The California Demonstration Program for Control of PM from Diesel Backup Generators (BUGs)

U.S. Department of Energy"s

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Today's Topics

- Current state of understanding about emissions from diesel backup generators.
- Background on California PM demonstration program for diesel backup generators.
- Approach to measurement of PM emissions
- Emission results for:
  - Uncontrolled sources
  - Controlled sources

EPA's AP-42 Emission Factors

	Small Engines (<440 kW)		Large Engines (>440 kW)	
Pollutant	Factor (g/kW-hr)	Rating	Factor (g/kW-hr)	Rating
NO_x	18.8	D	14.952	B
CO	4.06	D	3.34	C
CO_2	704	B	705.28	B
PM_{10}	1.34	D	0.426	B
HC exhaust	1.50	D		
TOC as CH_4			0.429	C
Aldehydes	0.28	D	0.07	E

Objectives for California Diesel Backup Generator (BUGs) Project

- **Cooperative project of the California Energy Commission and the California Air Resources Board**
- **Measure emissions from representative BUGs based on:**
  - **Size (>300kW)**
  - **Market share**
  - **Age/emission standards**
- **Measure "real world" emissions**
  - **Regulated gaseous emissions**
  - **Regulated particulate matter (PM) emissions**
  - **Speciated VOCs and SVOCs, including toxics for selected units**
- **Develop emission factors for BUGs.**
  - **Uncontrolled and controlled emission factors.**

PM Demonstration-Test Matrix

- Size Ranges
  - 12 engines (300 to 750 kW)
  - 3 engines (1000 to 2000 kW)
- Age Ranges
  - Pre 1987
  - 1987-1996
  - Post 1996
- Manufacturers
  - Caterpillar
  - Cummins
  - Detroit Diesel Corporation

PM Control Technologies Selected for Demonstration

- Emulsified Fuel
- Fuel-borne Catalysts
- Diesel Oxidation Catalysts
- Passive Filters
- Active Filter

UCR’s Mobile Emission Lab

Schematic of UCR's Heavy-duty Mobile Emission Laboratory (MEL)

Diluted Exhaust: Temperature, Absolute Pressure, Throat ΔP, Flow.

GPS: Pat, Long, Elevation, # Satellite Precision.

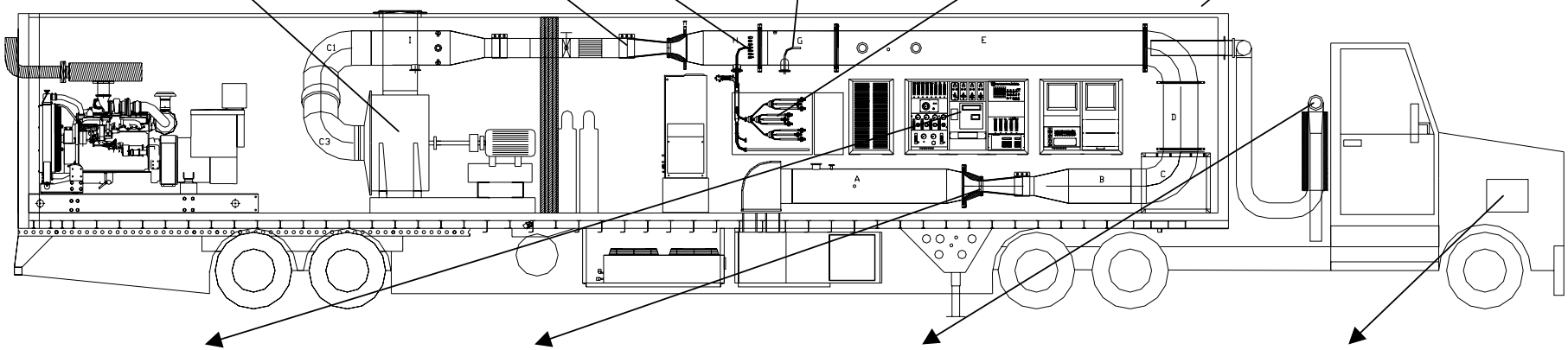
CVS Turbine: 1000-4000 SCFM, Variable Dilution.

Secondary Probe.

Gas Sample Probe.

Secondary Dilution System*
PM (size, Mass).

Drivers Aid.



Gas Measurements: CO_2 %, O_2 %, CO ppm, NO_x ppm, THC ppm, CH_4 ppm.

