Environmental Systems Products Holdings Inc.

Presented to ARAI on March 18th/19th, 2004

Dr. Donald Stedman, Niranjan Vescio, Gary Full

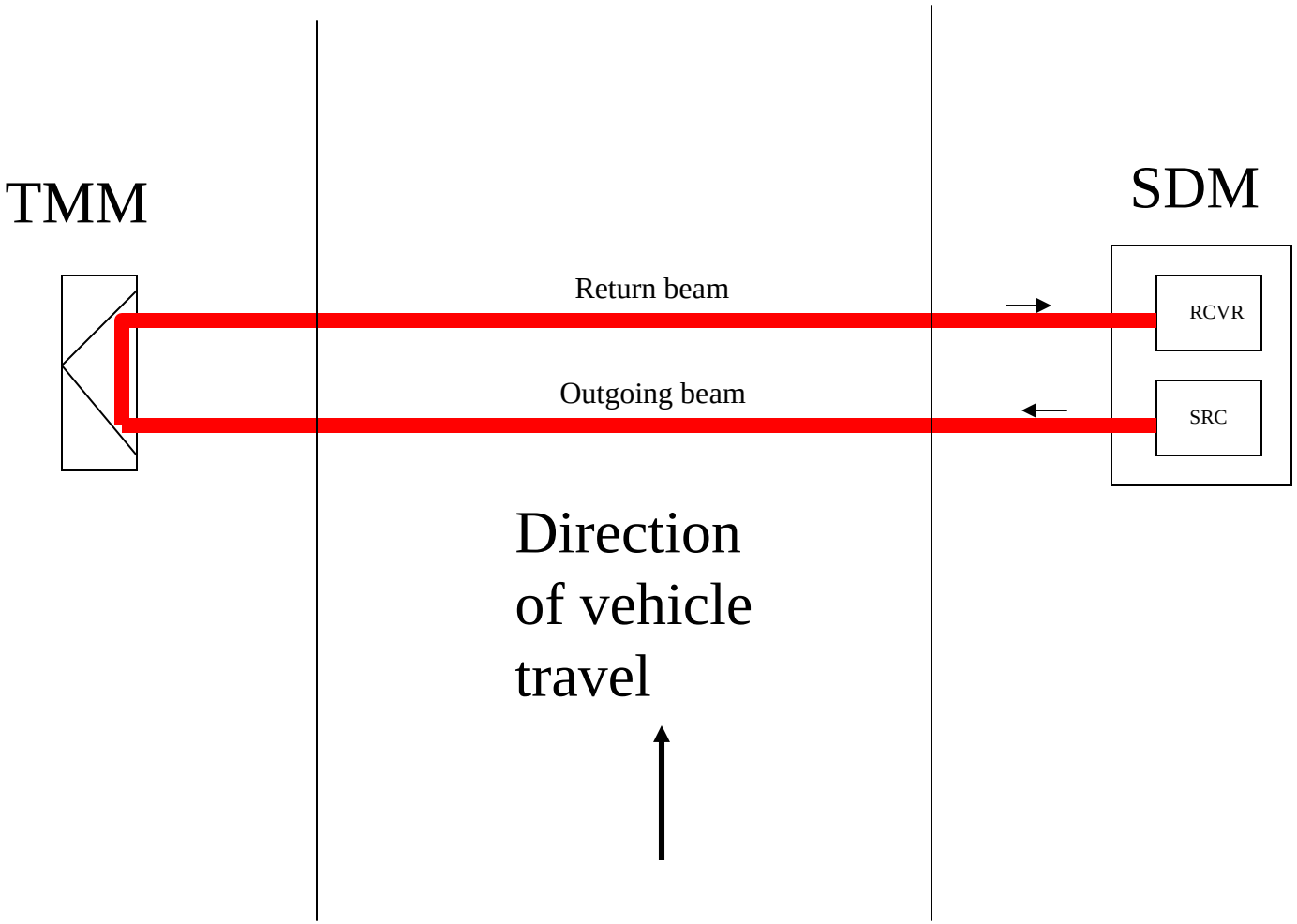
Agenda

- Instrumentation – Gary Full
- RSD Gas Calculations – Dr. Stedman
- Summary Statistics – Dr. Stedman
- 2-Wheeler Improvement – Gary Full
- Other Discussion - All

RSD4000 Technology Device Measurement Overview

Presented by Gary Full

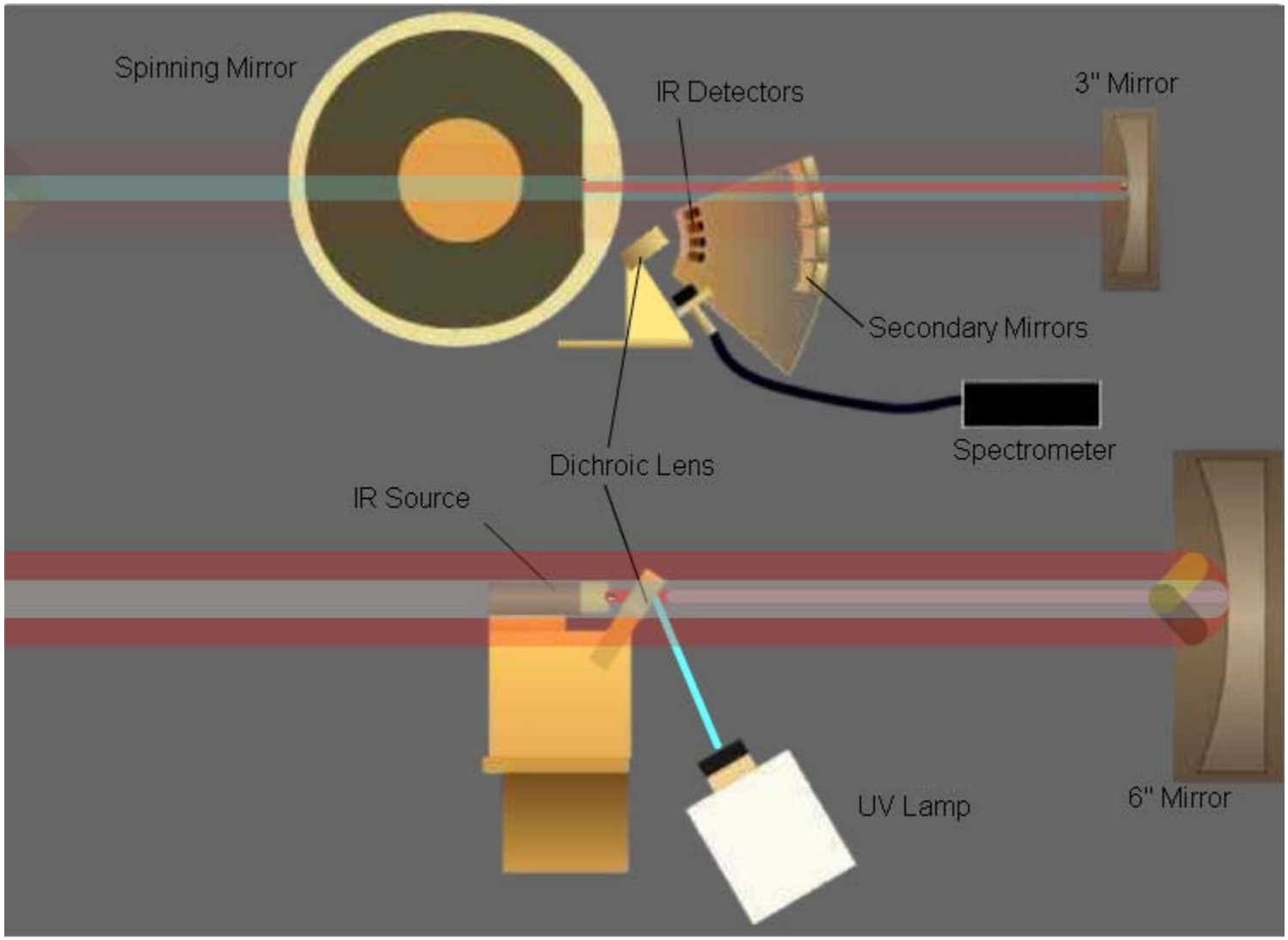
Optical Path



Optical Beam

- IR filament source and UV light source are combined and positioned so as to appear at the focus of the source mirror. Result is a collimated (nearly parallel rays) exit light beam.
- Transfer mirror offsets the beam and returns it to the receiver optical section of SDM.
- Receiver mirror collects and focuses the received light.
- UV light is split out via a dichroic mirror and distributed to a spectrometer via fiber optic cable for NO and SF measurements.
- IR light is sent to a rotating (12,000 RPM) spinning mirror scanner assembly which distributes light to individual IR detectors for CO, CO2, REF, and HC detection. Scanner produced 2400 light pulses/second at each detector.
- Thermoelectrically cooled detectors (~-5 degree C) produce stable, highly sensitive, low noise electrical signal outputs.

Optical Beam Path



Signal Conditioning/Firmware

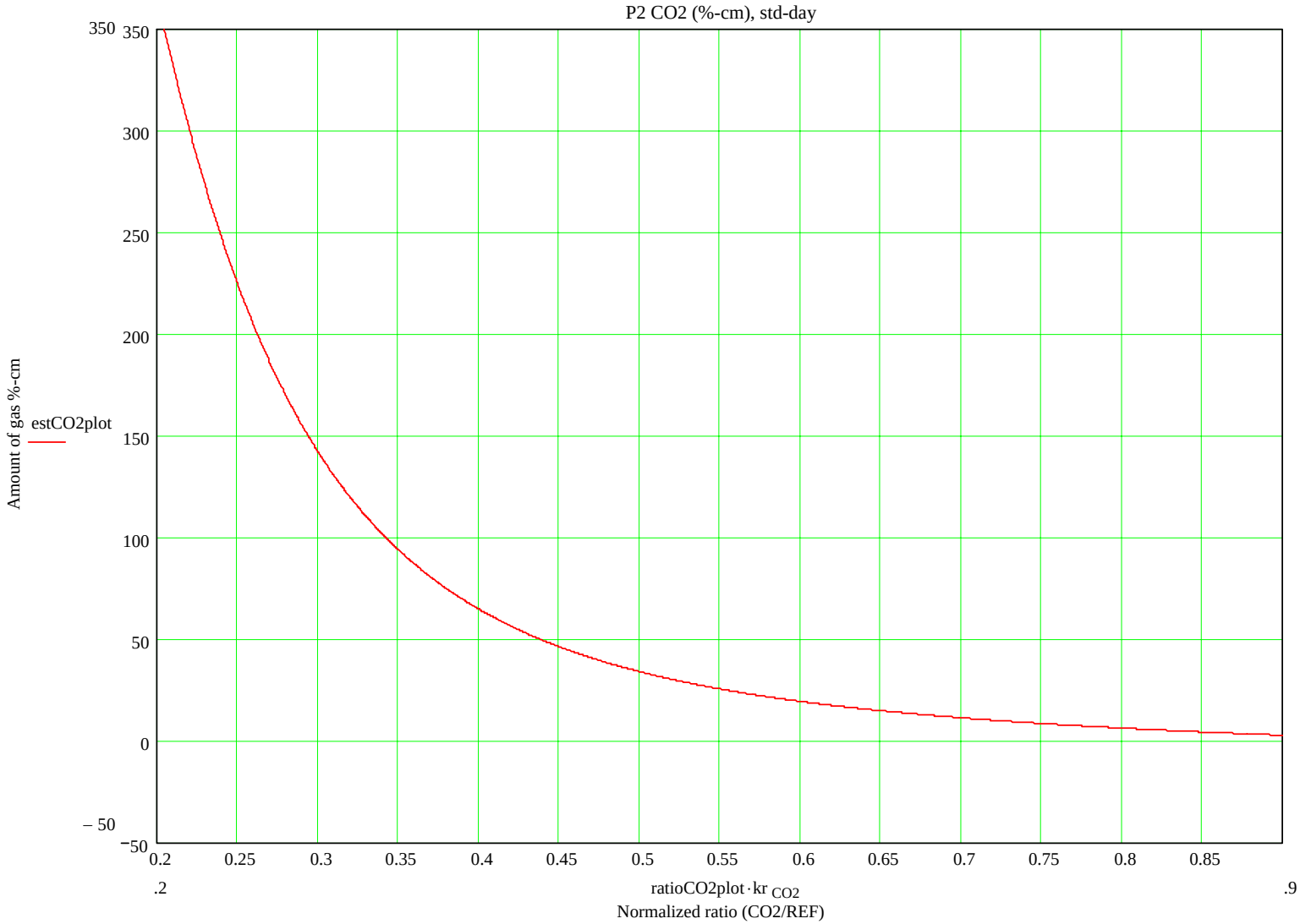
- Each detector output is AC-coupled via a preamplifier.
- Discrete gain selection (0.5, 1, 2, 4, or 8).
- Q=10 band-pass filter produces sine waves at carrier frequency of 2400 Hz. Gas information is represented by the amplitude modulation of the carrier.
- Sine waves are then rectified.
- A synchronous integrator provides an average over 24 sine wave periods to produce a result that is sampled by a 16-bit A/D converter every 10-milliseconds (100 samples/second).
- IR gas channel voltages (CO,CO2, and HC) are ratioed to the REF channel to provide a signal proportional to gas transmittance (ratio of emitted light to received light).

