EPA Analysis of the Exhaust Emission Impacts of Biodiesel

Presentation to the Mobile Source Technical Review Subcommittee

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EPA Technical Report

- Purpose was to provide a comprehensive analysis of exhaust emission impacts of biodiesel use at any concentration for regulated and unregulated pollutants
  - No full lifecycle emissions analyses
  - No durability or materials compatability issues
  - No storage stability or cold start impacts
  - No costs
- No regulatory controls are specified or implied

EPA Technical Report, cont.

- Technical report and database can be found at:
  - http://www.epa.gov/otaq/models/biodsl.htm
- Being released in draft form for public comment
- Independent peer review being sought
- Public workshop likely - stay tuned

Analysis Approach

- Collected all publicly available emissions data into a single large database (39 studies)
  - We did not generate new data
- Conducted statistical regression analysis to correlate biodiesel concentration with emissions

% change in emissions = f(% biodiesel)

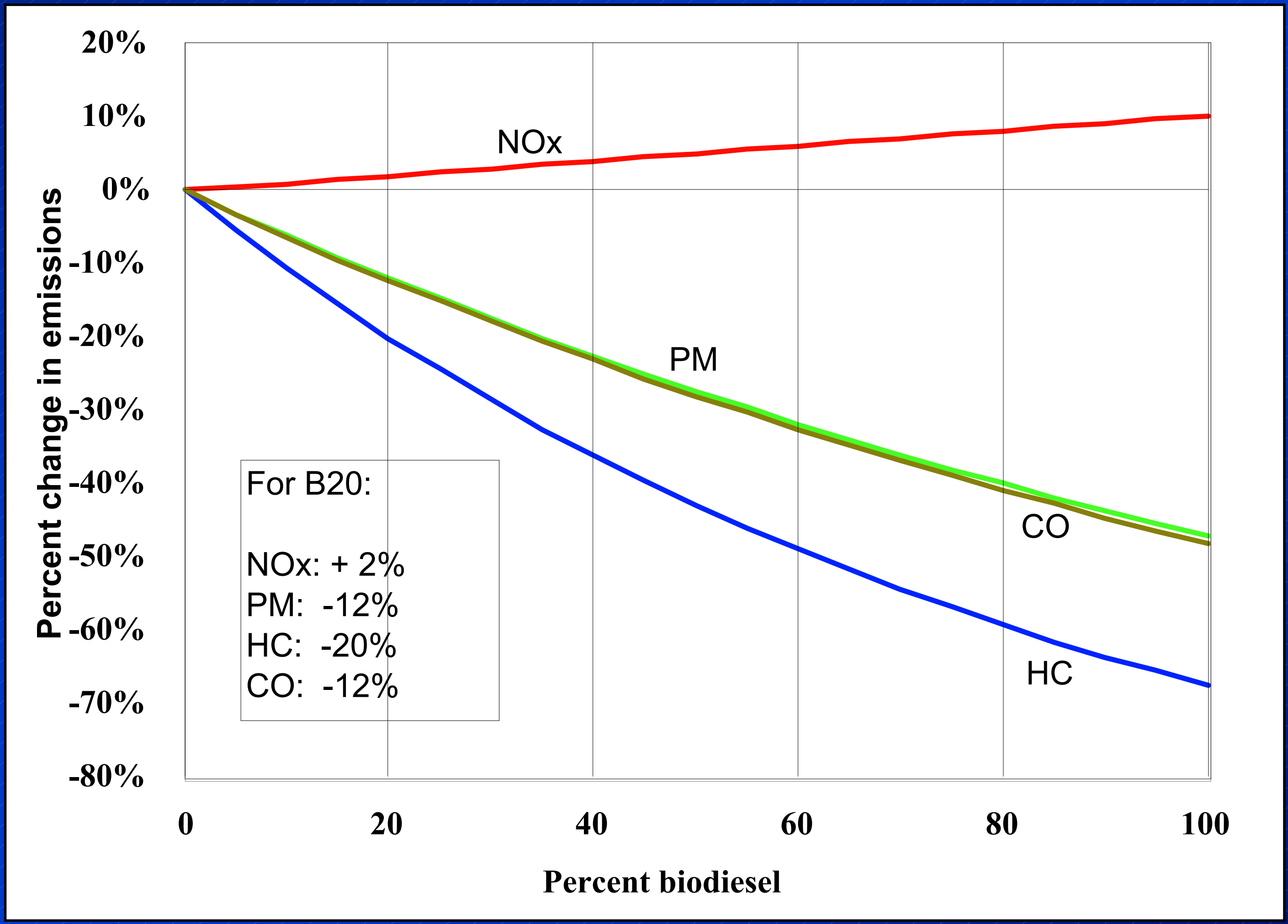
Regression Analysis

- Used the natural log of emissions
  - Helps address statistical variation concerns
  - Simplifies application
    - ln(NOx) = a x (%bio) + b
    - % change in NOx = {exp[a x (%bio)] - 1} x 100%
- Used mixed model in SAS
  - Maximum liklihood curve-fitting
  - Less prone to overweighting by repeat measurements

Regression Analysis, cont.

- Engines and base fuels treated as random variables
- Various adjustment terms considered only if they met our minimum data criterion of 20 observations
- Based correlations on heavy-duty highway engine data (80% of database)

Basic emissions effects



Deliberative draft for stakeholder review

Investigations

- We also investigated whether the emission effects might be:

– Nonlinear	No
– A function of engine technology	Mostly no
– A function of test cycle	Yes
– Different for soybean, rapeseed, and animal fats	Yes
– A function of the "cleanliness" of the base fuel	Yes

Engine Technology

- Information on test engine configuration and design was limited
- Decided to use model year groups as a surrogate for engine technology
- Investigated the need for adjustment terms representing engine standards groups

Engine Technology, cont.

