

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 compatibility 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

$$\% \text{ change in emissions} = f(\% \text{ biodiesel})$$

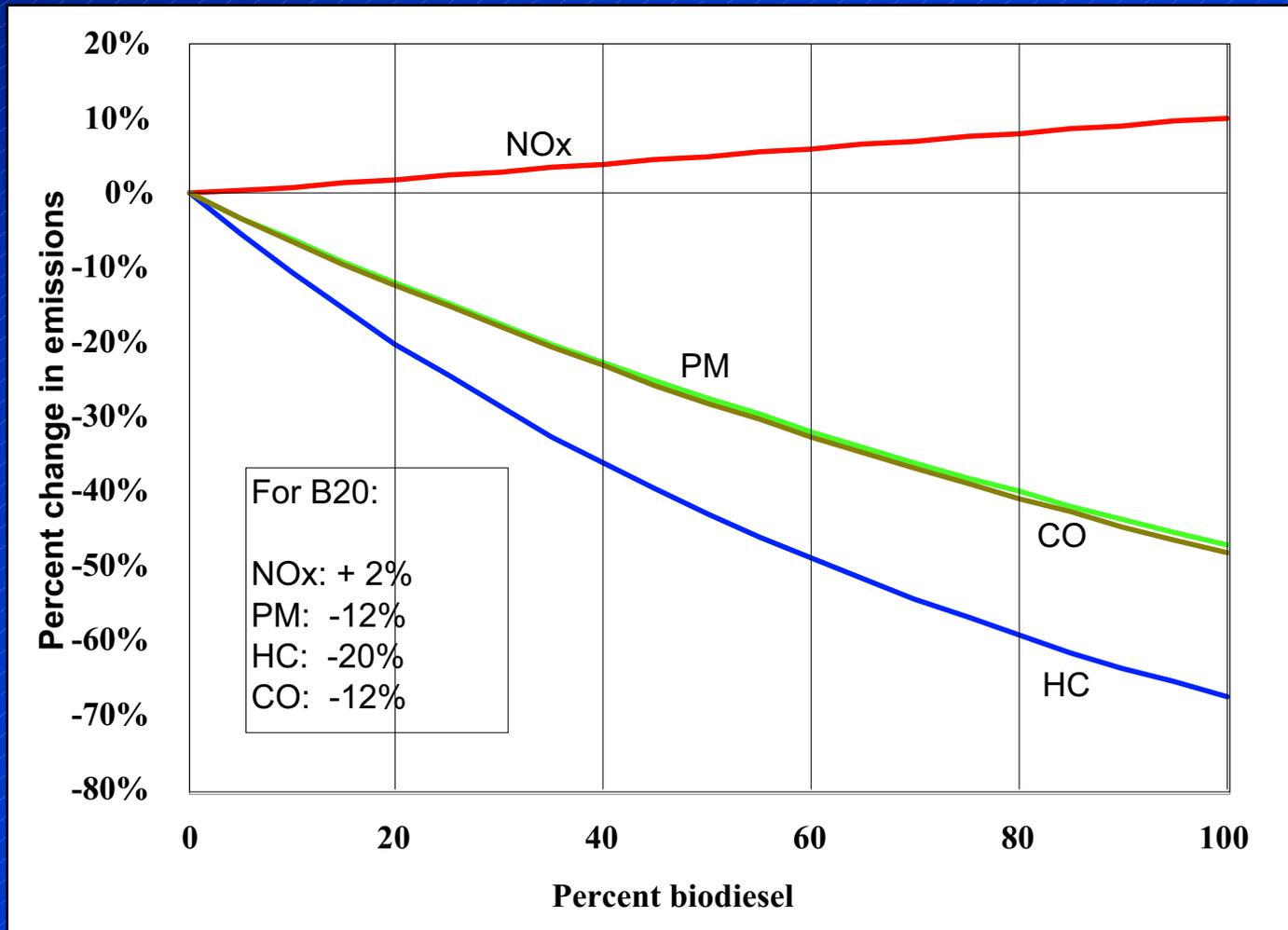
Regression Analysis

- Used the natural log of emissions
 - Helps address statistical variation concerns
 - Simplifies application
 - $\ln(\text{NO}_x) = a \times (\% \text{bio}) + b$
 - $\% \text{ change in NO}_x = \{\exp[a \times (\% \text{bio})] - 1\} \times 100\%$
- Used mixed model in SAS
 - Maximum likelihood 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



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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