Gas Measurement Processing

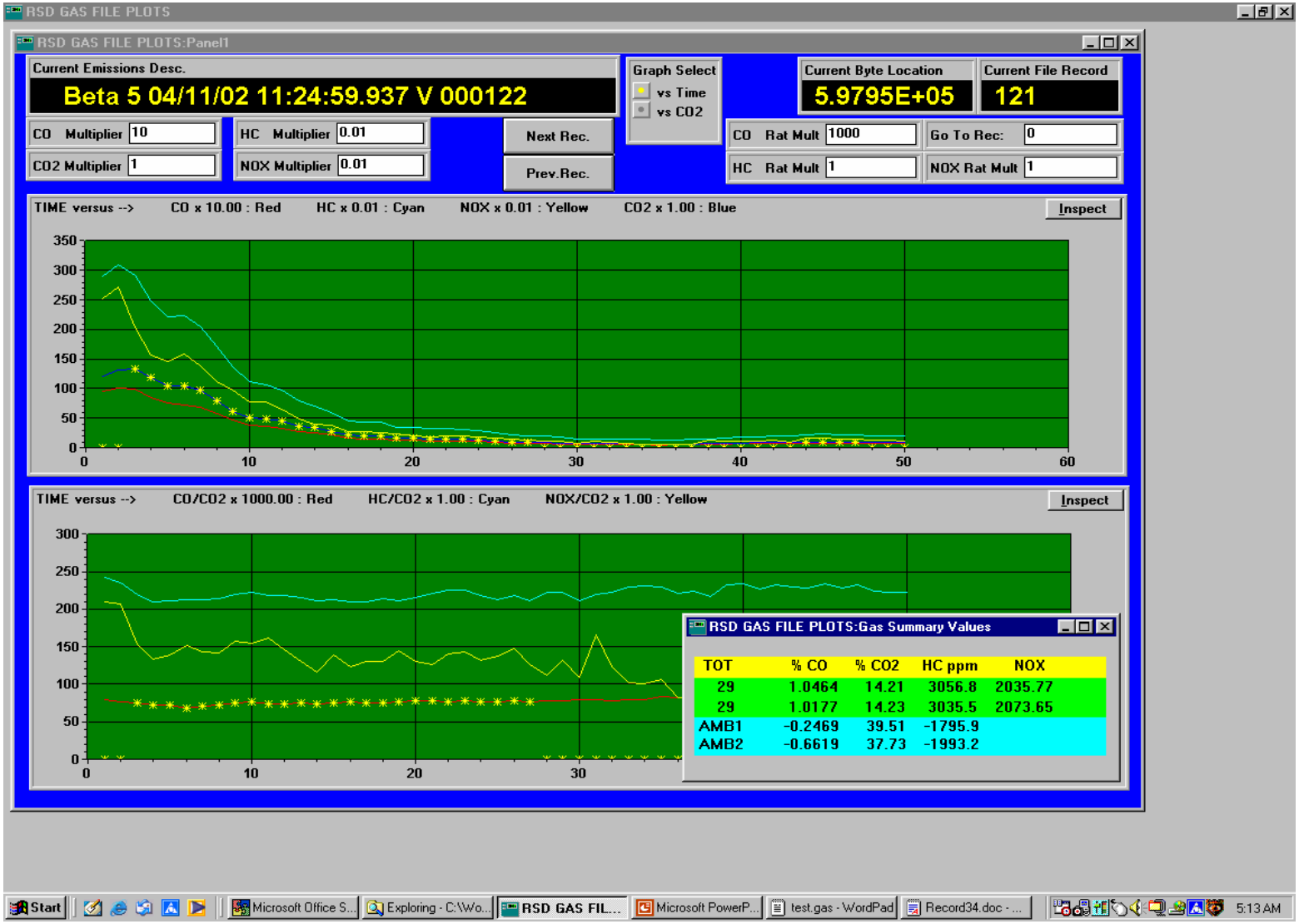
- Curves of gas transmittance versus gas amount (number of molecules/unit beam cross-section) are stored in the SDM.
- Measured transmittances are converted to gas amounts.
- Gas amount measurements (ambient gas readings) at front of the vehicle are recorded for CO, CO2, and HC.
- 50-samples of information are recorded at the rear of the vehicle.
- Amount of gas attributable to the vehicle is found by subtracting the ambient value from each of the 50 samples.

CO_2 Response Curve

3b-1



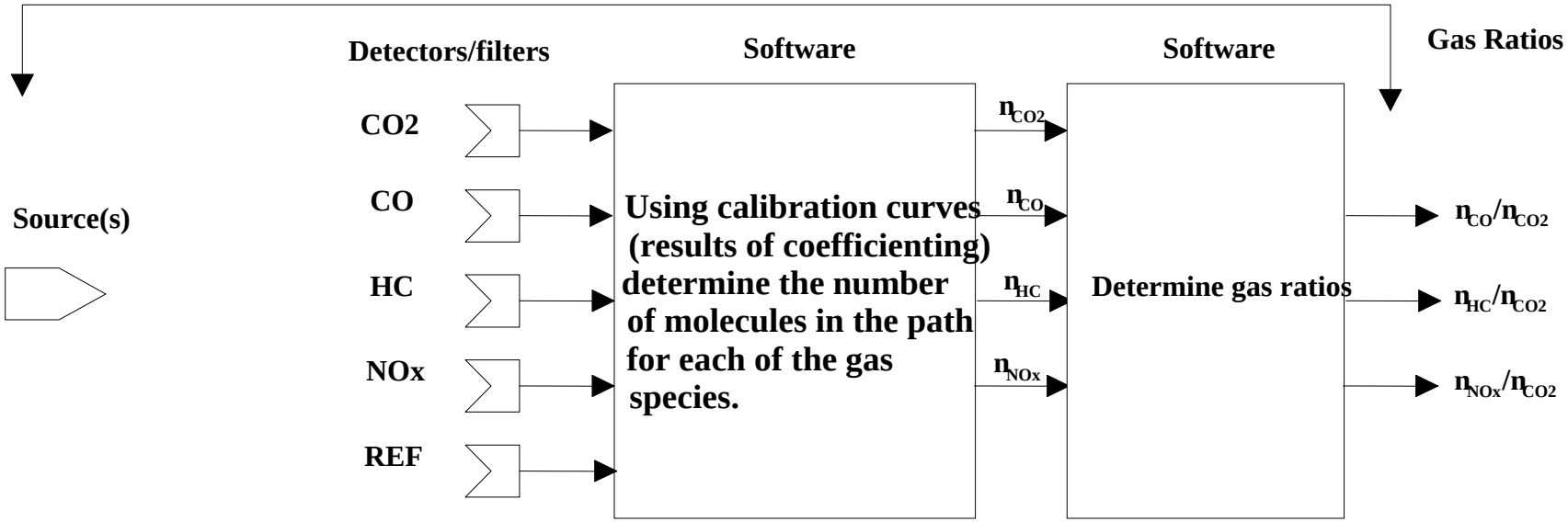
Plume Decay Graphs



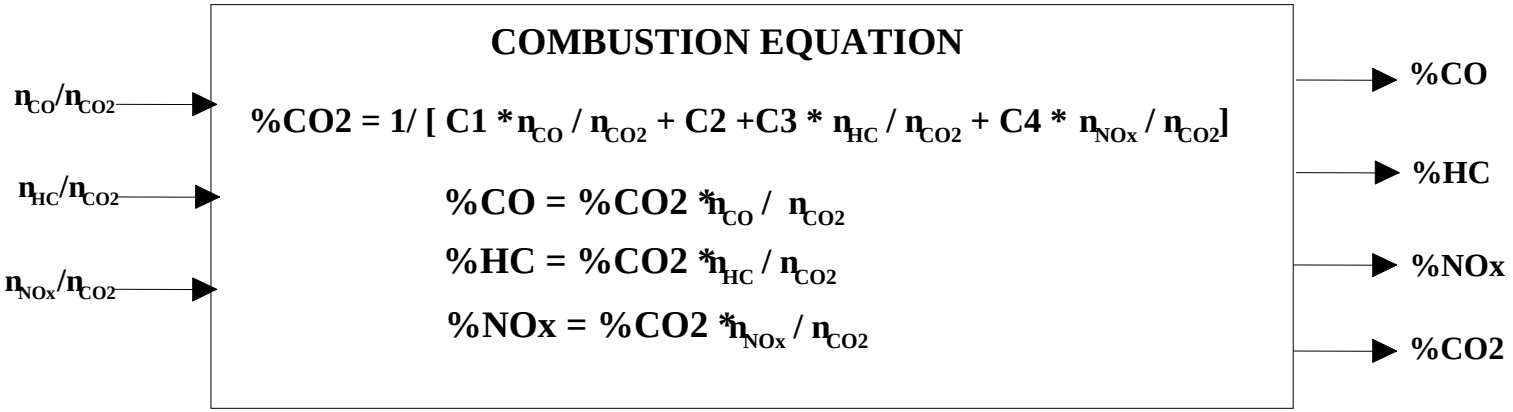
Gas Measurement Processing continued

- Aggregate gas ratios (a single value for the possible 50 point sets) are calculated for CO/CO2, HC/CO2, and NO/CO2. The aggregate values are least squares linear regression fits of the gas value array with respect to the CO2 array. E.g. CO array versus CO2 array. For the aggregate slope calculations we reject data points immediately before and after beam blocks/unblocks, and where the sum of the gas amounts are below a threshold.
- We consider a gas measurement “valid” if there are at least 5-points available in the slope calculation – “invalid” otherwise.

THE BASIC INSTRUMENT



Results Reporting



ASSUMPTIONS that impact determination of C1, C2, C3, and C4

1. **The measured gases are the results of combustion and only combustion gases.**
2. **The fuel hydrogen to carbon ratio is known.**
3. **The oxidizer is air.**

Gas Measurement Processing continued

- We also report “stoichiometric” (meaning the concentration that would be measured by a tail pipe probe if there were no excess air in the exhaust beyond what is needed for combustion) gas concentrations. These gas concentrations are the result of combustion chemistry where the basic assumptions are that the aggregate carbon to hydrogen content of the fuel is known and that air is the oxidizer in the combustion process.