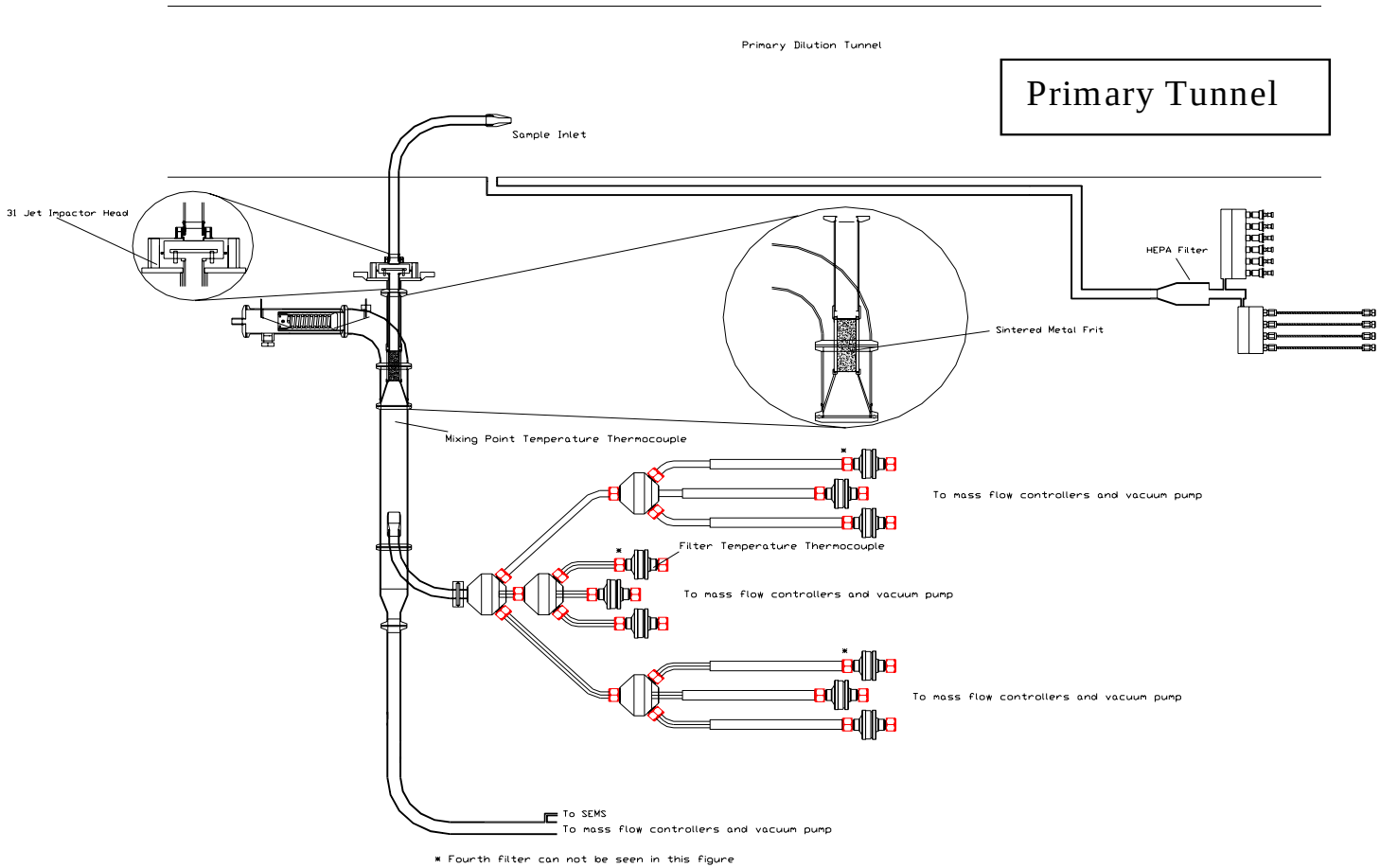
Other Sensor: Dew Point, Ambient Temperature, Control room temperature, Ambient Baro, Trailer Speed (rpm), CVS Inlet Temperature.

Dilution Air: Temperature, Absolute Pressure, Throat ΔP, Baro (Ambient), Flow, Dew Point (Ambient).

Exhaust: Temperature, ΔP (Exhaust-Ambient), Flow.