Group	Model years	% of database	Significant adjustment term? NOx	PM	HC	CO
B	2002 - 2006	0	n/a	n/a	n/a	n/a
C	1998 - 2001	2	n/a	n/a	n/a	n/a
D	1994 - 1997	19	No	No	No	No
E	1991 - 1993	50	No	**Yes**	No	No
F	1990	11	n/a	n/a	n/a	n/a
G	1988 - 1989	14	No	No	No	No
H	1984 - 1987	2	n/a	n/a	n/a	n/a
I	- 1983	1	n/a	n/a	n/a	n/a

Group E impacts on PM are twice as large as all other engine groups, but group E engines represent only 12% of the current in-use PM inventory

Test Cycle

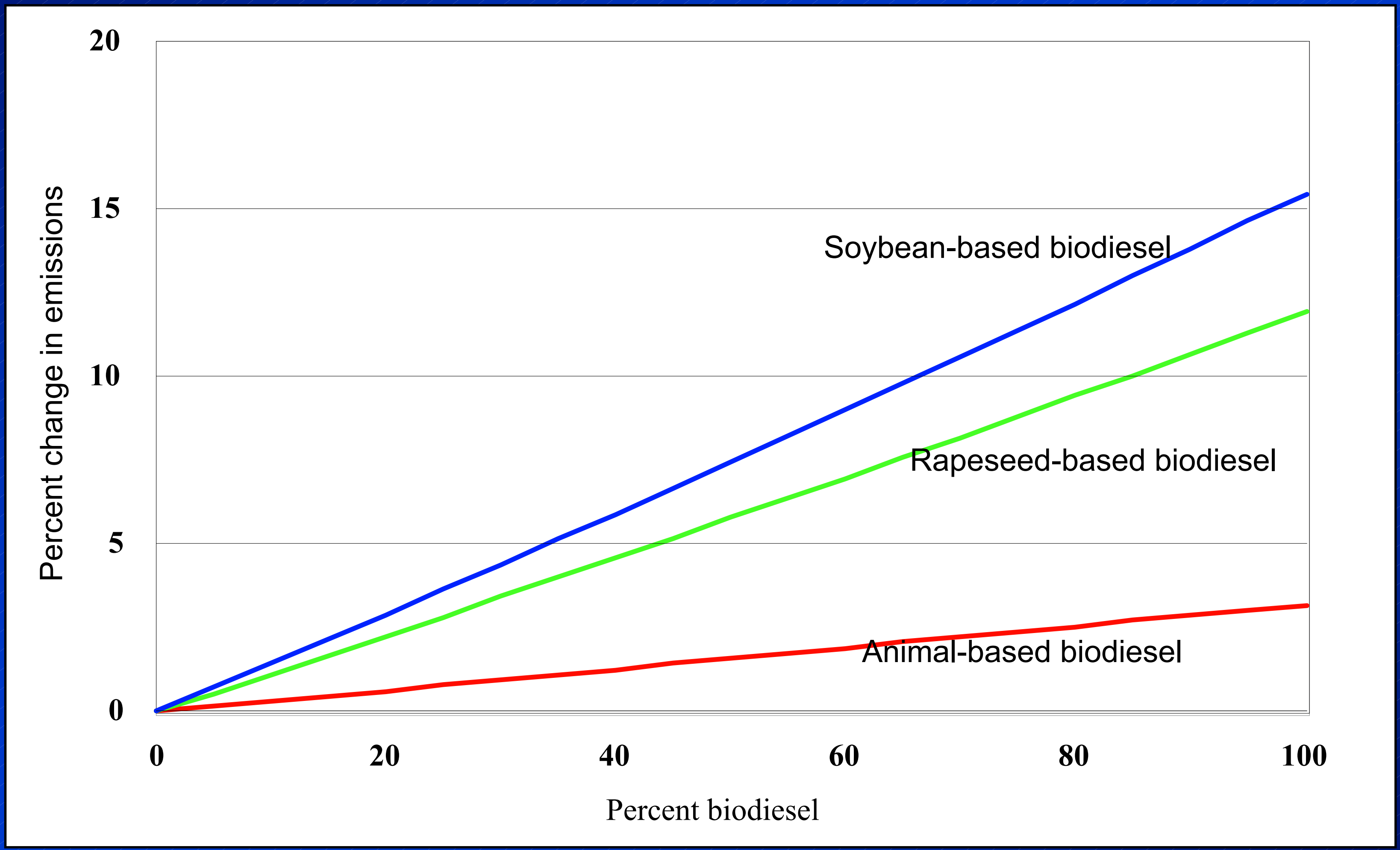
- Investigated whether steady-state cycles differed from transient cycles in terms of correlations between emissions and % biodiesel
- Discovered that PM and CO were in fact different
- Excluded all steady-state data from PM and CO analyses

Type of Biodiesel

Type of biodiesel	Percent of database
Soybean	75%
Rapeseed/canola	14%
All animal	11%

- Animal biodiesel was found generally to produce more benefit (PM, HC, CO) and less detriment (NOx) than other types

