QUANTIFYING THE EMISSIONS BENEFIT OF OPACITY TESTING AND REPAIR OF HEAVY-DUTY DIESEL VEHICLES

Robert L. McCormick, Michael S. Graboski, Teresa L. Alleman, Javier R. Alvarez
Colorado Institute for Fuels and Engine Research
Colorado School of Mines
Golden, CO 80401-1887
K.G. Duleep
Energy and Environmental Analysis, Inc.
Arlington, VA 22209

Acknowledgements:

This study was sponsored by the **Air Pollution Control Division** of the **Colorado Department of Public Health and Environment**. This study was also sponsored by the **Office of Transportation and Air Quality** of the **U.S. Environmental Protection Agency**. The authors wish to thank these entities for their support.

The authors also wish to thank the many truck owners, large and small, that allowed their vehicles to be used in this study.

Study Objectives:

- Begin to quantify the benefits of a smoke opacity (SAE J1667 test) based inspection and maintenance program.
- Provide data useful for selection of opacity failure points.

Approach:

- Identify smoking trucks by various means (calling fleets, smoking vehicle hot line, Colorado snap test,…... Obtain permission to test.
- Test these vehicles on HD chassis dynamometer via UDDS driving cycle with measurement of THC, CO, NO_x, PM.
- Repair vehicles to have reduced opacity. Repairs performed at OEM local reps or other authorized facilities.
- Repeat chassis dynamometer tests.
- Best possible I/M scenario-close monitoring of technicians to insure that real repairs were performed.

Scope and Limitations:

- Twenty six vehicles tested before repair
  - Seventeen pre-1991, four exhibited low opacity and were not repaired, two were repaired twice.
  - Nine 1991 and later, one exhibited low opacity and was not repaired, a second was not made available by the owner for final testing.
- Twenty vehicles in total repaired and tested a second time.
- Pre-repair opacity ranged from 23 to 99%.
- Engine model years ranged from 1986-1999.
- GVW from 11,000 to 80,000 lb.
- Engines manufactured by DDC, Caterpillar, Cummins, Isuzu, Ford, International, GMC.

Summary Results:

	Smoke Opacity, %	THC, g/mi	NO_x, g/mi	CO, g/mi	PM, g/mi	Range PM, g/mi
Pre-1991:						
Repaired vehicles (pre)	54	7.0	22.1	36.8	5.6	2.0-16.4
Repaired vehicles (post)*	39	2.1	30.9	29.9	3.3	0.89-5.4
1991 and Later:						
Repaired vehicles (pre)	66	5.5	12.1	17.6	2.2	0.35-6.2
Repaired vehicles (post)	39	0.74	14.4	14.8	1.3	0.44-4.8
NFRAQS Study[i]	24	1.3	21.0	16.8	1.7	--
Review of Diesel Emissions[ii]	--	2.2	24.4	11.0	1.6	--

*After all repairs for vehicles undergoing two rounds of repair.

