

Effects of Biodiesel on NO_x Emissions

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Advantages of Biodiesel

Inherent advantages of diesel engines:

- Up to 40% (or even higher) improved efficiency relative to gasoline
- Inherently very low hydrocarbon emissions (both tailpipe and evaporative)

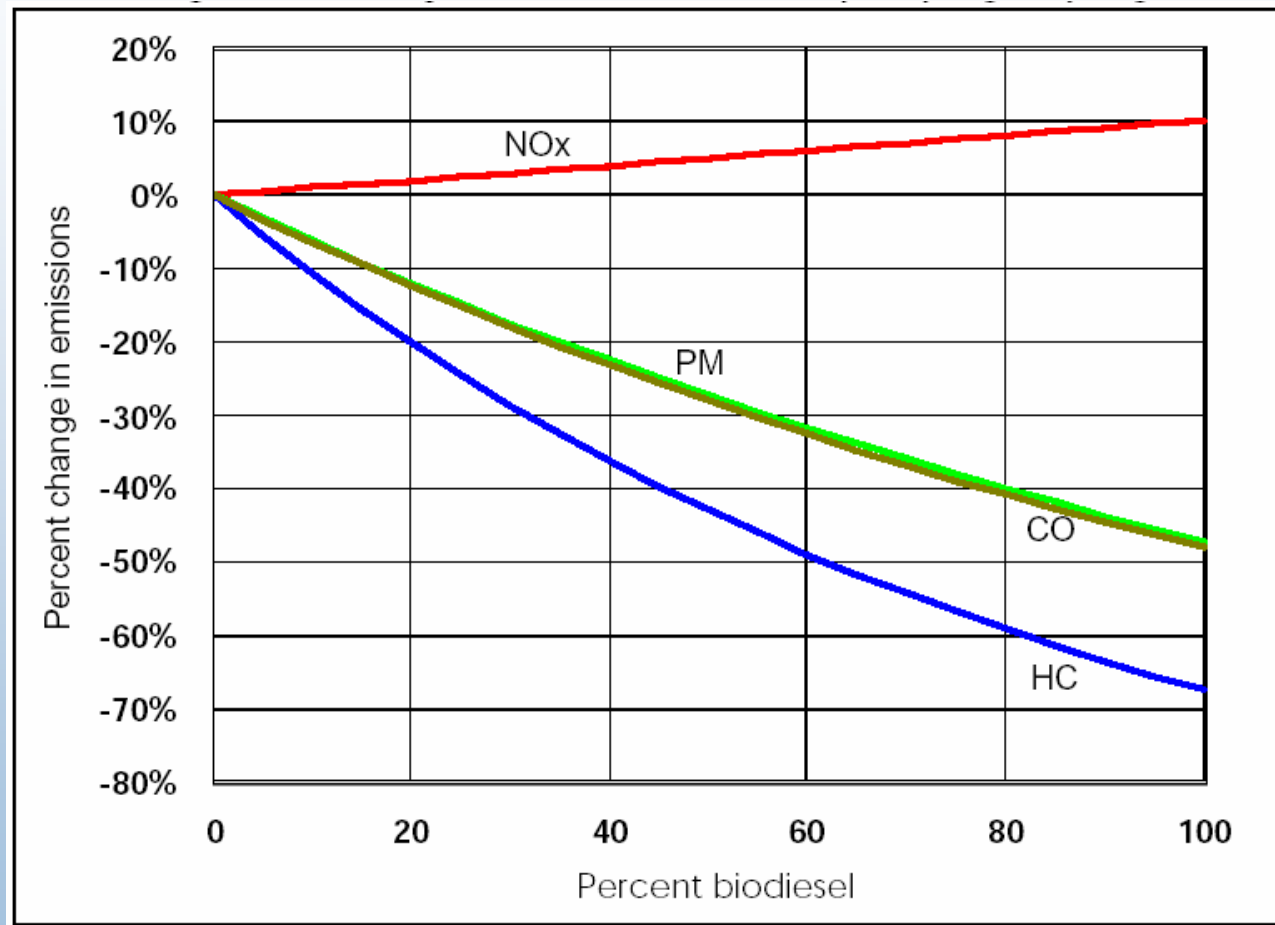
B20 Blends:

- Reduce life-cycle petroleum consumption by 19%
- Reduce life-cycle CO₂ emissions by 16%
- Further reduce hydrocarbon emissions by 20%
- Reductions in PM emissions

Biodiesel's Effect on Emissions – Older Engines

EPA analysis:

