

LUNG TOXICITY AND MUTAGENICITY OF EMISSIONS FROM HEAVY-DUTY COMPRESSED NATURAL GAS (CNG)-POWERED VEHICLES



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LUNG TOXICITY AND MUTAGENICITY OF EMISSIONS FROM HEAVY-DUTY COMPRESSED NATURAL GAS (CNG)-POWERED VEHICLES



Topics:

- **Results of CNG study**
- **Composition-Toxicity Analysis for CNG, Diesel, and Gasoline**
- **Status of Other Samples**

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TOXICITY OF CNG BUS EMISSIONS

3 HD buses from Ft. Worth & Houston transit systems:

New technology (NT)

**2002 Nova with DDC 50G + oxidation catalyst
216 miles (new in service)**

Normal emitter (NE)

**1997 New Flyer with DDC 50G (no after-treatment)
134,000 miles (in service)**

High emitter (HE)

**1992 Flexible with Cummins L10G (no after-treatment)
Over 250,000 miles (retired, odometer broken)**

Samples collected on chassis dyno at SwRI

- a. **Cold start at ambient temp. (~ 25°C)**
- b. **1 EPA HD Urban Dyno Driving Schedule**
- c. **3 DOT/FTA Central Business District cycles**
- d. **Repeat 7x/day**

Fuel = NG from San Antonio Public Service system

96-97% methane, ~ 2% ethane, ~ 1% CO₂, ~ 0.7% N₂ (S not meas.)

Crankcase oil as received

[Seagrave et al., *Toxicol. Sci.* 87: 232, 2005]



SAMPLES & TESTING

1. Collected PM and vapor-phase SVOC samples (*SwRI*)
 - Diluted exhaust in constant volume tunnel to 1:35
 - 25% of flow → teflon/glass filter → PUF/XAD-4 trap
 - Samples extracted in acetone, concentrated & re-combined
(Control = tunnel background)

2. Parallel samples analyzed chemically (*DRI*)

3. Toxicity (*LRRI*)

Lung inflammation and cytotoxicity

- F344 rats (3 mo old males, 5/group)
- Instilled into lung at multiple doses
- Measured at 24 hr:

Lung lavage (cells, LDH, protein, etc.)

Histopathology

Mutagenicity

Salmonella (Ames) strains TA98 and TA100

4. Statistics (*SKS, UNM*)

- Compared slopes of dose-response curves
By mass and emission rate
- Multivariate analysis of composition vs toxicity



RESULTS: PM EMISSION RATES & SVOC/PM RATIOS

Buses in Present Study:

	Vehicle PM Emission Rates (<u>mg/mile</u>)	SVOC/PM Mass Ratios <i>in</i> <u>Tested Samples^a</u>
NT	5	38
NE	7	46
HE	406	4

^aBased on mass extracted from filters and PUF/XAD

Vehicles from earlier study^b:

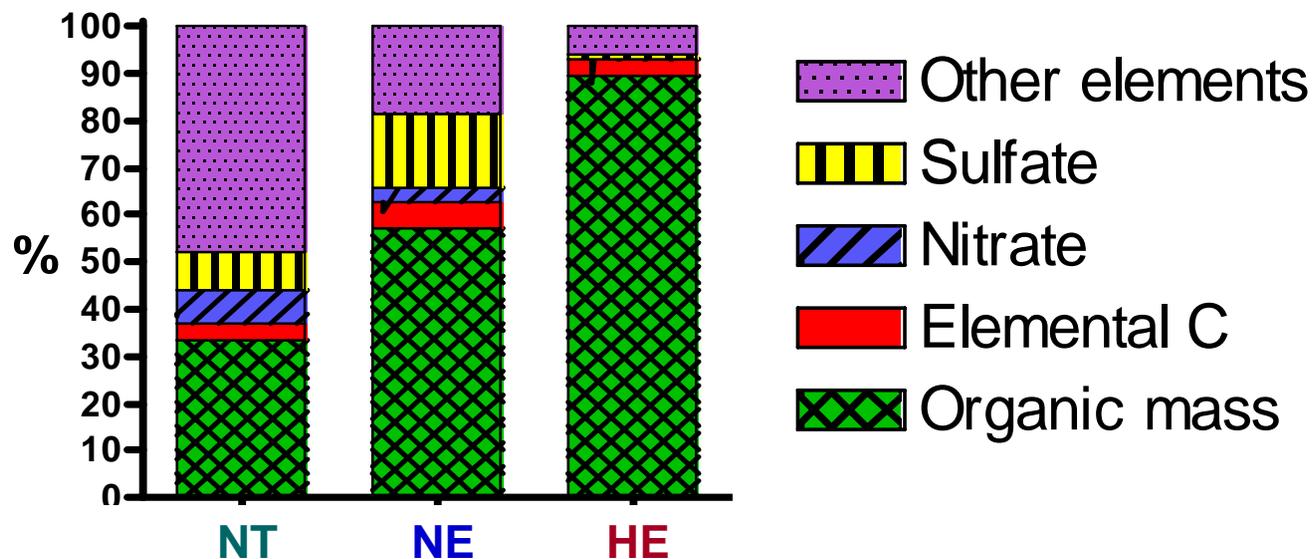
NE LD Gasoline (G)	10	5
Black S. HE LD Gasoline (BG)	67	5
White S. HE LD Gasoline (WG)	770	0.3
NE LD & MD Diesel (D)	144	0.6
HE MD Diesel (HD)	483	0.9