---

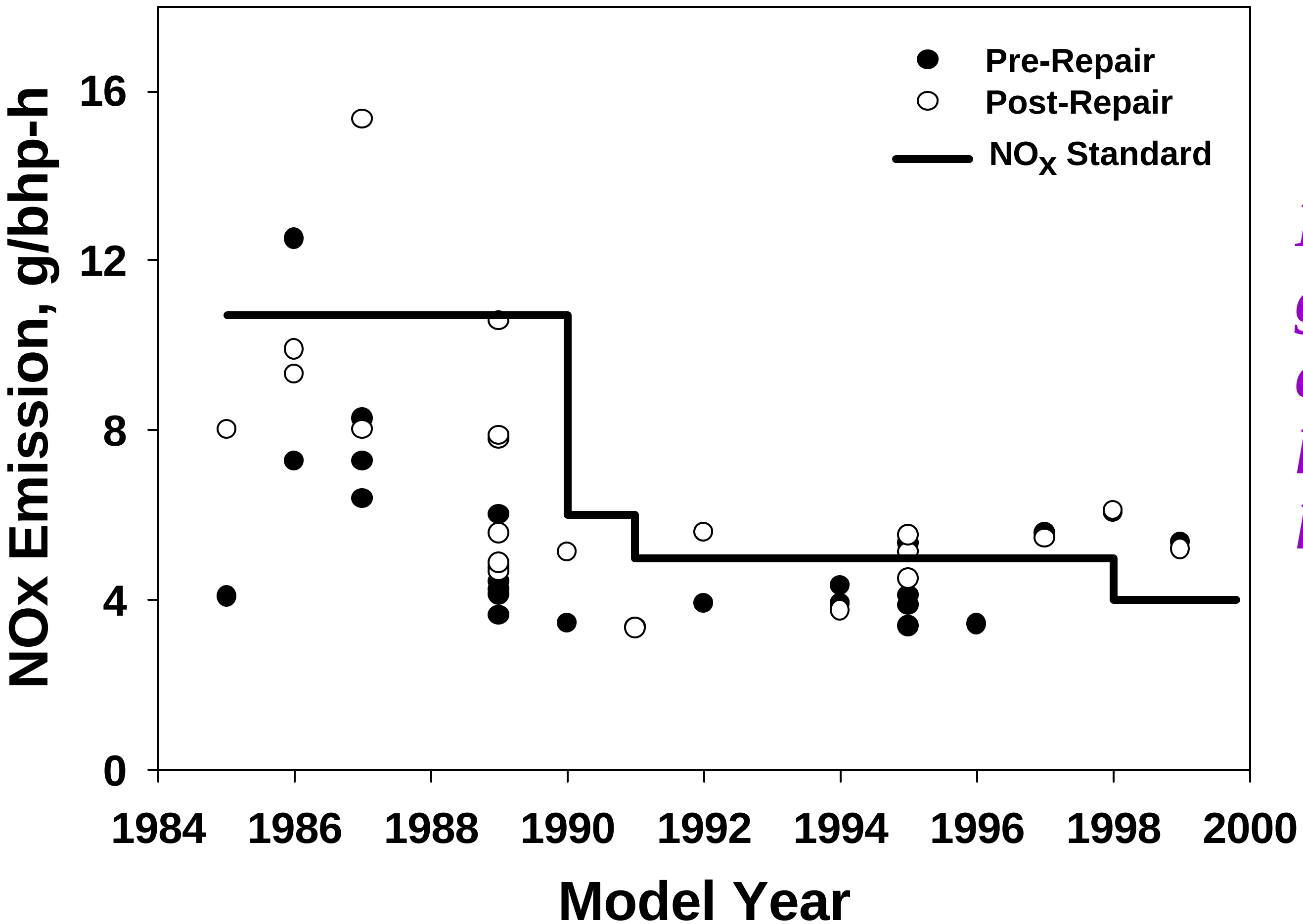
[i] Yanowitz, J., Graboski, M.S., Ryan, L.B.A., Daniels, T.L., McCormick, R.L. *Environ. Sci. Technol.* **1999**, *33*, 209-216.

[ii] Yanowitz, J., McCormick, R.L., Graboski, M.S. *Environ. Sci. Technol.* **2000,** *34*, 729-740.

Brake specific NO_x emissions before and after repair compared to the NO_x emission standards:

-Except for the newest engines, NOx goes up after repair

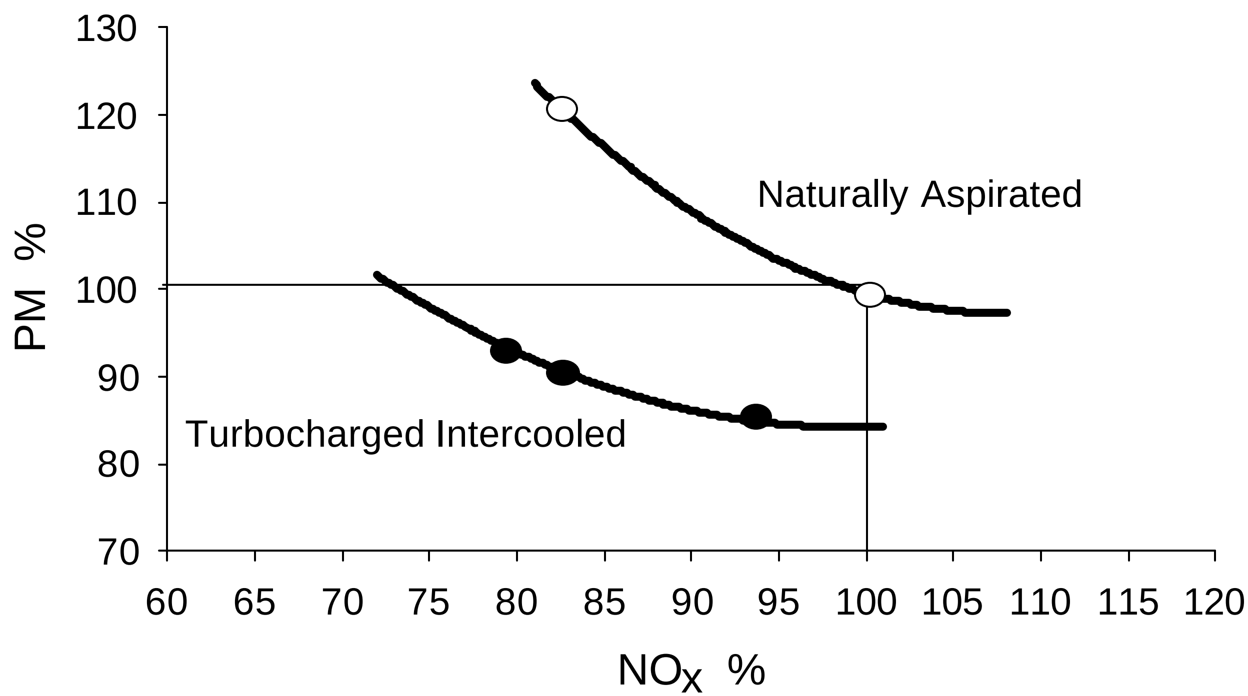
-but to levels that are close to the emission standards



Mechanically governed engines deteriorate to have higher PM and lower NO_x?

(The well-known) NO_x/PM Trade-Off:

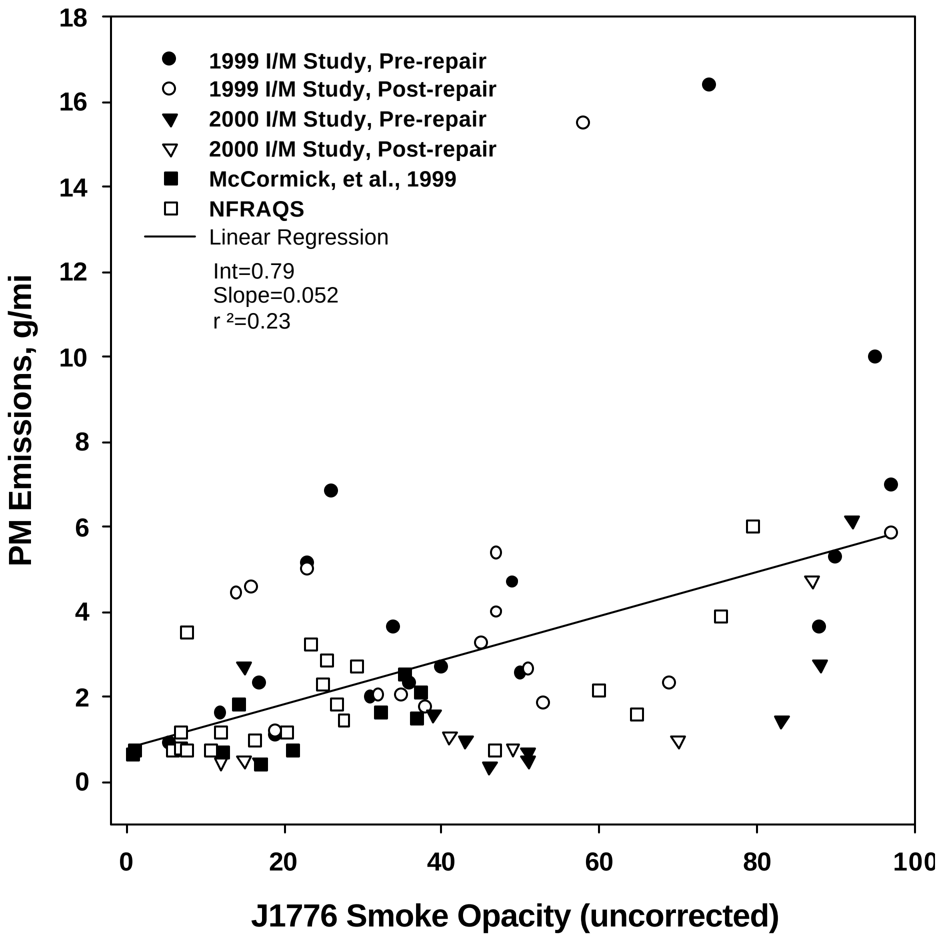
Engine operating strategies that lower NO_x cause a lowering of combustion temperature and increase in PM
-deterioration of injectors, pumps, etc lowers combustion temperature, reducing engine efficiency and lowering NO_x