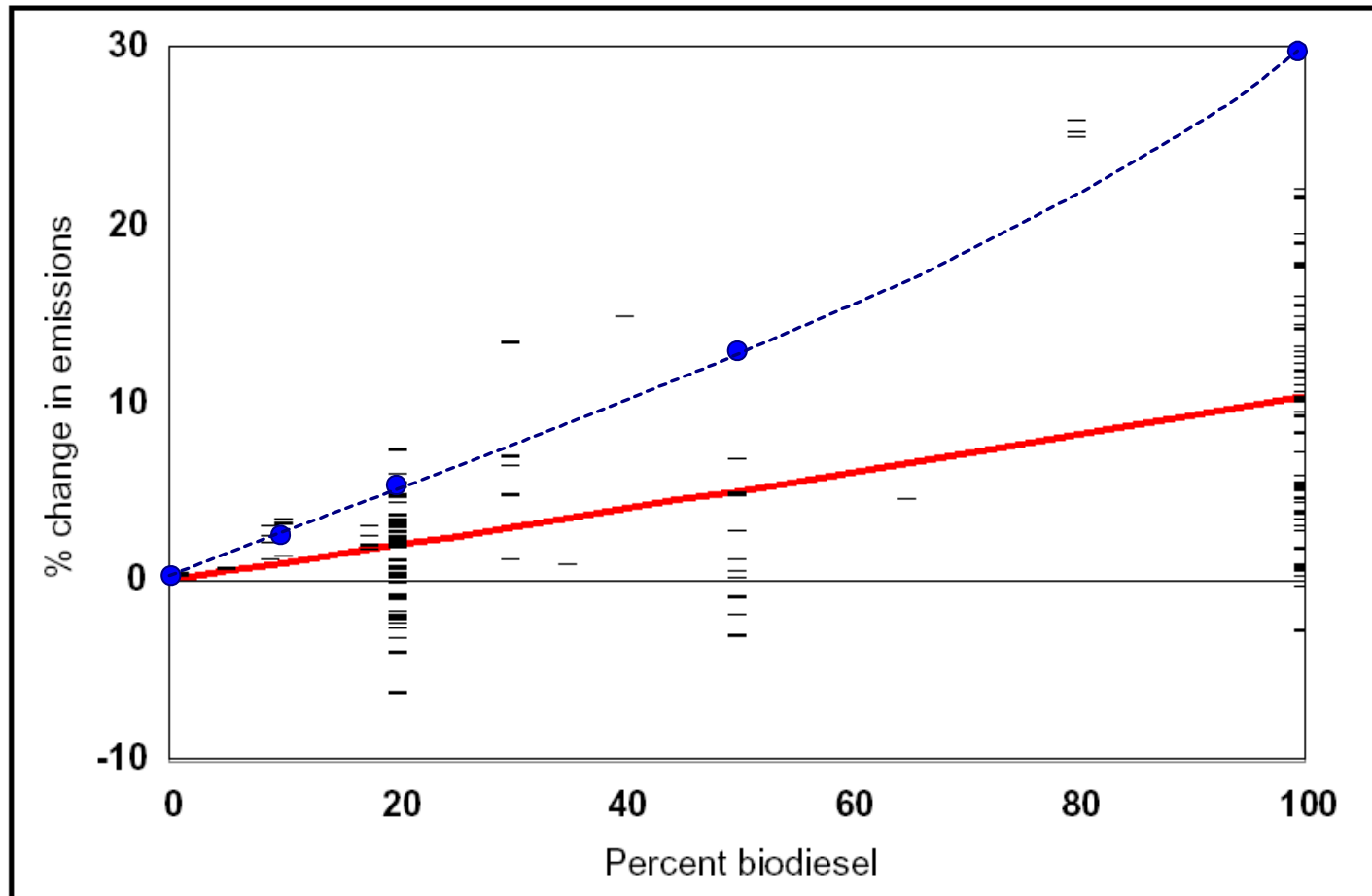
- data from many studies
- engine models through 1997
- NO_x
 - No change for B5
 - 2% up for B20
 - 10% up for B100
- PM
 - 5% down for B5
 - 12% down for B20
 - 48% down for B100



Biodiesel's Effect on NO_x Emissions -Engine Data

Typical Older Engines (thru 1997): B20 = +2%, B100 = +10%

Newer Engines (2004 compliant): B20 = +4%, B100 = +30%

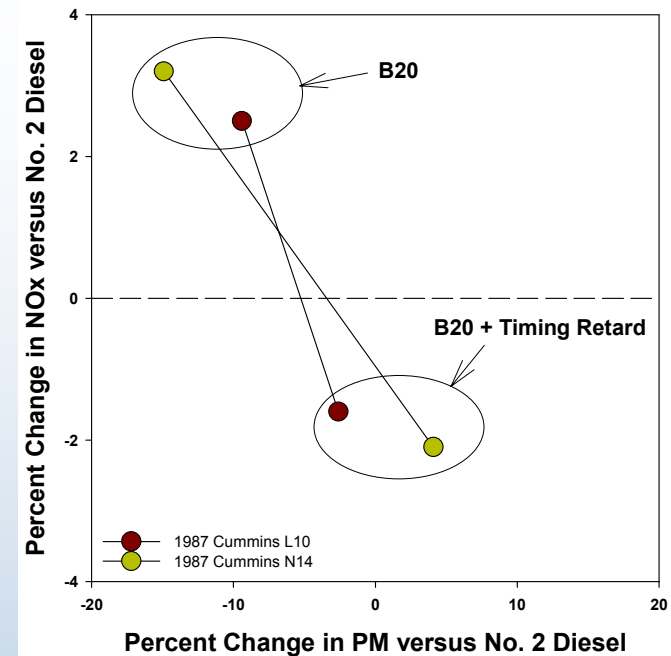


NO_x Reduction Strategies

Injection timing retard:

