Fuel-Engine Compatibility and Performance of Biodiesel

Bob McCormick
National Renewable Energy Laboratory

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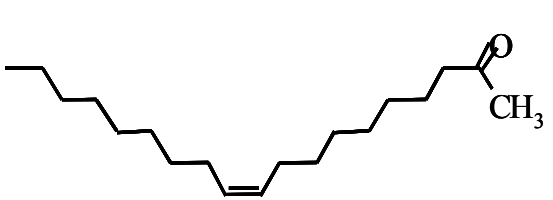
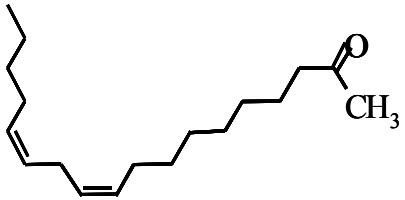
303-275-4432
robert_mccormick@nrel.gov

Biodiesel Overview

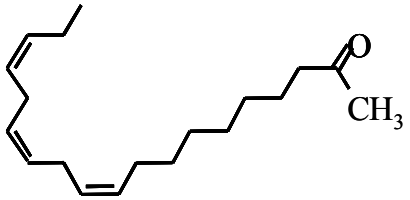
- Methyl esters of fatty acids



oleic acid

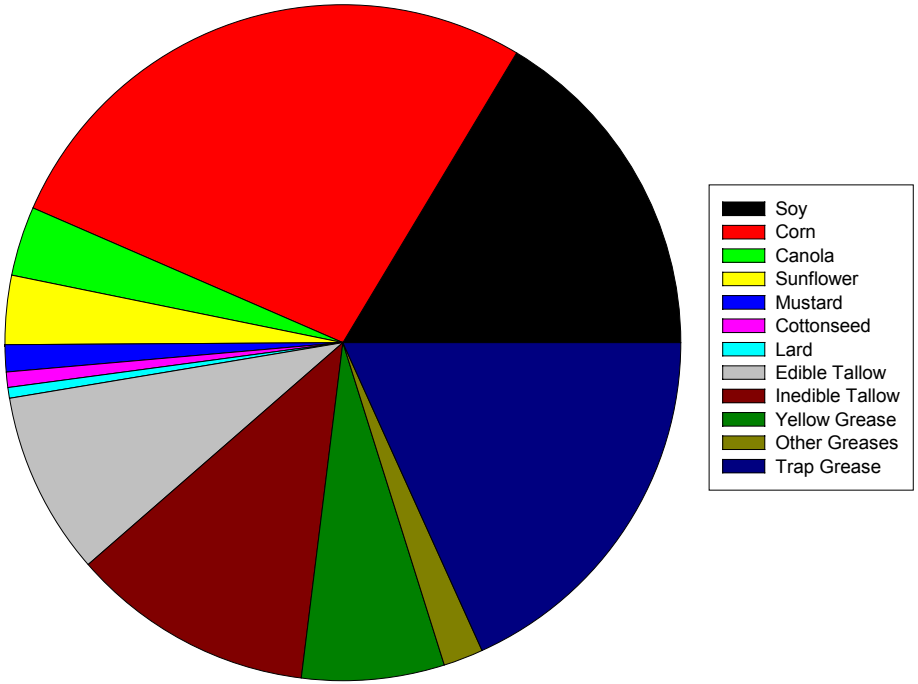


linoleic acid



linolenic acid

- US resource size roughly 2 billion annual gal
- ~20 million gal estimated in sales for 2002
- Annual European production ~200 million gal (600 million gal/yr capacity)



Energy Security and Global Warming Benefits

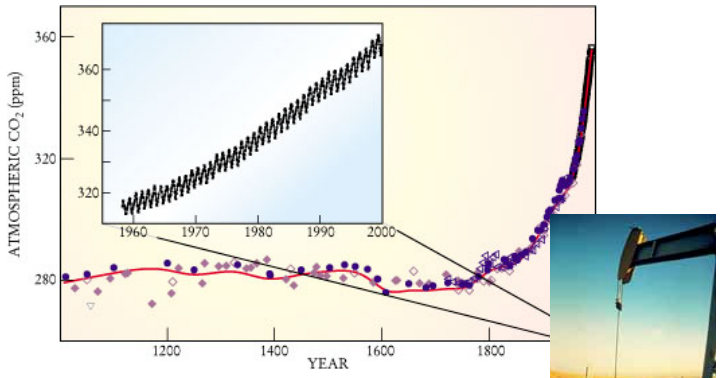
For Soybean-based biodiesel:

Life Cycle Energy Efficiency = 83% for petroleum diesel
= 81% for biodiesel

- *Roughly the same amount of energy is required to produce refined petroleum diesel and biodiesel*

Fossil Energy Ratio = *Fuel Energy/Fossil Energy Inputs* = 3

- *Fossil energy used in production is small fraction of fuel energy-truly renewable, highest ratio of any fuel currently produced*



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

Biodiesel Strategies & Regulatory Status

- Utilization strategy-blending with petroleum diesel
  - 20% (B20) blends initially pursued as economic compromise
  - May shift to 5% blends because of OEM concerns
  - 20% blends for EPAct fleets
- Energy security and environmental benefits proportional to total volume used, not blend level
- ASTM standard published in January, 2002
- EPA fuel registration requirements met (CCA 211b)

ASTM D6751:

TABLE 1 Detailed Requirements for Biodiesel (B100)[A]

Property	Test Method[B]	Limits	Units
Flash point (closed cup)	D 93	130.0 min	°C
Water and sediment	D 2709	0.050 max	% volume
Kinematic viscosity, 40°C	D 445	1.9–6.0[C]	mm^2/s
Sulfated ash	D 874	0.020 max	% mass
Sulfur[D]	D 5453	0.05 max	% mass
Copper strip corrosion	D 130	No. 3 max	
Cetane number	D 613	47 min	
Cloud point	D 2500	Report[E]	°C
Carbon residue[F]	D 4530	0.050 max	% mass
Acid number	D 664	0.80 max	mg KOH/g
Free glycerin	D 6584	0.020	% mass
Total glycerin	D 6584	0.240	% mass
Phosphorus content	D 4951	0.001 max	% mass
Distillation temperature, Atmospheric equivalent temperature, 90 % recovered	D 1160	360 max	°C

Biodiesel Compared to No. 2 Diesel

Property	Method	Typical No. 2	100% Soy Biodiesel	
LHV, btu/gal	D240	131,000	117,000	←10% lower energy content
Density, 15°C	D4052	0.85	0.88	
Viscosity, cP	D445	2.7	4.1	←More viscous
Distillation, °C	D86			
IBP		174	300	
10%		215	328	
50%		253	336	
90%		312	350	←Higher T90
FBP		344	360	
Carbon Residue	D524/D45	<0.35	<0.1	←Lower carbon residue
Cetane number	D613	45	~50	←Higher cetane
Sulfur, ppm	D5453	300	<1	←Very low sulfur and aromatics
Total Aromatics	D5186	~30	0	
Cloud Point, °C	D2500	-15	0	←Higher cloud point

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Biodiesel Blend Properties

Blending mitigates property differences

Property	Method*	Typical No. 2	B20	B5
LHV, btu/gal	D240	131,000	128,000	130,000
Density, 15°C	D4052	0.85	0.87	0.85
Viscosity, cP	D445	2.7	2.9	2.7
Distillation, °C	D86			
IBP		174	174	174
10%		215	225	215
50%		253	265	253
90%		312	335	320
FBP		344	346	346
Carbon Residue		<0.35	--	--
Cetane number	D613	45	46	45
Sulfur, ppm	D5453	300	240	285
Total Aromatics	D5186	~30	~24	~28
Cloud Point, °C	D2500	-15	-10	-15