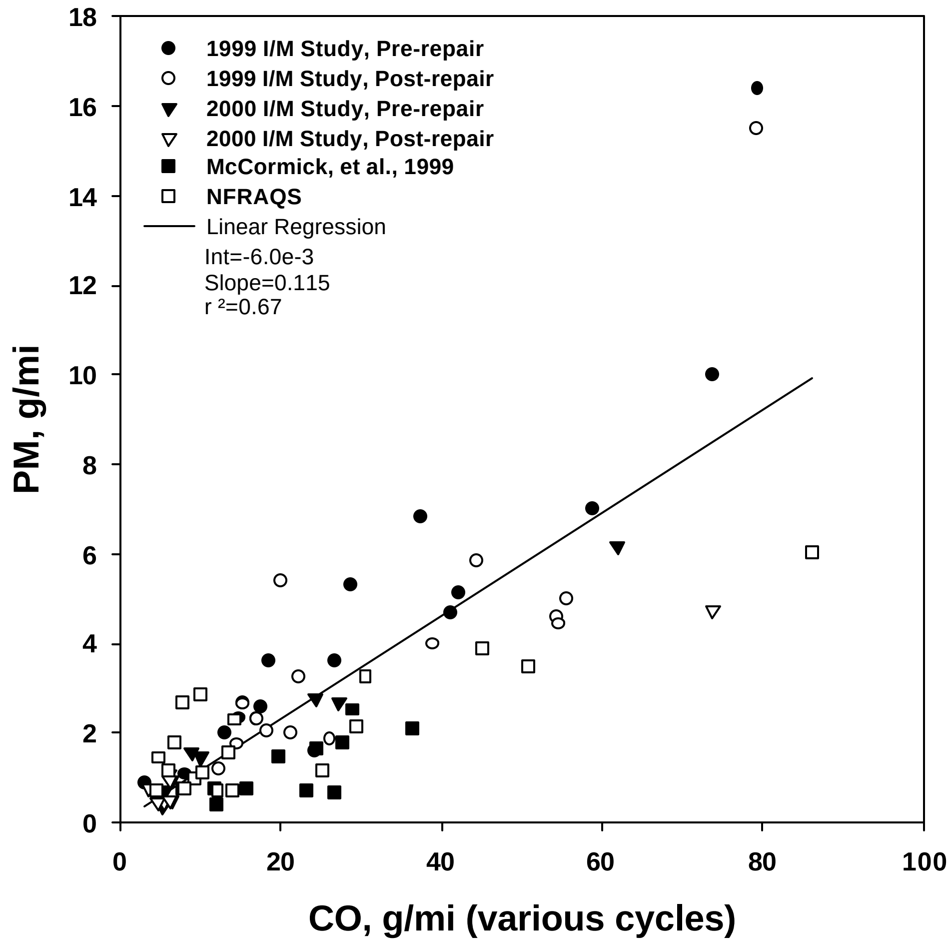


Opacity Testing/Repair Observations :

- Most repairs involved fuel injectors, fuel pumps, fuel pump calibration, throttle controls and injection timing.
- Average repair cost was $1,088 (range $699-$2053) and was similar for both pre-1991 and 1991+ engines. One outlier cost $85 to reduce opacity from 50 to 17% and reduce PM by 35%.
- Most vehicles were out of service for 2 days due to repair, but some required as long as two weeks-usually for multiple repairs.
- Repair of pre-1991 vehicles exceeding 45% opacity reduced PM emissions by 45-50%. A PM benefit was observed for *every* vehicle repaired. NOx increased by about 35% on average.
- Repair of 1991+ vehicles exceeding 40% opacity reduced PM emissions by 25-30%. For one vehicle there was no PM benefit. NOx increased by 7% on average.

