Biodiesel and Pollutant Emissions

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Results From Three Methods of Testing B20 for NO_x Emissions

Laboratory

Real-World

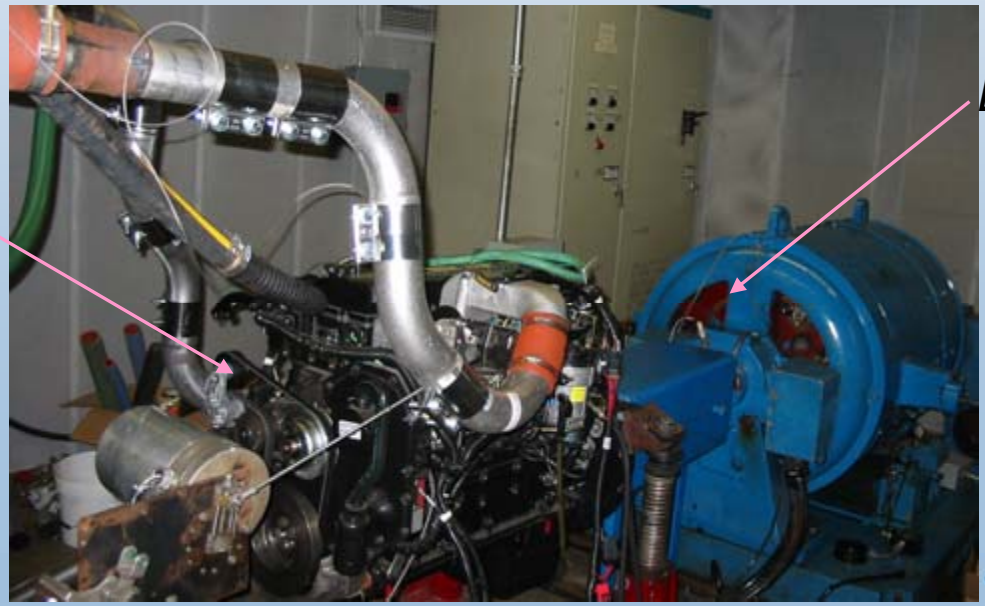
- Engine
  - 2 % increase

- Chassis
  - 0% average change

- PEMs
  - No change or decreasing

How are HD engines tested for compliance with emission standards?

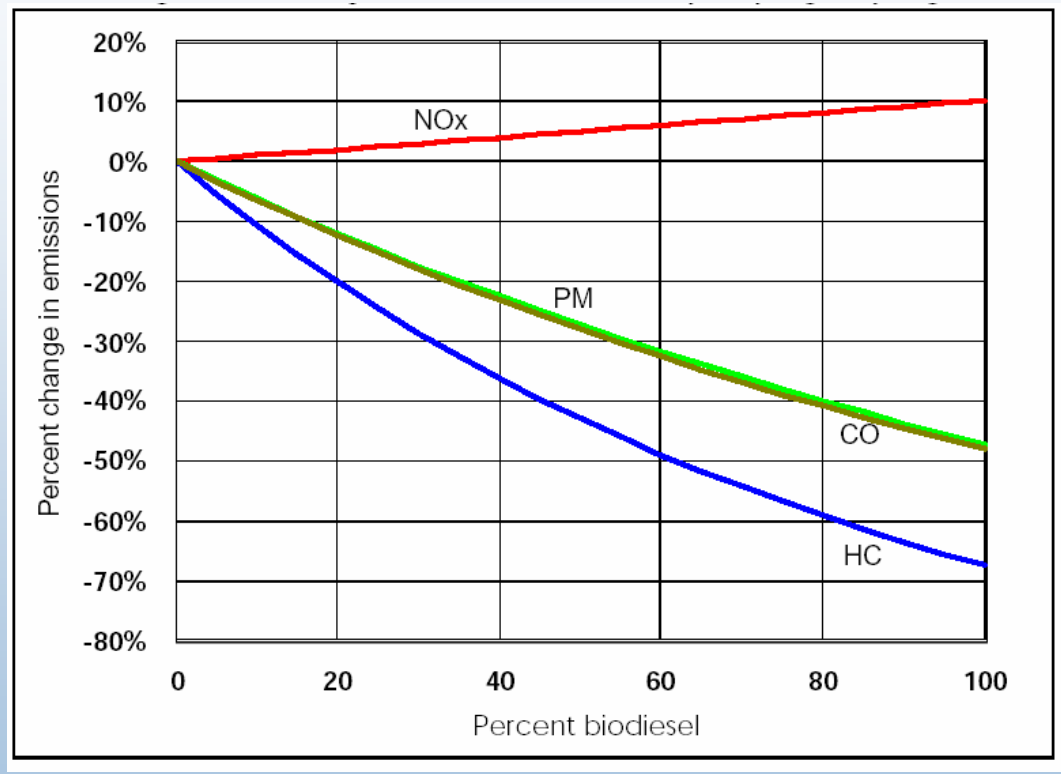
- Heavy duty engines are tested on an engine dyno
(Light duty vehicles are certified on chassis dynos)
- Bare engine is connected to large electric generator
- Operated over a range of speeds and loads
- Emissions are reported in g/bhp-h (vs g/mi for LD)
    - weight per unit of work done by the engine