^bSeagrave et al., Toxicol. Sci. 70:212-226, 2002

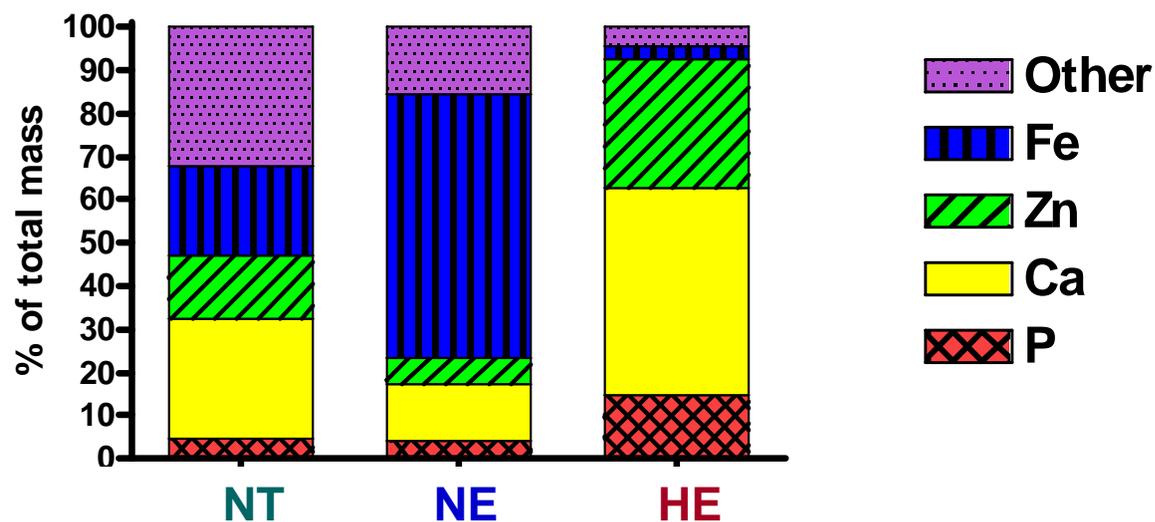


RESULTS: PM COMPOSITION

Percentage of Total PM Mass



Elements detected by XRF Analysis (excluding C and S)



RESULTS: PAH & HOPANE/STEARANE CONCENTRATIONS

In earlier gasoline & diesel samples:

Certain nitro-PAHs were associated with mutagenicity

Hopanes & stearanes were associated with lung toxicity

Concentrations in 1:35 diluted CNG exhaust:

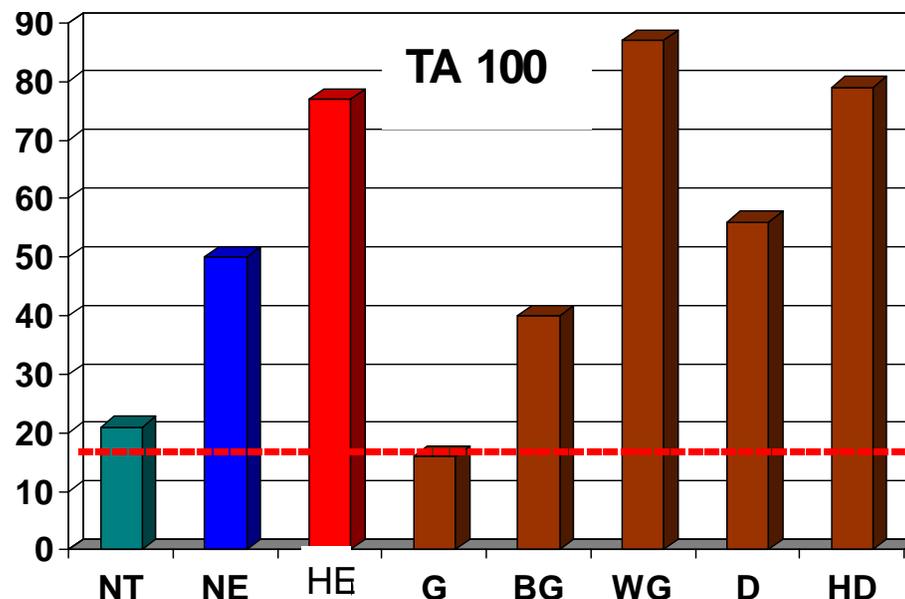
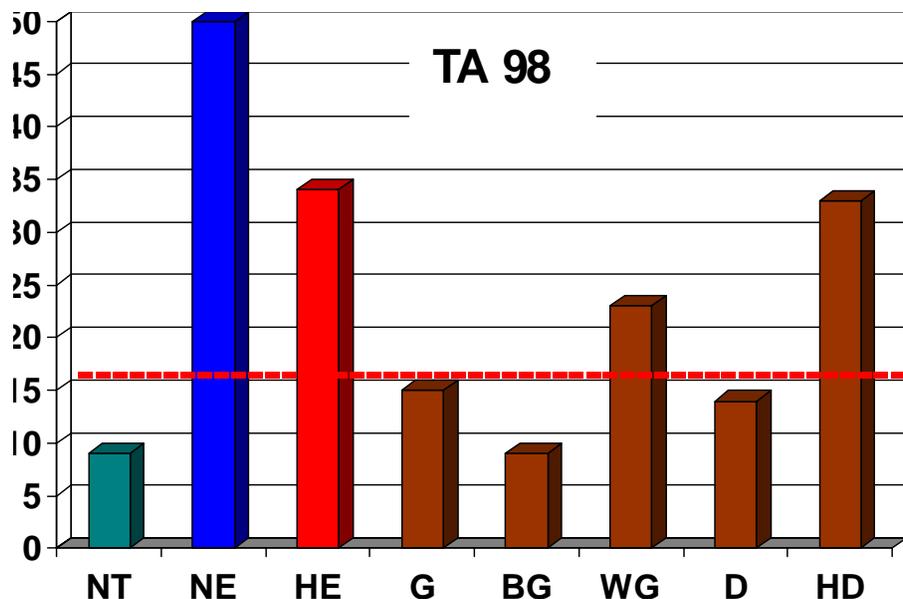
	Total PAH (<u>ng/m³</u>)	Hopanes/Stearanes (<u>pg/m³</u>)
NT	3.8	16
NE	1.2	23
HE	15.0	462

RESULTS: MUTAGENICITY IN BACTERIA

Revertants/ μg (x100) Combined PM and SVOC Mass (-S9)