Other RSD Subsystems/Options

- Speed/acceleration
- Vehicle/license plate picture
- Weather measurement
- GPS for time base as well as position
- Wireless communications links
  - 300 meters
  - Cellular links
- PC storage and transfer media
- “Smart” Signs / motorist displays

RSD Calculations

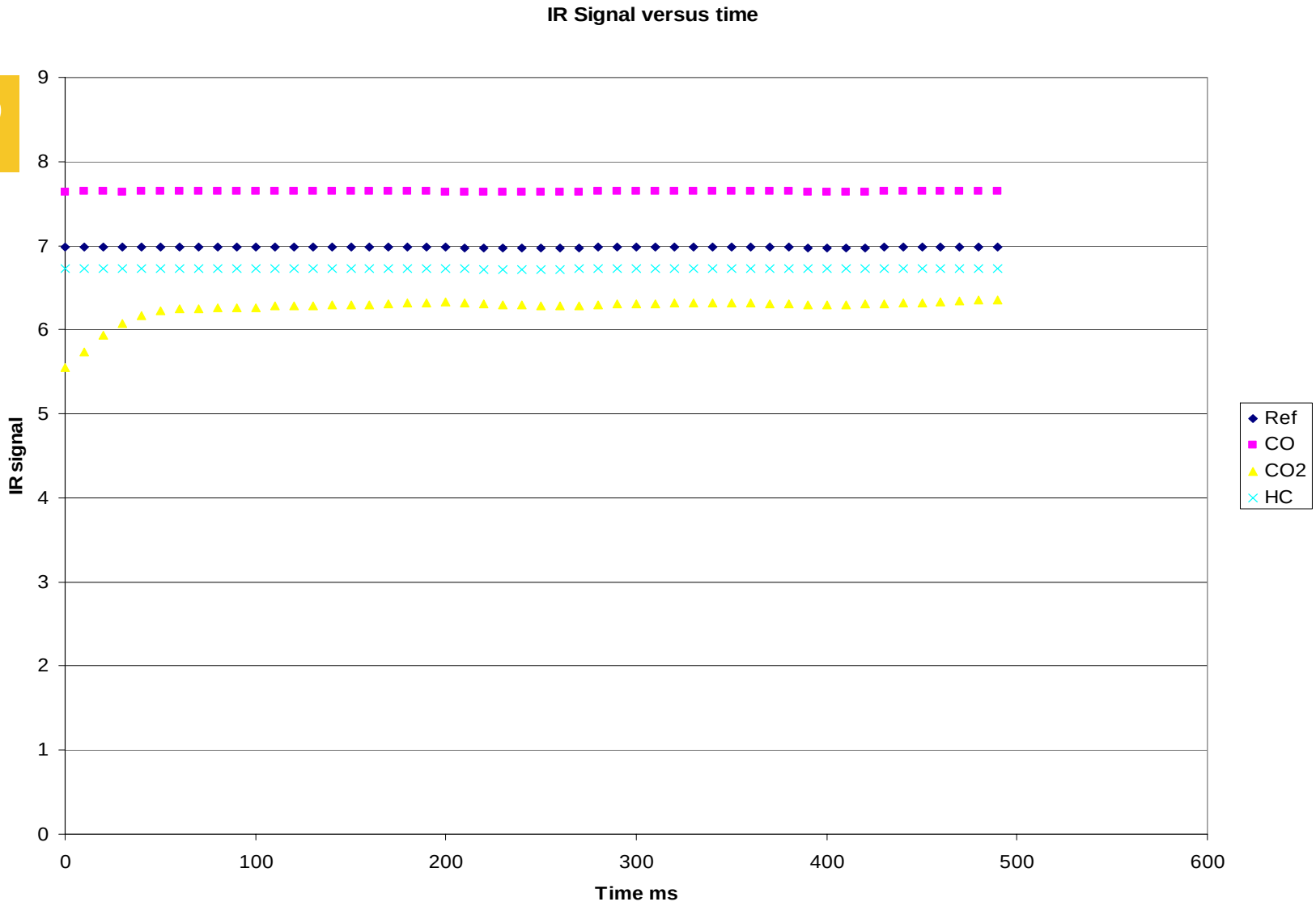
Presented by Dr. Donald Stedman

On-road Results from Denver

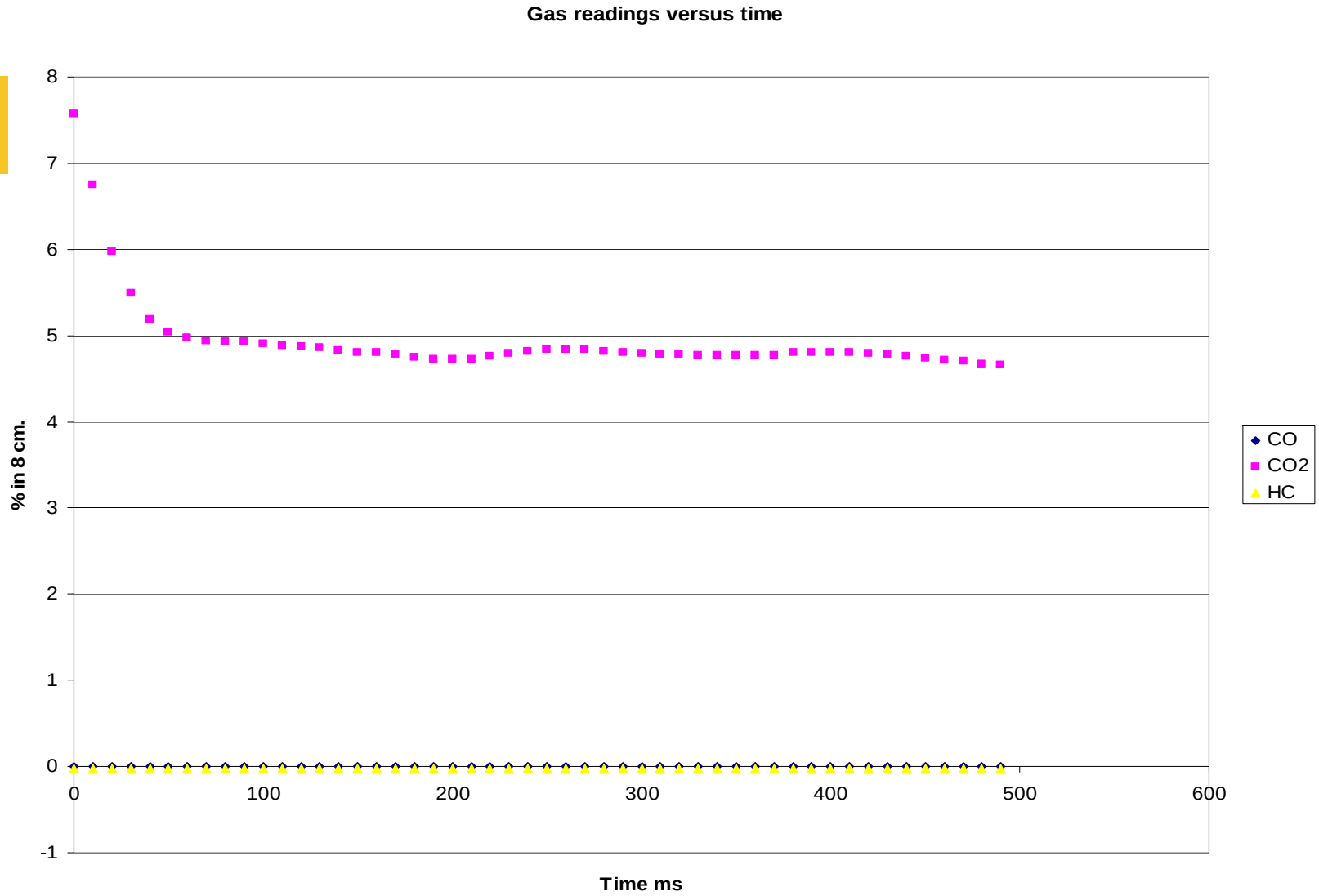
Sept 2003

Slides prepared by Donald H. Stedman, March 18, 2004 for ESP
www.feat.biochem.du.edu