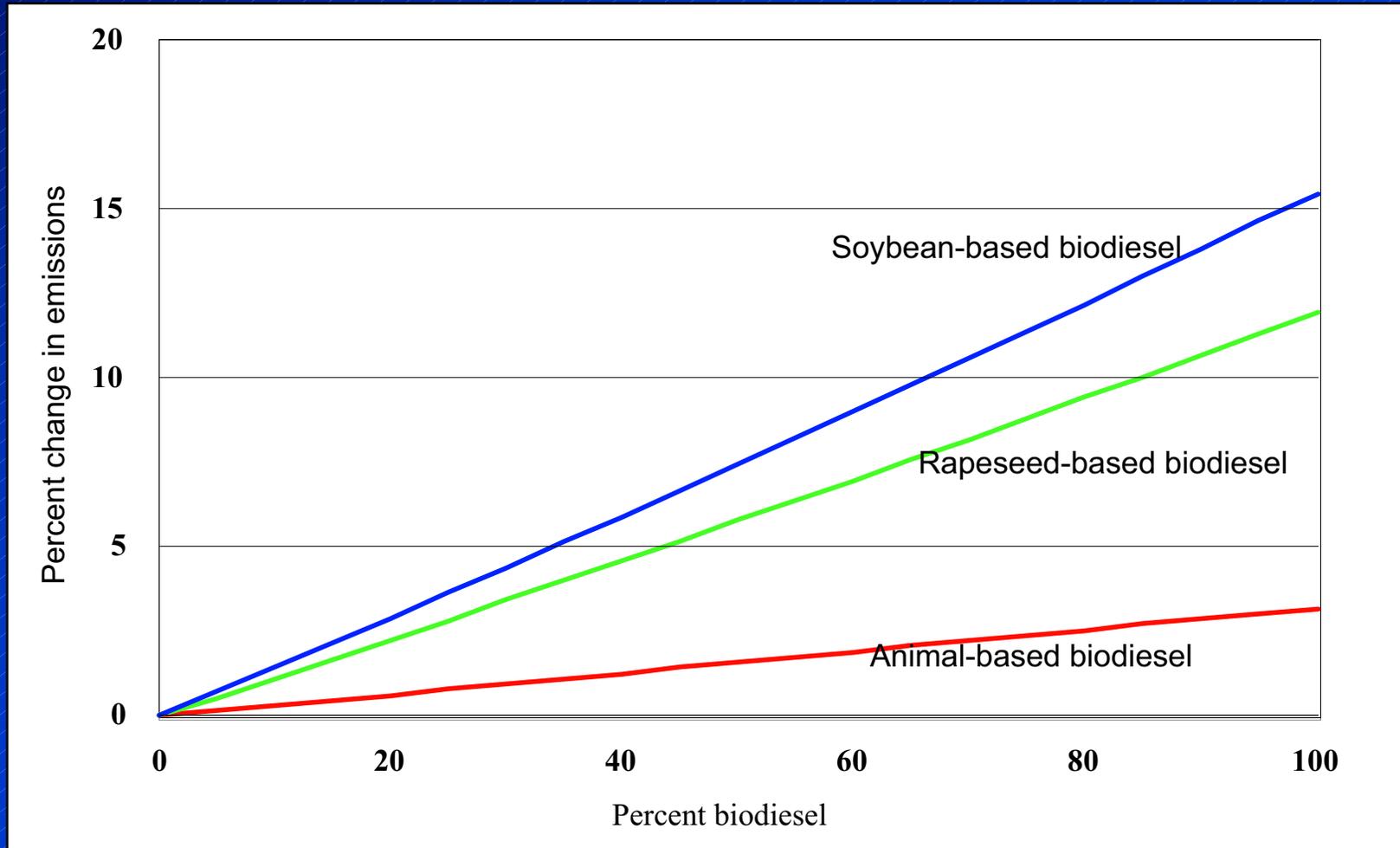
- Investigated whether steady-state cycles differed from transient cycles in terms of correlations between emissions and % biodiesel
- Discovered that PM and CO were in fact different
- Excluded all steady-state data from PM and CO analyses

Type of Biodiesel

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

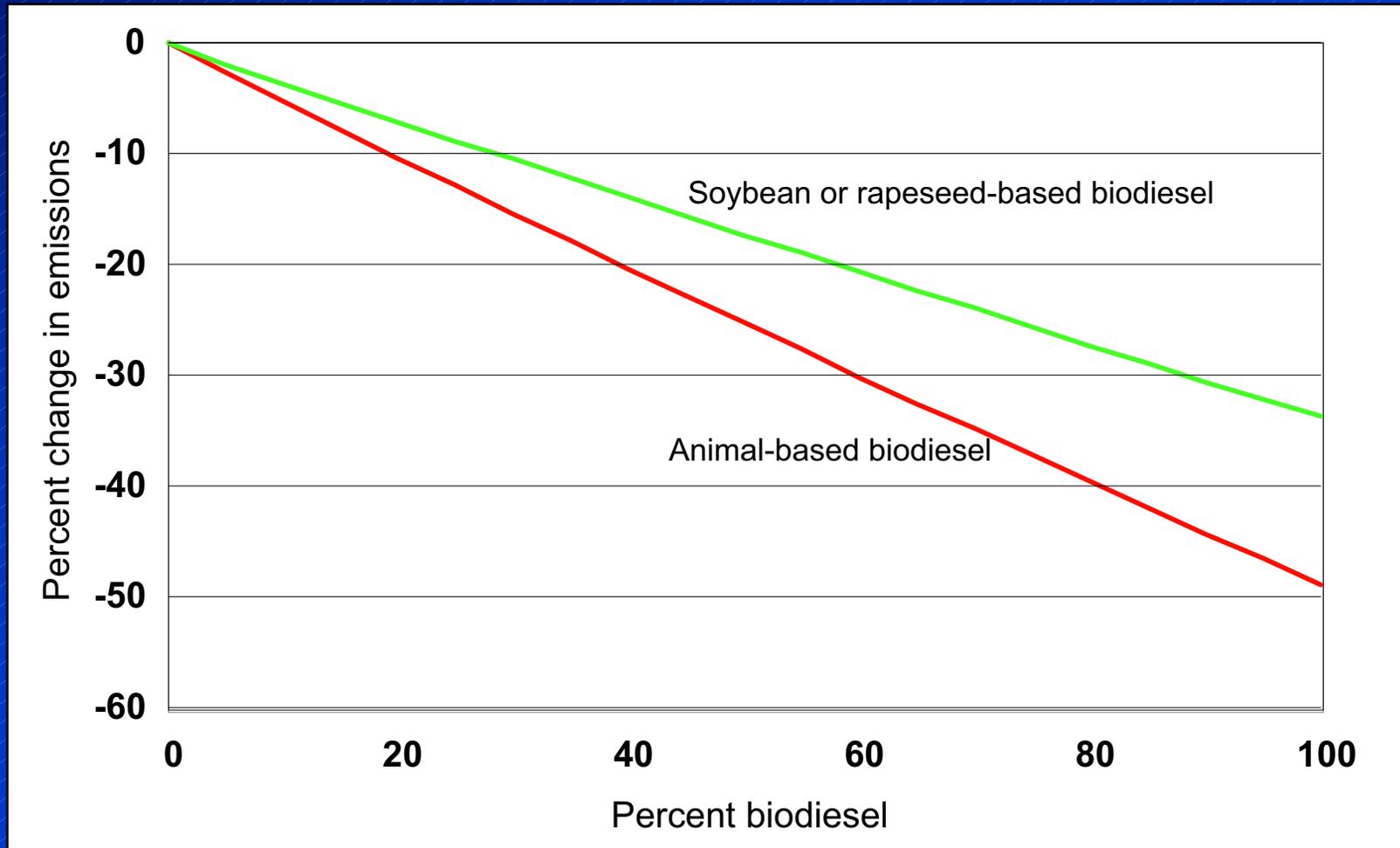
- Animal biodiesel was found generally to produce more benefit (PM, HC, CO) and less detriment (NOx) than other types