Type of Biodiesel - NOx



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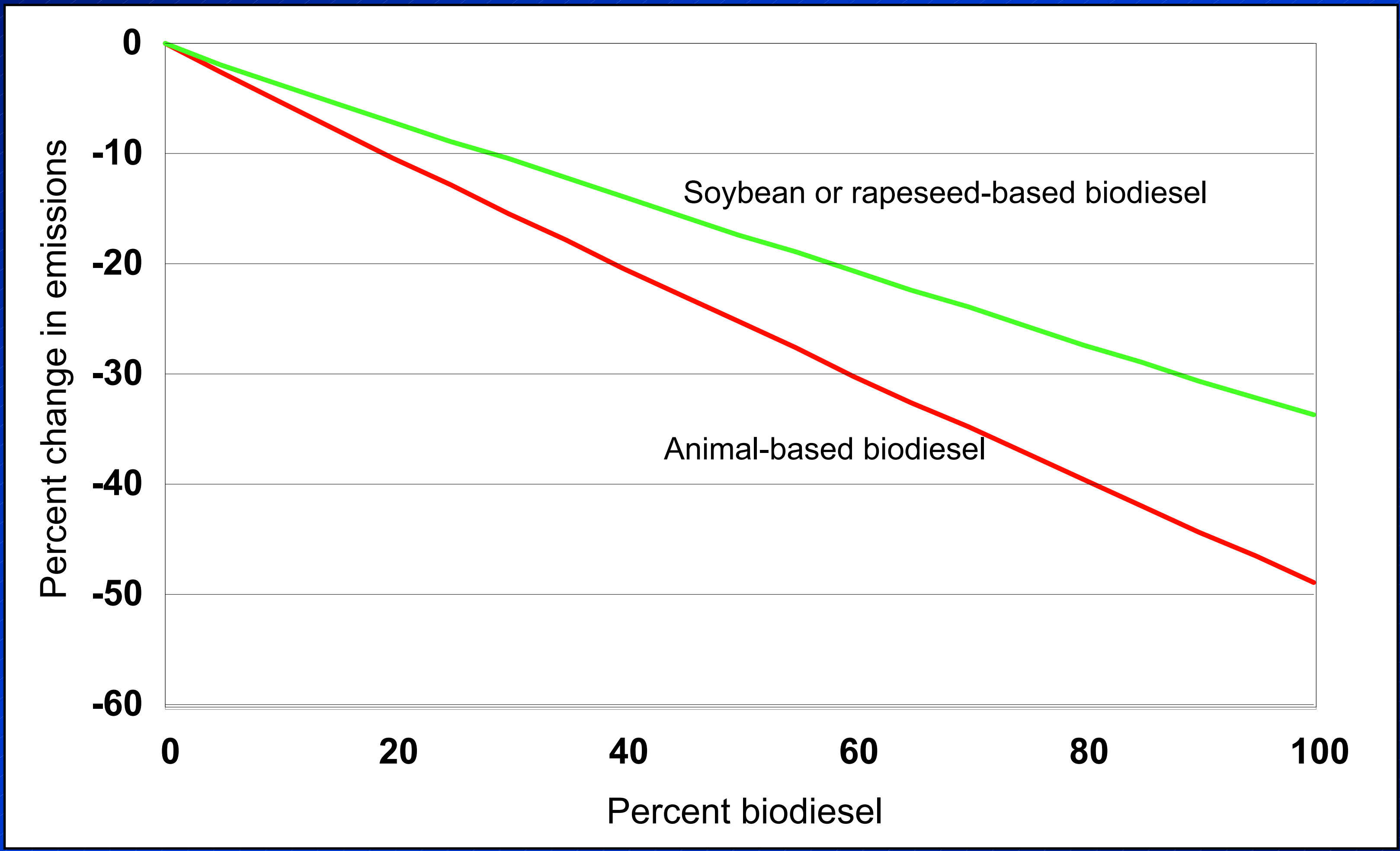
Type of Biodiesel - PM



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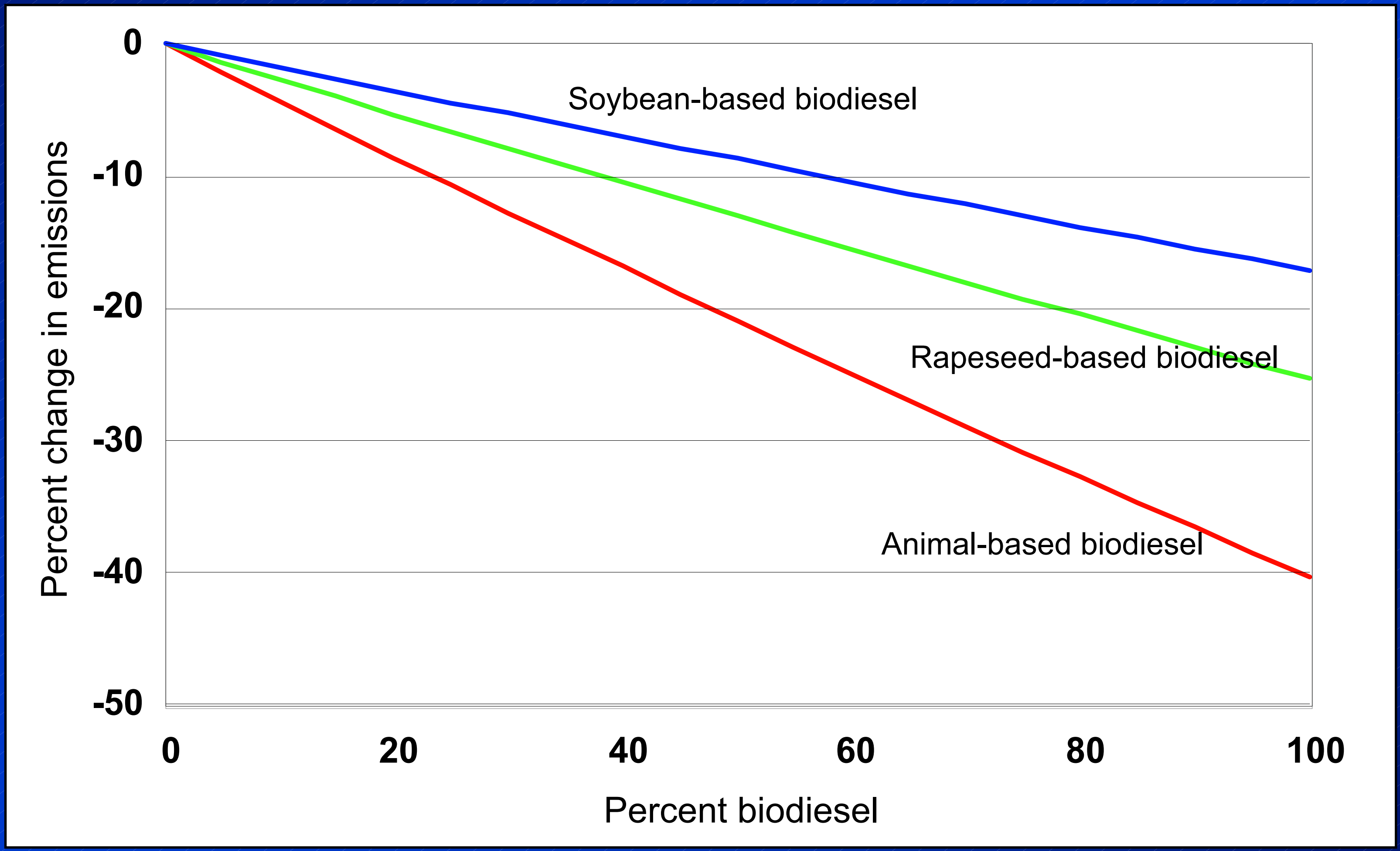
Type of Biodiesel - CO



