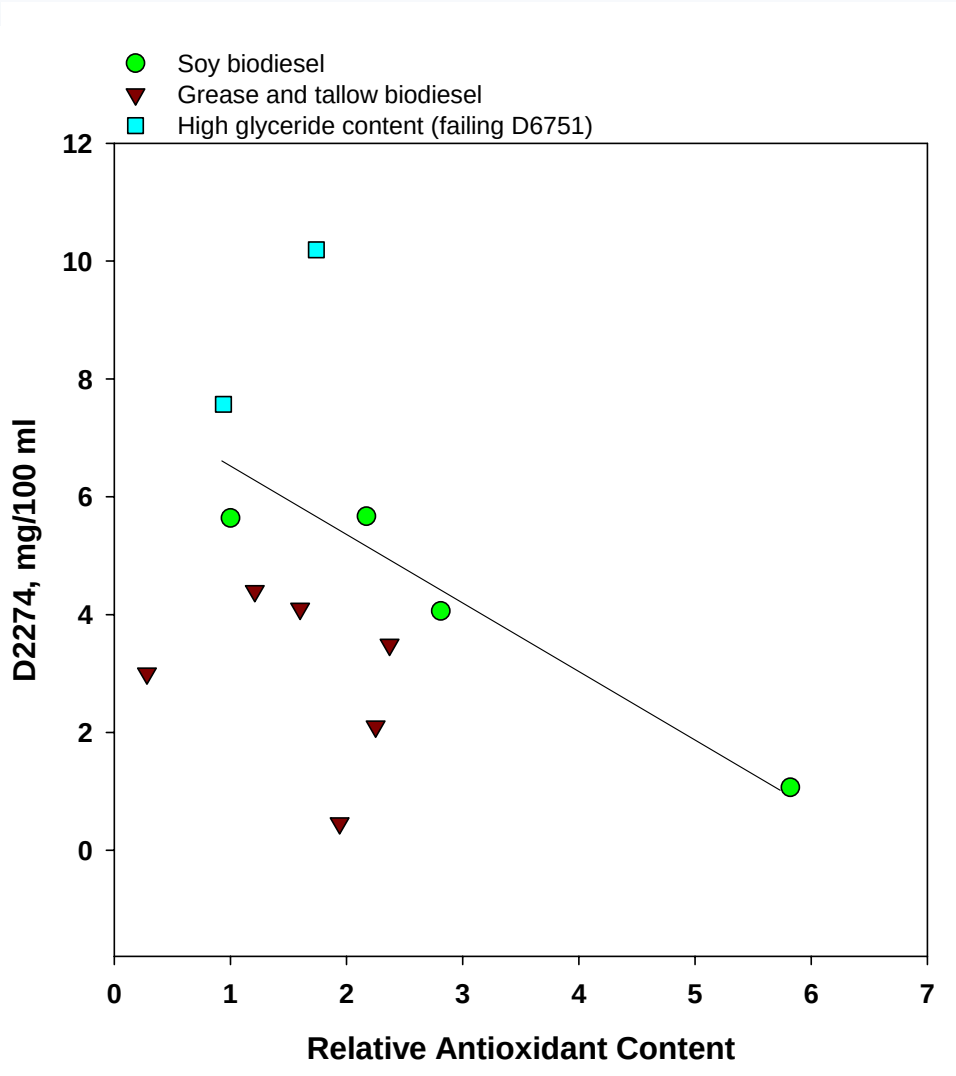
- ASTM D2274 (95°C/Oxygen/16 hr)
- Measures deposit formation
- Typical biodiesel produces 5 mg insolubles/100 ml





- Rancimat test,EN14112 (110°C, air)
- Measures induction time for volatile acid formation –may be related to time for start of deposit formation
- Typical biodiesel has less than 1 hr induction time

Factors Affecting Stability



- Higher natural antioxidant content leads to lower deposits
- Low C18:2/C18:3 content of grease and tallow derived biodiesel leads to lower oxidation deposits
- High glyceride content produces high oxidation deposits
  - D6751 limit may be adequate