Type of Biodiesel - NOx



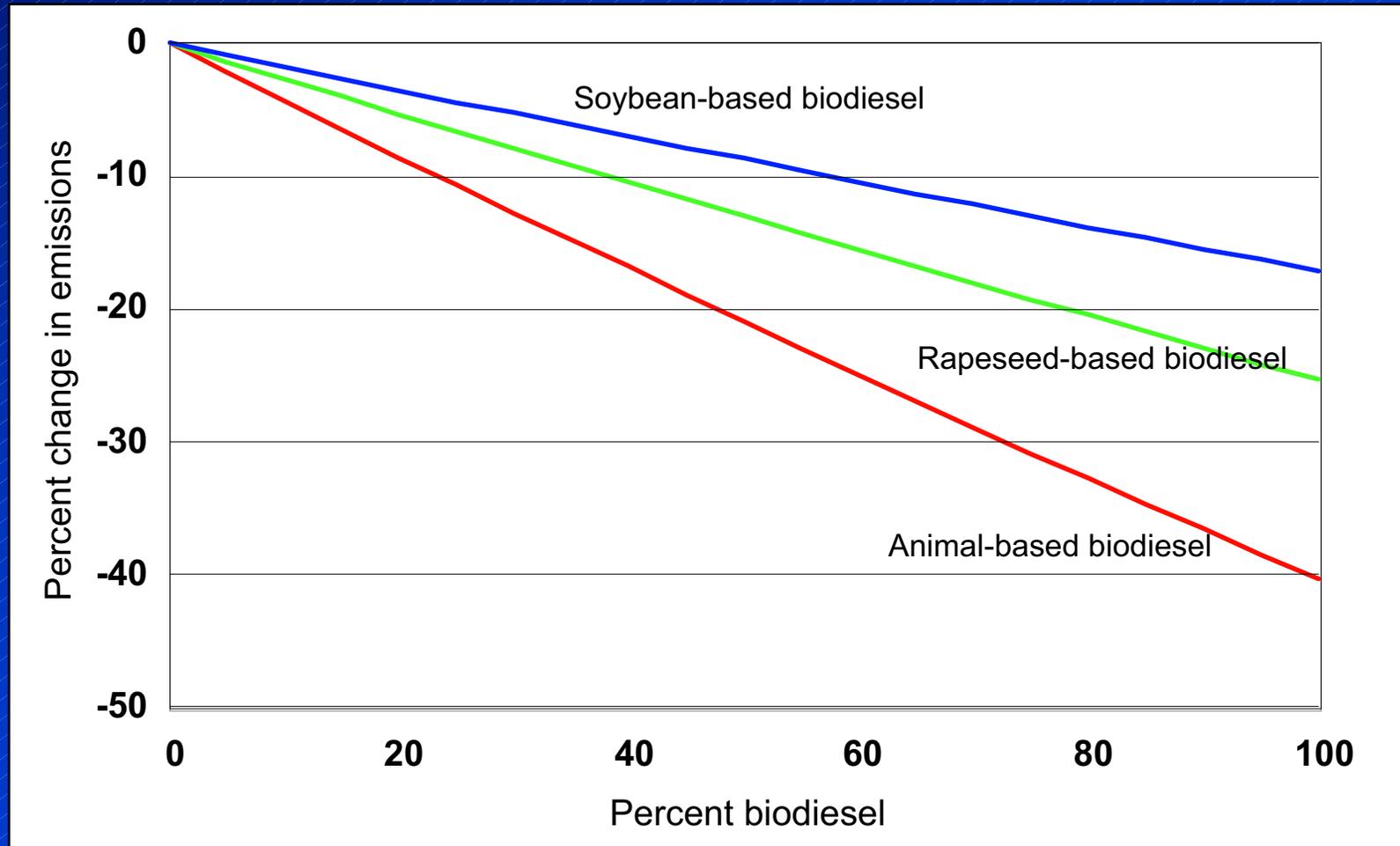
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Type of Biodiesel - PM