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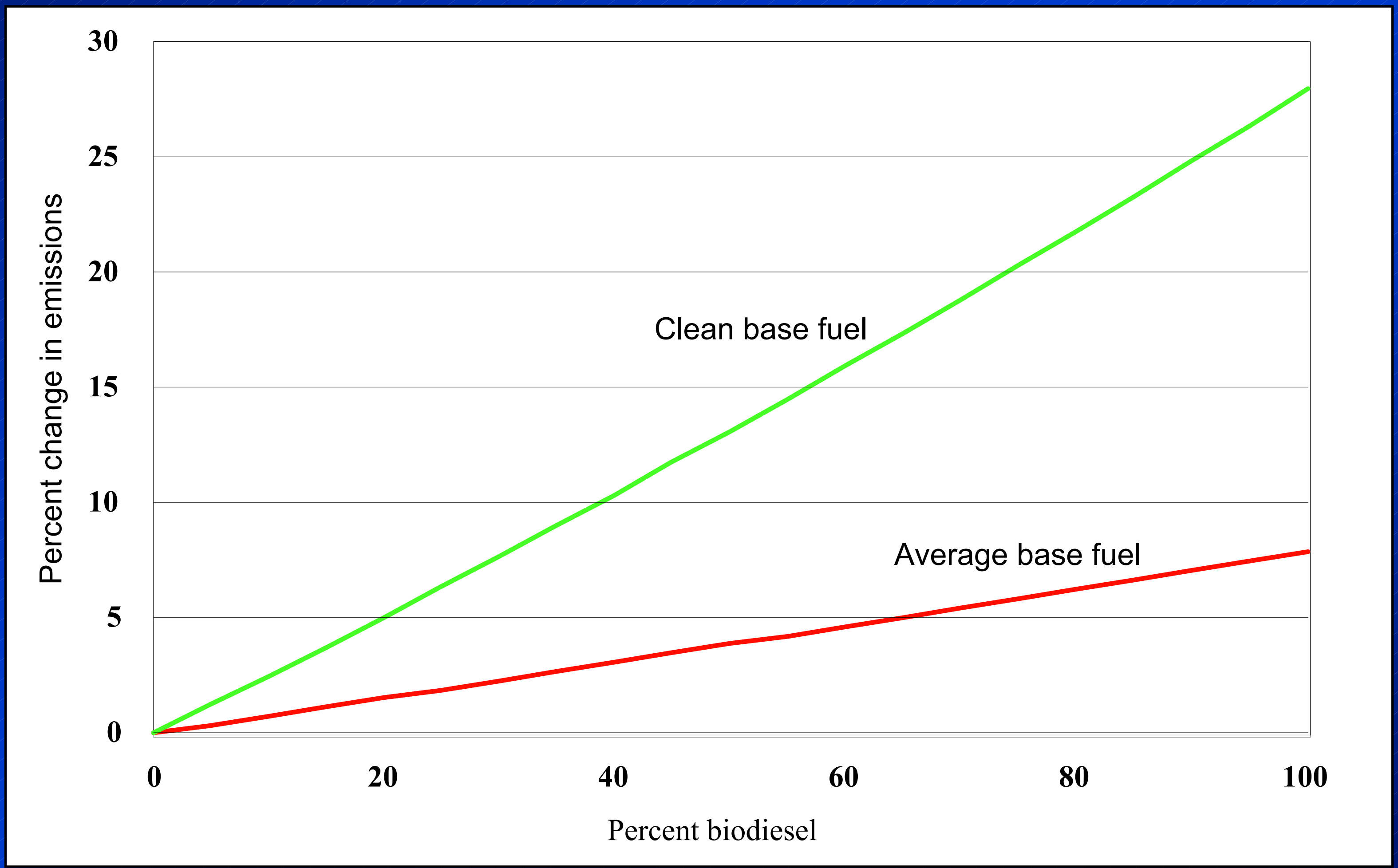
Base Fuel Impacts