Bottom Line on Quality Specifications

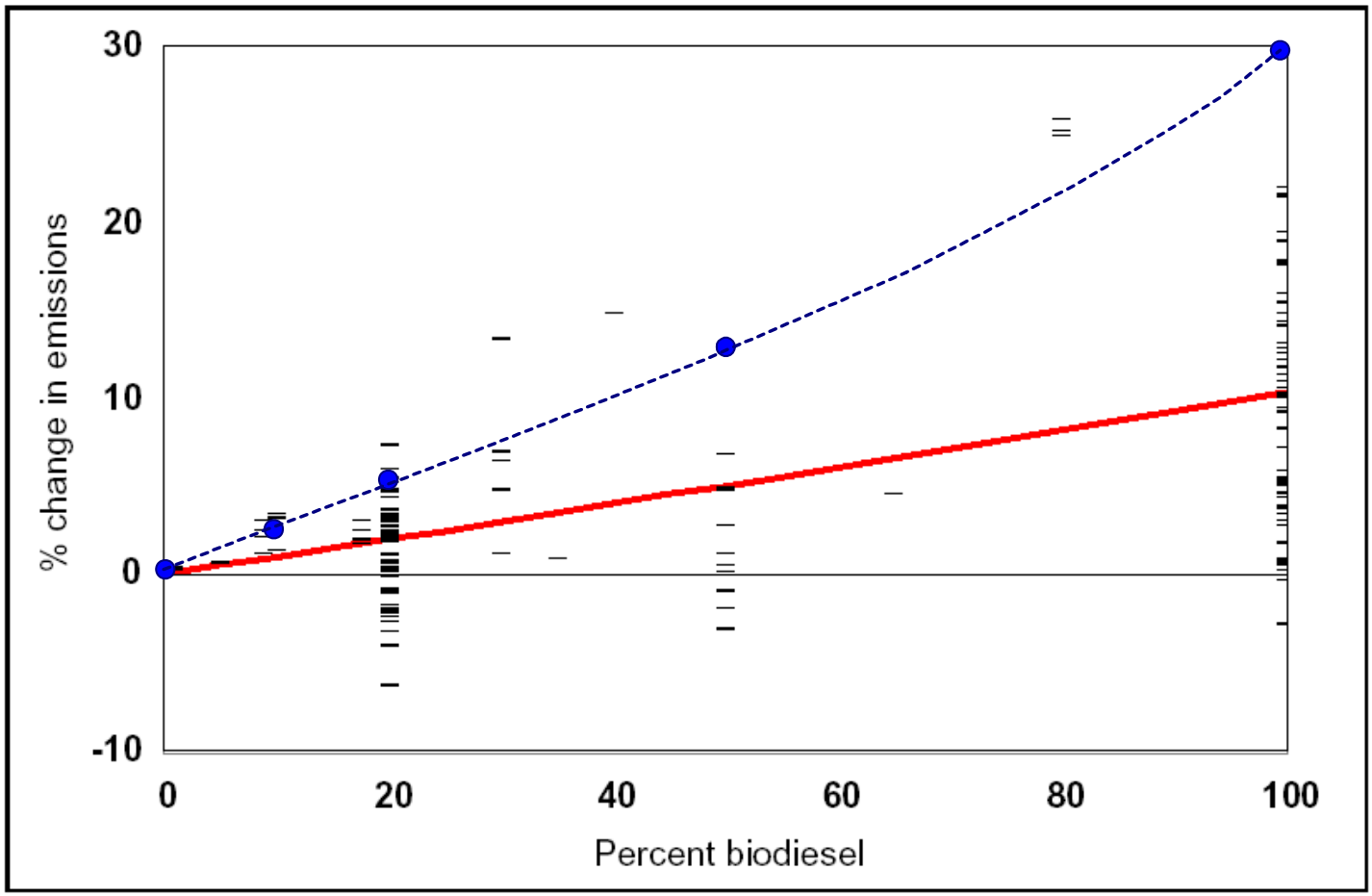
- Additional research is required to define test methods and specification limits

- Limiting factor is lack of data relating fuel stability, fuel stability test results, and deposit formation in engines