Engine Broadcast: Intake Temperature, Coolant Temperature, Boost Pressure, Baro Pressure, Vehicle Speed (mph), Engine Speed (rpm), Throttle Position, Load (% of rated).

Schematic of Secondary Sampling System



Inside the Mobile Laboratory

Field Testing of Backup Generators (BUGs)

Field Issues

- Identify participating sites
- Survey site to assess acceptability of BUG
- Fabricate parts & connect BUG to HDD lab.
- Install load bank & set operating modes
- Undertake QA/QC procedures
  - Primary & secondary tunnels
  - Analytical bench instruments

RENTAL POWER
RENTAL POWER
600 kw load bank
600 kg
Steps: 1kw @ 415volt

Vandenberg
FID LOOSE
Shutdown
Bypass 1
CRAFTSMAN

Testing Protocol for Backup Generators

1. Cold start/idle for 30 minutes
2. ISO-8178B -- Type D2 constant speed

Mode	1	2	3	4	5
Speed	rated speed				
Load	100%	75%	50%	25%	10%
Weighting Factor	0.05	0.25	0.3	0.3	0.1

Example:

$$GAS_x = \frac{\sum_{i=1}^{n} M_{GASi} \times W_{Fi}}{\sum_{i=1}^{n} P_i \times W_{Fi}}$$

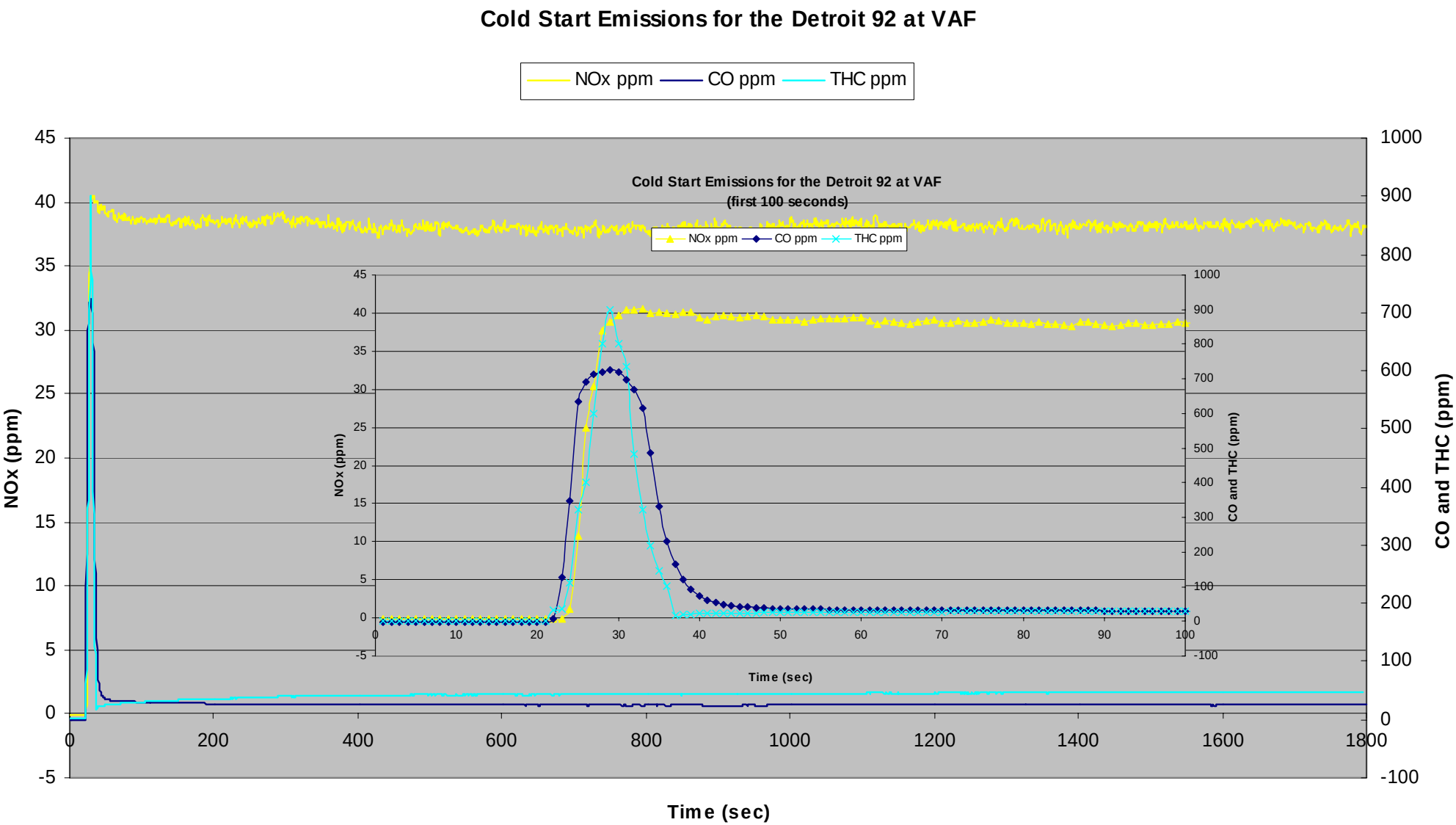
Where:

GAS_x **= overall emission factor of a given pollutant (lb/hp-hr or g/kW-hr)**

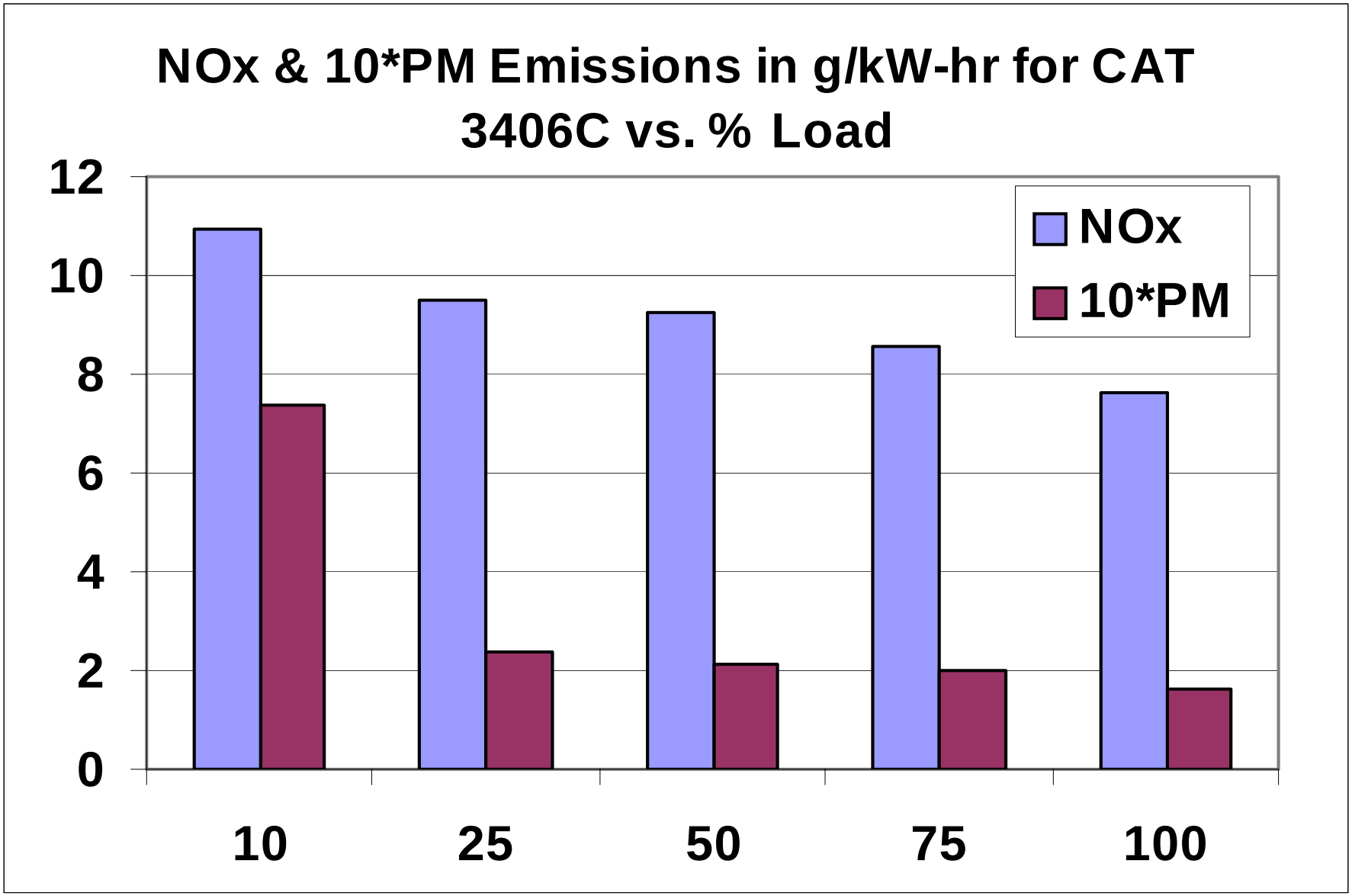
M_{GASi} **= emission factor of given pollutant at Mode i**

