

Biodiesel (B20) and Pollutant Emissions

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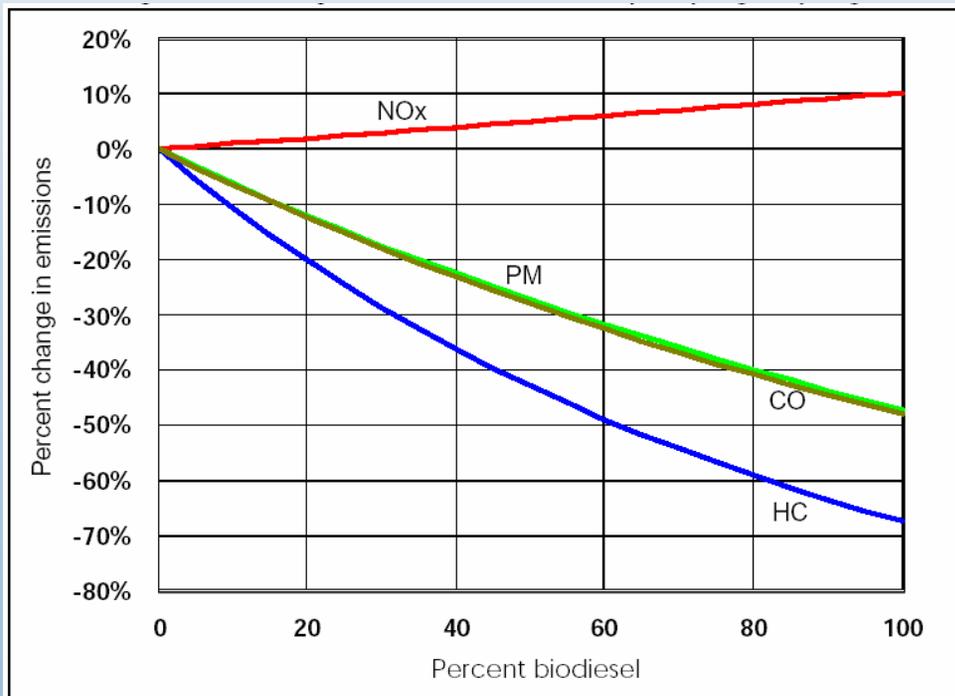
Emission Benefits of B20

- Broad agreement on emission reductions:
 - 10% to 25% reduction in PM, depending on engine, test cycle, and other factors
 - 10% to 20% reductions in CO, HC, and toxic compounds
- Impact on NO_x emissions uncertain
 - EPA compilation of published data found B20 causing NO_x to go up ~2%
 - But many studies in the review show NO_x going down
 - Many newer studies show NO_x going down

Biodiesel's Effect on Emissions:

Engine test results compiled by EPA

- Engine models through 1997
- Data from many published studies conducted by others for different purposes
- 2% increase in NO_x on average for B20
- 12% decrease in PM on average for B20

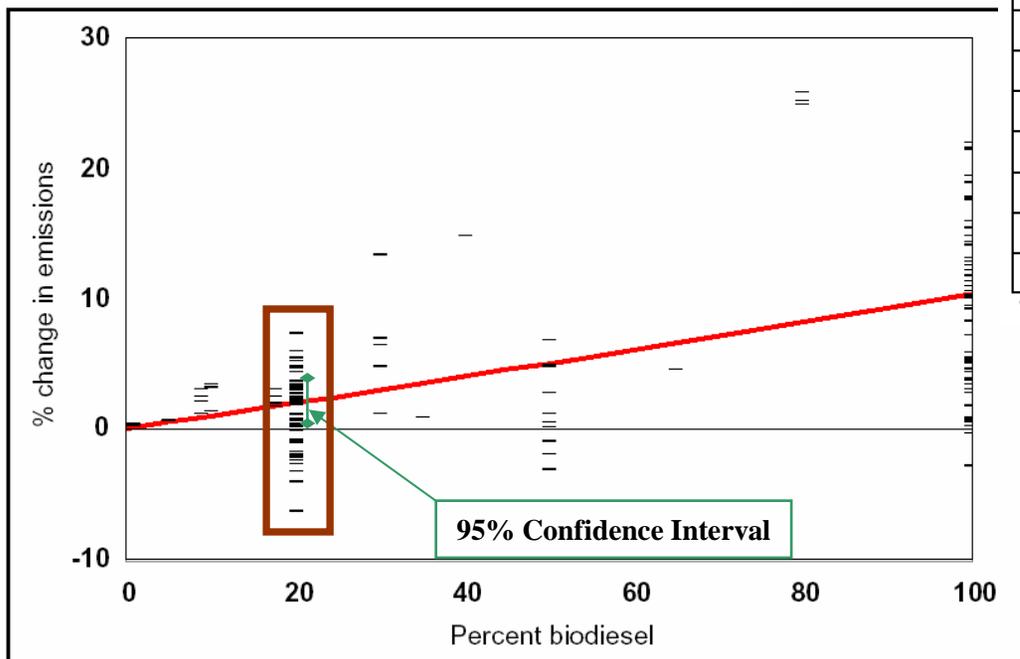


EPA420-P-02-001, October 2002

Biodiesel's Effect on NO_x Emissions

EPA Review - Engine Data

- Percent change in NO_x for B20 ranges from -7% to +7%
- Average change in NO_x +2%