Biodiesel's Effect on NO_x Emissions -Engine Data

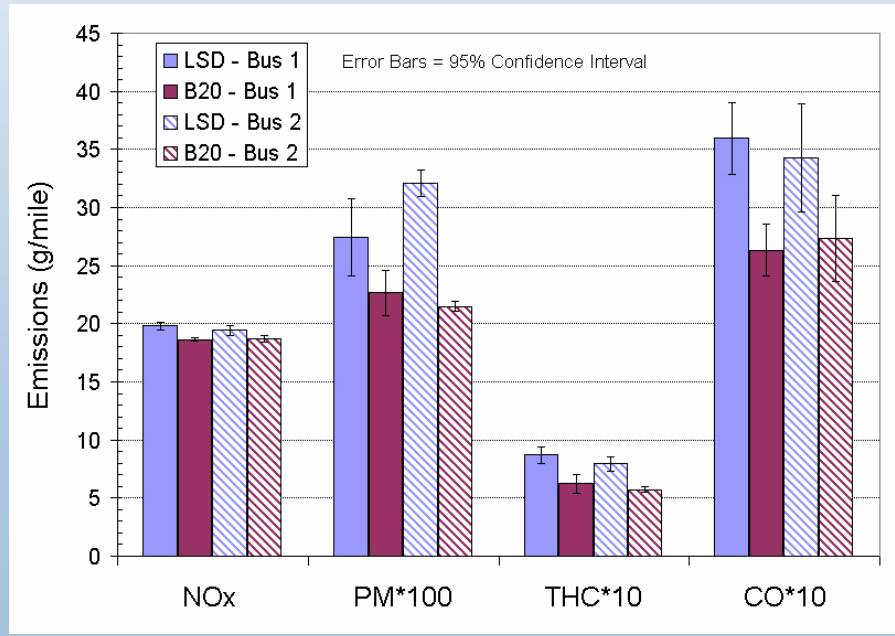
Typical Older Engines (thru 1997): B20 = +2%, B100 = +10% from EPA420-P-02-001, 10/2002

Newer Engines (2004 compliant): B20 = +4%, B100 = +30% SAE 2005-01-2200



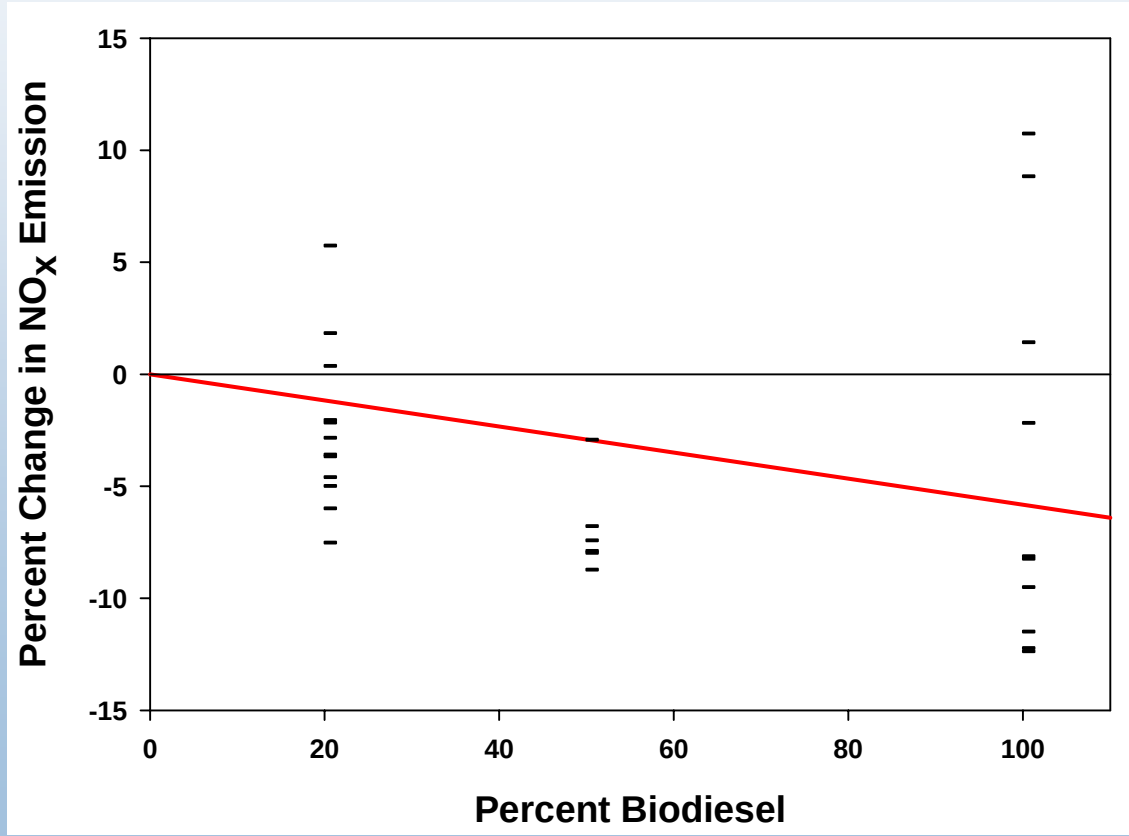
Biodiesel Bus Chassis Dynamometer Testing