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Type of Biodiesel - CO

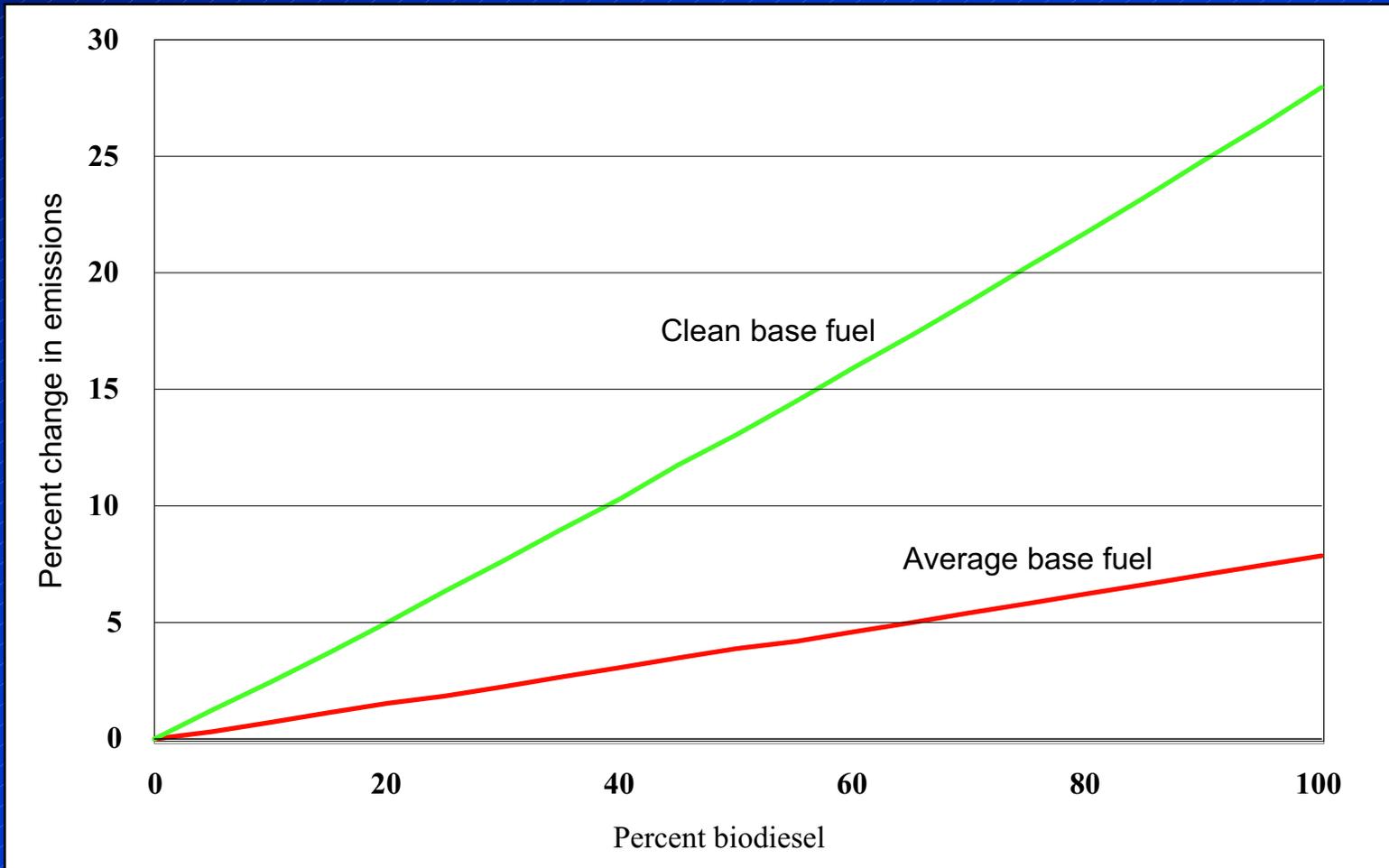


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Base Fuel Impacts

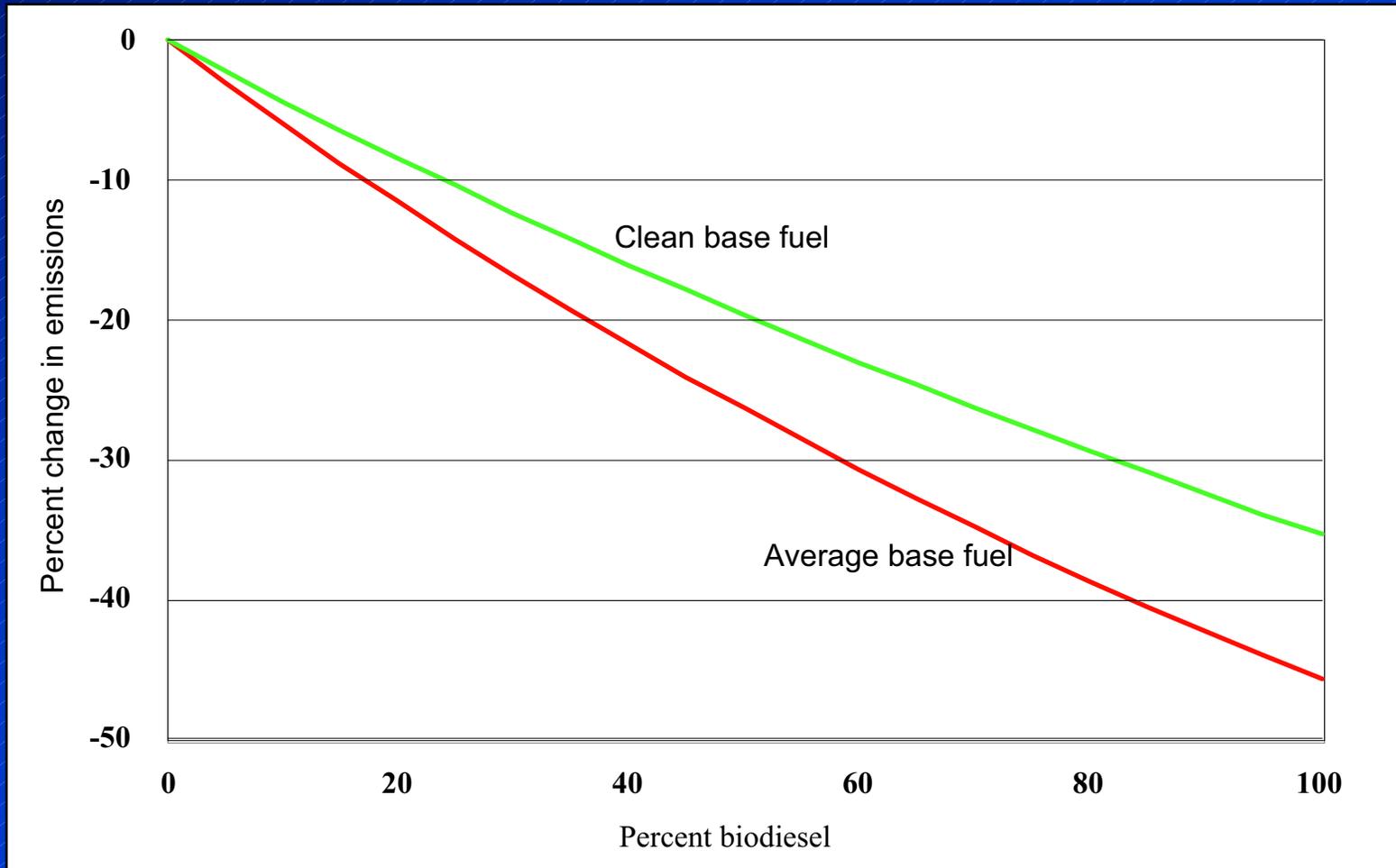
- Investigated whether the type of conventional diesel to which biodiesel is added has an impact on biodiesel emission effects