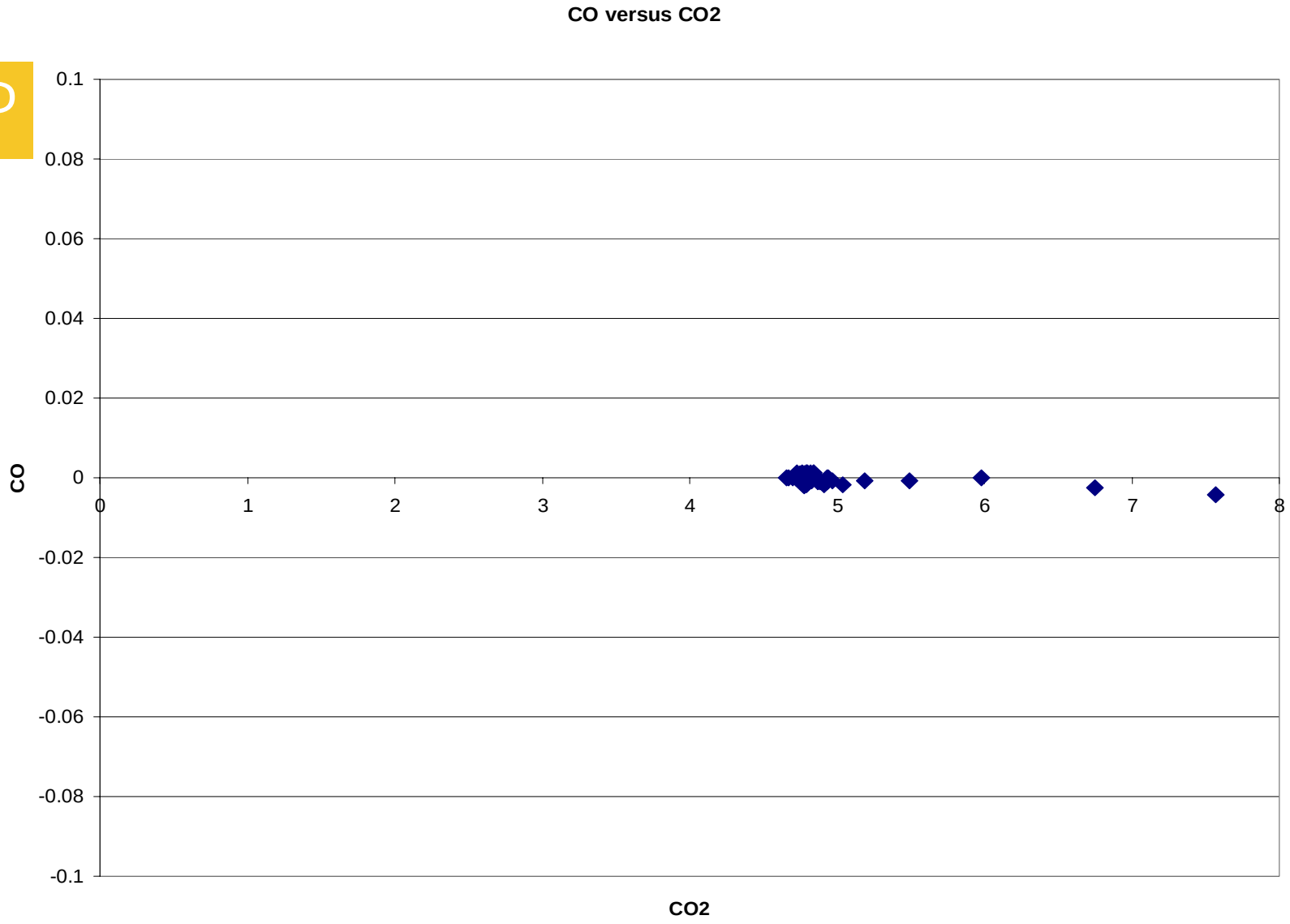
IR Signal vs Time



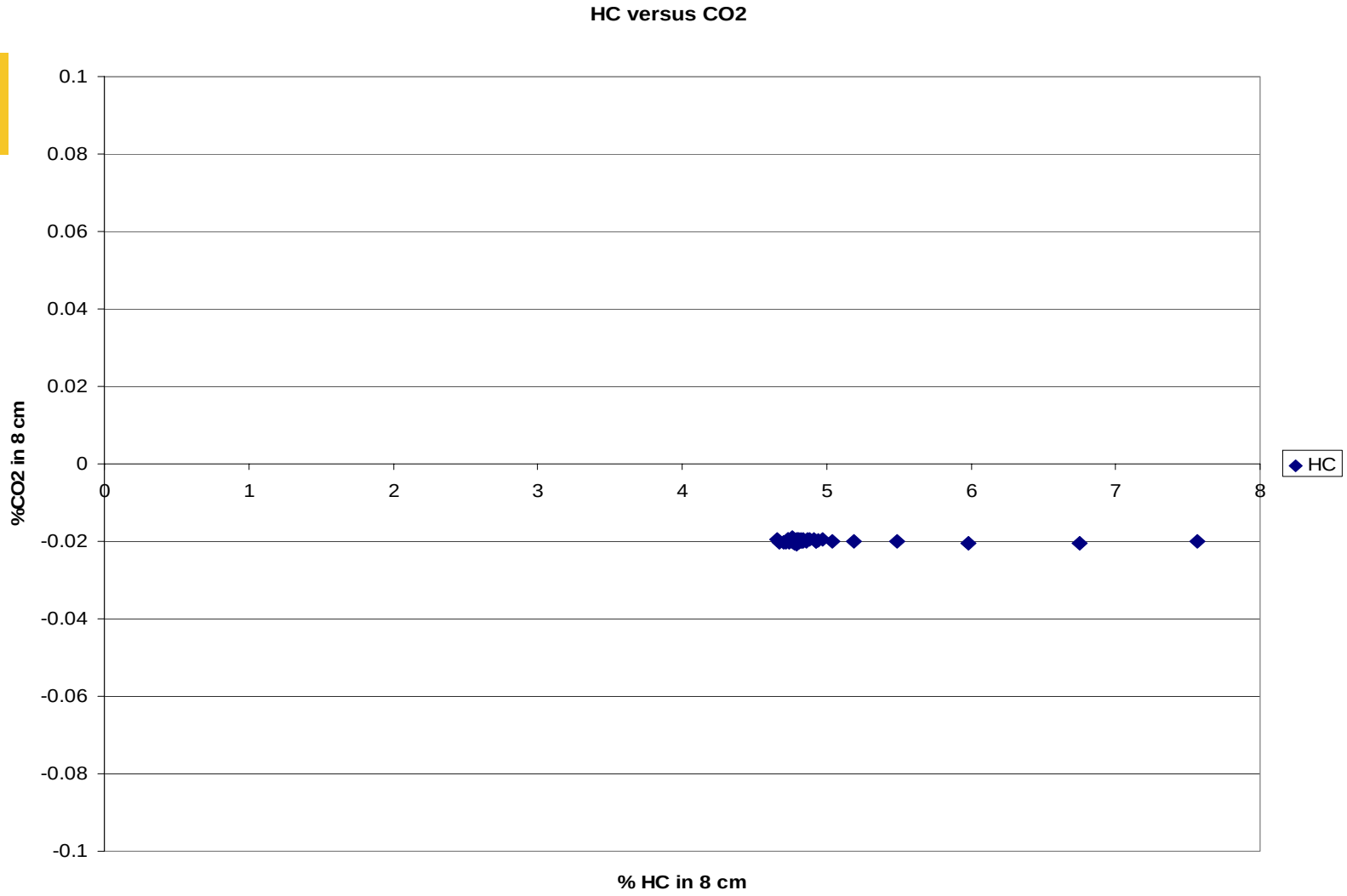
Gas Readings vs Time



CO vs CO_2

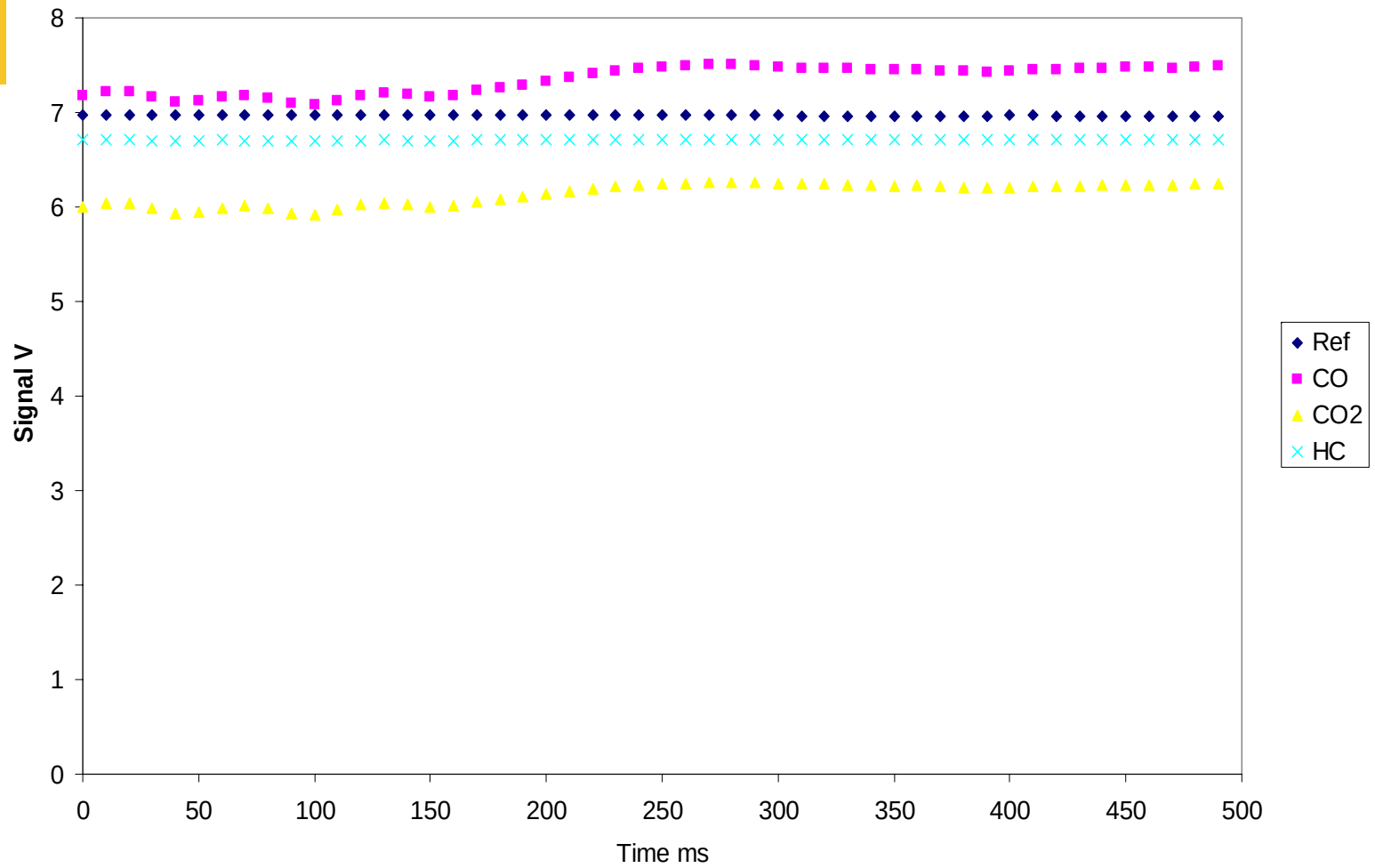

CO versus CO2
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
CO
0
1
2
3
4
5
6
7
8
CO2

HC vs CO_2


HC versus CO2
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
1
2
3
4
5
6
7
8
%CO2 in 8 cm
% HC in 8 cm
HC