- Can eliminate NO_x increase for pre-1998 engines
- Reduces or eliminates PM benefit
- Can reduce fuel economy
- Requires engine certified on and dedicated to biodiesel

Graboski & McCormick, Progress in Energy and Combustion Science, 24 125 (1998).



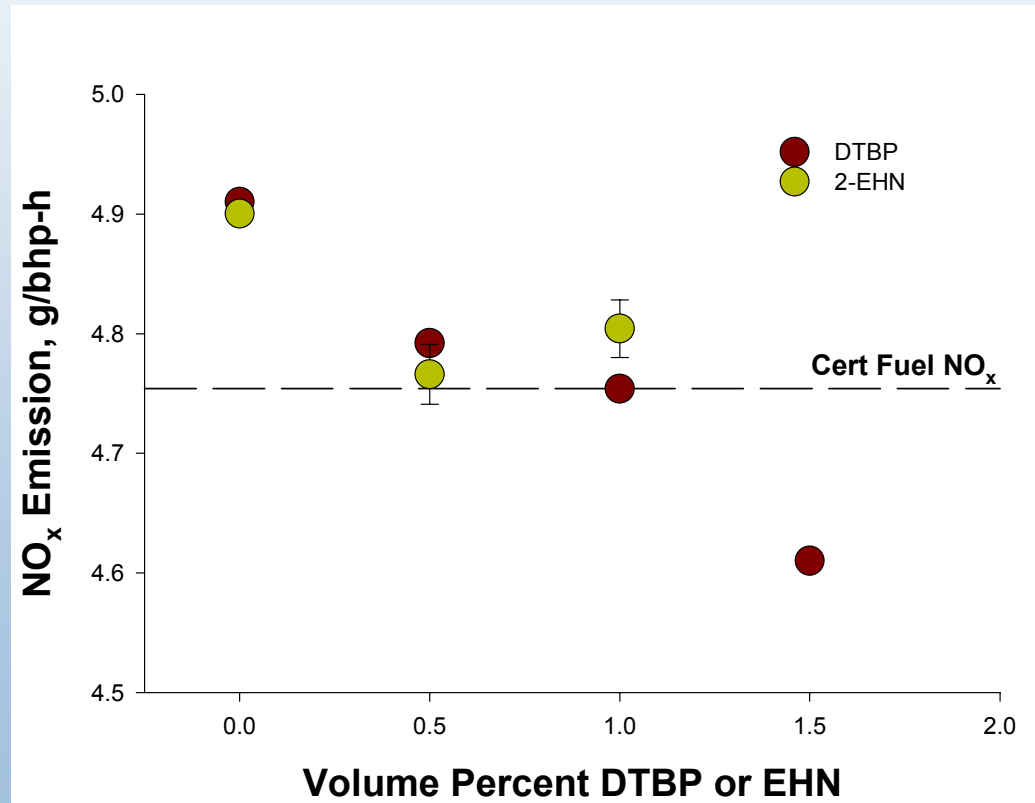
Cetane increasing additives

Use of more highly saturated biodiesel

Cetane Additives for Reducing NO_x