	<u>TA98</u>	<u>TA100</u>
NT	9	21
NE	50	50
HE	34	77

Comparative Mutagenicity per unit mass of CNG vs. Earlier Samples



RESULTS: LUNG TOXICITY

Responses expressed as slopes of dose-response curves

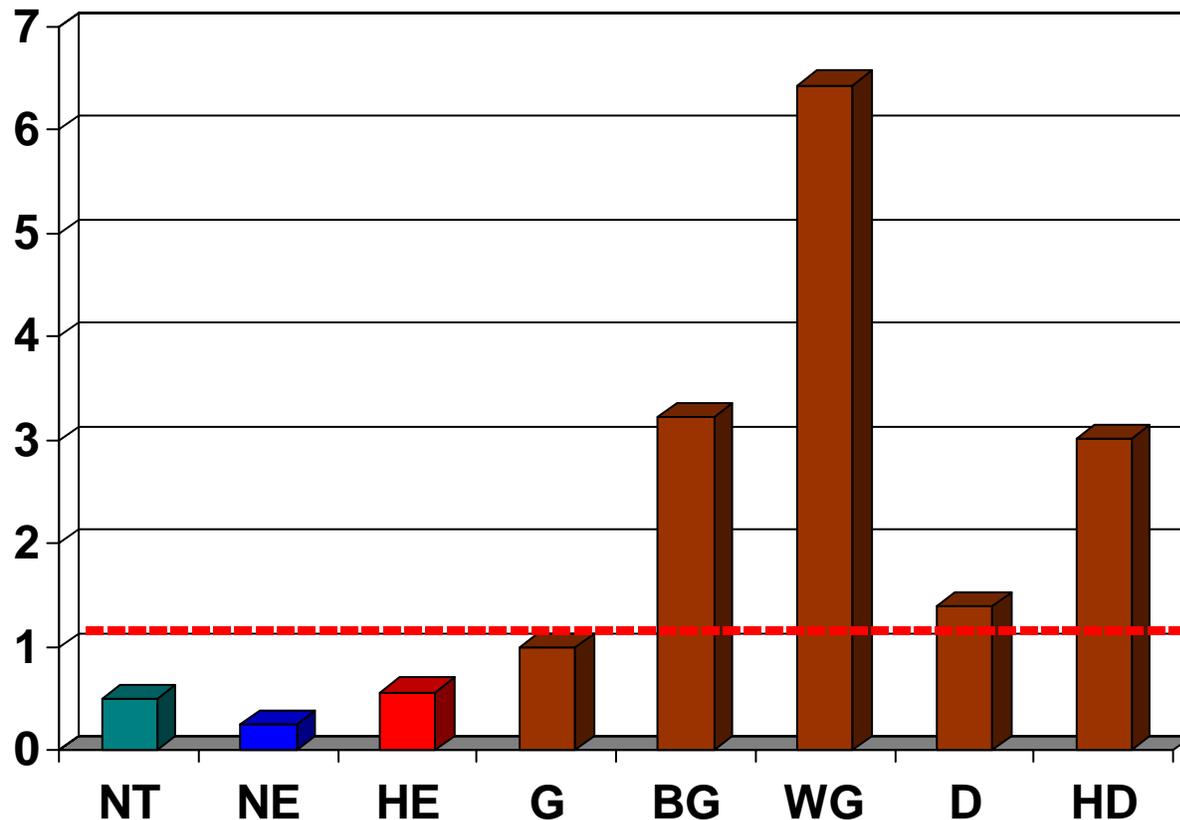
	<u>NT</u>	<u>NE</u>	<u>HE</u>	<u>G</u>
Bronchoalveolar Lavage				
LDH	0.25	<i>0.10*</i>	0.24	0.31
Protein	0.43	0.14	0.38	0.65
Total Cells	<i>0.27</i>	<i>0.06</i>	0.41	0.38
PMNs	<i>0.16</i>	<i>0.01</i>	0.17	0.23
Histopathology				
Total Score	<i>0.05</i>	<i>0.27</i>	<i>0.11</i>	0.72

*slope values in italics are not significantly different from zero at $p < .05$



COMPARATIVE LUNG TOXICITY of CNG vs. EARLIER SAMPLES

- Based on averaged responses per unit mass in 5 variables:
LDH, protein, total cells, PMNs, total histopathology score
- Toxicity of normal-emitter LD gasoline (G) arbitrarily set at a value of 1.0



MULTIVARIATE ANALYSIS OF RELATIONSHIP BETWEEN COMPOSITION AND TOXICITY

Same approach as used previously for gasoline & diesel samples

[McDonald et al., *Env. Health Perspect.* 112: 1527-1538, 2004]

- **Principal Component Analysis & Partial Least Squares Regression**
- **3 samples not enough for PCA/PLS of CNG data alone**
 1. **Combined data from gasoline, diesel, and CNG (10 samples)**
 2. **Separate analyses of lung toxicity and mutagenicity**
 3. **Determined optimum number of principal components**
 4. **Developed and validated best models for predicting toxicity from composition**
 5. **Determined importance of each composition variable to model**
- **Showing results for lung toxicity**