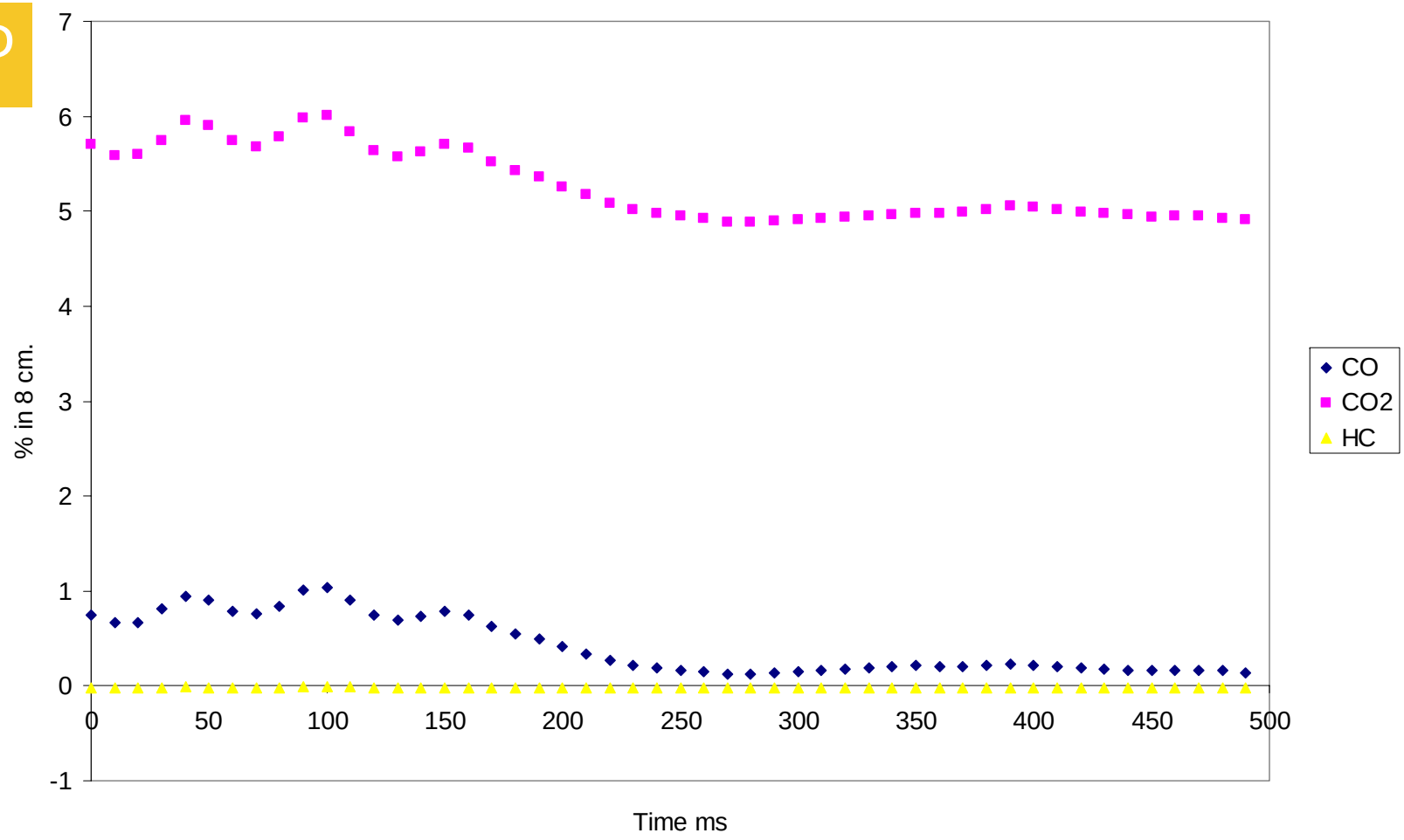
IR Signal vs Time

Figure 2b: IR Signal versus time



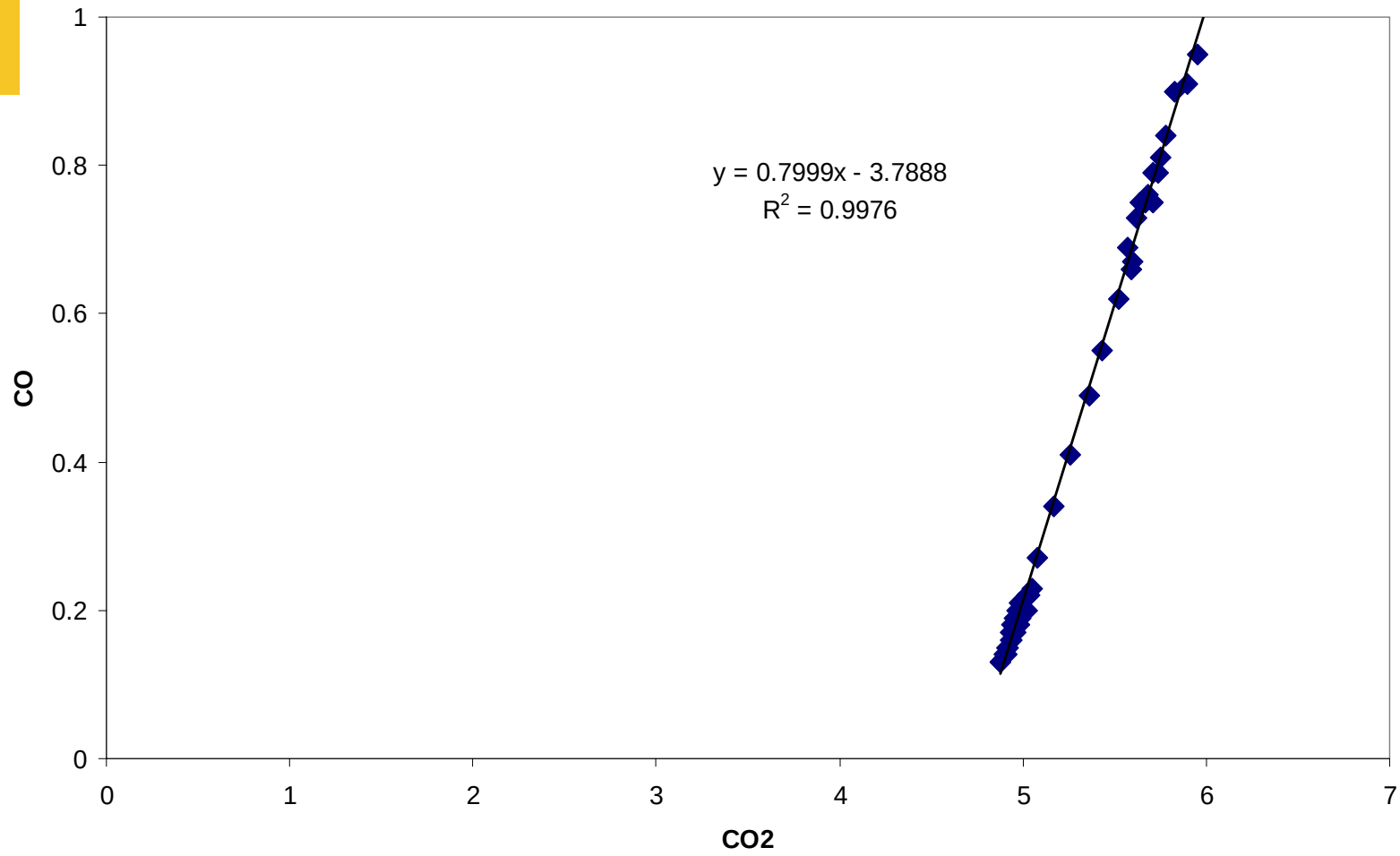
Gas Readings vs Time

Figure 3b: Gas readings versus time



CO vs CO_2

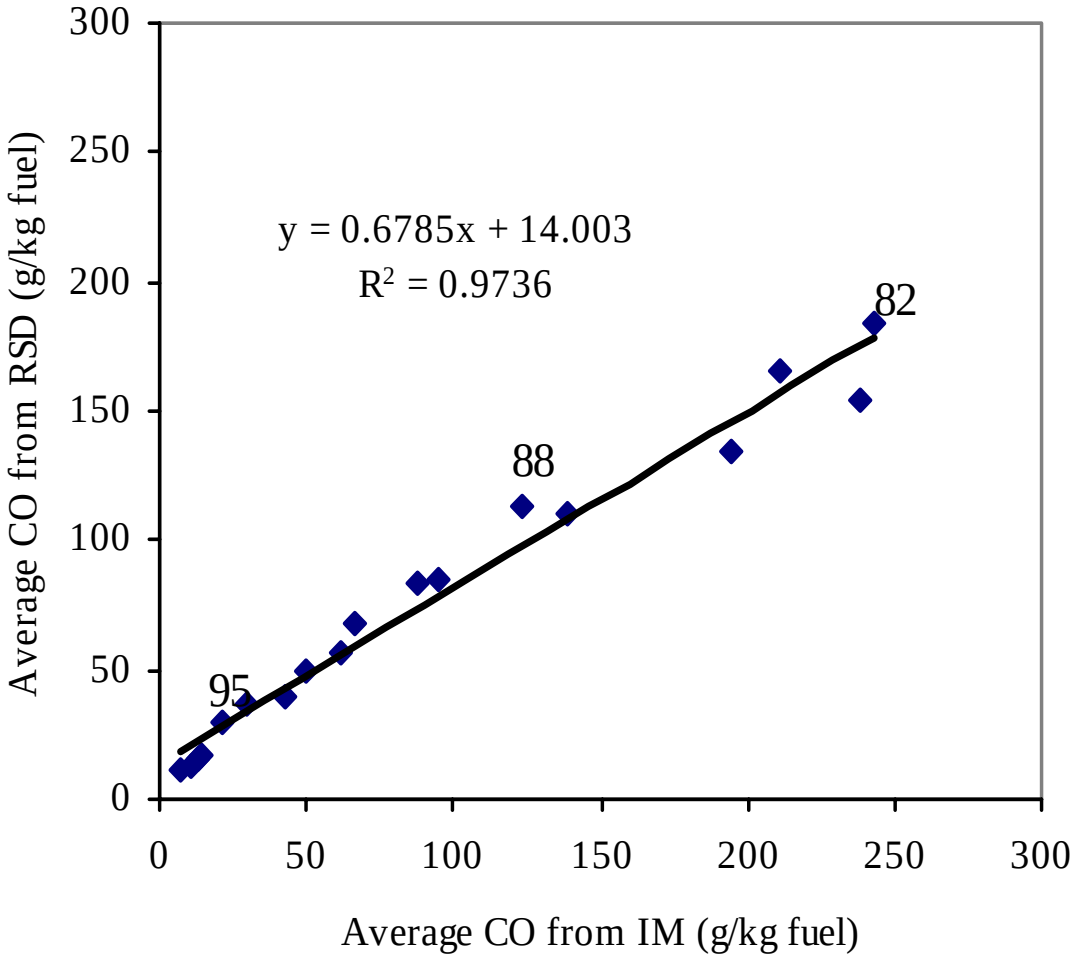
Figure 4b: CO versus CO2



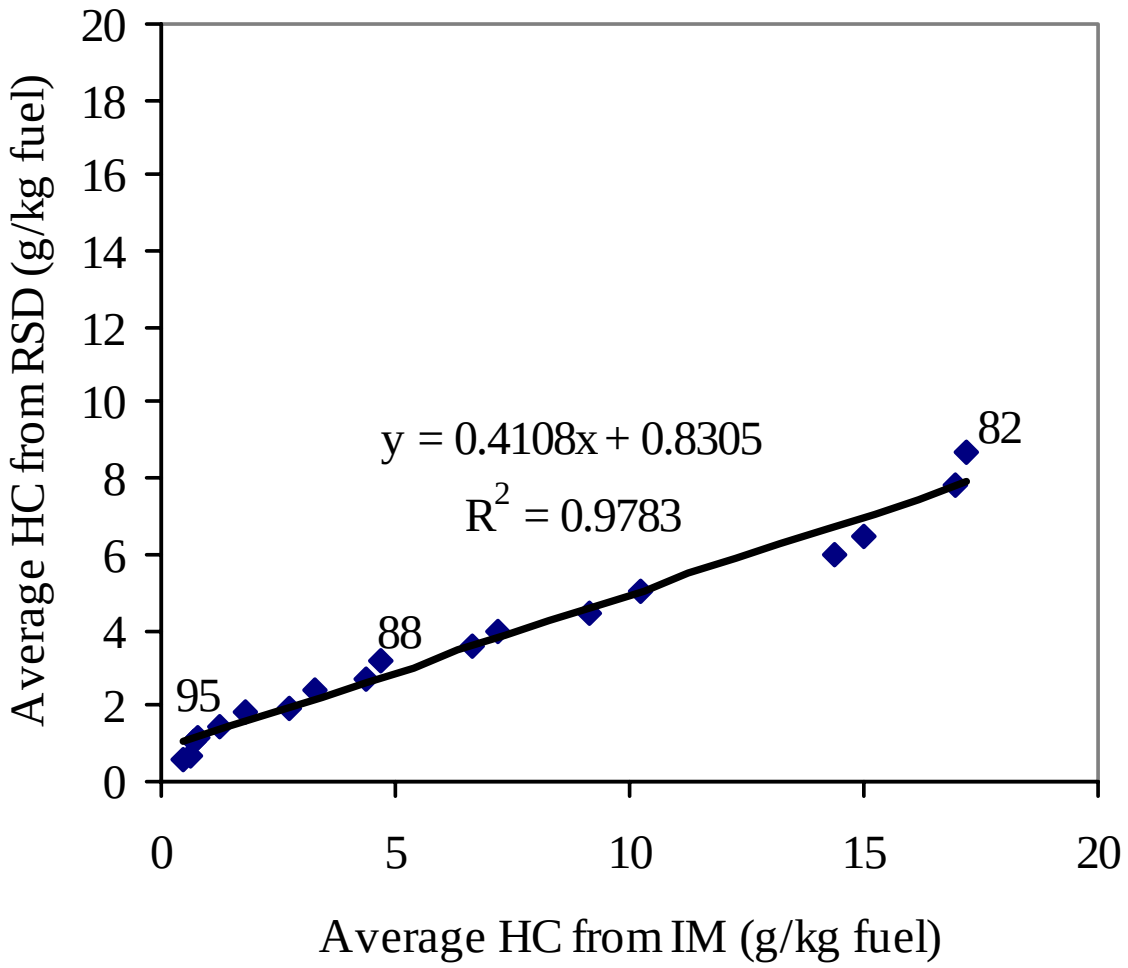
Proof that the on-road readings are correct

Excellent Correlation by MY to IM240, published and repeated in Chicago and Phoenix and other years.

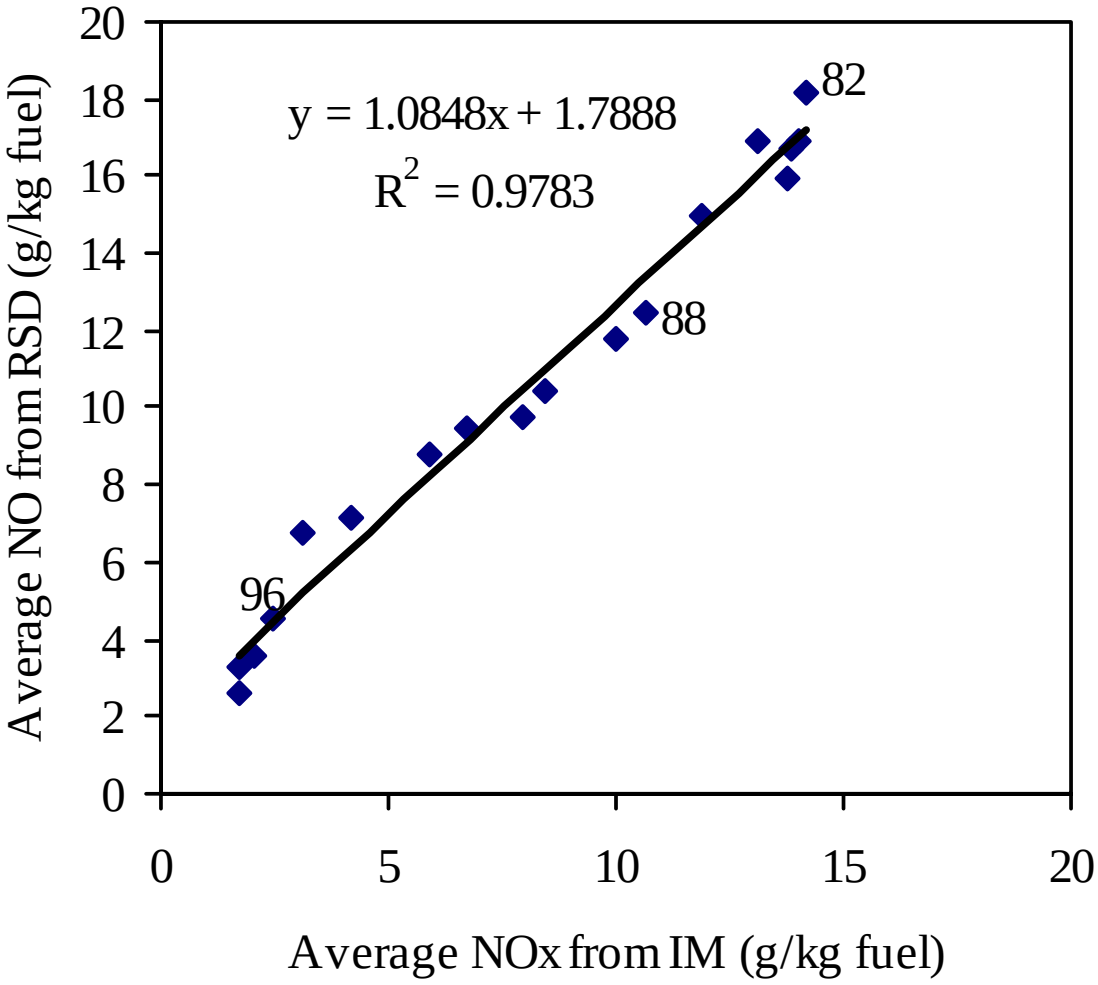
Denver 1999 CO



Denver 1999 HC



Denver 1999 NO



Proof from Roadside Pullovers

- Using a single remote sensor to pull over on-road high emitters, BAR found 83%-88% ASM failure rates on CO or HC or NO depending on the remote sensing cut point chosen.
- At a 10,000 vehicle per day site, a very high cut point (top 1%) will fail 100 vehicles per day!
- California Bureau of Automotive Repair, “Remote Sensing Device high emitter identification with confirmatory roadside inspection” Final Report 2001-06.

A few broken vehicles cause most of the emissions.