P_i **= load value at Mode i + auxiliary loads**

Gaseous Emissions at Cold-Start for a for BUG



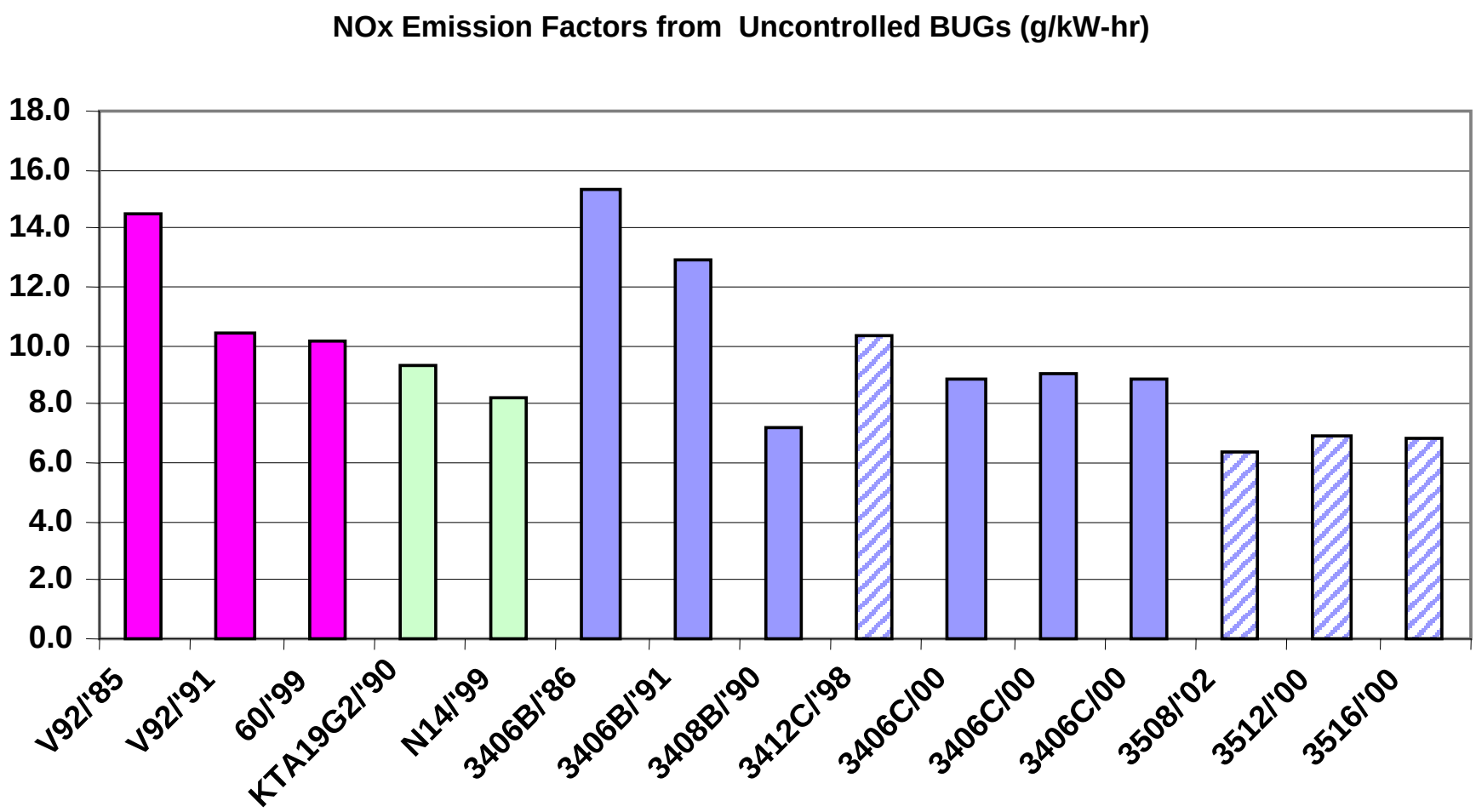
NOx & PM Emissions Factors for Uncontrolled BUG