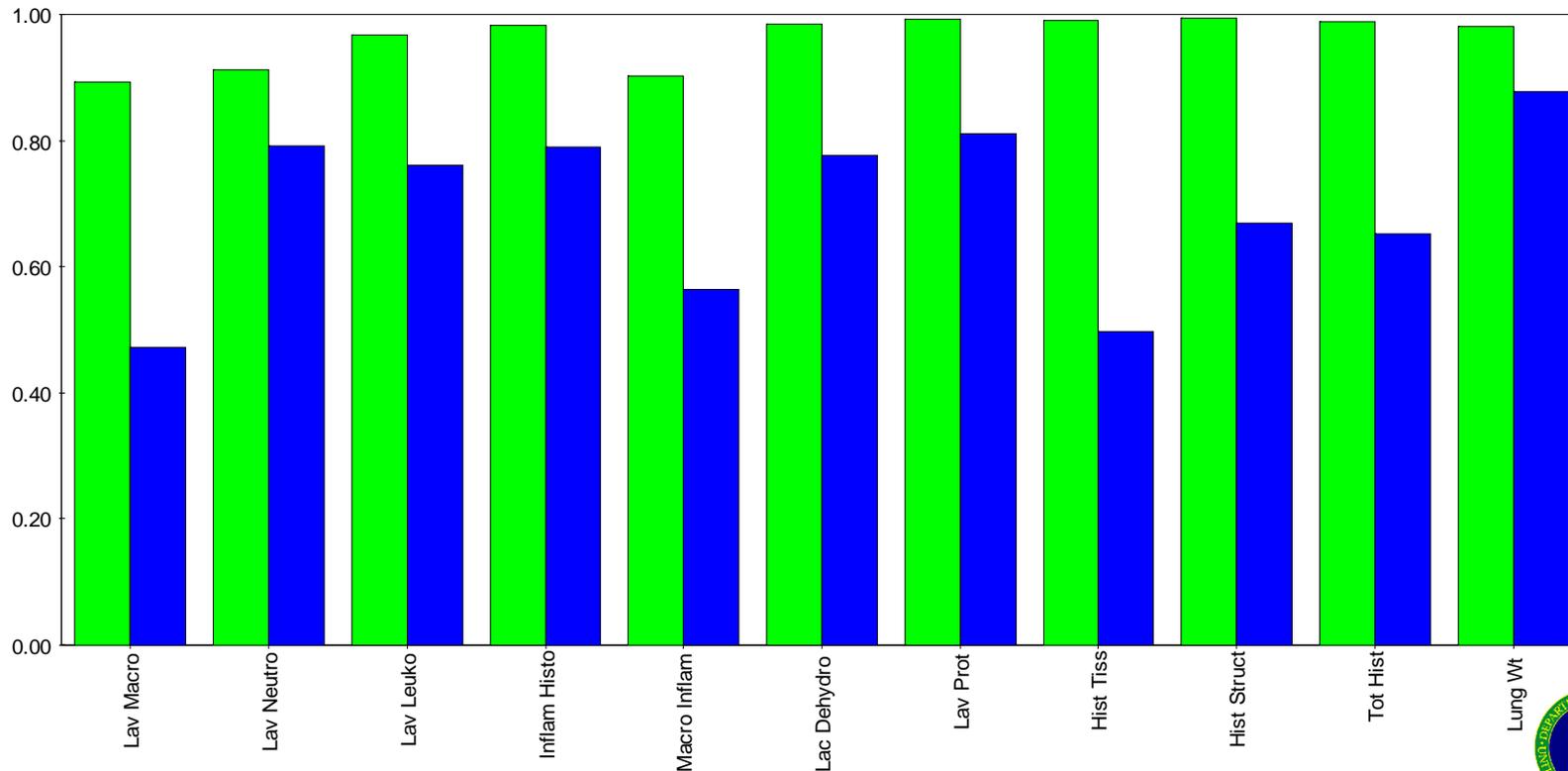
PCA/PLS RESULTS: LUNG TOXICITY

4 principal components gave the best fit

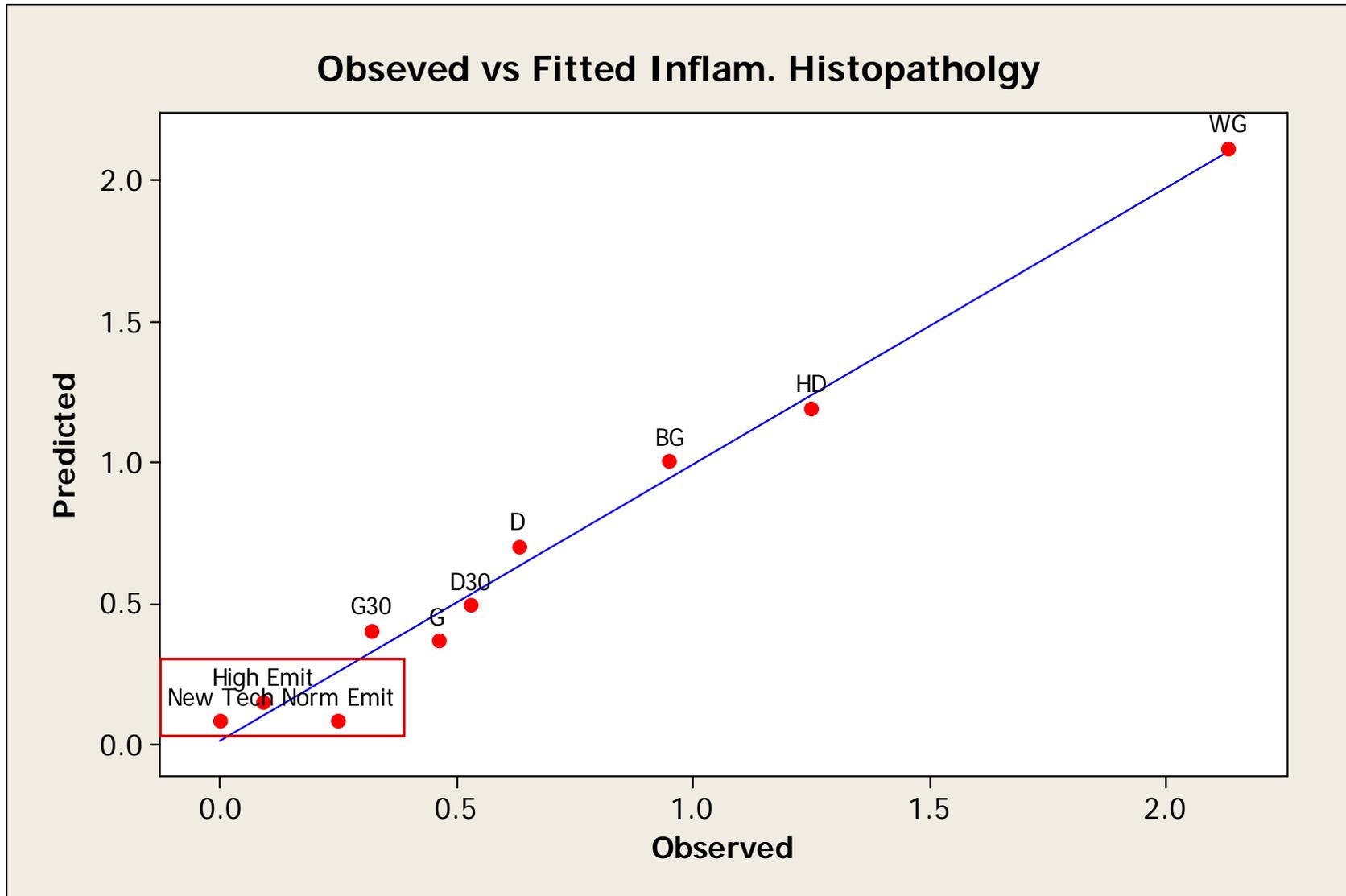
1 Component explained **65%** of differences in response