RSD is ideal for emissions inventory and to identify broken vehicles

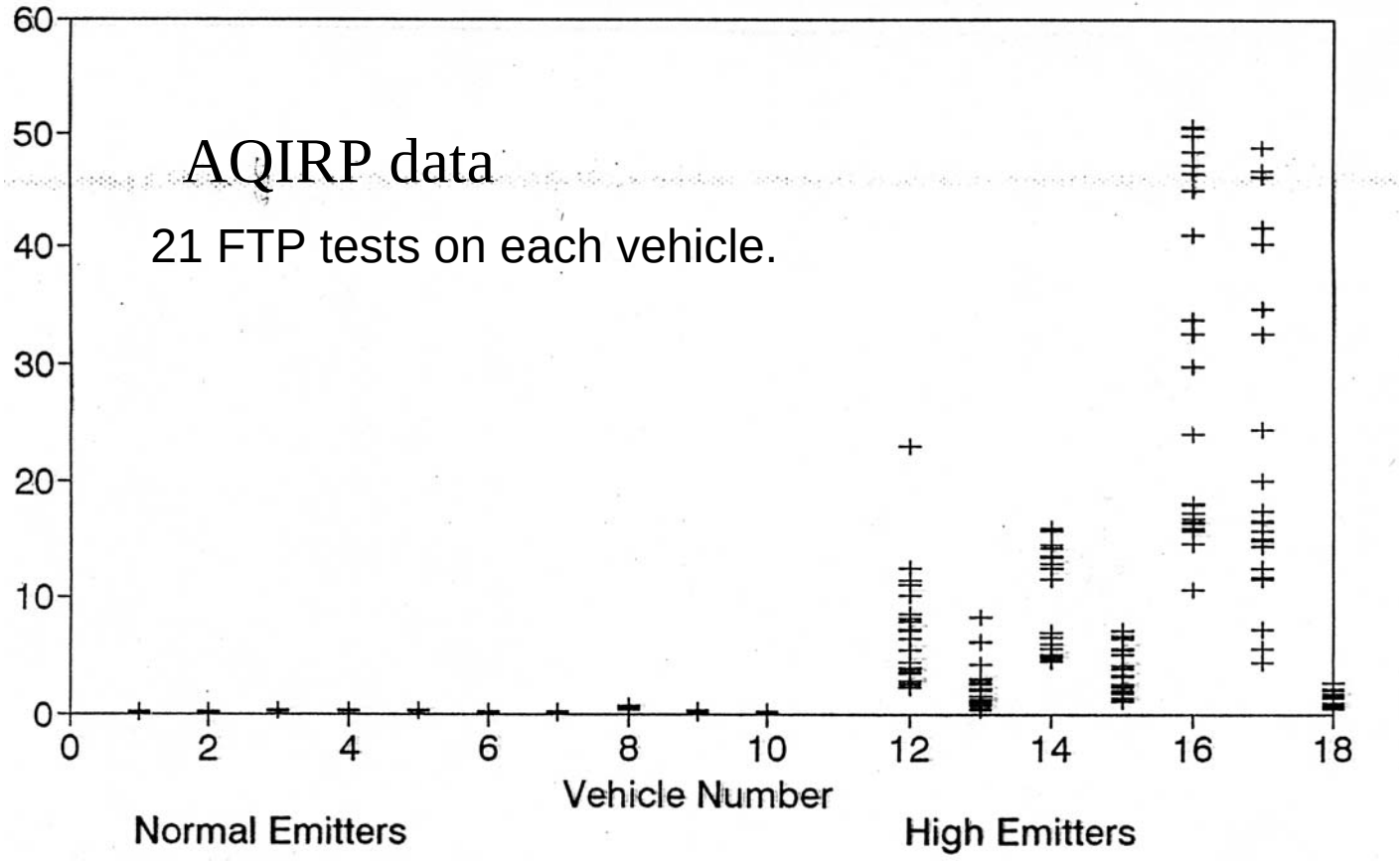
UNIVERSITY OF DENVER
1864

Repeatability

- Low emitters with good air/fuel ratio control have very repeatable emissions regardless of the test method.
- High emitters with poor air/fuel ratio control have very erratic emissions regardless of the test method.
- "Motor Vehicle Emissions Variability", G.A. Bishop, D.H. Stedman, L. Ashbaugh, J. Air Waste Manage. Assoc., 46:667-675, 1996.

Exhaust HC by FTP

Normal and High Emitters- All Fuels



Hit rates

- Exact validity criteria for University of Denver data see CRC reports on our web site www.feat.biochem.du.edu
- Hit-rate depends upon the exhaust plume magnitude (vehicle load, speed and engine size and measurement site) and software conservatism. With good sites we routinely observe a hit rate >96% on automobiles.
- With the folded optical beam system we observe >95% hit rate for 95 cc motorcycles.

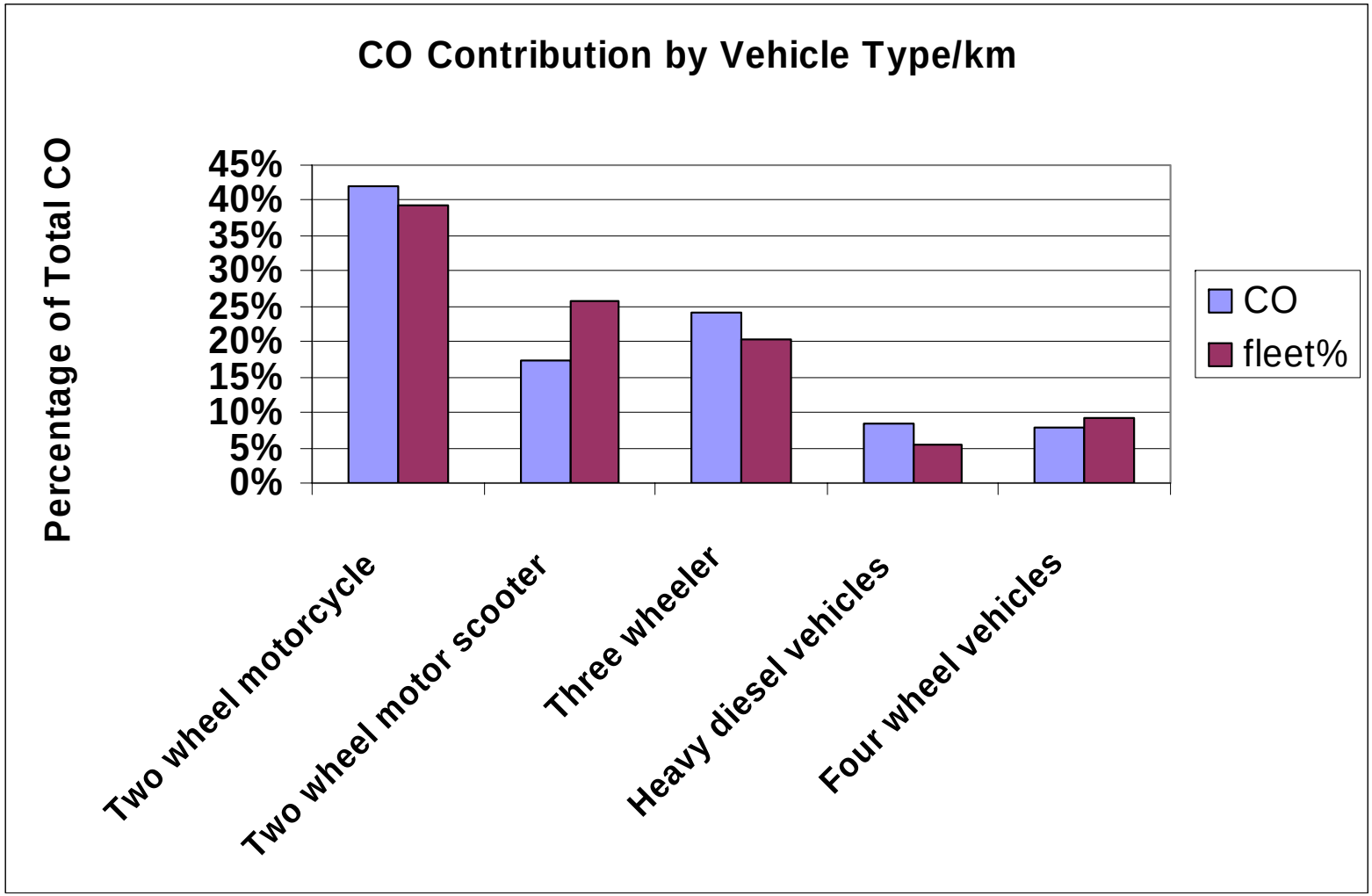
Data analysis from India

Presented by Dr. Donald Stedman

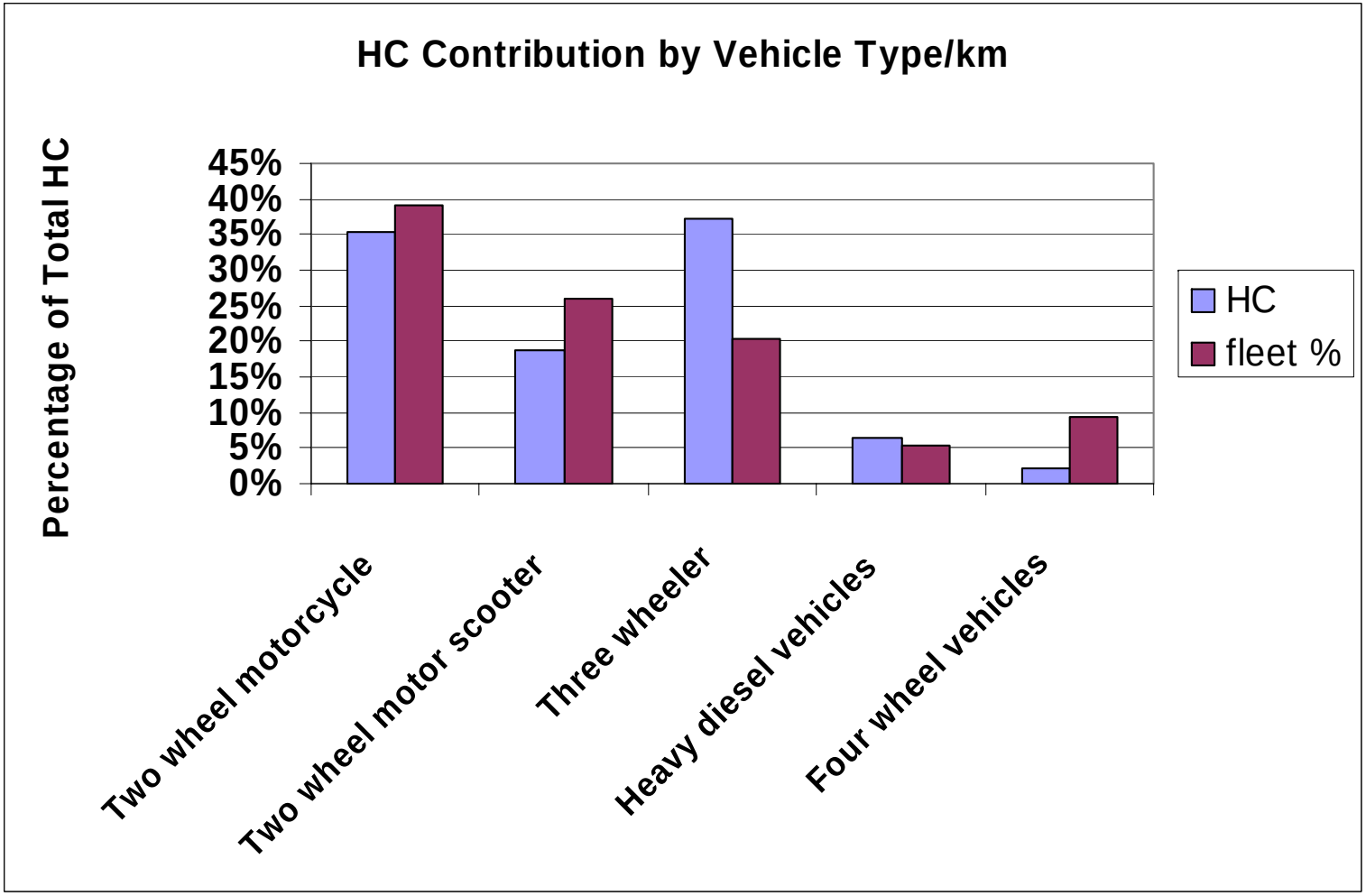
Gas Flag

Type	C	V	x	Total	V %	Fleet%
2WM		**2095**	5031	7126	29%	39.18%
2WS		**1326**	3378	4704	28%	25.86%
3WV		**2065**	1630	3695	56%	20.31%
4WD		**759**	216	975	78%	5.36%
4WV		**1558**	131	1689	92%	9.29%
		7803	10386	18189		