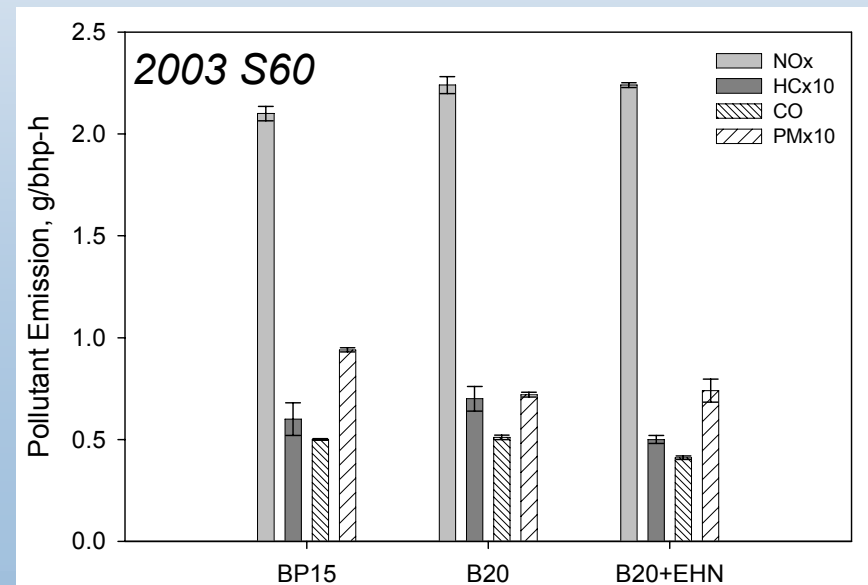
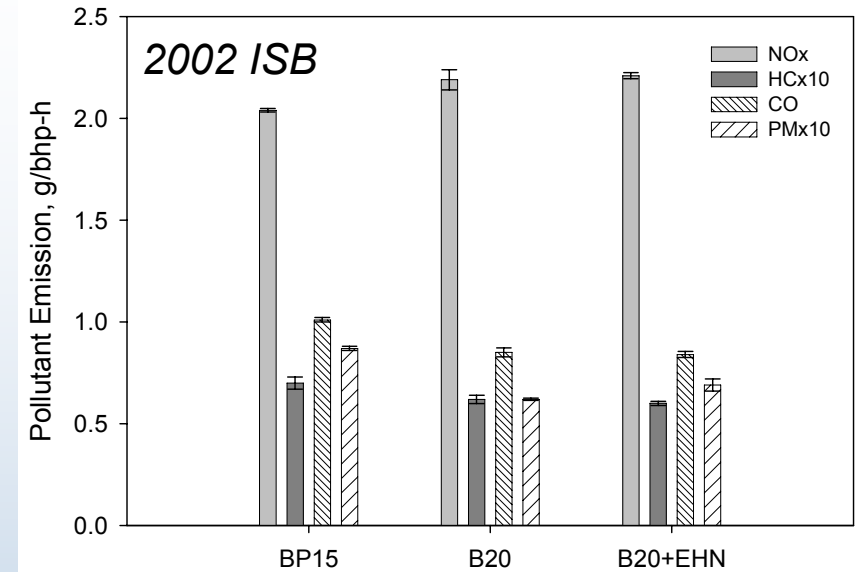
For testing in older engines:

- Effective for soy B20
- NO_x reductions significant at 95% confidence or greater
- No change in PM emissions or fuel economy

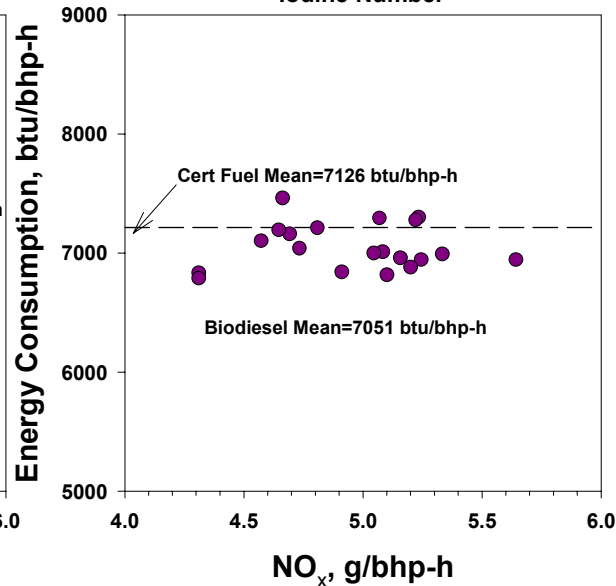
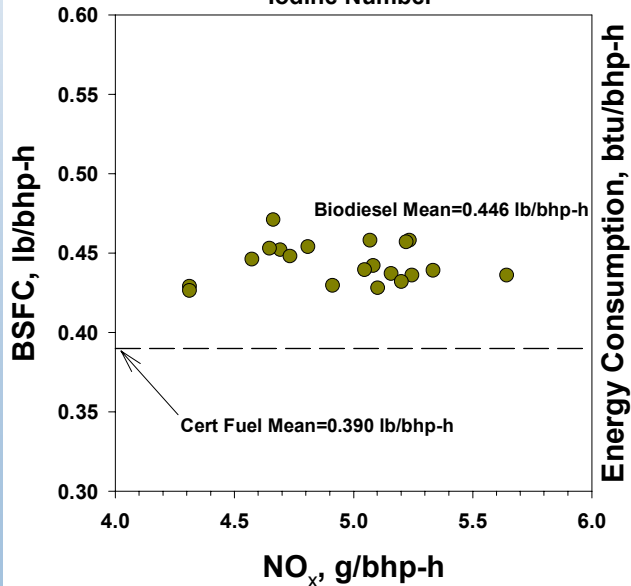
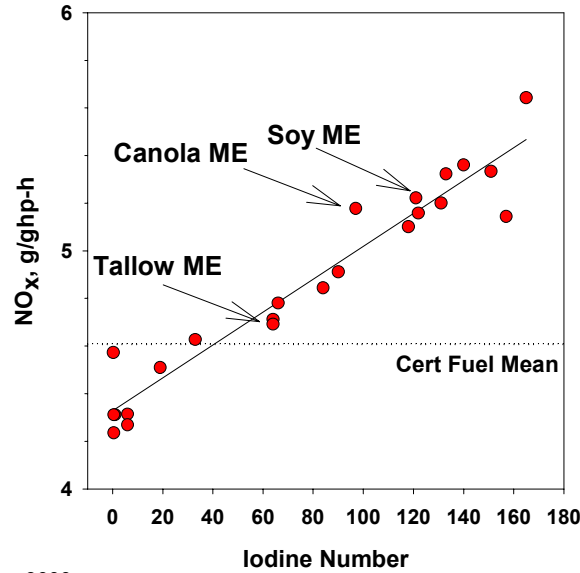
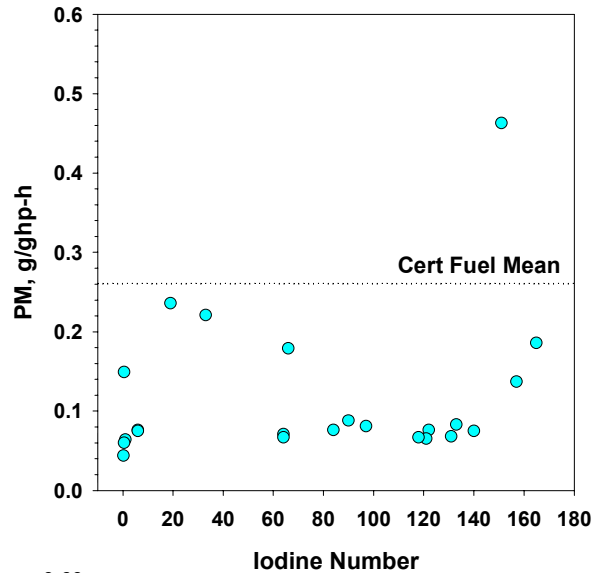