Relationship Between PM and Opacity or CO:





Predicting PM with Snap Acceleration Peak CO:

-CO is well correlated with PM.

-Opacity and idle emissions of CO are poorly correlated with PM.

-This suggests a simple tail-pipe CO measurement to identify high PM emitters.

-gaseous emissions measured during snap-test identical to J1667

-1991+ vehicles only (7 vehicles)

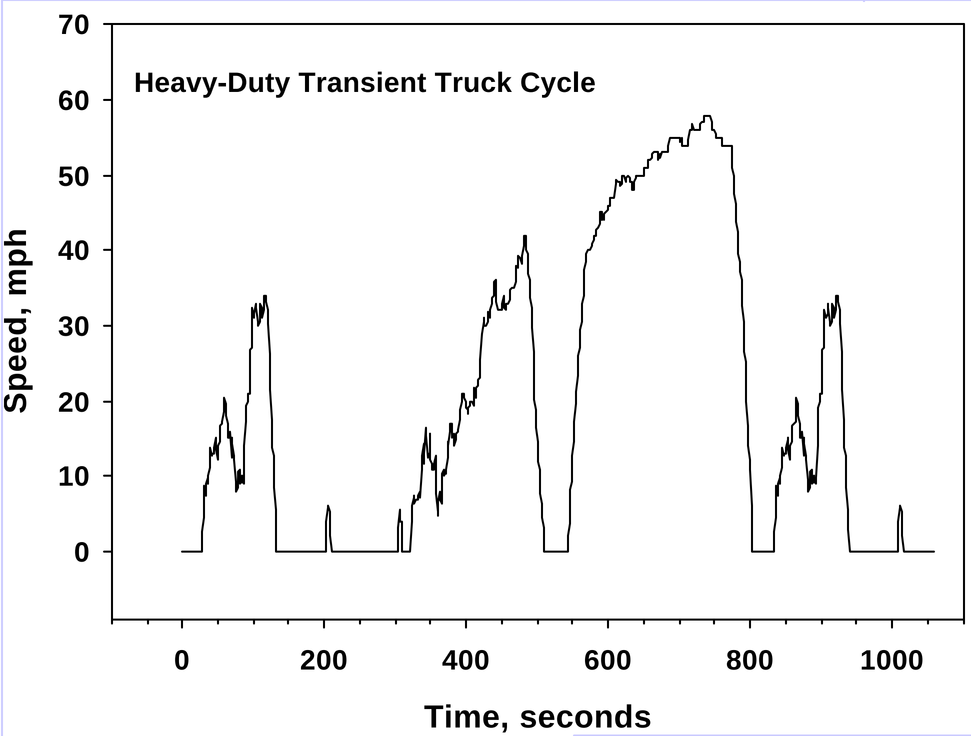
-peak CO during snap predicts PM with r^2=0.74

-peak CO is a much better predictor of PM than opacity

Conclusions:

- Repair of high opacity vehicles significantly reduced PM emissions in essentially every instance.
- Opacity is a poor predictor of PM. While considerable R&D would be required, a simple tail-pipe measurement of CO during a snap acceleration might be a more accurate predictor.
- In general, repair of high opacity vehicles also causes NO_x emissions to increase.