- Since base fuel property data was largely lacking, we placed all base fuels into one of three groups: clean, average, and dirty
- Found that base fuel is significant for all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

Base Fuel Impacts - NO_x



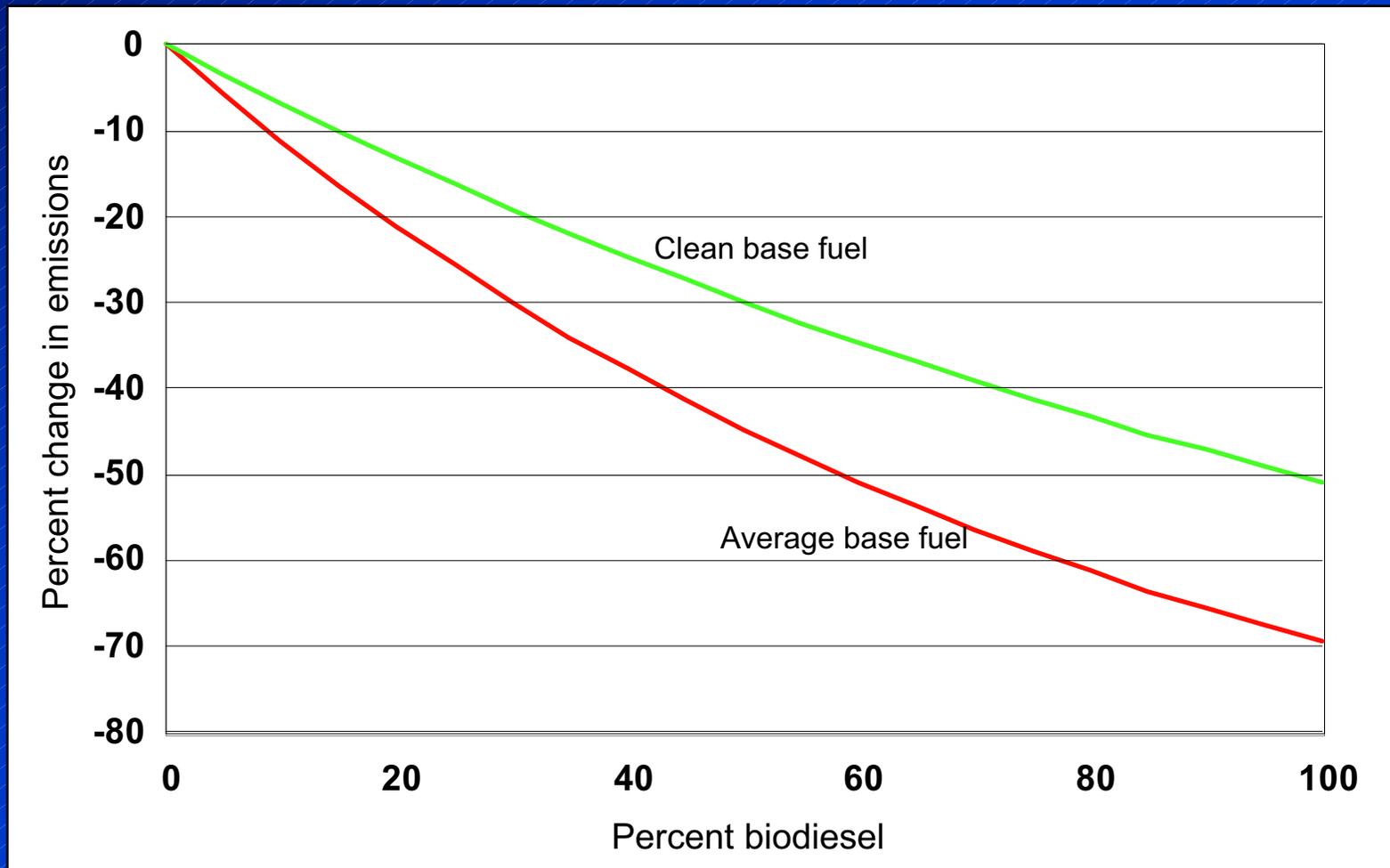
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Base Fuel Impacts - PM