Cetane Additives for Reducing NO_x

No significant effect observed for B20 in 2004 emission standard engines



Effect of Biodiesel Composition on NO_x



Results for 1991 engine

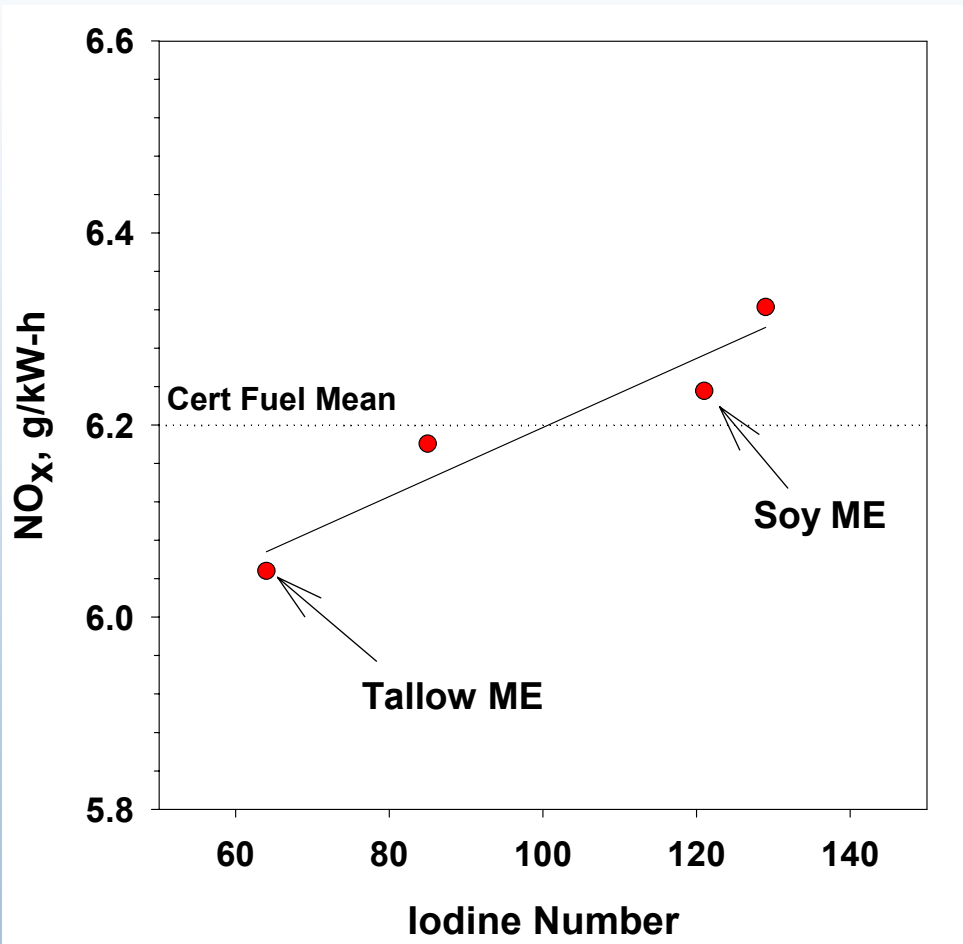
- NO_x emissions correlated with fuel unsaturation