- 5% blends no significant change
- 20% blends show small property changes

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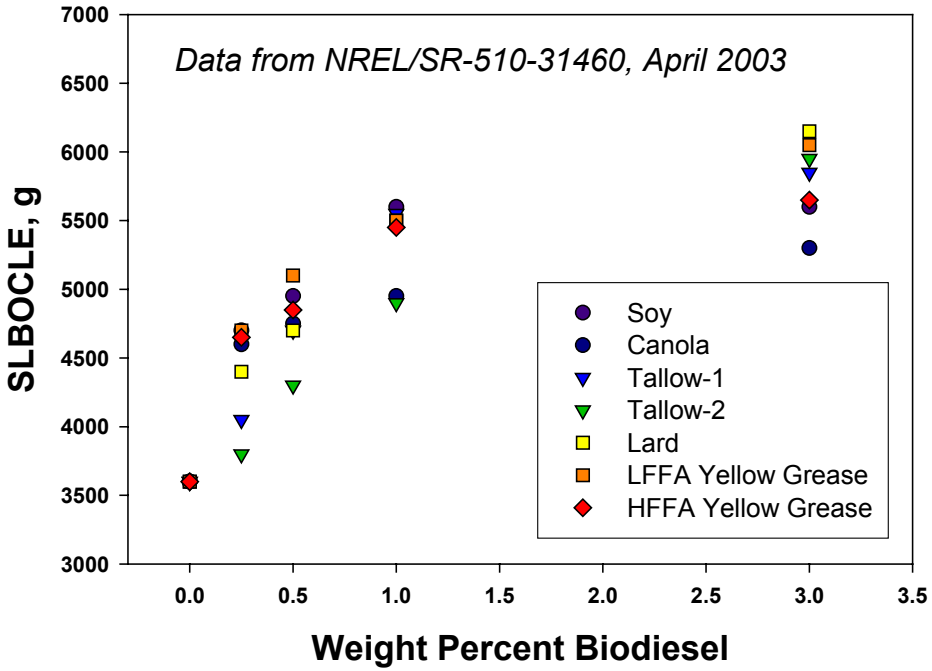
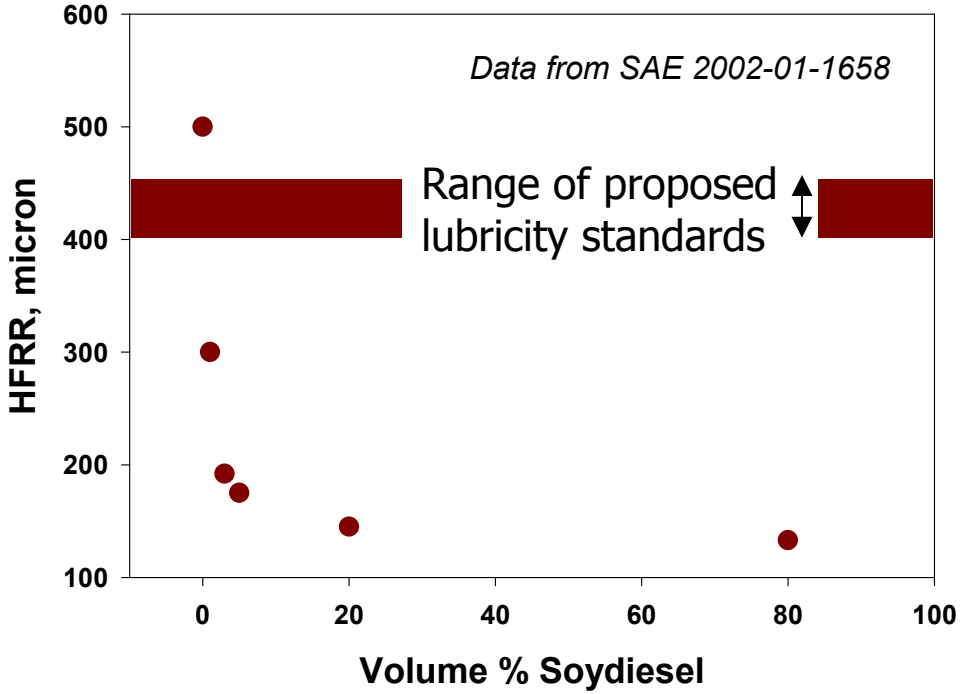
Biodiesel Effect on Lubricity

ASTM is currently considering a lubricity standard for diesel fuel

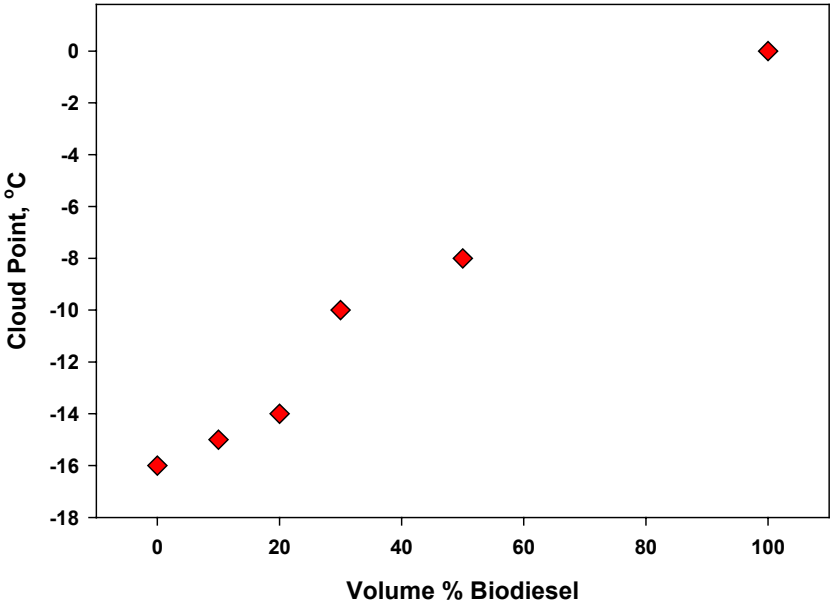
- 0.5wt% biodiesel can increase SLBOCLE by roughly 1000 g or reduce HFRR 200 micron
- Thus low biodiesel blends may reduce engine wear

