# Instrumentation and Methods for Monitoring Concentrations of Gases Emitted by Diesel Engines

George Schnakenberg, Jr.
NIOSH Pittsburgh Research Laboratory
gis3@cdc.gov 412-386-6655



June 5 & 6, 2007 DPM WORKSHOP Elko, NV

# Where gas concentrations should be monitored

- Equipment emissions
  - Tailpipe output
  - Engine out
- Occupational
  - Personal exposures
  - Workplaces

# Importance of equipment emission measurements

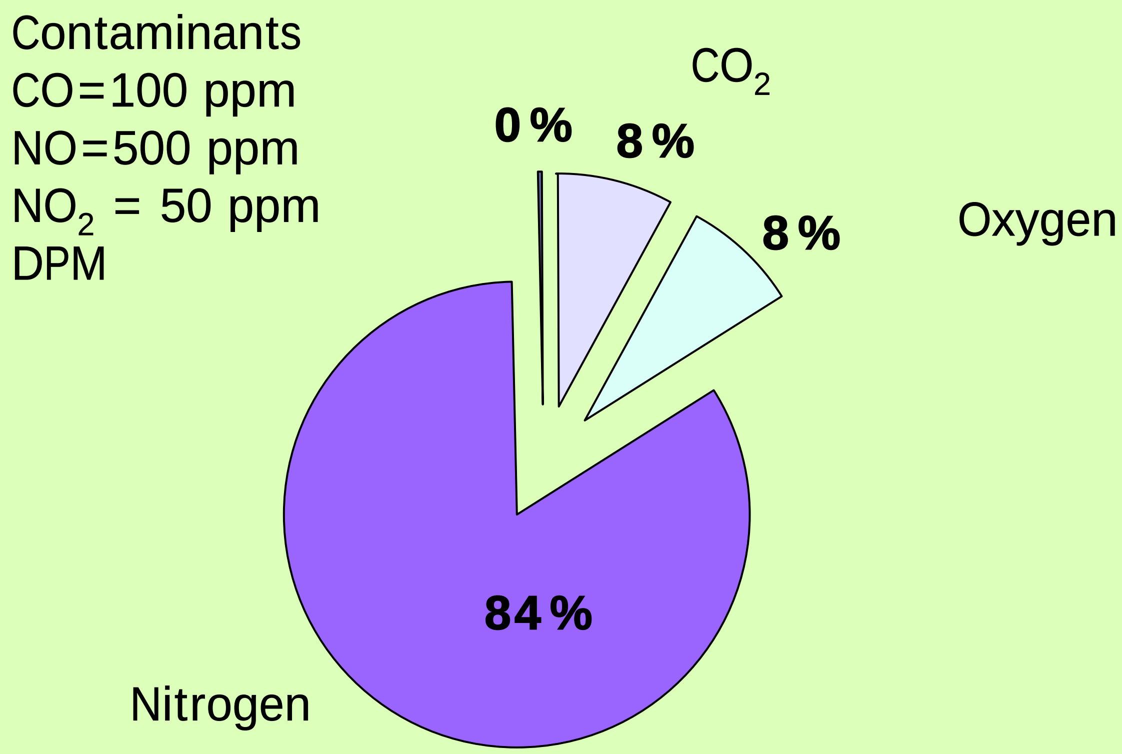
- ►Engine “health” diagnostic
- ►Aftertreatment performance monitoring
- ►Detecting adverse influence of controls
- ►Estimating ventilation requirements

Provide the QC on the major source of air contaminants and personal exposures (exclusive of blasting by-products)