- Investigated whether the type of conventional diesel to which biodiesel is added has an impact on biodiesel emission effects
- Since base fuel property data was largely lacking, we placed all base fuels into one of three groups: clean, average, and dirty
- Found that base fuel is significant for all pollutants

Base Fuel Impacts - NOx



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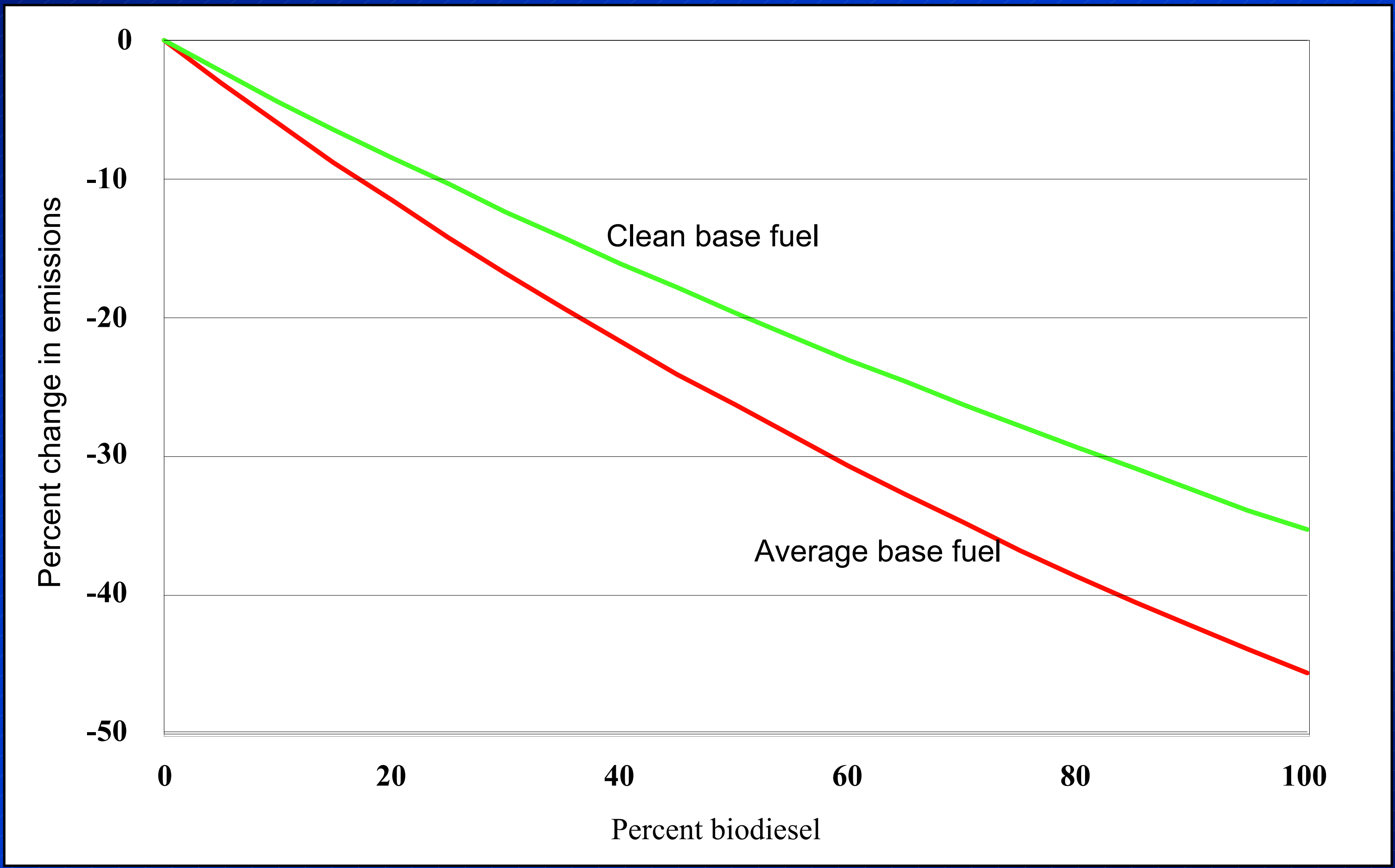
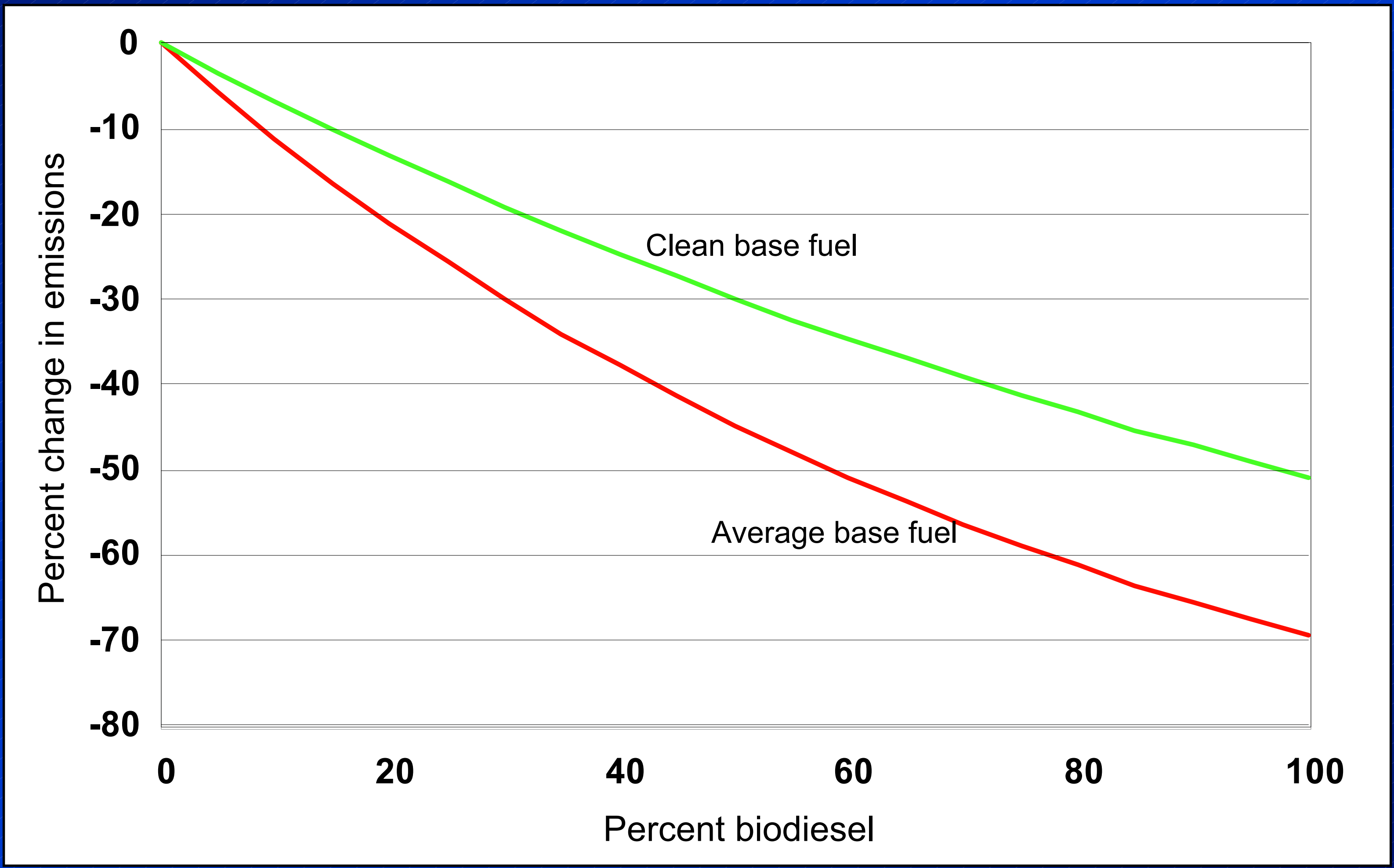
Base Fuel Impacts - PM