Biodiesel's Effect on Emissions: Engine Compliance Test Results

EPA data compilation:
- data from many studies
- engine models < 1997

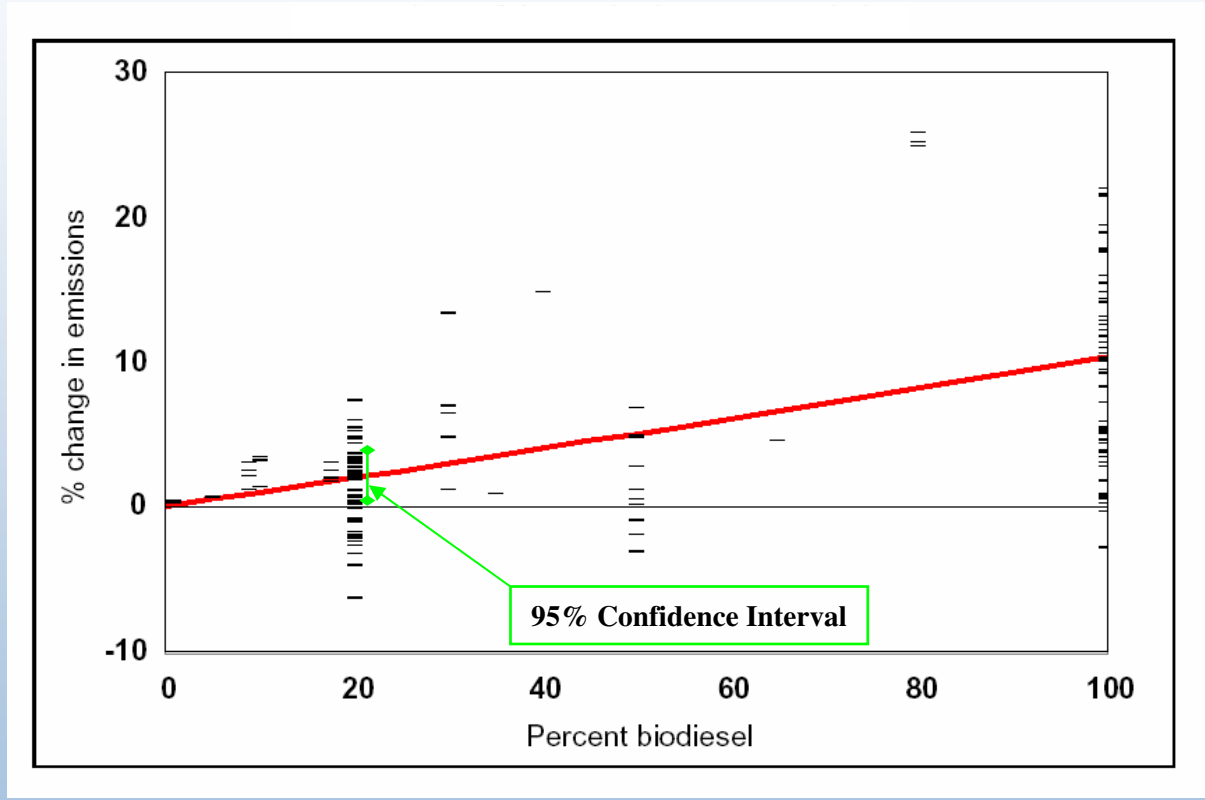
- NO_x
  - 2% up for B20
  - 10% up for B100
- PM
  - 12% down for B20
  - 48% down for B100