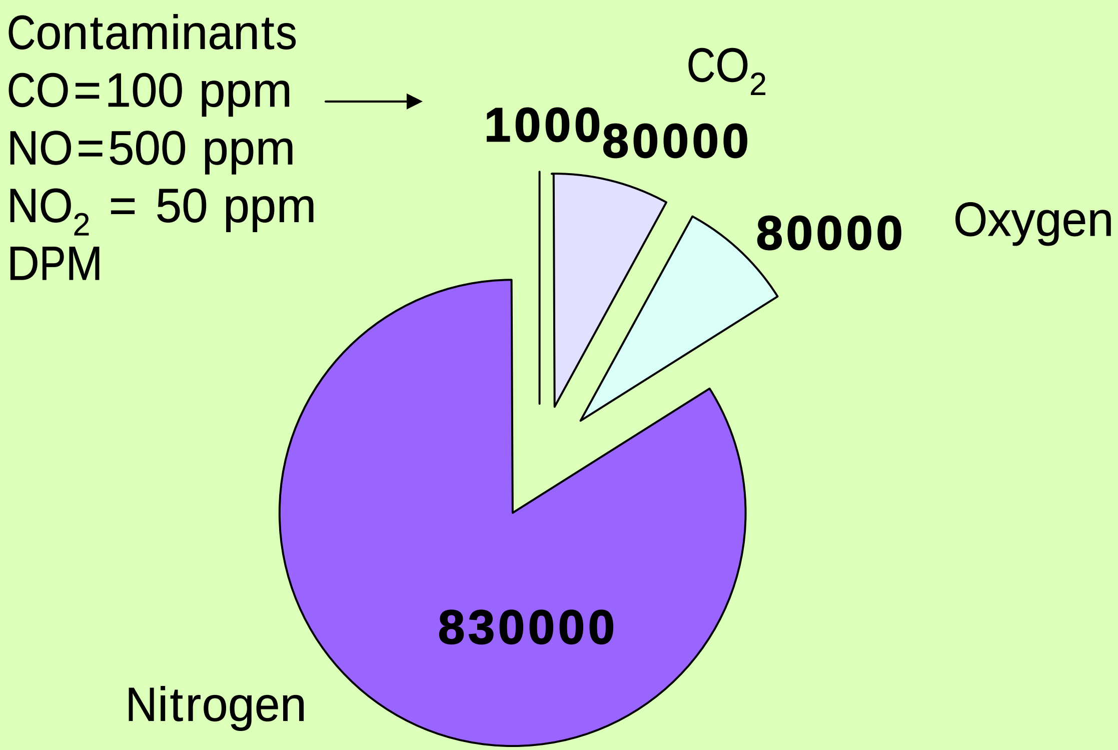
# Exhaust Measurement Procedure

- Consistent loading of engine – Torque Stall – using torque converter and possibly hydraulic system stall to load engine to maximum
- Measure exhaust concentrations of CO, NO, $NO_2$, $CO_2$ and smoke using one of several combustion analyzers available
- Measure before and after aftertreatment (DOC, DPF)
- Maintain emission records of test conditions (rpm and loading) and results

# Exhaust constituents at 8% $CO_2$



# Exhaust constituents at 8% $CO_2$
# Concentrations in parts per million




- Contaminant increase or decrease has no effect on $CO_2$ concentrations.

# Exhaust concentration of $CO_2$ depends only on fuel consumption rate

- Half the fueling rate that produces 8% $CO_2$ and you will get 4% $CO_2$.
- Fueling rate is related to power.

- Workplace $CO_2$ concentration depends only on the amount of fuel burned (number of vehicles and the work done by each) and the air quantity diluting the exhaust

# Usefulness of $CO_2$

- Day 1: Measure EC at 200 $ug/m^3$ average over a 4 hour period in workplace
- Time passes, you decide to use 50% biodiesel in production vehicles
- Day 2: Measure EC at 200 $ug/m^3$
- You conclude that going to biodiesel didn't make a difference. Is this valid?

# Usefulness of $CO_2$

- Day 1: Measure EC at 200 ug/$m^3$ average over a 4 hour period in workplace
- Time passes, you decide to use 50% biodiesel
- Day 2: Measure EC at 200 ug/$m^3$
- You conclude that going to biodiesel didn't make a difference. Is this valid?
- Day 1: Measure $CO_2$ at 1400 ppm.
- Day 2: Measure $CO_2$ at 2400 ppm.
- Would this information change your conclusion?

# Analysis

- Twice as much $CO_2$ was produced on Day 2 either from a reduced ventilation, additional vehicle, or increased engine loading or all of these.
  - Background $CO_2$ is 400 ppm
  - 2000/1000 = 2
- Assume that vent rate was halved for Day 2
- Thus 200 ug/$m^3$ on Day 2 is actually 100 ug/$m^3$ when converted to the conditions of Day 1.
- Day 1 200ug/$m^3$ per 1000 ppm $CO_2$ (2/10)
- Day 2 200 ug/$m^3$ per 2000 ppm $CO_2$ (1/10)
- Biodiesel reduced EC emission at tailpipe by 50%.