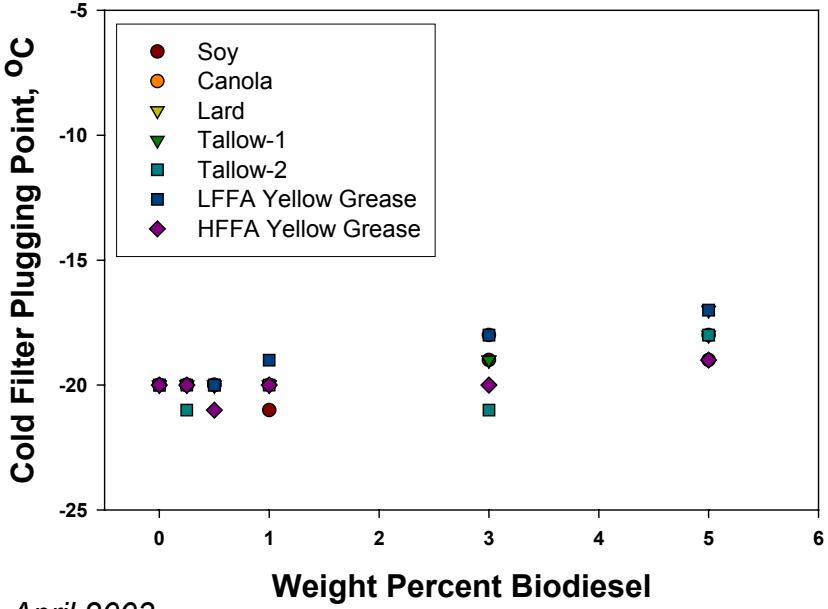




Cold Flow of Biodiesel Blends

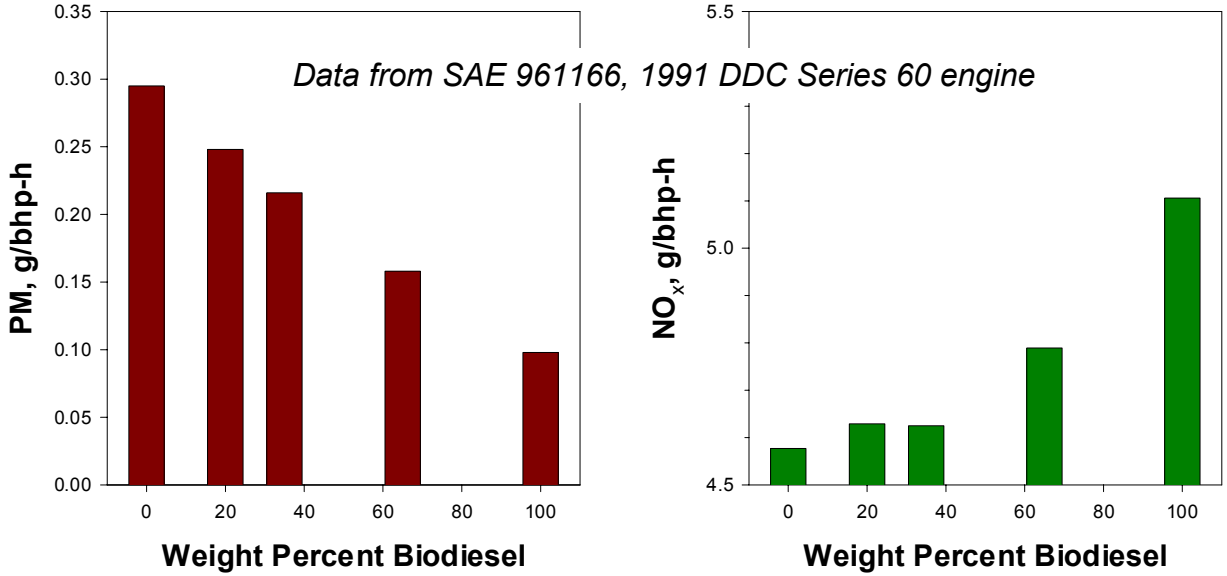
- Pure biodiesel begins to freeze at inconvenient temperatures-above 32°F
- Below 20% blend the impact on cold flow is small,
- And even smaller below 5%:
  - Vegetable oil-derived fuels have no impact on CP or CFPP
  - Impact is larger but manageable for more saturated animal fat-derived fuels
- Blending of No. 1 diesel and use of cold flow additives are effective strategies for B20