Base Fuel Impacts - HC



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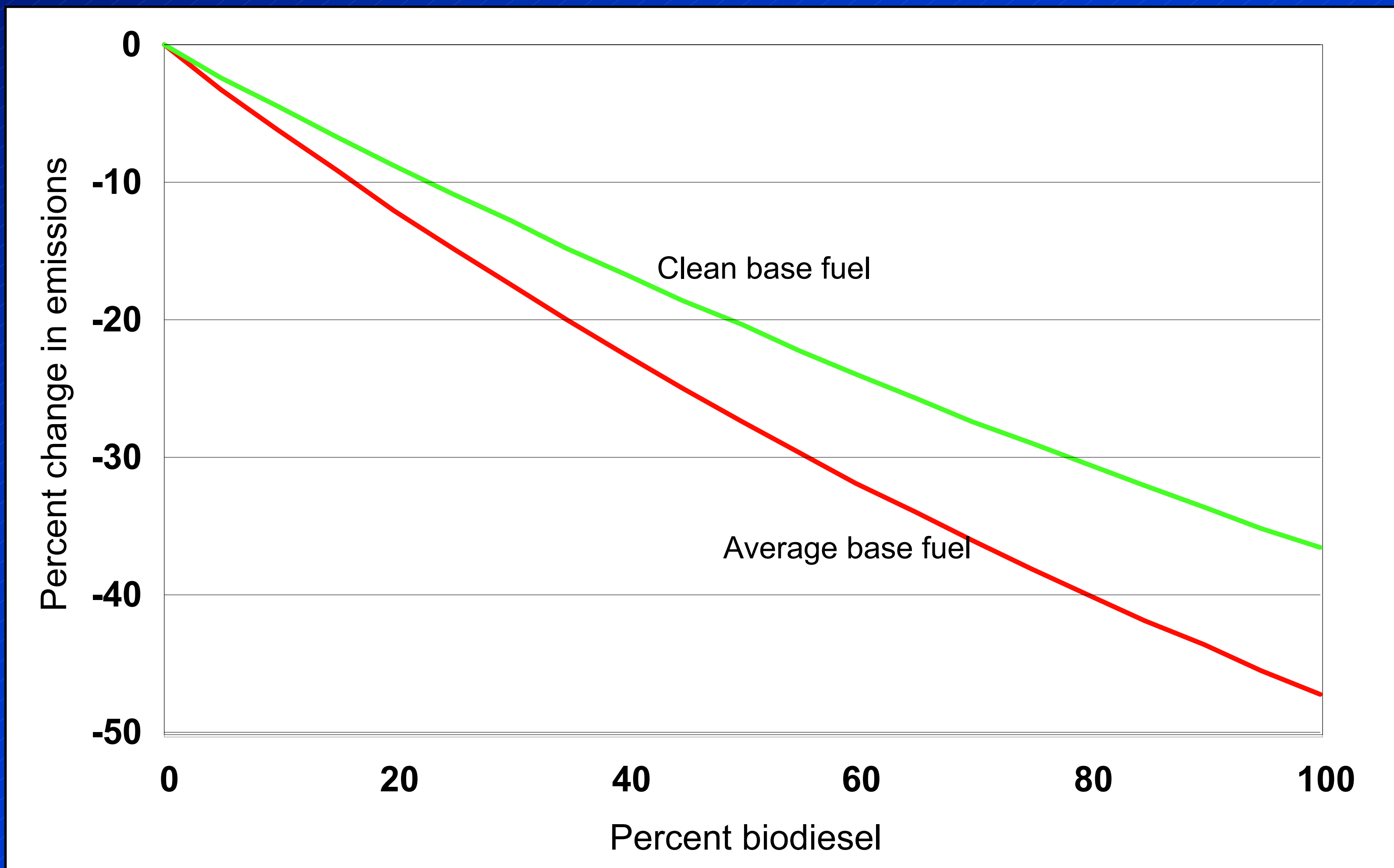
Base Fuel Impacts - CO