Driving Cycle and Chassis Dynamometer:

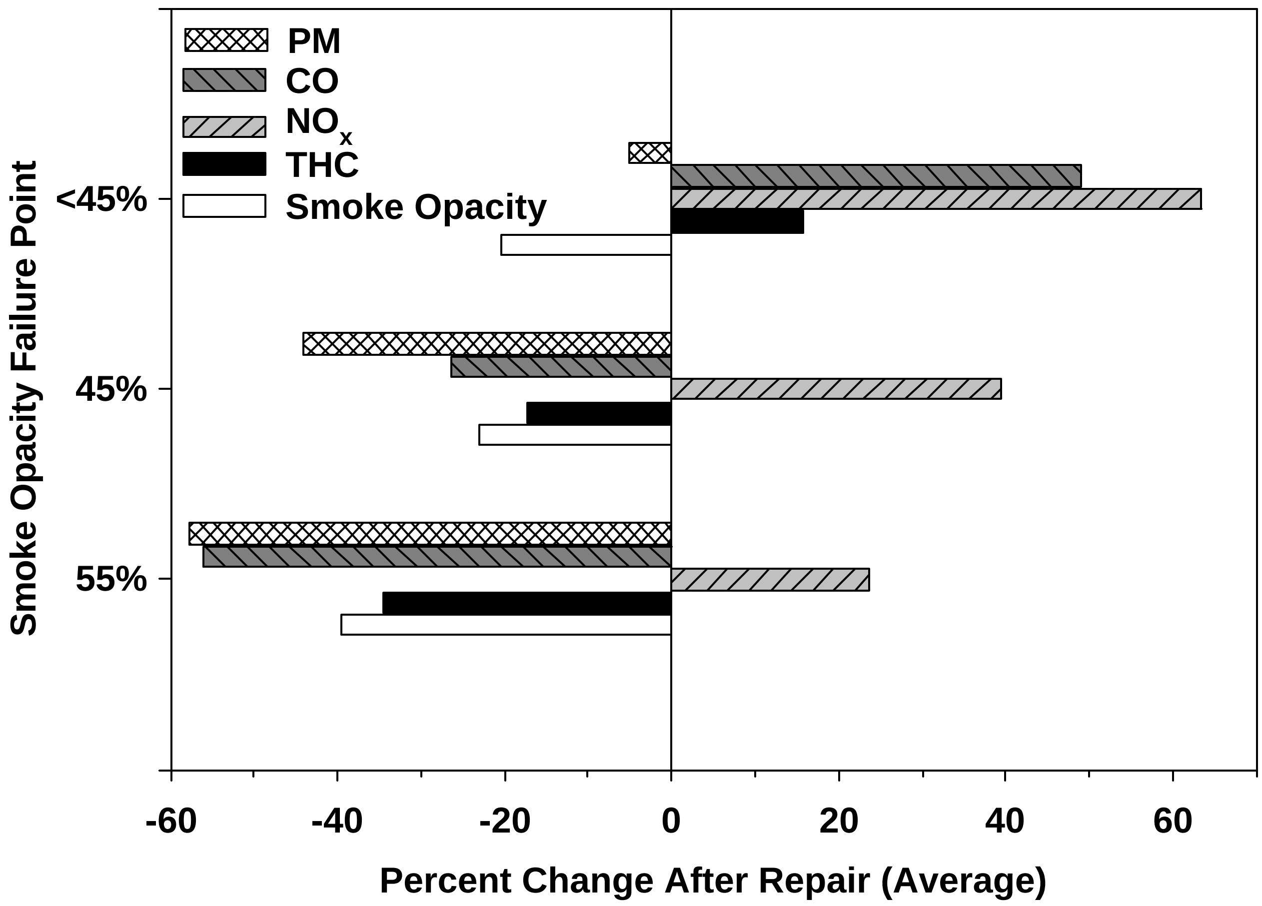


SAE J1667 Opacity Test:

- Vehicle warmed up and in neutral.
- Accelerator is rapidly pushed to the floor held for 5 seconds or until the engine reaches maximum (governed) speed, while smoke opacity is measured.
- The maximum opacity observed is reported and the average of three tests is reported.
- Opacity is corrected for stack diameter. Altitude correction is a part of the procedure but was not used in this study as it is not believed accurate or meaningful.
- EPA recommends that states use opacity failure points developed by the State of California (55% for pre-1991 and 40% or 1991 and newer engines) to insure uniformity across state lines.[1]