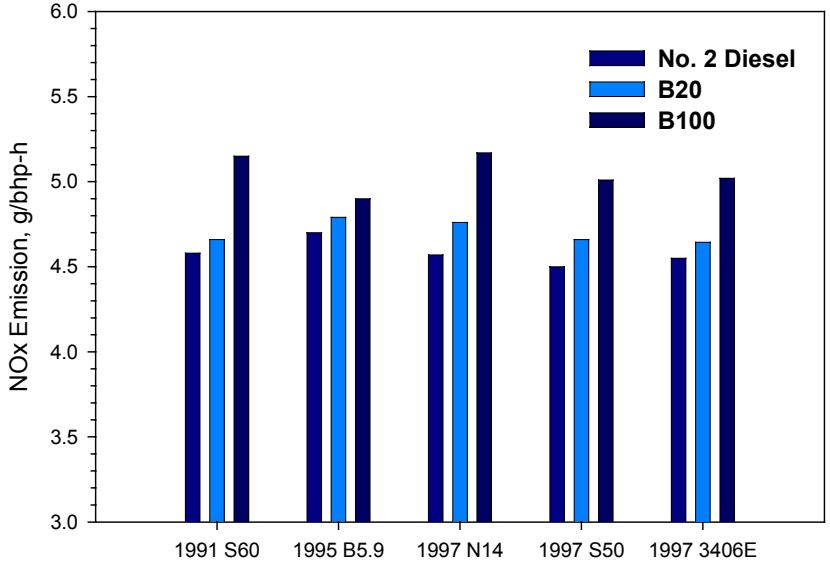


Data from NREL/SR-510-31460, April 2003

Biodiesel Emissions

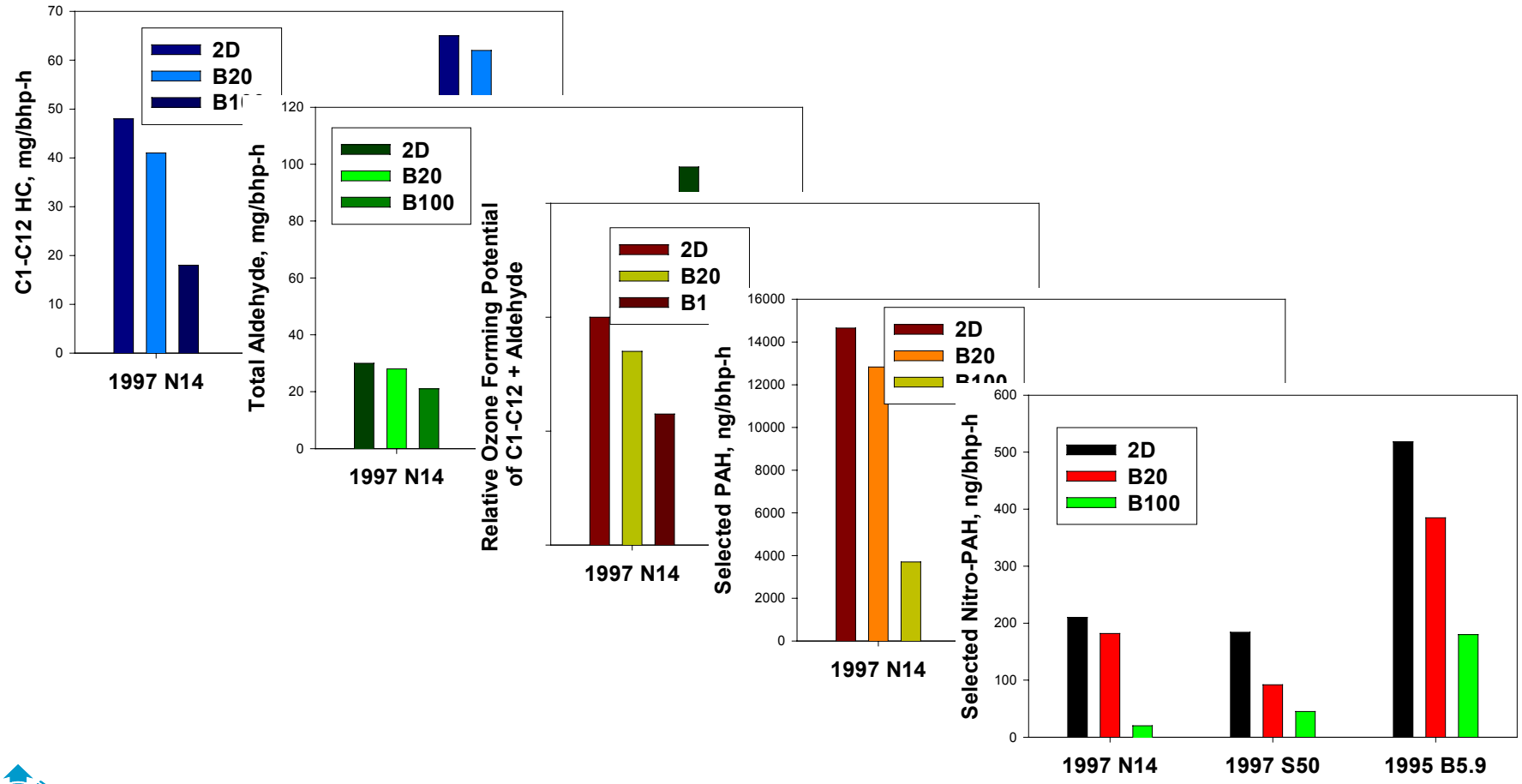


- PM reduction, NO_x increase roughly linear with blend level
- NO_x Increase, 2-4% for B20 over a range of engines
- Apparently no data for engine meeting 1998 (4 g/bhp-h) or 2004 (2.5 g/bhp-h) NO_x emission standards



Toxics Emissions

Generally lower for biodiesel:



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).

Ongoing research:

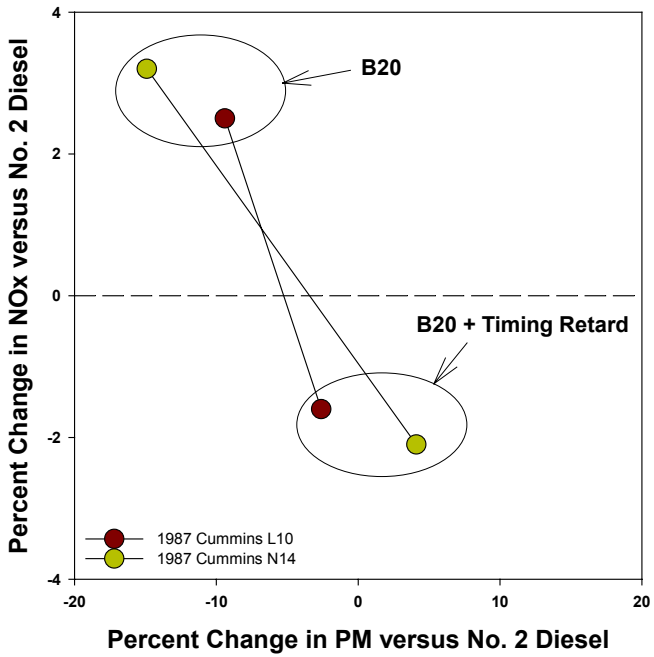
- Fuel and injection sensors for feedback control of injection timing

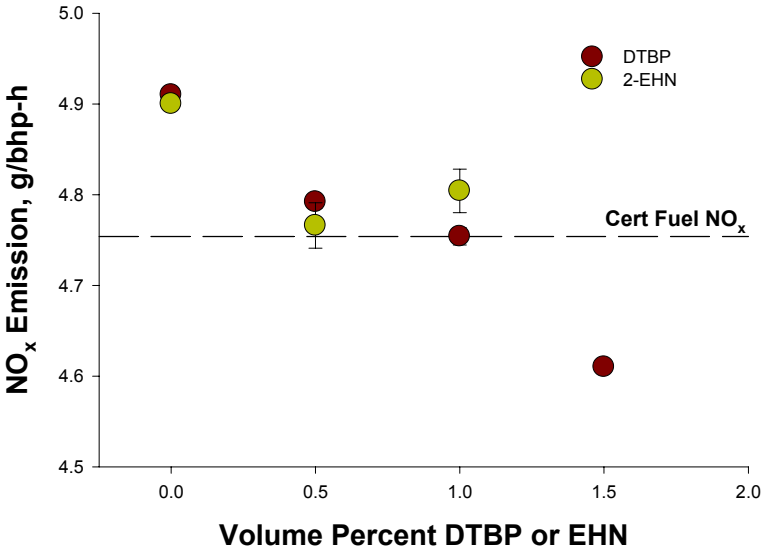
  Tat & Van Gerpen, Applied Eng. In Agr., 19 125 (2003)

Cetane increasing additives:

- Both EHN and DTBP effective for soy B20
- NO_x reductions significant at 95% confidence or greater
- No change in PM emissions or fuel economy