Standards group	Model years	HD highway engines	NOx observations
B	2002 - 2006	0	0
C	1998 - 2001	2	14 (2) ^a
D	1994 - 1997	10	152 (19)
E	1991 - 1993	16	394 (50)
F	1990	3	87 (11)
G	1988 - 1989	8	112 (14)
H	1984 - 1987	2	16 (2)
I	- 1983	2	10 (1)

^a Values in parentheses are percent of total observations

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



Many B20 tests show NO_x decreasing:

- All are for soy biodiesel
- Engine standards groups D and E

Recent Engine Testing Results

Engine	Cycle	%Biodiesel	NO _x	HC	CO	PM
Navistar 7.3-L (5 g/bhp-h NO _x)	AVL 8-Mode	100 (RME)	≈0	--	--	≈-20%
Volvo 9.6-L	ECE R49	30 (RME)	1.7	0	-9.4	-24
International DT466 (4 g/bhp-h NO _x with DOC)	Hot FTP	20 (SME)	-10.3	-20	-38	-2.9
-with DPF		20 (SME)	0	≈0	≈0	≈0
-with EGR and DPF		20 (SME)	1.8	≈0	≈0	≈0
Cummins 8.3-L (4 g/bhp-h NO _x Mech)	Hot FTP	20 (SME)	1.1	-12	-25	-31
		20 (Waste Grease)	0.3	-7.0	-25	-20
		20 (Animal Fat)	-1.5	-13	-17	-22
Cummins 8.3-L (4 g/bhp-h NO _x Elec)	Hot FTP	20 (SME)	1.7	-21	-28	-17
		20 (Waste Grease)	-4.5	-25	-31	-14
		20 (Animal Fat)	-2.9	-30	-25	-7.8
Cummins 5.9-L (4 g/bhp-h NO _x)	AVL 8-Mode	20 (SME, 325 ppm S Base)	0	--	--	-27
		20 (SME, 15 ppm S Base)	-3	--	--	-6
Cummins 5.9-L (2.5 g/bhp-h NO _x)	Hot FTP	20 (SME)	3.6	-4.2	-10.5	-22
DDC S60 (4 g/bhp-h NO _x)	Hot FTP	20 (SME)	6.0	0	0	-26
Caterpillar 3126E (4 g/bhp-h NO _x)	Hot FTP	20 (SME)	0	-16	-6.7	-1.1
		B20 Average	-0.6	-12.4	-17.2	-14.1
		95% Confidence	2.0	5.4	7.0	5.7

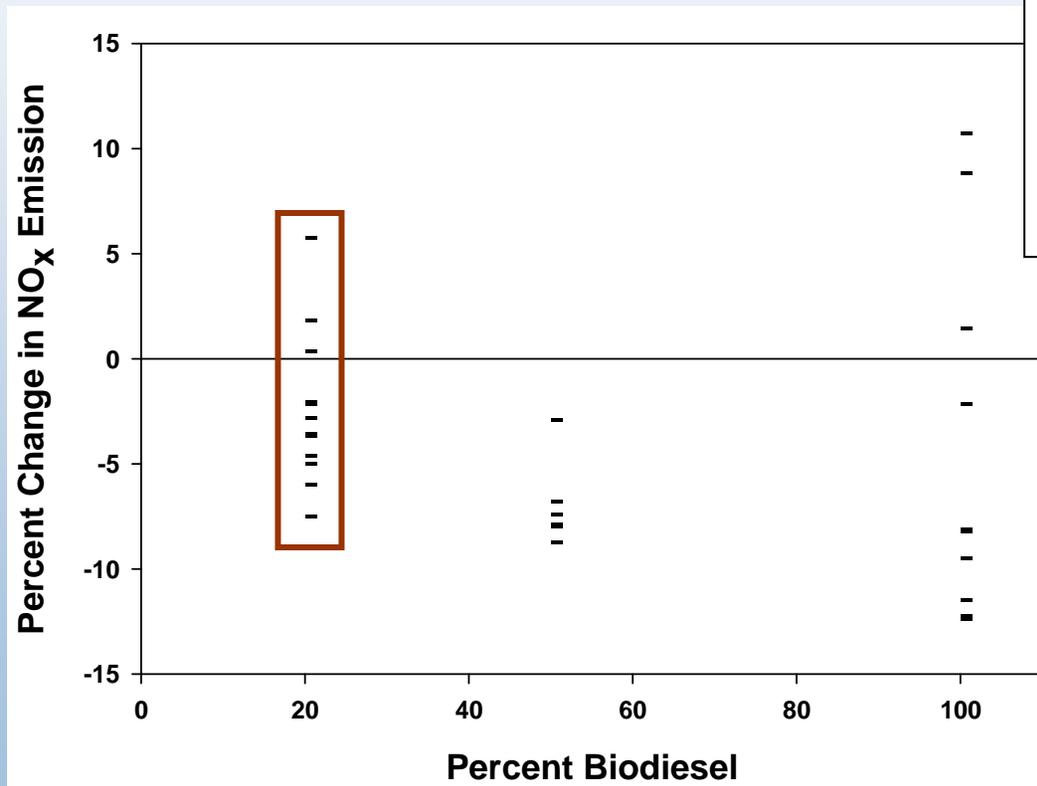
- Engine dyno results published since release of EPA review
- Percent change in NO_x ranges from -10% to +6%
- Average change in NO_x for B20 is -0.6%±2.0%
 - Change is not significantly different from zero
- Average change in NO_x for soy-derived B20 is 0.1%±2.7%
 - Change is not significantly different from zero