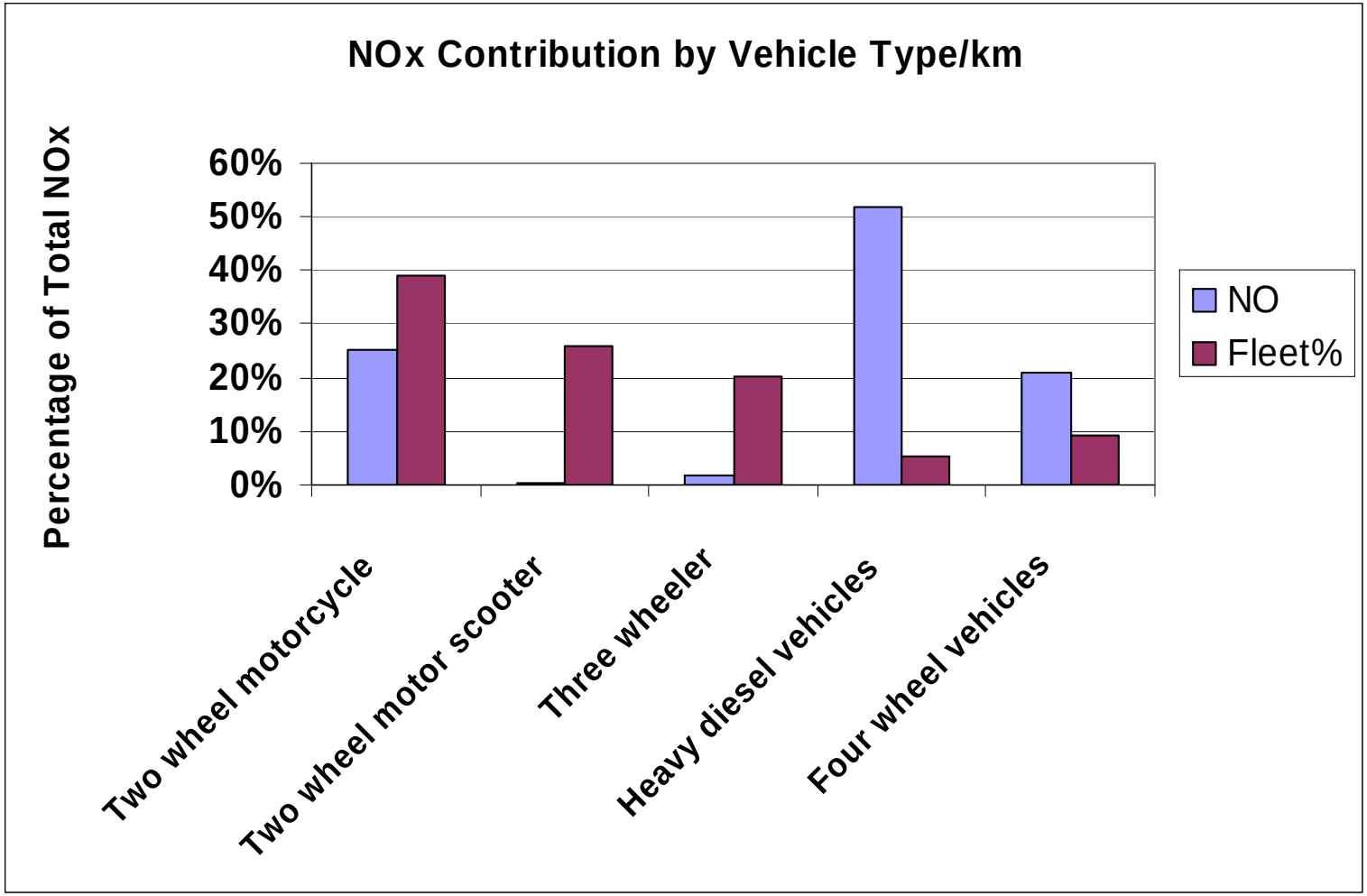
CO


CO Contribution by Vehicle Type/km
Percentage of Total CO
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Two wheel motorcycle
Two wheel motor scooter
Three wheeler
Heavy diesel vehicles
Four wheel vehicles
CO
fleet%

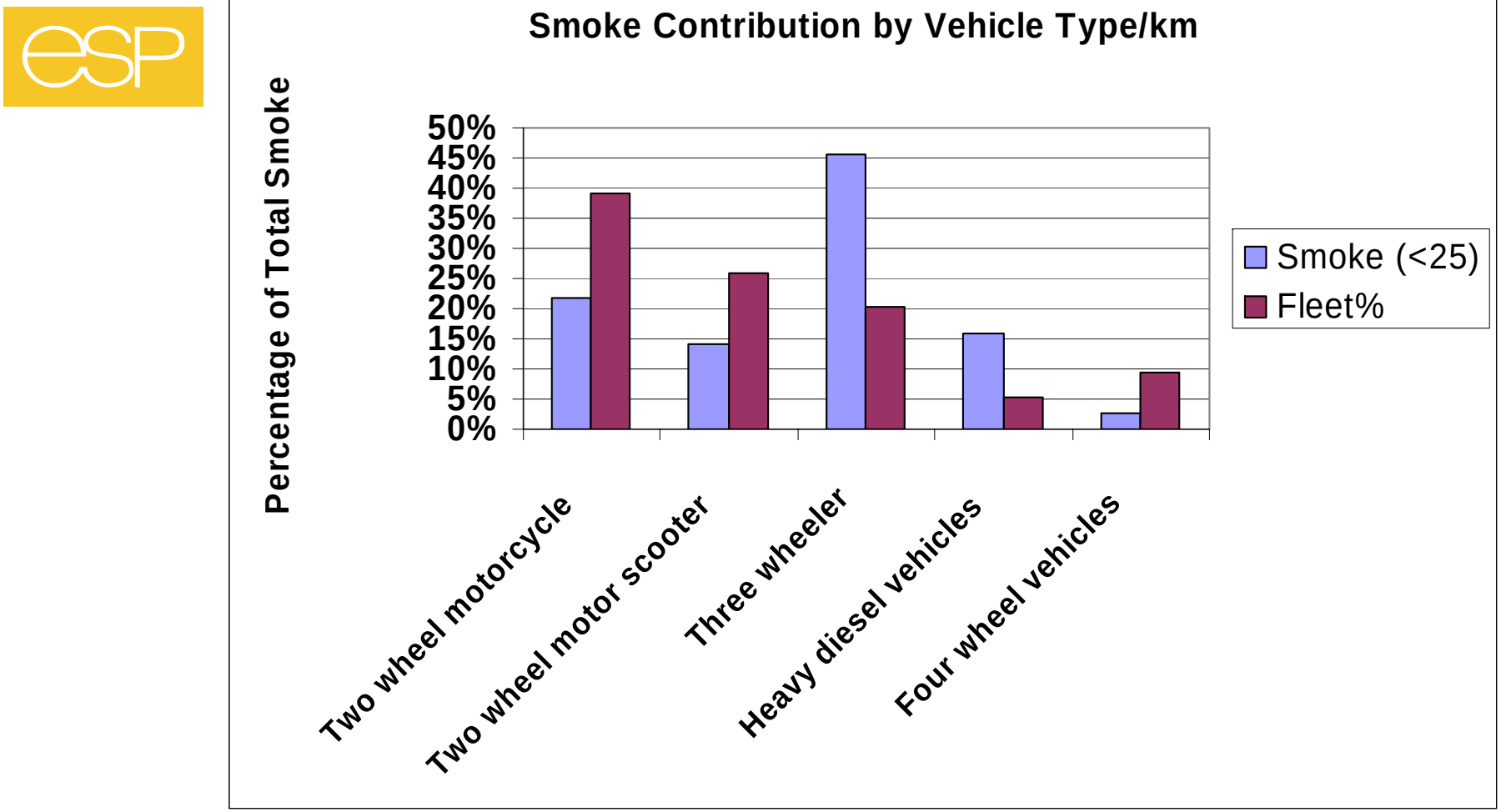
HC


HC Contribution by Vehicle Type/km
Percentage of Total HC
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Two wheel motorcycle
Two wheel motor scooter
Three wheeler
Heavy diesel vehicles
Four wheel vehicles
HC
fleet %

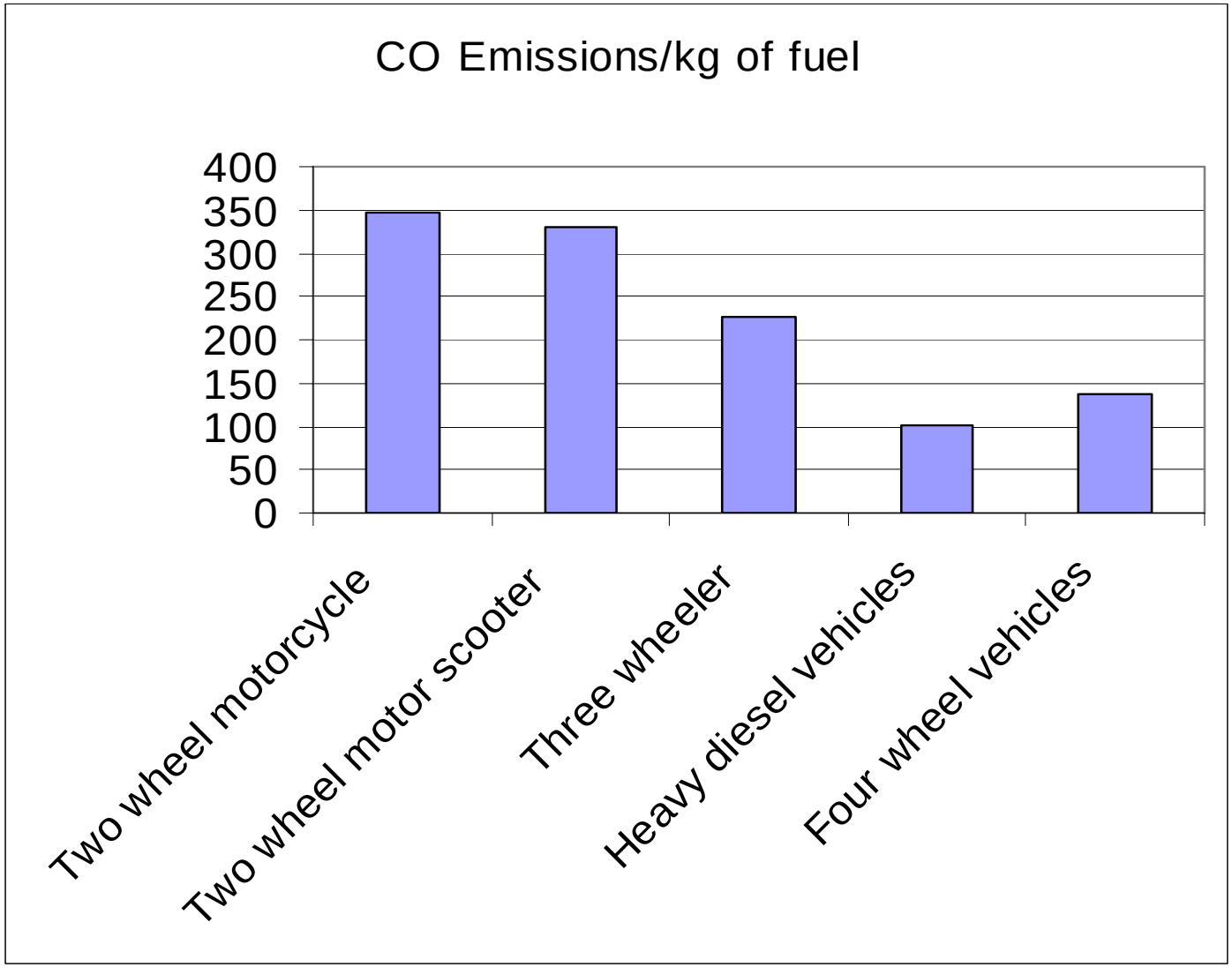
NOx


NOx Contribution by Vehicle Type/km
Percentage of Total NOx
60%
50%
40%
30%
20%
10%
0%
Two wheel motorcycle
Two wheel motor scooter
Three wheeler
Heavy diesel vehicles
Four wheel vehicles
NO
Fleet%