- B20 vs. conventional diesel fuel
- 2 in-use buses tested (40,000 lb GVWR)
- City Suburban Heavy Vehicle Cycle (CSHVC) at 35,000 lb inertia
- Cummins ISM 2000 Engine – No EGR
- Expected reductions (g/mile basis)
  - PM ≈ 18%
  - HC ≈ 29%
  - CO ≈ 24%
  - Fuel Economy ≈ 3%
- **Unexpected reductions in NOx**
  - 4% reduction
  - statistical confidence > 99%



Biodiesel's Effect on NO_x Emissions -Vehicle (Chassis) Data

- *EPA study also reviewed published vehicle test data*
- *On average, NO_x was reduced in vehicle test studies*
  - *by 1.2% for B20*



Data from EPA420-P-02-001, October 2002

Uncertainty of Biodiesel Effect on NO_x

- *Engine tests on average show NO_x increasing*
  - *NO_x can go up or down depending on engine and test cycle - this is not well understood fundamentally*
  - *NO_x increase is not based on testing of a representative sample of in-use engines*
  - *NO_x increase is not based on a market share weighted average*

- *Vehicle tests on average show NO_x decreasing*
  - *Very limited dataset*
  - *Again, not based on representative sample or market share weighted average*

Bottom Line on Biodiesel and NO_x

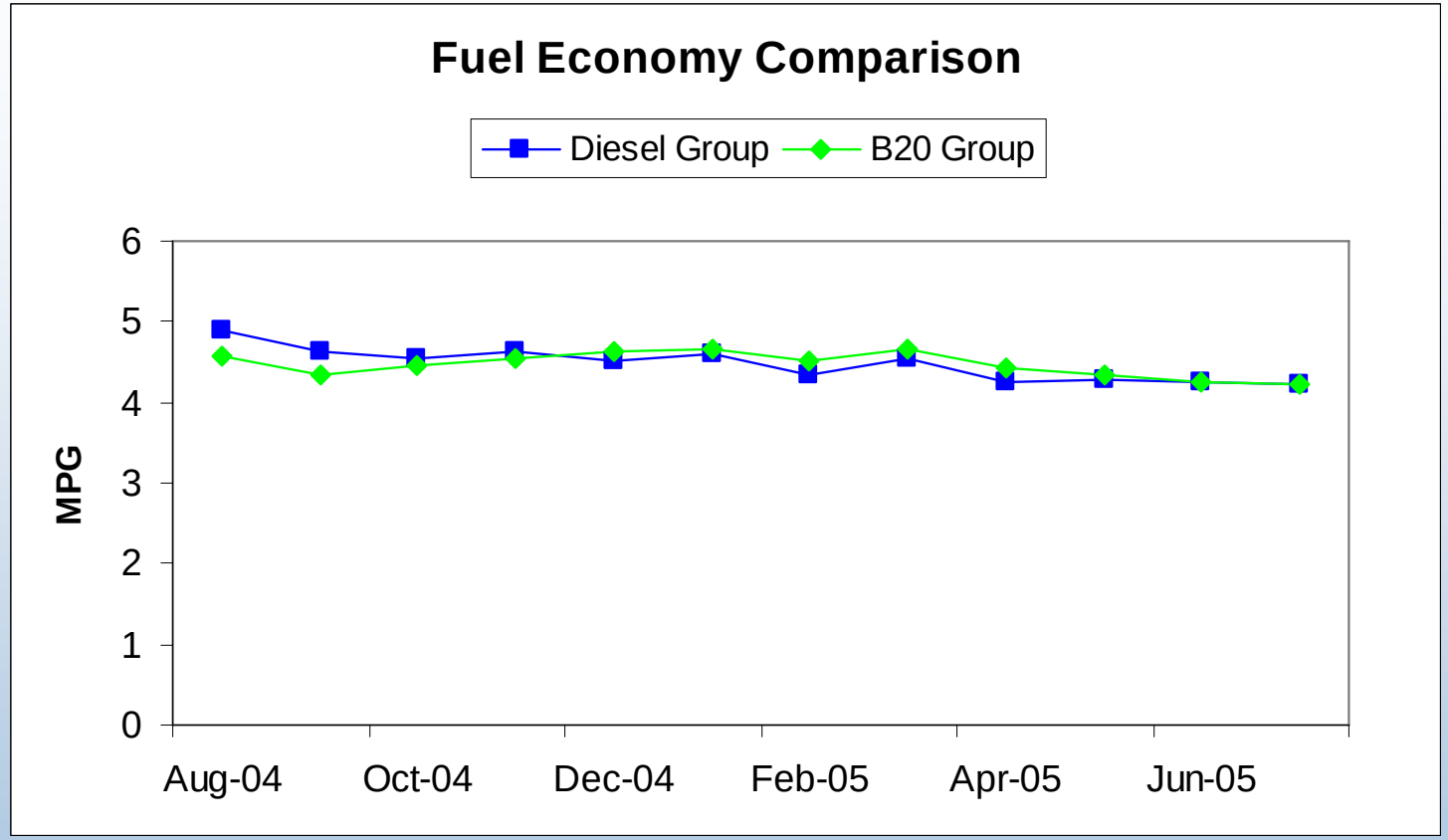
There are insufficient data, and insufficiently representative data, to draw any conclusions regarding the average effect of biodiesel on NOx emissions, even directionally