EPA420-P-02-001, Draft Report, October 2002

Biodiesel's Effect on NO_x Emissions -Engine Data

B20 = +2%, B100 = +10%



Model years	HD highway engines	NOx observations
2002 - 2006	0	0
1998 - 2001	2	14 (2)[a]
1994 - 1997	10	152 (19)
1991 - 1993	16	394 (50)
1990	3	87 (11)
1988 - 1989	8	112 (14)
1984 - 1987	2	16 (2)
- 1983	2	10 (1)

s are percent of total observations

- 43 engines included
- 72% of engines pre-1994
- 95% pre-1997

EPA420-P-02-001, Draft Report, October 2002

Emission Benefits of B20

- Broad agreement on reductions of PM
  - 10 to 25% reduction in PM, depending on engine, test cycle, and other factors
- Impact on NO_x emissions less certain
  - EPA compilation of published data found B20 causing NO_x to go up ~2%
  - But many newer studies show NO_x going down
- Definitive conclusion for NO_x requires a dataset more representative of today's fleet

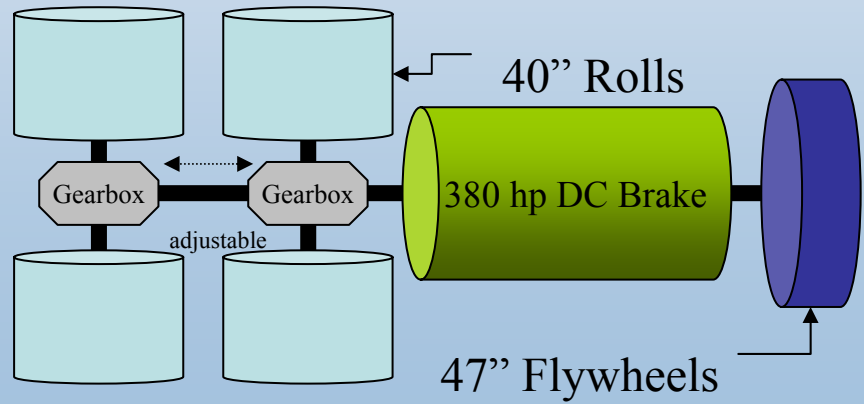
Recent Engine Testing Results

- **Engine dyno results published since release of EPA review**
- **Average change in NO_x for B20 use is 0.8%+/-0.8%**
  - –Change is not significantly different from zero
- **Average change in NO_x for soy-derived B20 use is -0.1%+/-1.1%**
  - –Change is not significantly different from zero