- NO_x varies by 1 g/bhp-h but energy consumption varies by less than 2%

- Data from *Environ. Sci. & Technol.* 35 1742-1747 (2001),
- DDC Series 60 engine (1991)
- HD FTP
- B100 compared to LSD

Effect of Biodiesel Composition for Blends

NO_x emissions for B20 blends versus biodiesel Iodine Number:

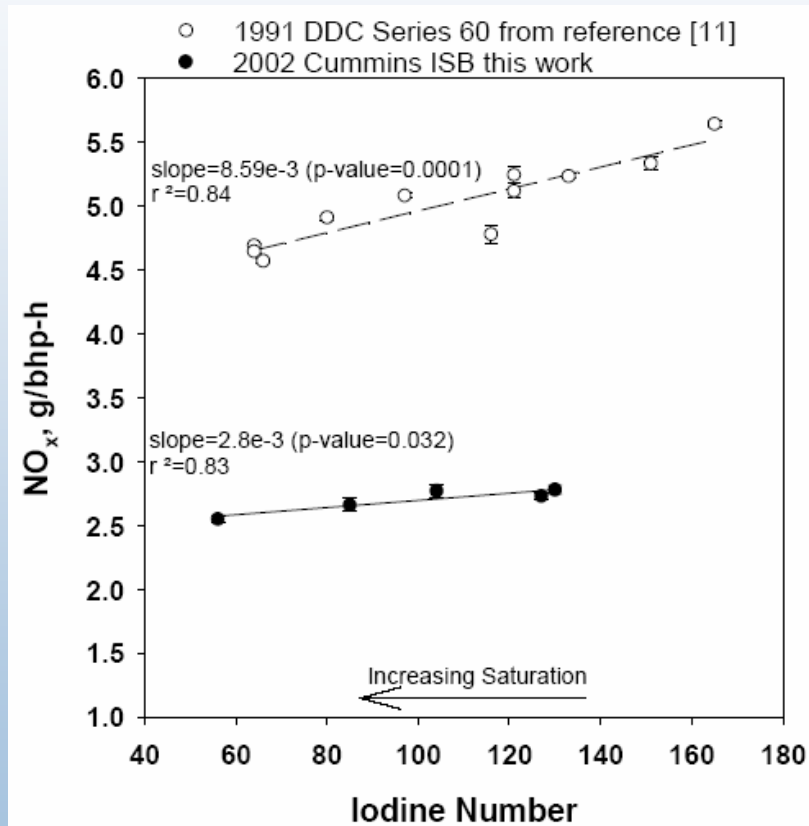


- NO_x neutrality at Iodine Number of roughly 95
- I.N. is typically >120 for soy
- Suggests blending of high and low I.N. fuels may be a strategy to eliminate the NO_x increase -older engines