Biodiesel (B20) Fleet Evaluation - I

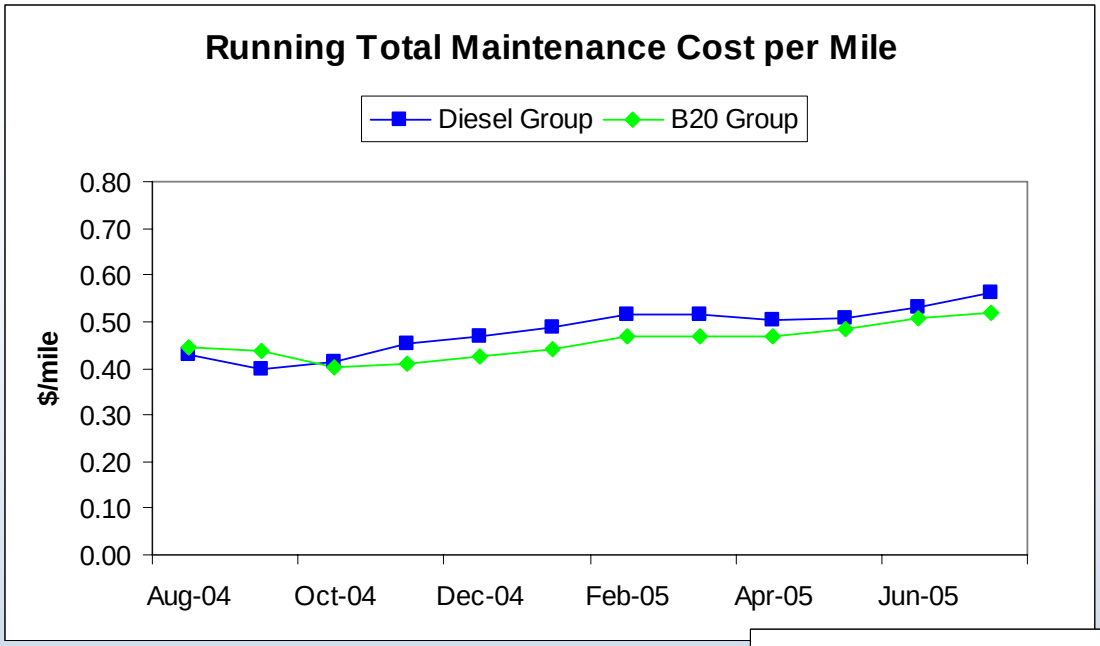
Comparative Operating Costs

- 9 mechanically identical buses
  - 2000 Orion V; Cummins ISM
  - 5 operated on B20, 4 on diesel
  - identical duty cycle
- Documenting mileage accumulation, fuel use, maintenance costs