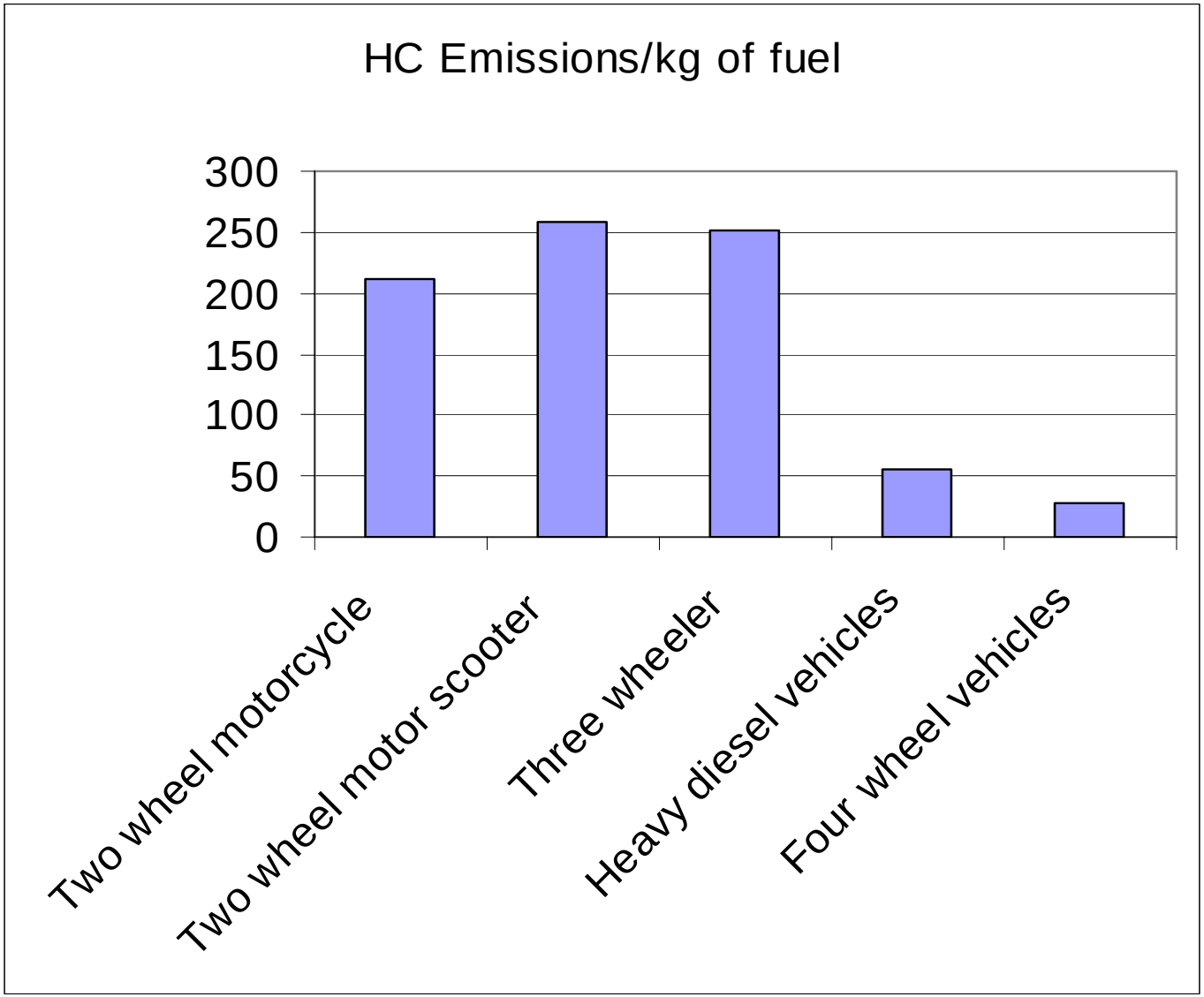
Smoke


Smoke Contribution by Vehicle Type/km
Percentage of Total Smoke
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Two wheel motorcycle
Two wheel motor scooter
Three wheeler
Heavy diesel vehicles
Four wheel vehicles
Smoke (<25)
Fleet%

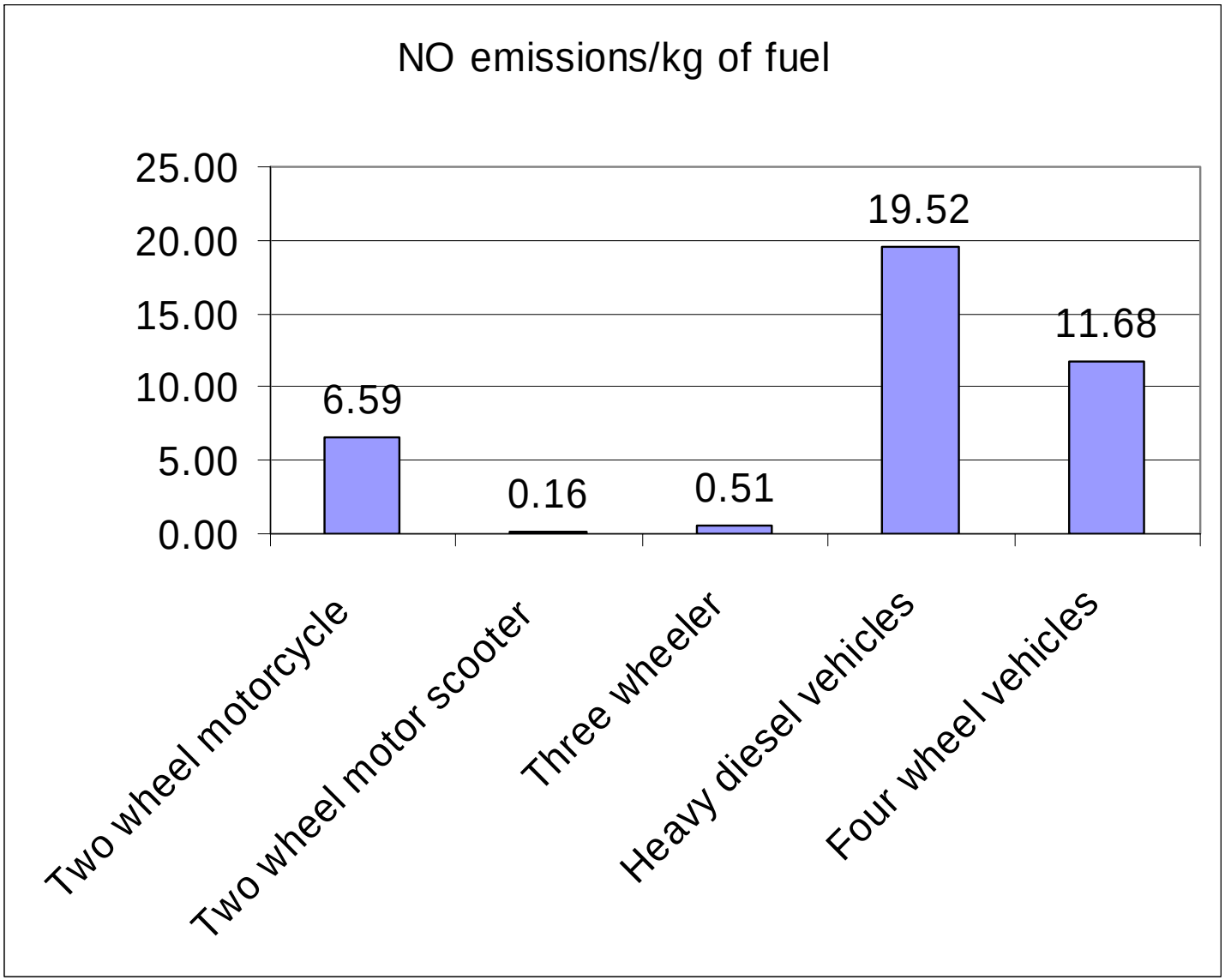
CO Emissions



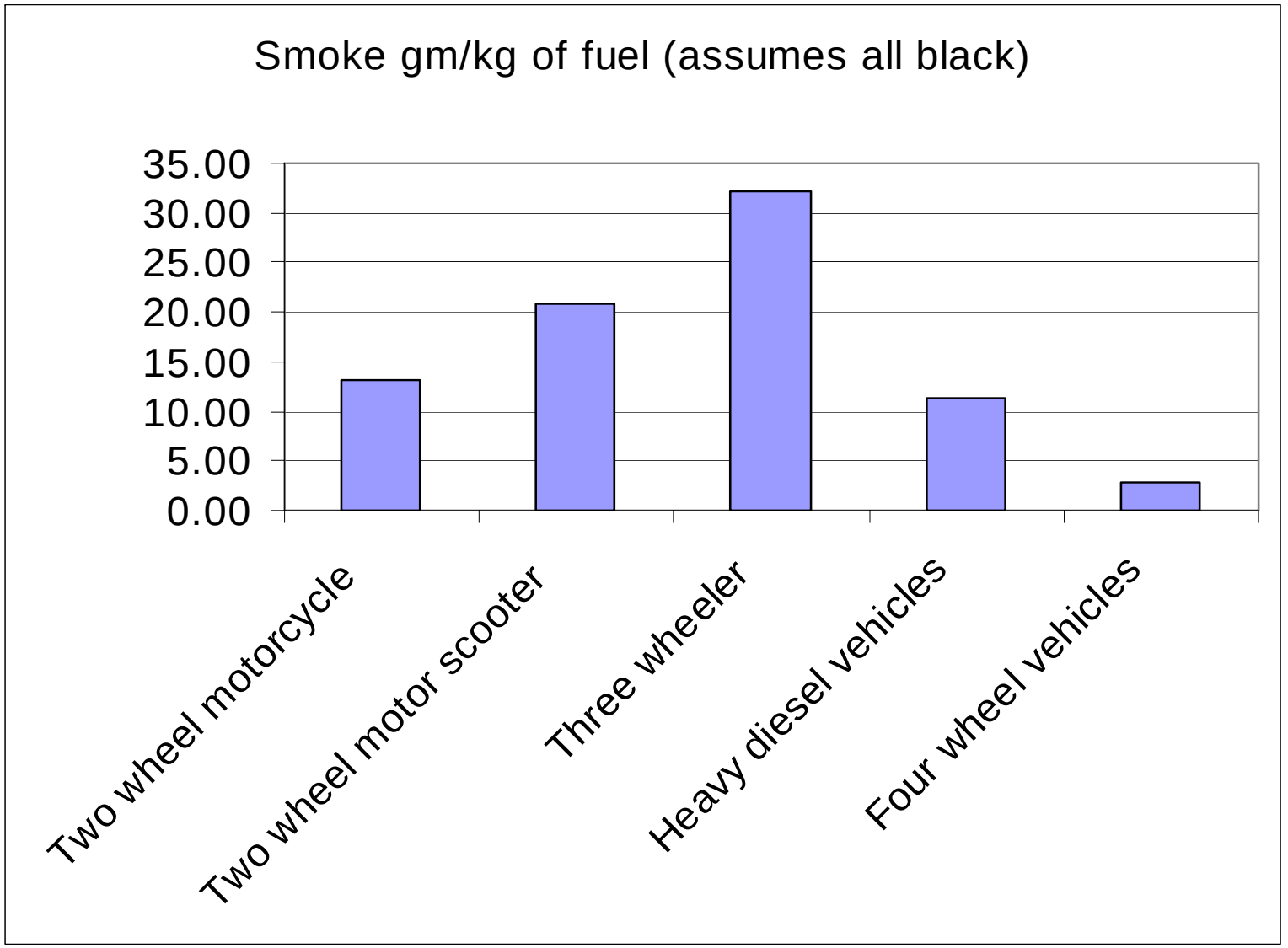
HC Emissions



NO Emissions



Smoke


Smoke gm/kg of fuel (assumes all black)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Two wheel motorcycle
Two wheel motor scooter
Three wheeler
Heavy diesel vehicles
Four wheel vehicles

Improvements Necessary for Improved 2-wheeler measurement

Presented by Gary Full

1. Traffic Diversion

- 2-wheeler and 3-wheeler traffic must be diverted to a single file lane in which measurement equipment can be deployed.

2. Equipment Modification

- Present technology equipment must be operable for measurements for path lengths of 3 to 5 meters.
- Present equipment is calibrated for measurement path lengths of 5 to 10 meters.

3. Loading Mechanism

- Suggest that a portable ramp be deployed at the measurement station. 0.3 meter rise over a 3-meter length. Similar ramp down.

4. Multiple Analyzers

- Two analyzers may be required deployed at two different heights to assure plume intersection with measurement beams.

Other Discussion

- Cutpoints
- Correlations