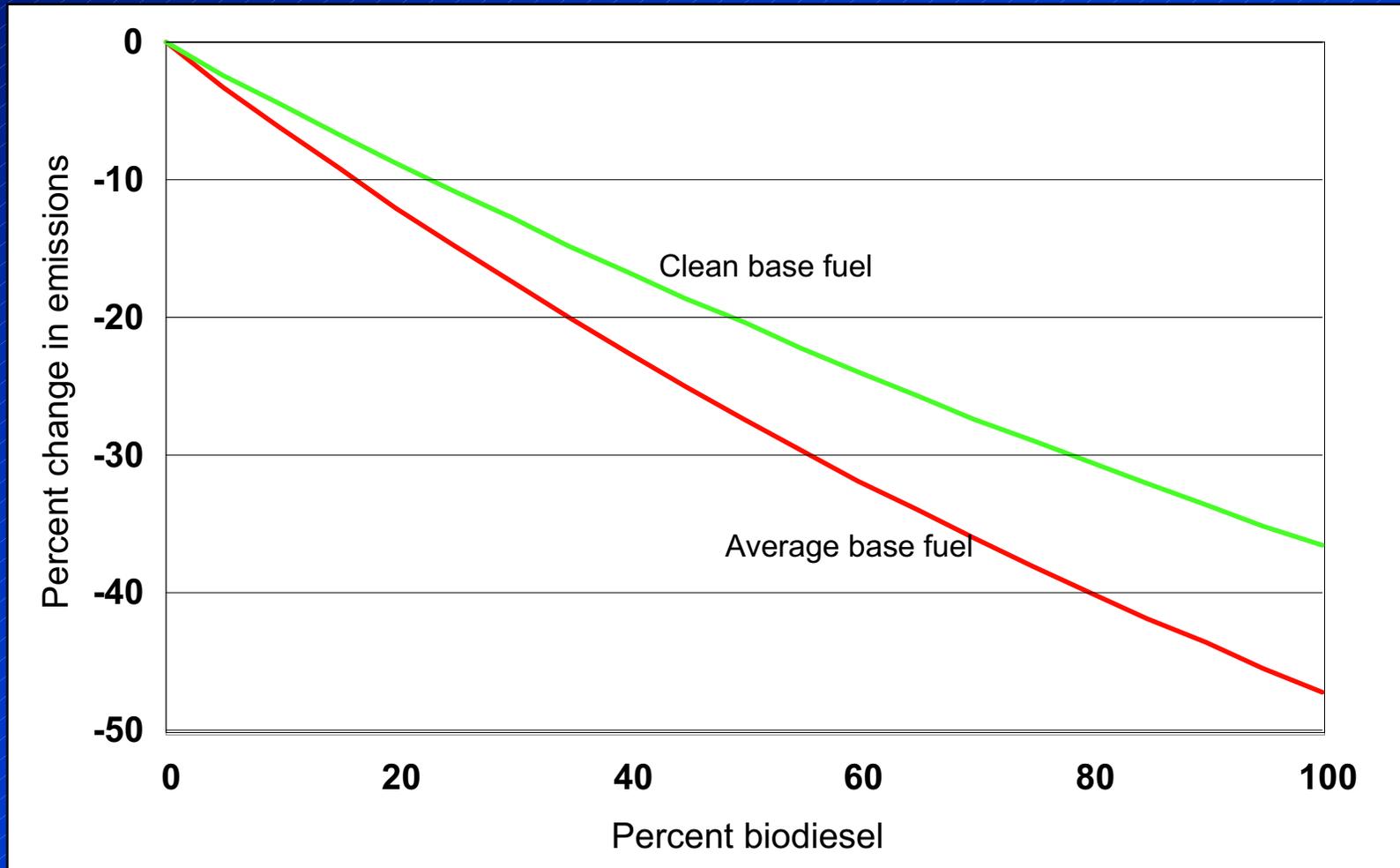


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Base Fuel Impacts - HC



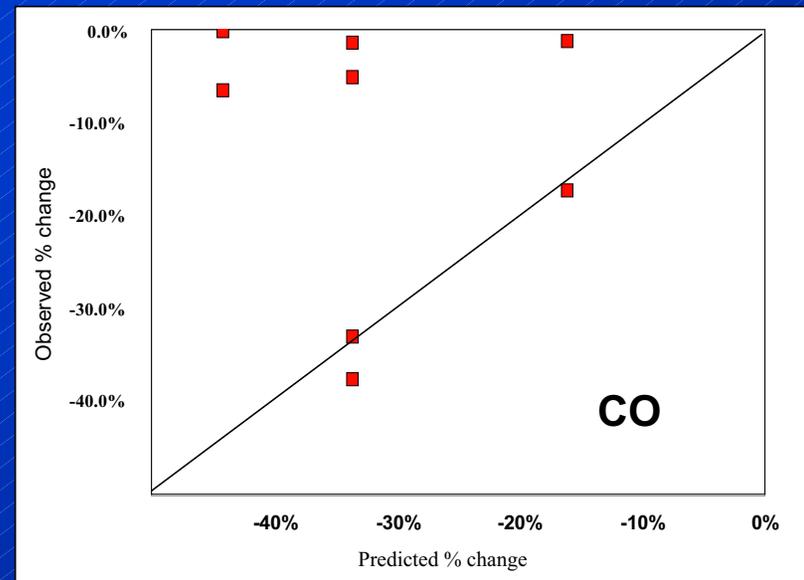