	Engine	Cycle	%Biodiesel	NO_x	HC	CO	PM
Frank, et al., 2004	International DT466 (4 g/bhp-h NO_x with DOC)	Hot FTP	20 (soy)	-10	-20	-38	-2.9
Souligny, et al., 2004	Cummins 8.3L (4 g/bhp-h NO_x Mech)	Hot FTP	20 (Veg Oil)	1.1	-12	-25	-31
			20 (Waste Grease)	0.3	-7.0	-25	-20
			20 (Animal Fat)	-1.5	-13	-17	-22
	Cummins 8.3L (4 g/bhp-h NO_x Elec)	Hot FTP	20 (Veg Oil)	1.7	-21	-28	-17
			20 (Waste Grease)	-4.5	-25	-31	-14
			20 (Animal Fat)	-2.9	-30	-25	-7.8
Alam, et al., 2004	Cummins 5.9L (4 g/bhp-h NO_x)	AVL 8-Mode	20 (soy- 325 ppm S Base)	0	--	--	-27
			20 (soy-15 ppm S Base)	-3	--	--	-6
McCormick, et al., 2005	Cummins 5.9L (2.5 g/bhp-h NO_x)	Hot FTP	20 (soy)	3.6	-4.2	-10.5	-22
	DDC S60 (4 g/bhp-h NO_x Elec)	Hot FTP	20 (soy)	6.0	0	0	-26
Environment Canada, 2005	Caterpillar 3126E (4 g/bhp-h NO_x)	Hot FTP	20 (soy)	0	-16	-6.7	-1.1
	Average			**-0.8**	**-14.8**	**-20.6**	**-16.4**
	95% Confidence Interval			**0.8**	**2.0**	**2.5**	**1.9**

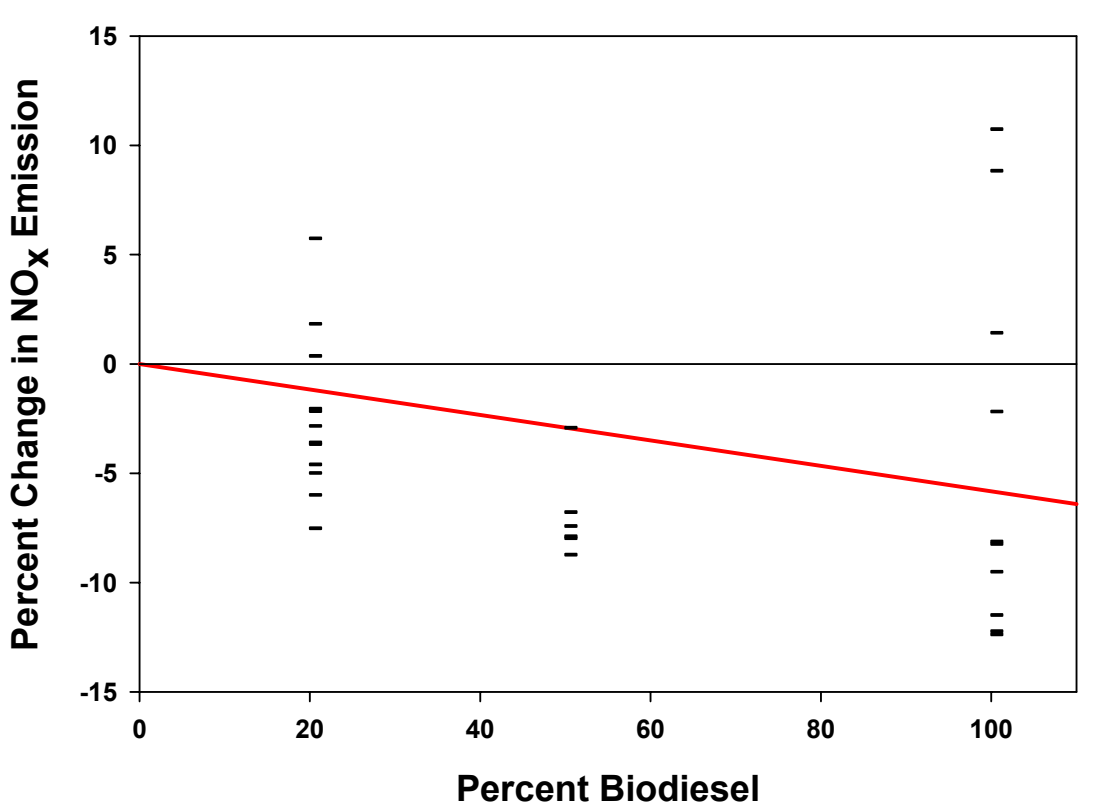
A Second Way to Measure Emissions

- **Test entire vehicles**
  - More realistic than engine testing
- NREL's HD chassis dyno
  - One of six in the US
  - 2007 CFR Emissions Sensitivity
  - 8,000–80,000 lb Range