Biodiesel's Effect on NO_x Emissions

EPA Review - Vehicle (Chassis) Data

- EPA compilation also included published vehicle test data
- B20 produced a wide range of NO_x changes -7.7% to +5.8%
- *B20 average change -2.4%±2.3%*



Standards Group	Model Years	#Vehicles
B	2002-2006	
C	1998-2001	
D	1994-1997	6
E	1991-1993	
F	1990	1
G	1988-1989	2
H	1984-1987	1
I	-1983	1

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



Recent Chassis Testing Results

- Chassis dyno results published since release of EPA review
- NO_x ranges from -3% to +14%
- *Average change in NO_x for B20 is 1.4%±4.5%*
 - 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

Engine	Cycle	%Biodiesel	NO _x	HC	CO	PM
1994 Cummins ISB	UDDS	20 (REE)	-3.1	-36	-37	-12
Audi TDI	FTP75	30 (RME)	0	-13	5.5	-22
2003 Cummins ISM	UDDS	20 (SME)	-3.1	-8.2	-16	-20
	WVU 5 Pk	20 (SME)	-2.5	-23	-19	12
2004 MBE4000	UDDS	20 (SME)	14	-23	-19	-20
1999 Caterpillar C12	UDDS	20 (SME)	3	-21	-17	-27
	WVU 5 Pk	20 (SME)	1.5	-21	-7.6	-2.9
		Average	1.4	-21	-16	-13
		95% Confidence	4.5	6.5	9.5	10

NREL Vehicle Testing Summary

- Percent change in NO_x ranges from -5.8% to +6.2%
- *Average change in NO_x is 0.6% ±1.8%*

Vehicle	Cycle	NO _x % Change	PM % Change	CO % Change	THC % Change
Transit Bus #1	CSHVC	-5.8	-17.4	-26.8	-28.3
Transit Bus #2	CSHVC	-3.9	-33	-20.3	-28
Transit Bus #3	CSHVC	-3.2	-18.85	-15.25	-24.05
Freightliner Class 8	CSHVC	2.1	-19.4	-10.7	-15.2
	Freeway	3.6	-26.2	-6.9	-16
Motor Coach	CSHVC	2.8	-28.1	-22.3	-14.5
	UDDS	3.4	-30	-19.2	-3.4
International Class 8	CILCCmod	-0.1	-27.2	-15.3	-16.8
	Freeway	2.3	-34.7	-14.5	-12.4
Green Diesel School Bus	CSHVC	-0.8	28	-15.9	35.2
	RUCSBC	2.3	15.6	-41.7	-7
Conventional School Bus	CSHVC	-0.7	2.5	9.5	-1.1
	RUCSBC	6.2	-24	-22.6	-19.6
	Average	0.6	-16.4	-17.1	-11.6
	95%+/-	1.8	10	6.1	8.6



*Vehicle equipped with diesel particle filter, changes in PM, CO, and THC not statistically significant

Effects of Biodiesel Blends on Vehicle Emissions:
<http://www.nrel.gov/docs/fy07osti/40554.pdf>

Results of PEMS Studies

- North Carolina: 12 Dump Trucks
 - Measured only NO, not NO+NO₂
 - *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 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 on NO_x*
 - Texas Transportation Institute at Texas A&M, August 2006