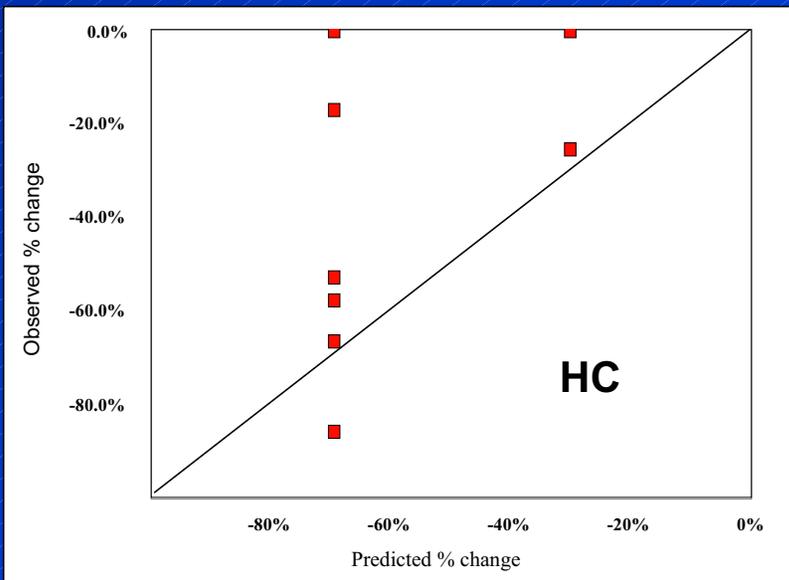
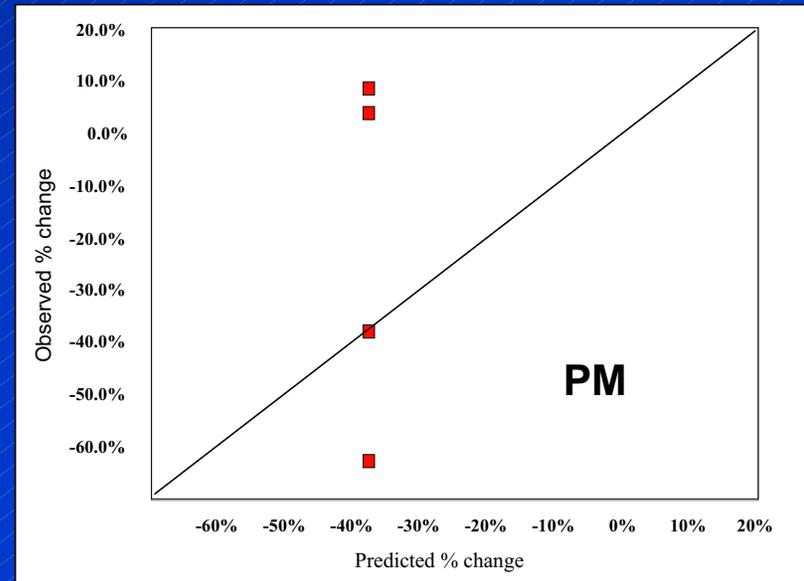
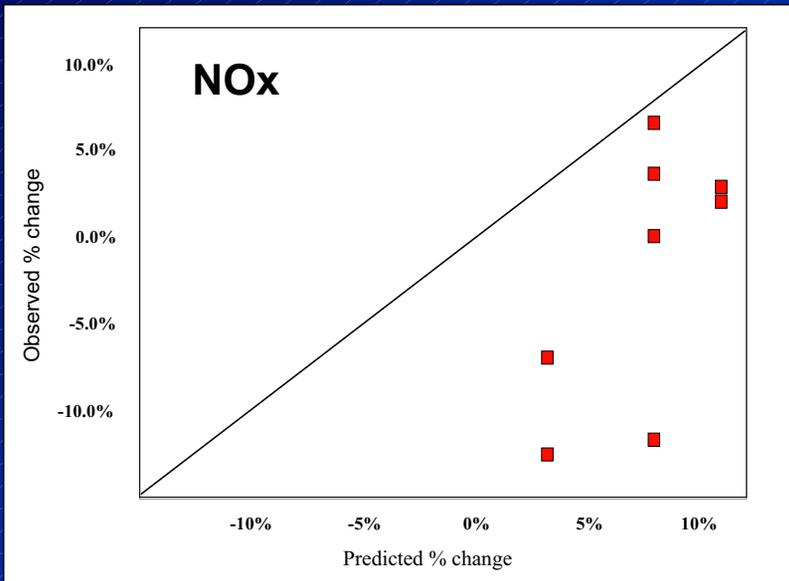
Base Fuel Impacts - CO