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

- *EPA draft report also included some vehicle test data*
- *For these vehicles, on average, biodiesel has no impact on NO_x*
  - *Slope is not statistically significant (p=0.5)*



Model Years	#Vehicles
2002-2006	
1998-2001	
1994-1997	6
1991-1993	
1990	1
1988-1989	2
1984-1987	1
-1983	1

8 pickup trucks tested on UDDS
3 transit buses on various cycles

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

NREL Vehicle Testing Summary

- **Average change in NO_x for B20 use is 0%**
  - No statistically significant change (less that +/- 0.4%)
  - Versus +2% in EPA analysis
- Magnitude, direction of NO_x impact is cycle dependent
- **Average change in PM for B20 use is -21%**
  - Versus -12% in EPA data compilation

Vehicle	Engine		MY	Cycle	NOx % Change	PM % Change
1	Cummins ISM	Transit Bus	2000	CSHVC	-3.8	-17.4
2	Cummins ISM	Transit Bus	2000	CSHVC	-6.2	-49.3
3	Cummins ISM	Transit Bus	2000	CSHVC	-4.1	-22
4	Cummins ISM	Class 8	2005	CILCC	0.0	-27
4	Cummins ISM	Class 8	2005	WVU Interstate	2.0	-35
5	International Green Diesel	School Bus	2005	RUCSBC	1.5	0*
5	International Green Diesel	School Bus	2005	CSHVC	-1.0	0*
6	Cummins ISB	Motorcoach	2003	CSHVC	2.8	-28.1
6	Cummins ISB	Motorcoach	2003	UDDS	3.4	-30
7	DDC S60	Class 8	2000	CSHVC	2.1	-19.4
7	DDC S60	Class 8	2000	WVU Interstate	3.6	-26.2
8	International 7.6L	School Bus	2004	CSHVC	-0.7	2.5
8	International 7.6 L	School Bus	2004	RUCSBC	6.2	-24

**Vehicle equipped with diesel particle filter*

Recent Chassis Testing Results

- **Chassis dyno results published since release of EPA review**
- **Average change in NO_x for B20 use is 1.6%+/-1.8%**
  - –Change is not significantly different from zero
- **In addition, DoD study of 6 on-highway vehicles found on average no affect of B20 on NO_x**
  - –Holden et al., Technical Report TR-2275-ENV, June 2006

Reference	Engine	Cycle	%Biodiesel	NO_x	HC	CO	PM
Petersen et al., 2000	1994 Cummins ISB	UDDS	20 (REE)	-3.1	-36	-37	-12
Environment Canada, 2005	2003 Cummins ISM	UDDS	20 (soy)	-3.1	-8.2	-16	-20
		WVU 5 Pk	20 (soy)	-2.5	-23	-19	12
	2004 MBE4000	UDDS	20 (soy)	14	-23	-19	-20
	1999 Caterpillar C12	UDDS	20 (soy)	3	-21	-17	-27
		WVU 5 Pk	20 (soy)	1.5	-21	-7.6	-2.9
		Average		**1.6**	**-22.0**	**-19.3**	**-11.7**
	95% Confidence Interval			**1.8**	**2.4**	**2.7**	**3.9**

A Third Way to Measure Emissions: PEMS

- Portable Emissions Measurement System
  - On-board vehicle
  - Measures emissions during normal operation
- The most real-world emission measurement
- Basis for new EPA inventory model MOVES