2 “ “ **86%** “ “ “ “
3 “ “ **94%** “ “ “ “
4 “ “ **97%** “ “ “ “

Models using 4 components fit the data well

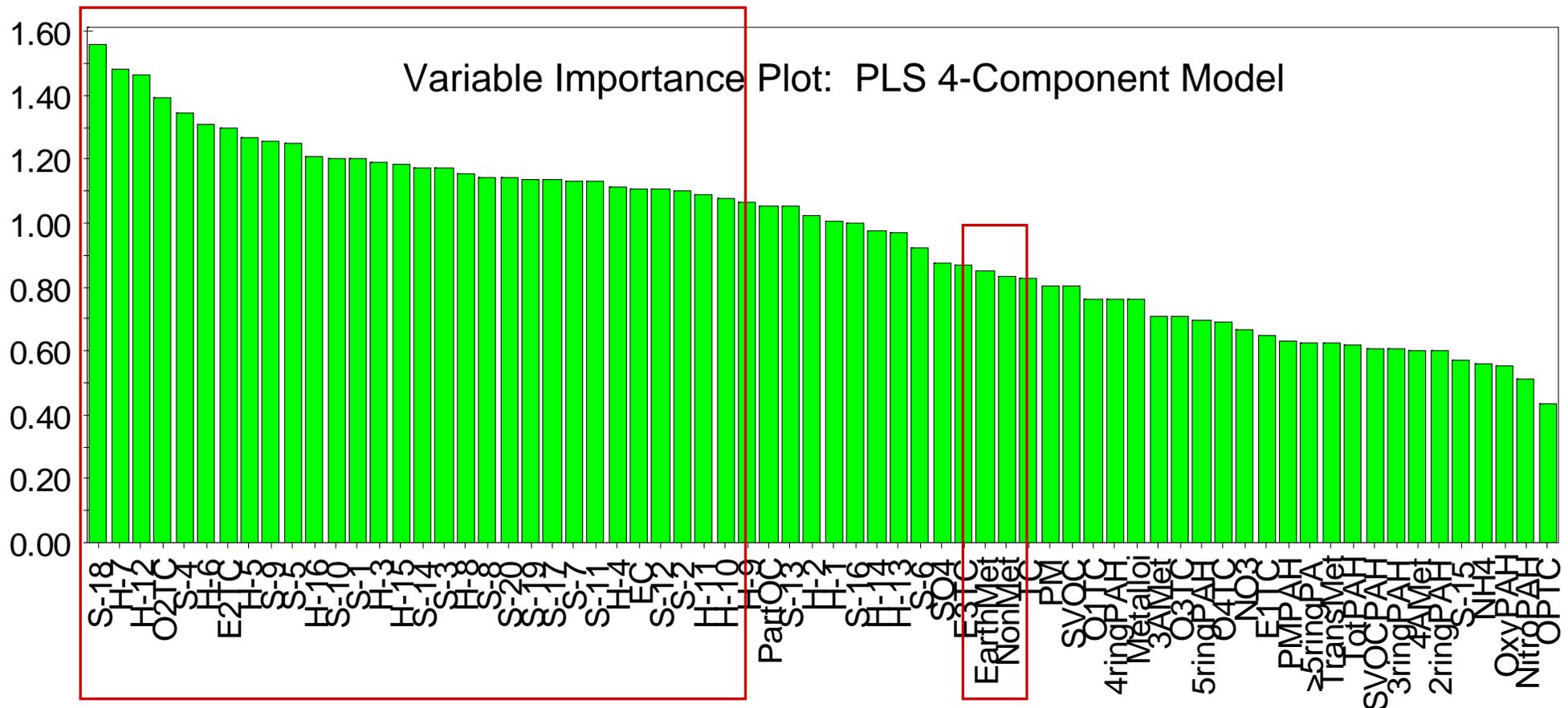
Goodness of Fit (R^2) and Prediction Ability (Q^2) for 11 Response Variables