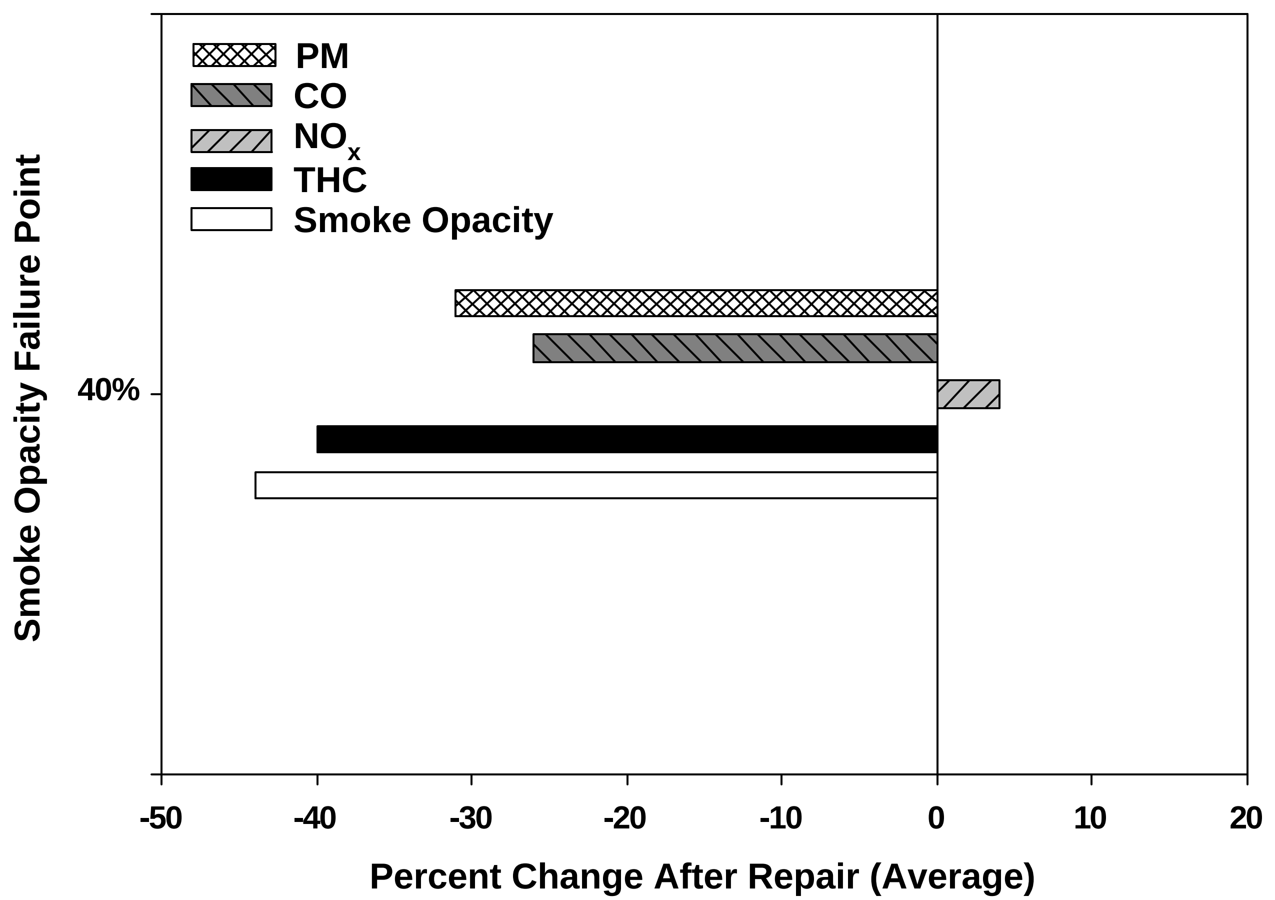
[1]Oge, M.T., Guidance to States on Smoke Opacity Cutpoints to be used with the SAE J1667 In-Use Smoke Opacity Test Procedure U.S. Environmental Protection Agency, February, 1999.

Average percent change in g/mi emissions with repair, pre-1991:



55% as recommended by EPA and 45% as recommended in the study by EEA, Inc. performed for State of Colorado.

Average percent change in g/mi emissions with repair, 1991+:



40% as recommended by EPA. All vehicles also failed 33% as recommended in the study by EEA, Inc. performed for State of Colorado.