  McCormick, et al., SAE Tech. Pap. No. 2002-01-1658





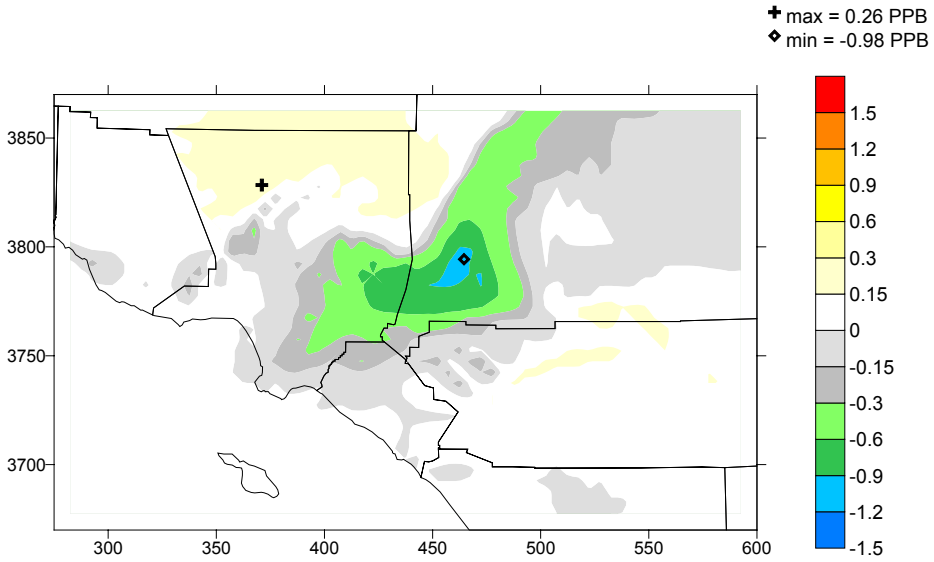
Does +2% NO_x Matter?

Air Quality Modeling

- Impact of 100% market penetration of B20 on air quality in South Coast.
- NO_x from B20 use has no negative air quality impact (changes in ozone less than 1 ppb).
- PM emission reduction showed no positive impact.
- Study by Environ, for details see NREL/SR-540-33793, April 2003

Week End Ozone Effect

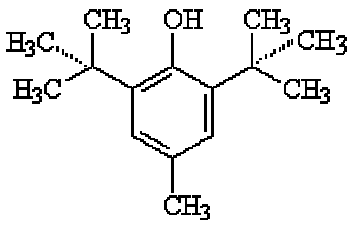
- Study suggests uncertainty in air quality implications of small changes in NOx emissions
- See EM, July 2003 pages 17 and 27



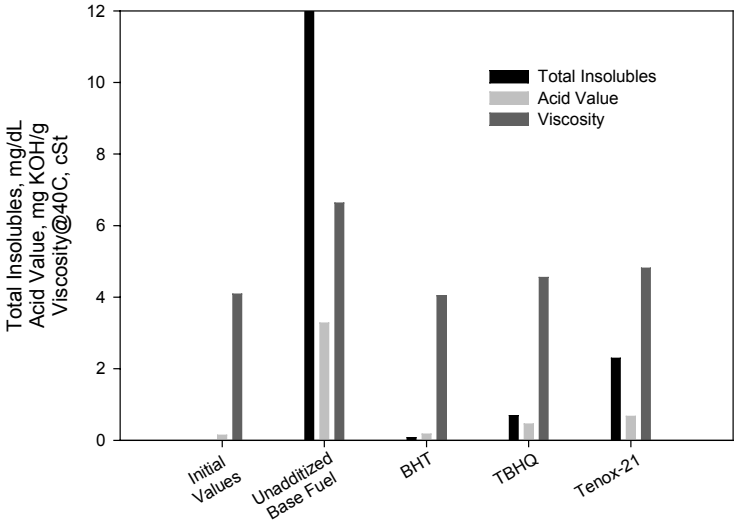
Difference in Daily Max 1-Hour Ozone (ppb)
August 07, 1997
NREL Biodiesel -- 100% Penetration B20 Biodiesel minus Base