Results of recent PEMS Studies

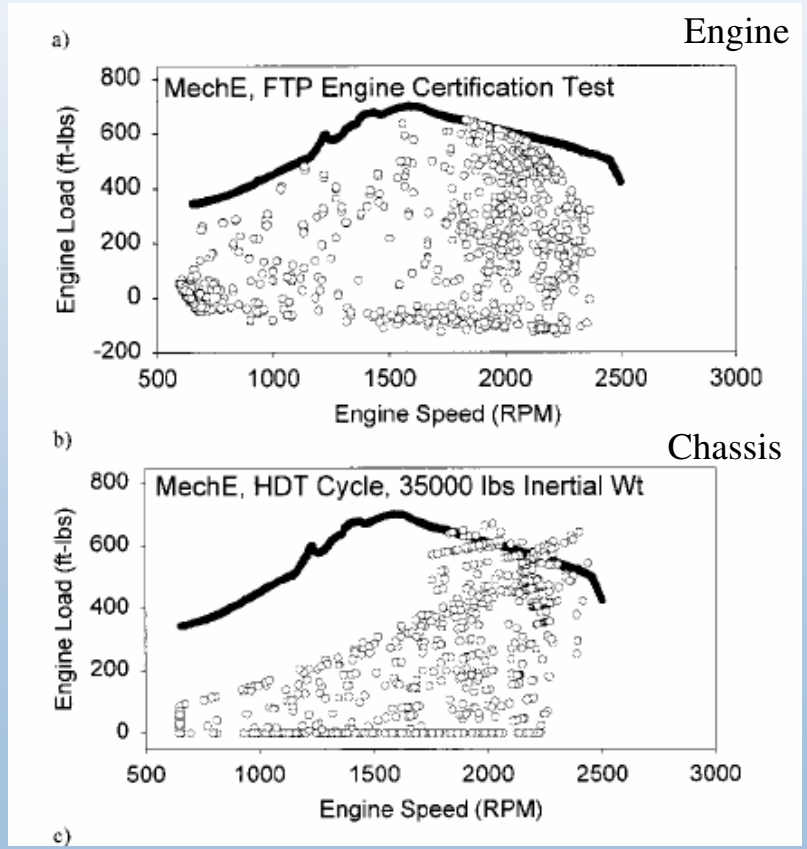
- North Carolina: **12 Dump Trucks**
  - NO was **reduced by 10%** on average
  - http://www.ncdot.org/doh/preconstruct/tpb/research/download/2004-18FinalReport.pdf
- New Jersey: **3 School Buses**
  - NO_x **results mixed**: increased in some buses, decreased in others
  - **SAE 2005-01-1616**
- Texas: **5 School Buses**
  - Compare TxLED, B20 (market), B20 (soy)
  - B20 had **no effect** NO_x
  - Texas Transportation Institute at Texas A&M, August 2006

Biodiesel Effect on NO_x- Uncertainty!

- *NO_x can go up or down depending on engine and test cycle*
  - *Not well understood quantitatively*
- *Very limited dataset exists today, esp. for a representative sample of post-1996 engines/vehicles*
- *Thus it is very difficult to make a directional or quantitative finding regarding the impact of B20 on NO_x*
  - *Change is likely in the range of +/- 2% or less*
  - *An average impact of zero seems probable*
- *Impact on PM and other Carbon-containing pollutants is more robust, and very favorable*

Engine and Vehicle Tests are Fundamentally Different

- *Differences in NO_x emissions between engine and vehicle tests may be test cycle differences*
- *For vehicles, the transmission limits actual speeds and loads*