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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

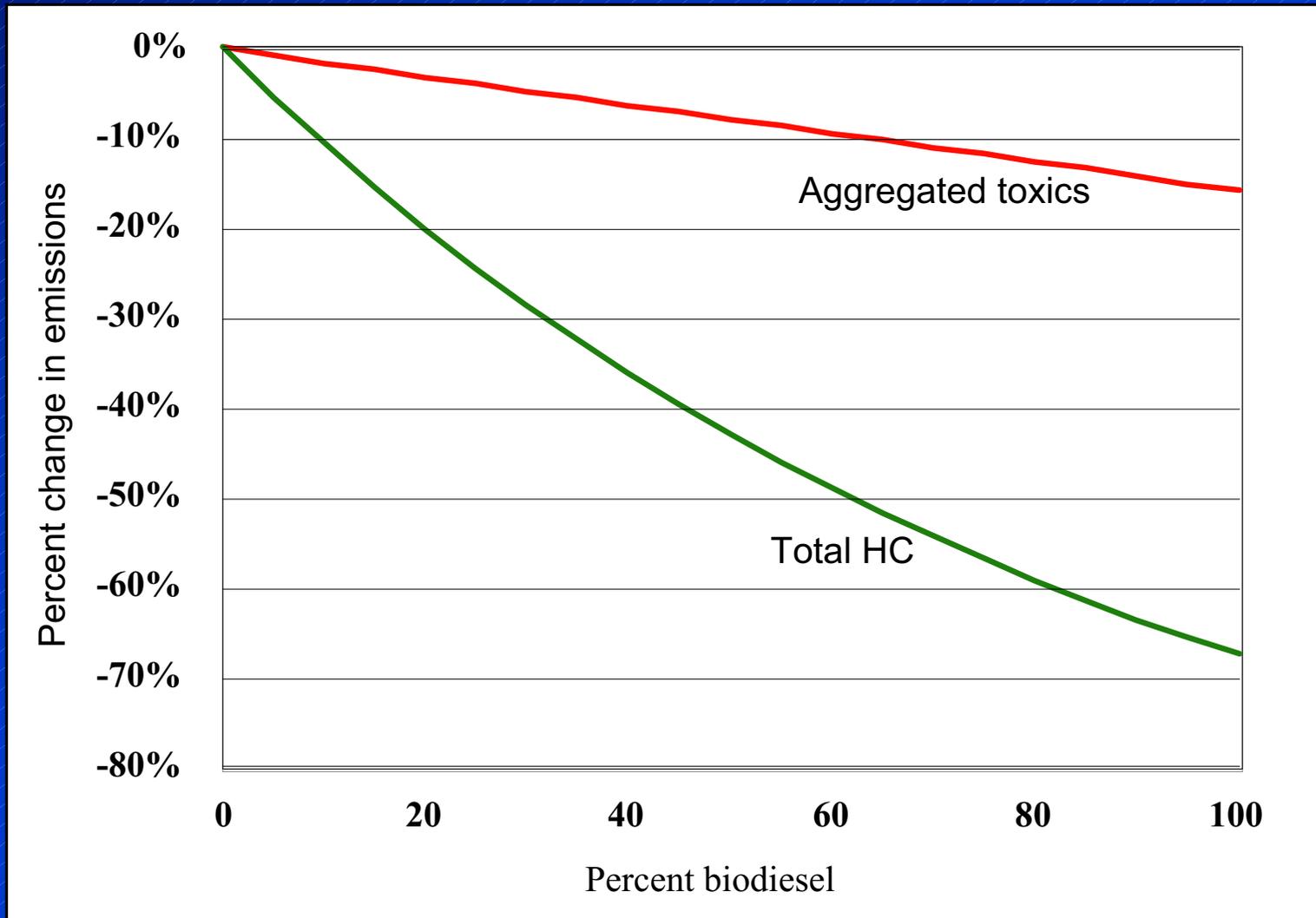


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Toxics

- Only a few studies included toxics
- Used a different analytical approach
 - Aggregated toxics = $f(\% \text{ biodiesel})$
 - Toxic/HC ratios = $f(\% \text{ biodiesel})$
 - % change in individual toxics = $f(\% \text{ biodiesel})$
 - 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



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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 CO₂ 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 CO₂
- 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