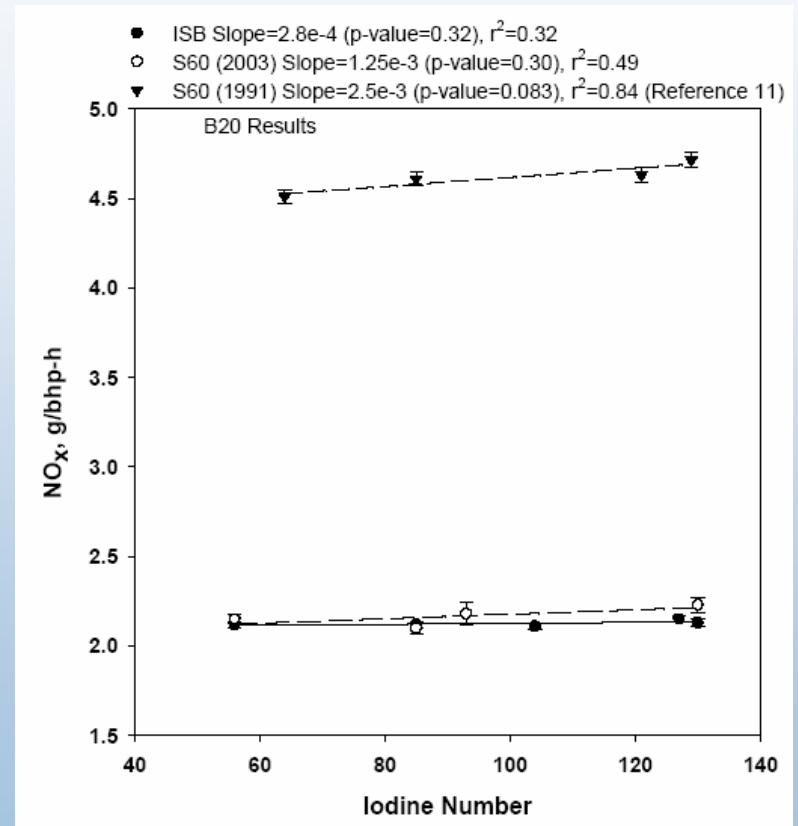
Effect of Biodiesel Composition

Results for 2004 engines

Much smaller effect of degree of unsaturation



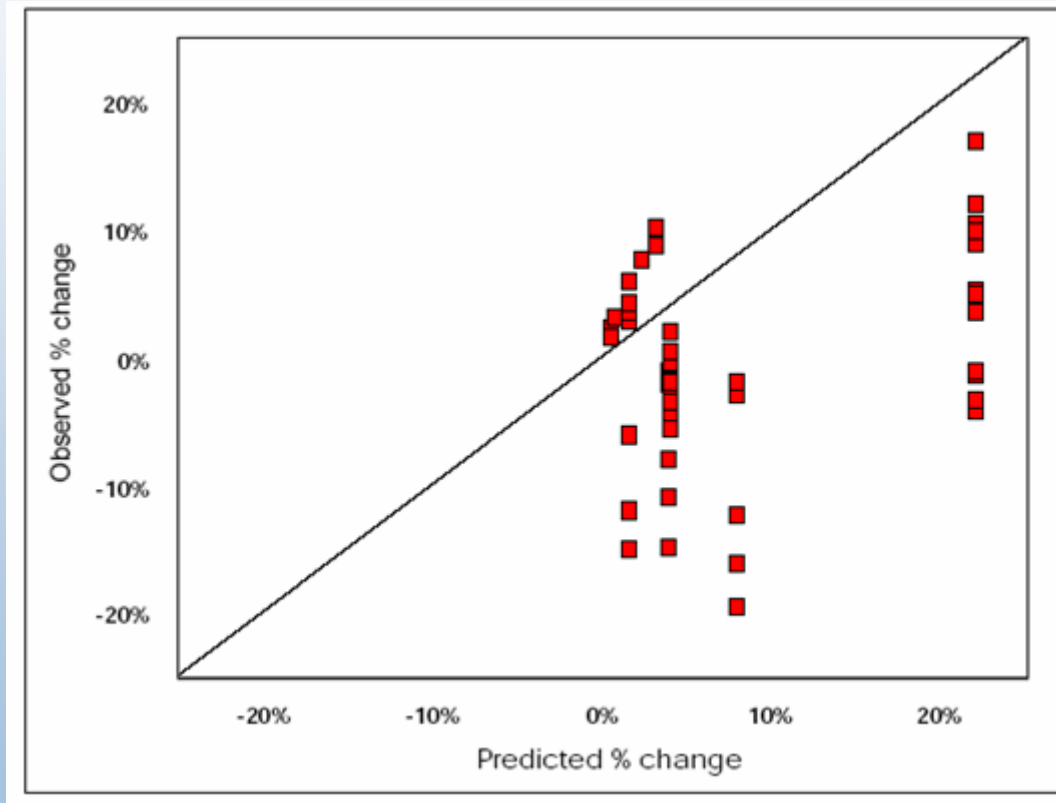
B100



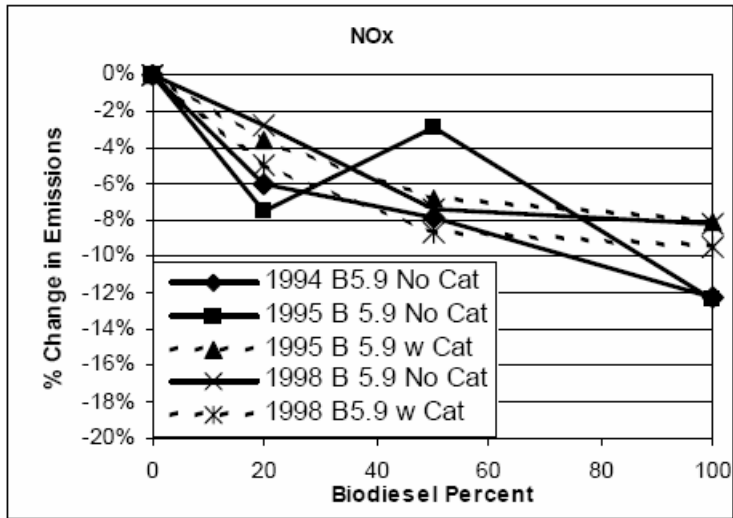
B20

Comparison of Engine and Vehicle Emissions

- *EPA predictive model based on engine dyno data*
- *Results compared to vehicle (chassis dyno) results*
- *On average, NO_x was reduced in vehicle test studies*