# Conclusions from all of this

- Comparison of workplace concentrations among different days or locations must be accompanied by corresponding concentration measurements of $CO_2$ to account for ventilation, production, vehicles, etc.
- Background of 380 ppm must be first subtracted from all workplace $CO_2$ measurements.
- If vent air is not fresh, concentrations in incoming air must be made simultaneously and subtracted from those of the workplace
- Goal of tailpipe emissions controls is to reduce the contaminant to $CO_2$ ratio.

# Workplace ventilation rates can be estimated from tailpipe emission measurements

- What you need to know
  - Tailpipe concentrations
- Exhaust gas volume
  - Engine rpm for concentration measured
  - Displacement of engine in liters
  - Turbo charger cooling
  - A formula
- Exposure limits (ACGIH TLV)

# Exhaust gas volume estimation

- $V_{cfm}$=F x RPM x DISP x (.0176)
- F=
  - 0.85 for no turbo
  - 1.7 for non cooled turbo
  - 2 for turbo with intercooler
- RPM is engine speed at emissions meas.
- DISP is engine displacement in liters

# Dilution requirements

Dilution air quantity = Exhst $V_{cfm}$ x Exhaust contaminant concentration/ACGIH limit

Example

500 ppm NO and exhaust volume of 500 cfm

The air quantity needed dilute exhaust to TLV of 25 ppm would be

500 x 500/25 = 10000 cfm

Note that this is “worst case” when engine is under maximum load; actual requirements for actual work situations of intermittent loads would be lower.

# Engine Emissions, Limits, Dilution, & Air Quantity for Engine Tailpipe Exhaust Flow of 500 cfm

| **Gases** | Name | Emission TCS | ACGIH Limit | Dilution Required | Air Quantity for 500 cfm |
|---|---|---|---|---|---|
| $CO_2$ | Carbon Dioxide | 8%/ 80000 ppm | 0.5%/ 5000 ppm | 16 | 8000 cfm |
| CO | Carbon Monoxide | 0-200 ppm | 50 ppm | 0-4 | 0-2000 |
| NO | Nitric Oxide | 500 ppm | 25 ppm | 20 | **10,000** |
| $NO_2$ | Nitrogen Dioxide | 30 ppm | 3 / 5 ppm | 10 / 6 | 5000/3000 |
| $NO_2$ | (Elevated) | 120 - ? | 3 / 5 ppm | 40 / 24 | 20,000/12,000 |

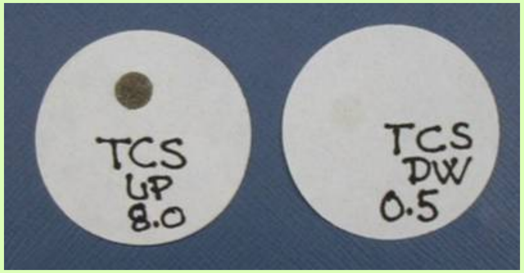
- Note: One would expect approximately the same or lower ratios of contaminant to $CO_2$ to be found in the workplace. For example for NO, 500 ppm per 80000 ppm or 1 ppm NO for every 160 ppm $CO_2$ (0.00625:1). A finding of 2000 ppm $CO_2$ would imply an expected maximum of 12.5 ppm NO.

# Engine Emissions, Limits, Dilution, & Air Quantity for Engine Tailpipe Exhaust Flow of 500 cfm

| **Particles** | **Basis** | **MSHA PI** | **MSHA limit (metal)** | **Dilution** | **Air Quantity** |
|---|---|---|---|---|---|
| DPM | 1000 µg/m$^3$ | 10,000 cfm | (500 µg/m$^3$) | 2 | 20,000 cfm |
| TC | (800 µg/m$^3$) | (10,000) | 400/160 | 2/5 | 20000/50000 |
| EC | (616 µg/m$^3$) | (10,000) | 308/??? | 2 | 20,000 |
| | | | MSHA limit (coal) 2.5g/hr | Filter | |
| DPM | 1000 µg/m$^3$ | 10,000 cfm | **17 g/hr** | **88%** | N/A |