Results From Three Methods of Testing B20 for NO_x Emissions

Laboratory



- Engine
 - 2 % increase (EPA review)
 - 0% change (newer studies)
- Chassis
 - 0% change (EPA review)
 - 0% newer (newer studies)
 - 0% change (NREL study)

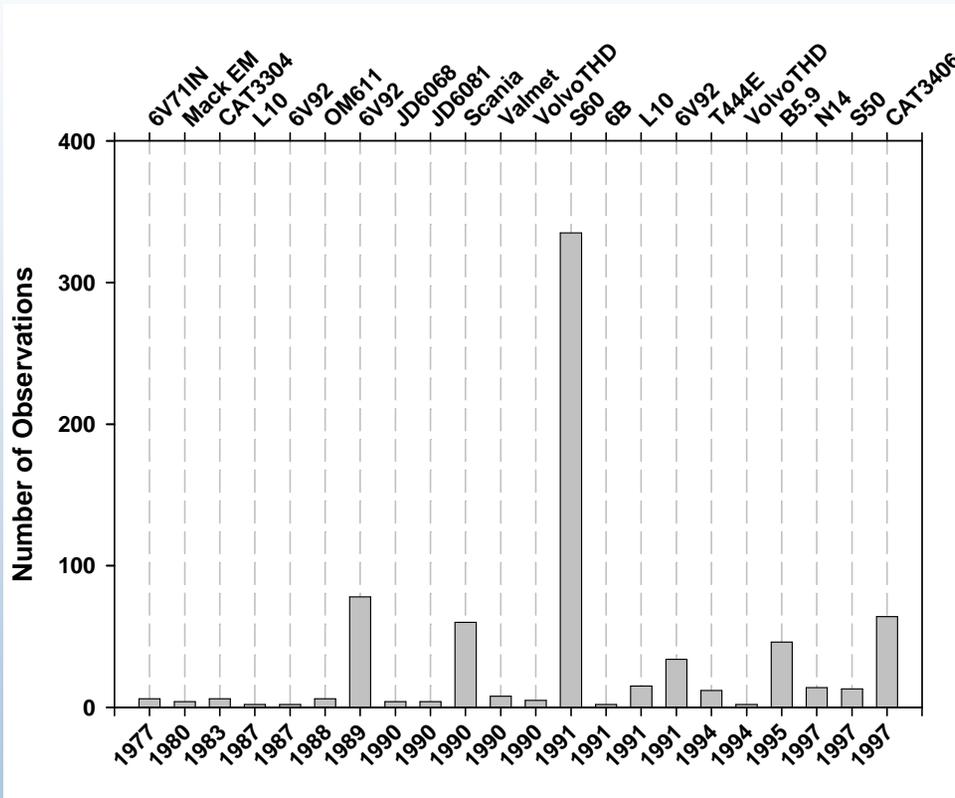


Real-World

- PEMs
 - 0% change



Engines Included in EPA Review



- 785 NO_x observations considered in EPA review
- ~45% of the data are for 1991 DDC Series 60 engines
 - Shows a consistent small increase in NO_x for B20
- Given engine-to-engine variability for B20:
 - EPA analysis weights results for this engine too heavily

Biodiesel Effect on NO_x

- *NO_x can go up or down depending on engine*
 - *This is not well understood quantitatively*
 - *Hypothesis: Varying ECU response to small change in density/energy density for B20 versus diesel*
- *Data compilations that are not weighted to one engine model show no change in NO_x on average for B20*
- *Based on the additional data available today:*
 - ***B20 appears to have no significant or consistent impact on NO_x emissions***
- *Reduction in PM and other pollutants is robust*

Effects of Biodiesel Blends on Vehicle Emissions:

<http://www.nrel.gov/docs/fy07osti/40554.pdf>

Detailed citations:

- Holden, B., Jack, J., Miller, W., Durbin, T. “Effect Of Biodiesel On Diesel Engine Nitrogen Oxide and Other Regulated Emissions” Technical Report TR-2275-ENV, Naval Facilities Engineering Command, Port Hueneme, California. May 2006.
 - Tested 6 on-highway vehicles, found no change in NO_x on average
- Farzeneh, M., Zietsman, J., Perkinson, D.G. “School Bus Biodiesel (B20) NO_x Emissions Testing” Texas Transportation Institute at Texas A&M University, August 2006
 - Tested 5 school buses, found no change in NO_x on average
- Frey, H.C., Kim, K. “Operational Evaluation of Emissions and Fuel Use of B20 versus Diesel Fueled Dump Trucks” Research Project No. 2004-18 FHWA/NC/2005-07, September 2005.
 - Tested 12 DOT dump trucks, found NO going down