EXAMPLE OF MODEL FIT TO DATA: Histological Evidence of Lung Inflammation

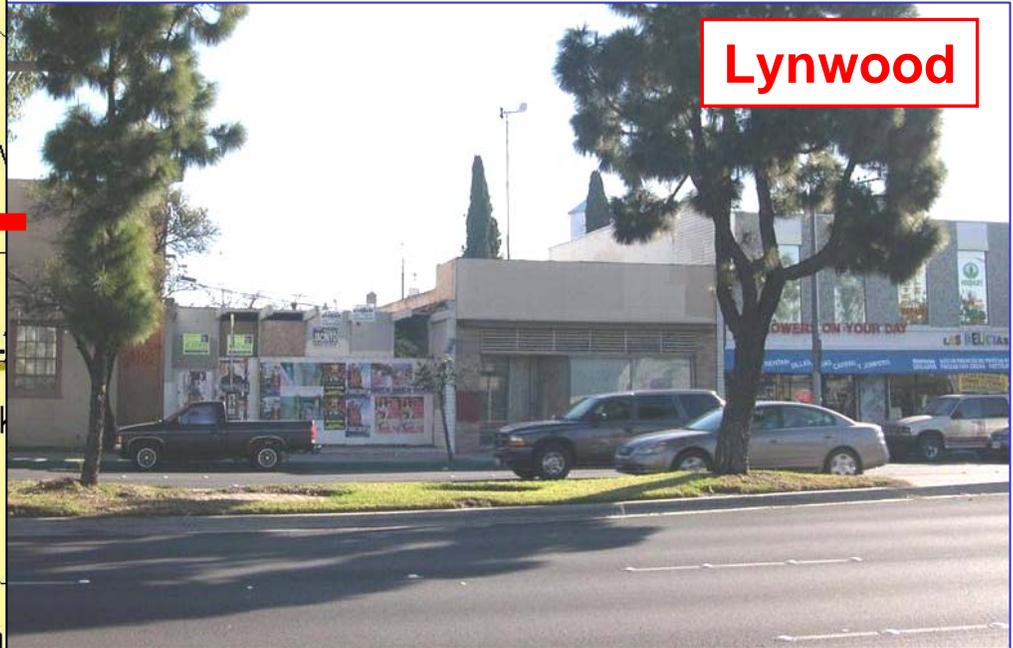


RELATIVE IMPORTANCE OF COMPOSITION VARIABLES TO LUNG TOXICITY MODEL



- 27 of top 30 composition variables are hopanes or steranes
- Calcium and phosphorous, also oil markers, are less important