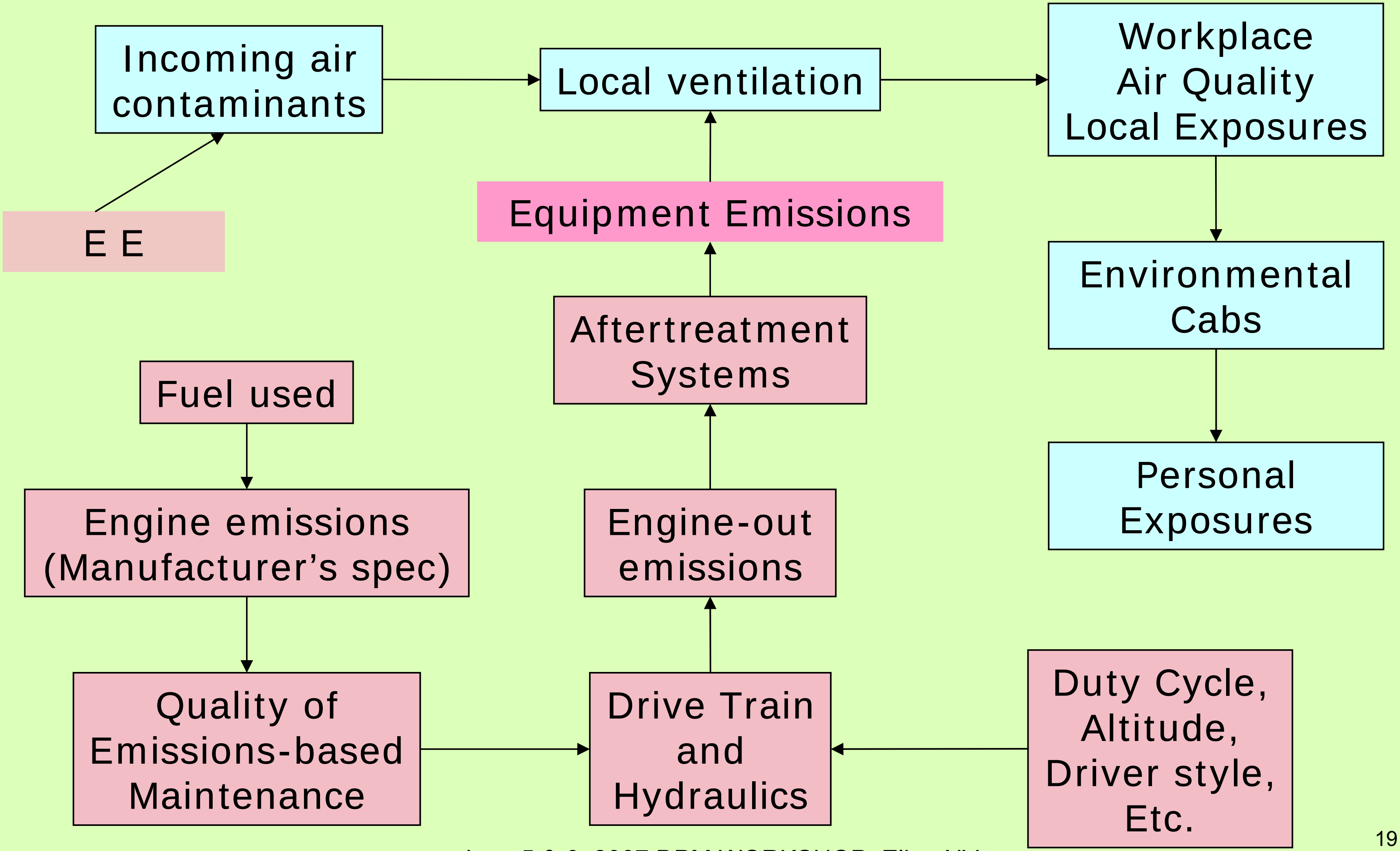
# Simple Tailpipe Diagnostics

- DOC reduce CO: Does 100 ppm before DOC go to 5 ppm after?
- DOC may increase $NO_2$: Check for increase (factors of 2 or more) after vs. before DOC
- DPF reduce DPM: Smoke dot check before and after.



- Did smoke number decrease after converting to biodiesel? Has it increased since then?
- Track measurements. There are instruments and software for this (ECOM and UGAS).

# Getting Control over Air Quality and Personal Exposures



# Summary

- Ensure reliable control of tailpipe emissions
- Use personal exposure surveys to verify exposures are under control
- Time logged exposures of contaminants AND $CO_2$ can locate trouble spots or limit exposure times
- Workplace studies require measurement of contaminants and $CO_2$ of incoming air and workplace air
- Before/after comparisons or diagnosing cause of an unacceptable concentration requires use of $CO_2$ levels.
- When tailpipe emission levels can be guaranteed, workplace measurements of $CO_2$ are sufficient to ascertain whether ventilation is sufficient to ensure other contaminants are at safe levels.

# Questions

Isle of Mull, Scotland, May 26, 2007