Yanowitz, Graboski, and McCormick *Environ. Sci. Technol.* **2002**, 36, 270-275

Results From Three Methods of Testing B20 for NO_x Emissions

Laboratory

Real-World

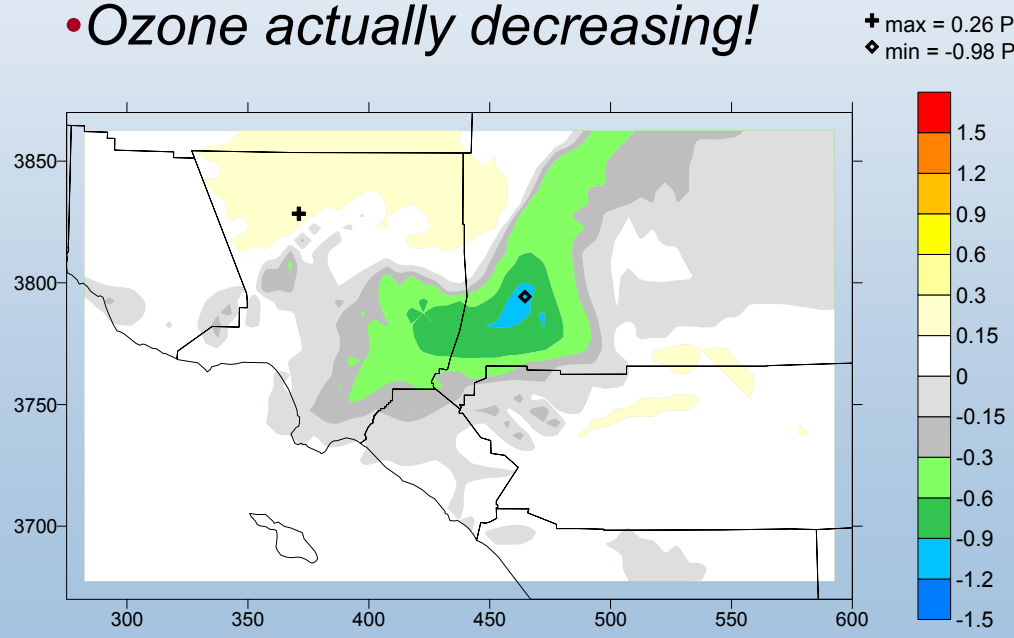
- Engine
  - 2 % increase (EPA review)
  - 0% change (newer studies)
- Chassis
  - 0% change (EPA review)
  - +1% newer (newer studies)
  - 0% change (NREL study)
- PEMs
  - No change or decreasing

Literature Review/DOE Milestone Report due October 2006

- NREL will publish this analysis in MP-540-40554 on our website:
  - http://www.nrel.gov/vehiclesandfuels/npbf/publications.html
- Includes ~ 50 references
  - engine data from 7 studies, MY2001+
    - NOx changes avg. 0.1% +/- 1.1%
  - chassis data from 4 studies
    - NOx changes avg. +1.2% +/- 1.0%

Air Quality Modeling for Biodiesel

- Impact of 100% market penetration of B20 on air quality in Chicago area, Northeast Corridor, and South Coast Air Basin.
- Air-shed scale effects –assuming 2% increase in NO_x:
  - *NO_x from B20 use has no negative air quality impact*
    - *Changes in ozone less than ~1 ppb*
    - *Ozone actually decreasing!*



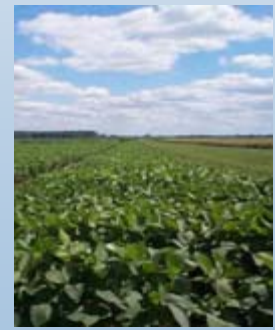
Difference in Daily Max 1-Hour Ozone (ppb)
August 07, 1997
NREL Biodiesel -- 100% Penetration B20 Biodiesel minus Base

Analysis from NREL/SR-540-33793, April 2003

Biodiesel is truly renewable

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

- **Petroleum diesel uses 1.2 MJ of fossil energy to produce 1 MJ of fuel product energy; *FER = 0.83***
- **Biodiesel uses 0.31 MJ of fossil energy to produce 1 MJ of fuel product energy; *B100 FER = 3.2***
- ***B20 reduces life cycle petroleum consumption by 19%***
- ***B20 reduces life cycle CO_2 emissions by 16%***



Biodiesel is a significant sustainable energy resource for the United States

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

What's next?

Stay tuned for more data!

Thank you