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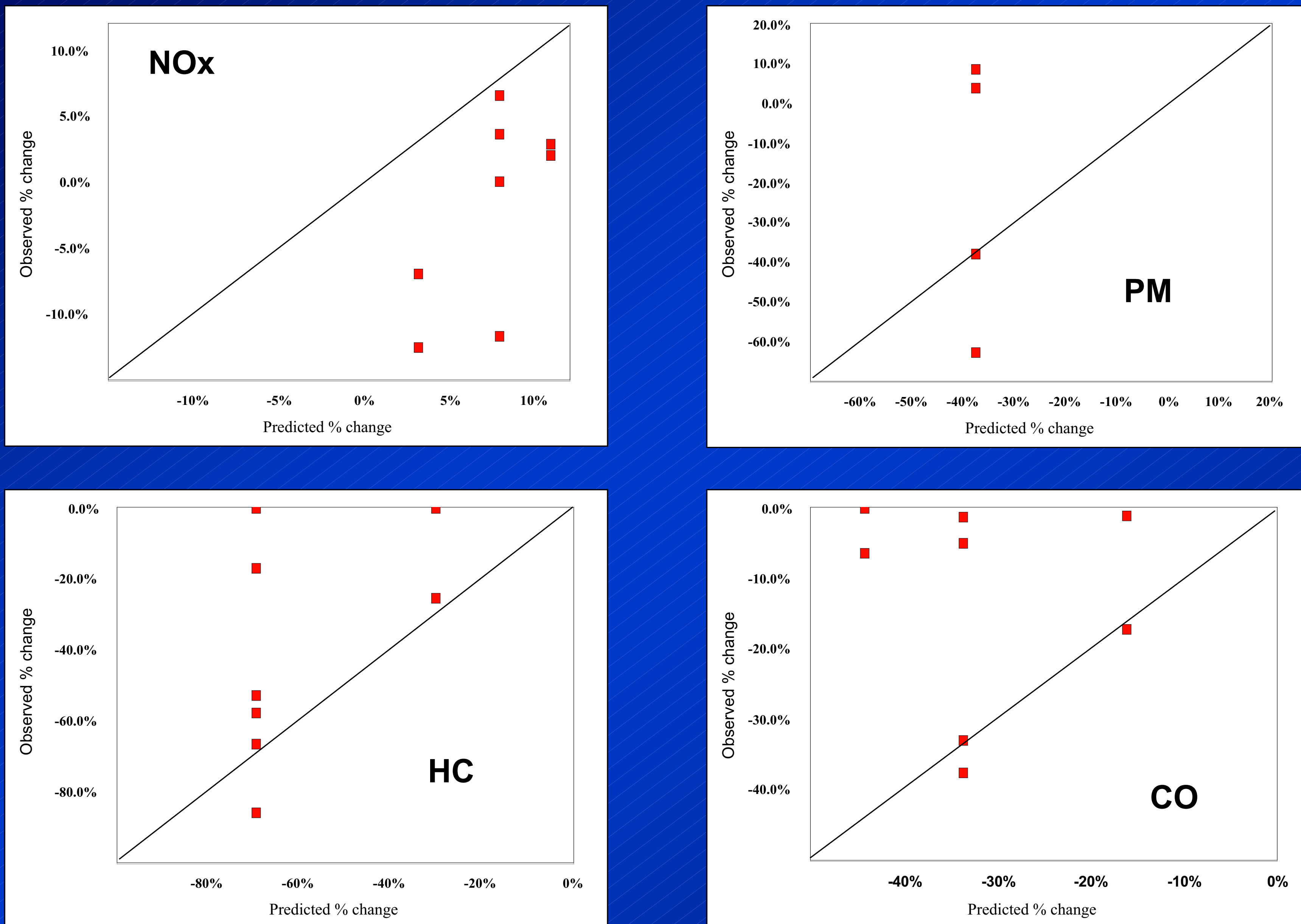
Nonroad impacts