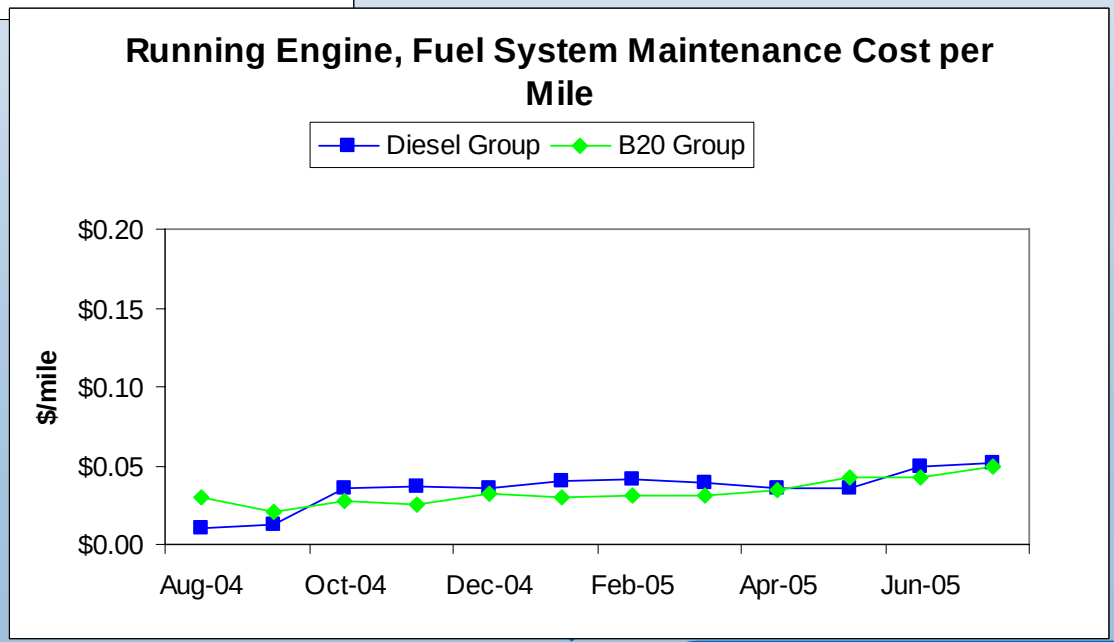
Fuel Economy



Maintenance Costs



Running or cumulative average costs per mile



Comparative Operating Cost Assessment: Interim Conclusions

Based on one year of data collection:

- Usage
  - average mileage comparable
- On-road fuel economy
  - no significant difference
- Road calls
  - similar for both groups
- Total maintenance costs
  - comparable
- Fuel System and Engine maintenance costs
  - no significant difference

Biodiesel (B20) Fleet Evaluation - II

Engine Wear Assessment

- U.S. Postal Service Vehicles
  - –4 operated for several years on B20
  - –Matched controls operated on petrodiesel
- Engine tear down and assessment at end of useful life

Teardown Inspection

1993 Ford 9-Ton Cargo Van

1996 Mack Tractor

Engine Wear Assessment: Preliminary Conclusions

- All engines, B20 or petrodiesel fueled, showed normal wear for their mileage
- Ford engines showed no difference in maintenance costs for the two fuels
- Mack engines experienced 28% higher engine and fuel system maintenance costs on B20
  - Caused by extra fuel filter and injector nozzle replacements
  - Some evidence that this was caused by chronic microbial contamination of the fuel, or possibly by out of specification fuel
- Difference between Ford and Mack engines indicates that differences in fuel system design and duty cycle may create different susceptibility to fuel quality issues

SAE Paper No. 2005-01-3641 to be published at Commercial Vehicle Congress in November

Closing Remarks

- Biodiesel is a significant sustainable energy resource for the United States
- Poor understanding of oxidation stability is limiting development of ASTM specifications for blends
  - additional research is required to relate fuel stability to engine durability
- There are not sufficient data to say if B20 blends cause NO_x, on average, to go up or down
- Interim results show no difference in operating costs or engine wear for use of petrodiesel versus B20
  - much more in-use data is required to fully understand B20 impacts
- A major research need is testing of biodiesel in post-2006 engines