Biodiesel Oxidative Stability

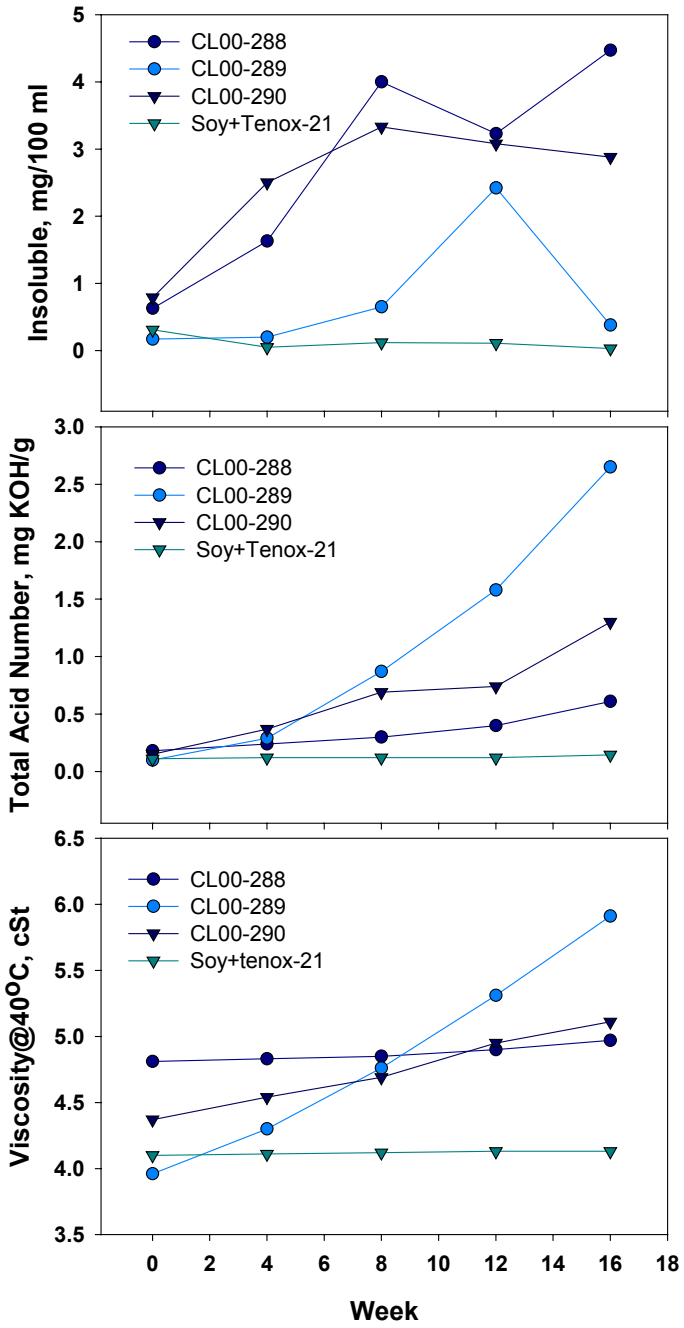
- Long-term tests show that biodiesel is unstable to oxidation
- Anti-oxidants can be effective, some biodiesel contains natural antioxidants
- B20 and B100 have different stability issues
- Issue of major concern to engine manufacturers: deposits and acidity can cause reduced life or failure of components



BHT
butylated hydroxytoluene



ASTM D4625 Standard Test for Distillate Fuel Storage, 43°C



Biodiesel Warranty Issues

- *Manufacturers warrant their products against defects in materials and workmanship*
- *In general use of a particular fuel should have no effect on the materials and workmanship warranty*
- *Use of biodiesel does not "void the warranty", this is prohibited by the Magnuson-Moss Warranty Act*
- *Manufacturers are concerned that extensive use of biodiesel will result in increased numbers of warranty claims for what are actually problems caused by the fuel*

Position Statements

While manufacturers do not warrant fuel, many have position statements and recommendations on biodiesel:

Manufacturer:	***Position:***
Engine	
EMA	Up to 5% biodiesel
Caterpillar	Many engines approved for use with B100, other limited to B5. Must meet ASTM D6751.
Cummins	All engines approved for up to 5% biodiesel.
Detroit Diesel Corporation	Approve up to 20% biodiesel if produced from virgin soybeans or rapeseed. Must meet DDC specific fuel specification.
International	No position on biodiesel specifically.
John Deere	All engines approved for 5% biodiesel if produced from soybeans and meets ASTM D6751.
Mack	No specific position, fuel additives and extenders not recommended.
Volvo	No specific position.
FIE	
Bosch	Up to 5% biodiesel accepted but must meet ASTM D6751.
Delphi	Up to 5% biodiesel accepted but must meet ASTM D6751.
Stanadyne	Up to 20% biodiesel accepted, must meet ASTM D6751.

Concerns about fuel quality and stability are what is preventing approval of blending levels above 5% for most manufacturers

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Summary

- Truly renewable petroleum displacement fuel
- Low biodiesel content blends (<5%) are fully compatible with fuel systems and should not lead to durability or maintenance issues.
- 20% biodiesel blends have some minor property and performance differences relative to conventional diesel:
  - Possibly higher T90
  - Possibly poorer stability
  - ~2% higher NOx emissions but significantly lower PM emissions
- Many manufacturers “are comfortable” with B20, but most prefer limiting biodiesel content to 5% at present