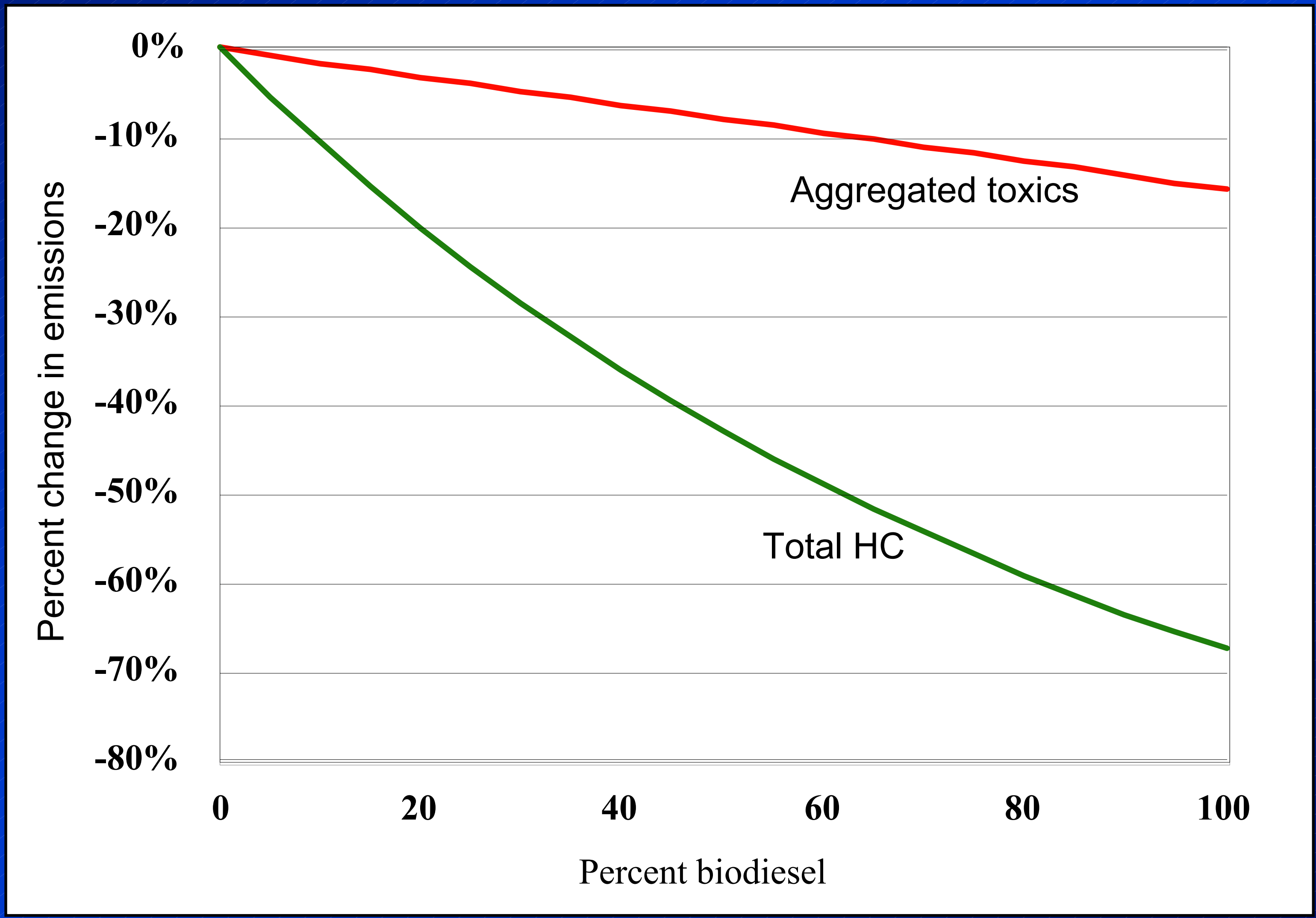
- Much less data on nonroad engines
- We compared the predictions from our correlations to the actual nonroad data
- Correlations and data did not line up very well
- Alternative analyses of nonroad data were also inconclusive


NOx
Observed % change
10.0%
5.0%
0.0%
-5.0%
-10.0%
-10%
-5%
0%
5%
10%
Predicted % change
PM
20.0%
10.0%
0.0%
-10.0%
-20.0%
-30.0%
-40.0%
-50.0%
-60.0%
-60%
-50%
-40%
-30%
-20%
-10%
0%
10%
20%
HC
0.0%
-20.0%
-40.0%
-60.0%
-80.0%
-80%
-60%
-40%
-20%
0%
CO
0.0%
-10.0%
-20.0%
-30.0%
-40.0%
-40%
-30%
-20%
-10%
0%

Toxics

- Only a few studies included toxics
- Used a different analytical approach
  - Aggregated toxics = f(% biodiesel)
  - Toxic/HC ratios = f(% biodiesel)
  - % change in individual toxics = f(% biodiesel)
  - Binomial distributions
- Drew conclusions in three groups:
  - Tier 1: Effects can be quantified
  - Tier 2: Direction of effects can be determined, but the effects cannot be quantified
  - Tier 3: Nothing can be said

Aggregated toxics



Individual toxics

- Tier 1:
  - Acetaldehyde is reduced
  - Ethylbenzene is reduced
  - Formaldehyde is reduced
  - Naphthalene is reduced
  - Xylene is reduced
- Tier 2:
  - Small reduction in acrolein
  - Small reduction in n-hexane
  - Small increase in styrene
- Tier 3
  - Benzene
  - 1,3-butadiene
  - Toluene

Exhaust CO_2 Impacts

- Used both regression analysis and carbon content
- Results were directionally ambiguous, but small (0 - 3% for 100% biodiesel)
- Concluded that there is insufficient evidence that biodiesel changes exhaust emissions of CO_2
- No implications for renewability

Fuel Economy Impacts

- Used both regression analysis on BSFC and comparative energy content
- Plant-based biodiesel may have a slightly smaller detriment than animal-based

	% reduction in mi/gal
20 vol% biodiesel	0.9 - 2.1
100 vol% biodiesel	4.6 - 10.6