Chassis Data Examples

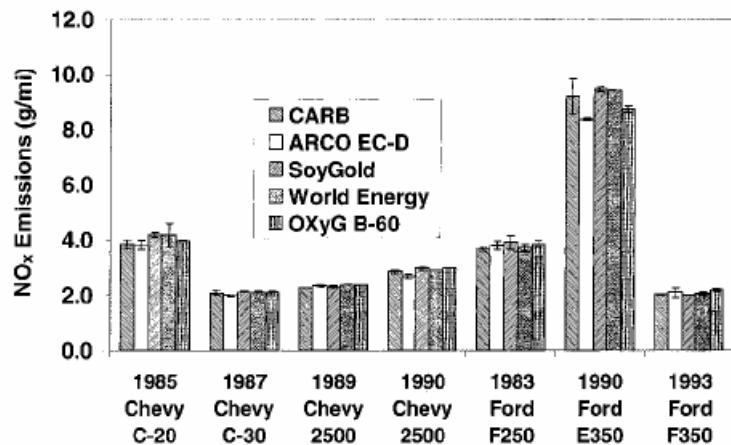


Plot: Weaver, report to SCAQMD, November 2004.

Data:

Peterson and Reece, SAE Paper No. 961114.

Taberski and Petersen, BioEnergy '98, Expanding Bioenergy Partnerships, available at www.biodiesel.org.



Durbin and Norbeck Environ. Sci. Technol. **2002**, 36,1686.
Light-duty FTP test cycle for B20 blends of three biodiesels

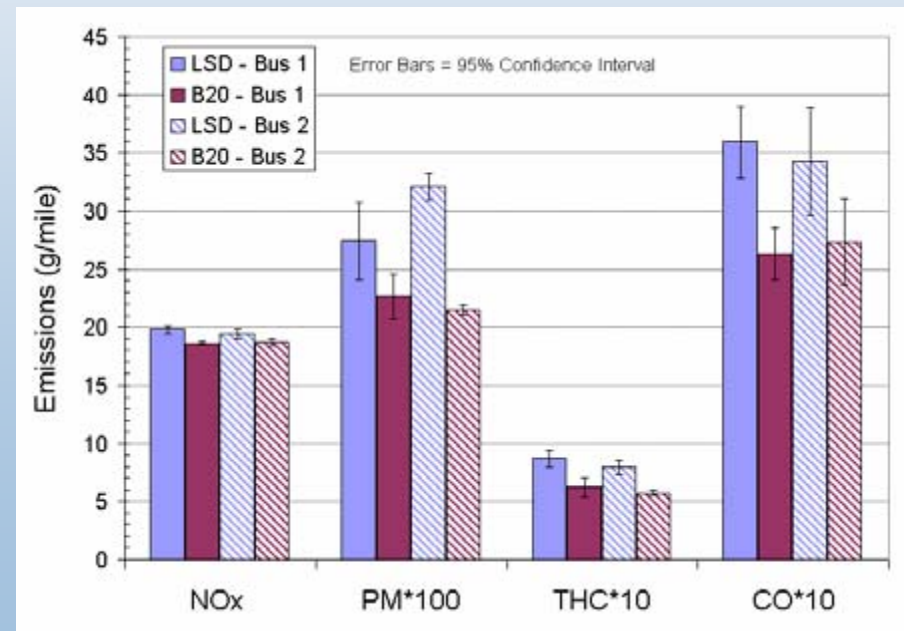
General observation: very high power-to-weight vehicles, such that engine operation is at light load.

Speculate: biodiesel may reduce NO_x at lighter loads?

FIGURE 4. FTP NO_x emissions. All data are presented as the mean \pm twice the standard error. The 20% biodiesel blends are each denoted in the legend according to the biodiesel fuel used in the blend.

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 \approx 24%
 - HC \approx 40%
 - CO \approx 32%
 - Fuel Economy \approx 3%
- **Unexpected reductions in NOx**
 - 5% reduction
 - statistical confidence > 99%



Biodiesel Effect on NO_x Uncertainty

- *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*
 - *Finding of a NO_x increase is not based on testing of a representative sample of in-use engines*
 - *Finding of NO_x increase is not based on a market share weighted average*
- *Vehicle tests on average show NO_x reductions*
 - *Very limited dataset*
 - *Again, not based on representative sample or market share weighted average*

Closing Remarks

- There is considerable uncertainty regarding biodiesels impact on NO_x emissions
- Additional research is required to fundamentally understand the cause of the NO_x increase and to understand why engine and chassis tests give directionally different results
- The main benefits of biodiesel use are reductions in petroleum consumption and greenhouse gas emissions

<http://www.nrel.gov/vehiclesandfuels/npbf/publications.html>