NOW TESTING ENVIRONMENTAL SAMPLES

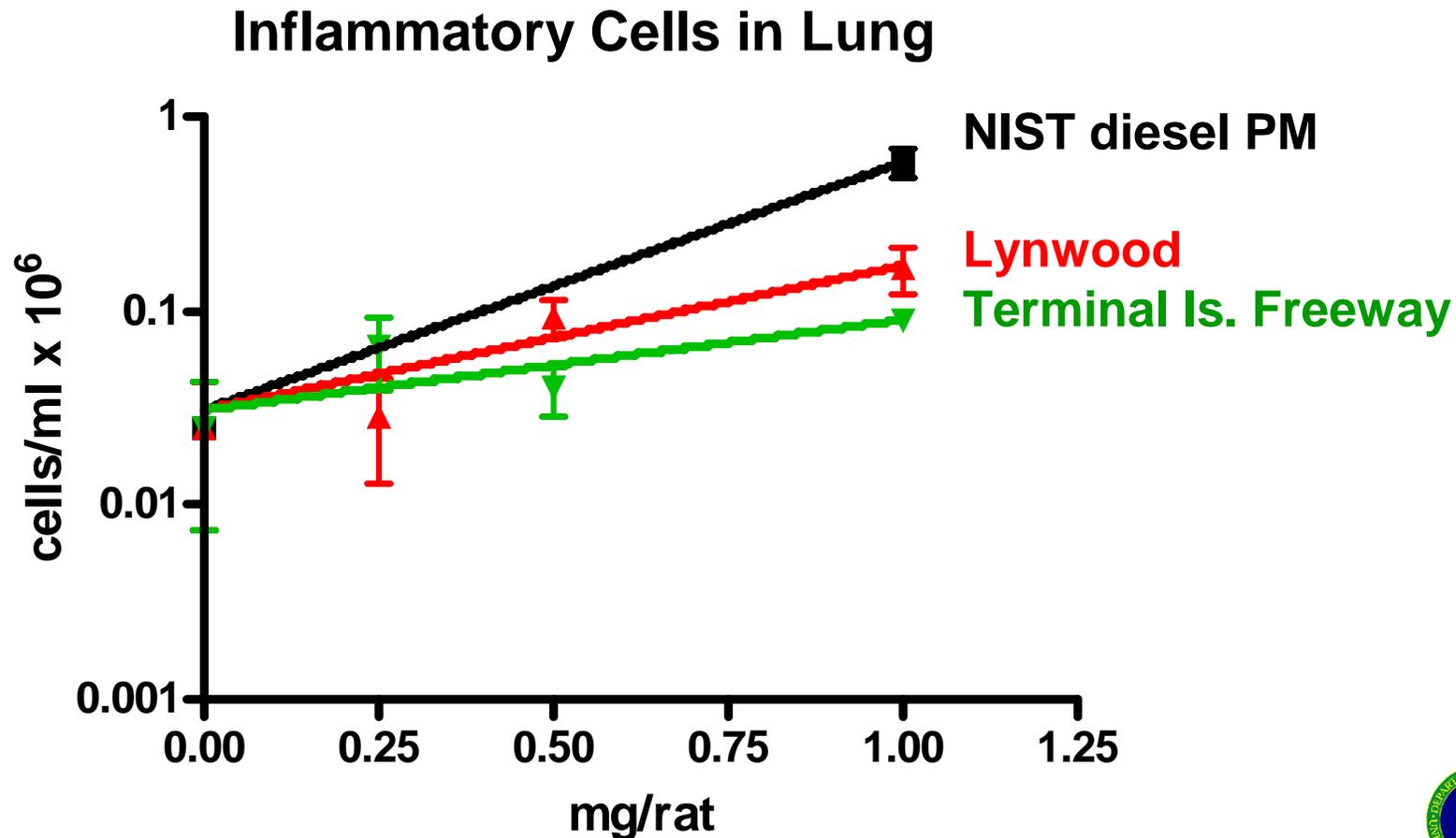


Terminal Island Freeway



STATUS OF ENVIRONMENTAL SAMPLES

- Tests are still underway - not yet complete
- Preliminary results indicate that Lynwood sample (LD) is more toxic than Terminal Island Freeway (HD) sample



SUMMARY

Cumulative results continue to indicate:

- **High-emitters contribute disproportionately to hazards**
- **Crankcase oil emissions are important**
- **LD emissions are important (as well as HD)**

Next steps:

- **Complete work on additional samples:**
 - Environmental roadside**
 - Gasoline pre- and post-catalyst light-off**
 - New technology diesel**
- **Directly determine toxicity of oil emissions**
 - Hopanes & stearanes: markers or culprits?**
 - New vs. used**
 - Petroleum vs. synthetic**
- **Directly test toxicity of “nanoparticle” emissions**
- **Evaluate emissions from emerging technologies**