NOx Emission Factors from Uncontrolled BUGs

AP-42= 18.8 & 14.95 g//kW-hr

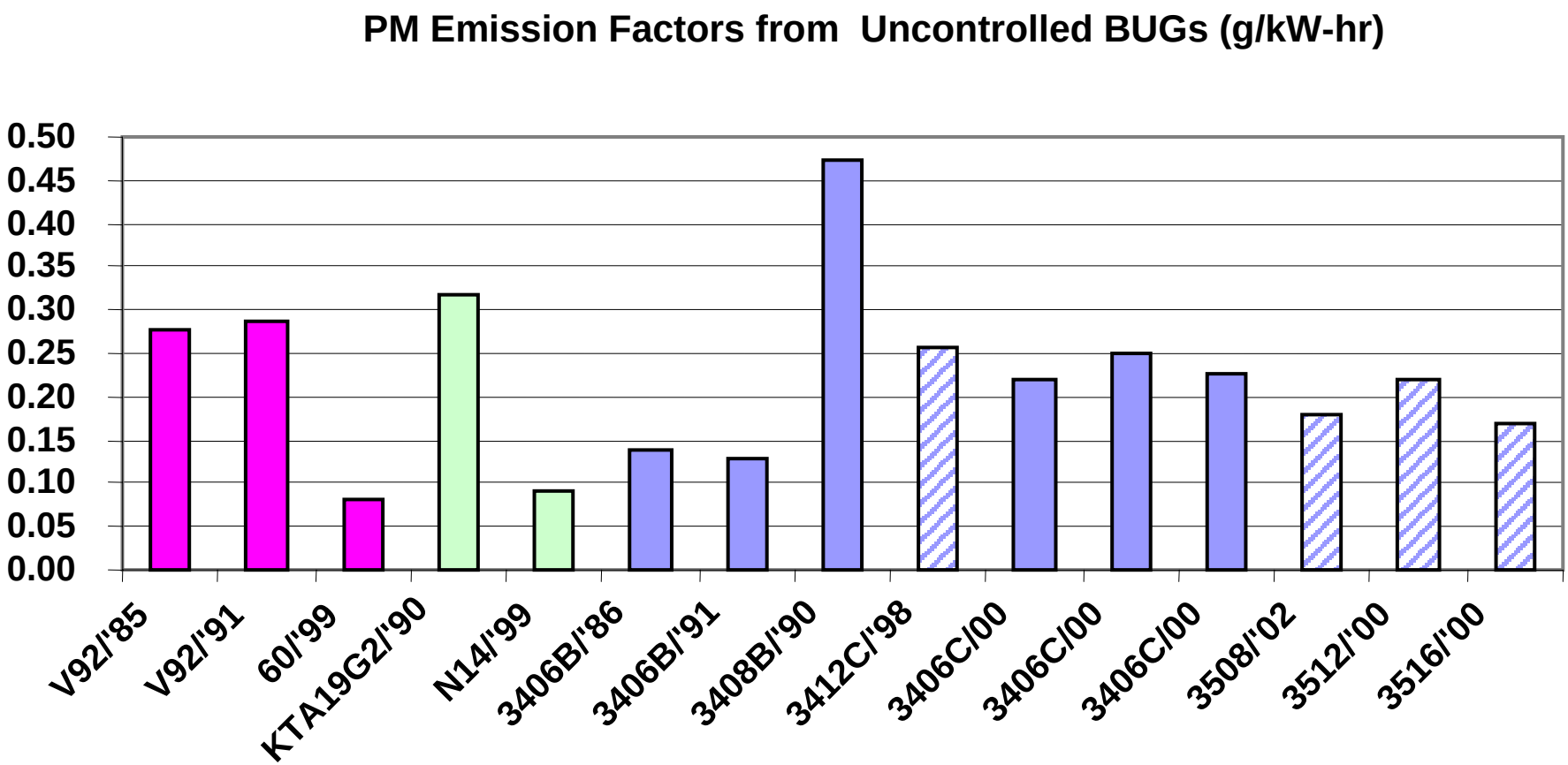
Certification: T1 = 9.2, T2= 6.4



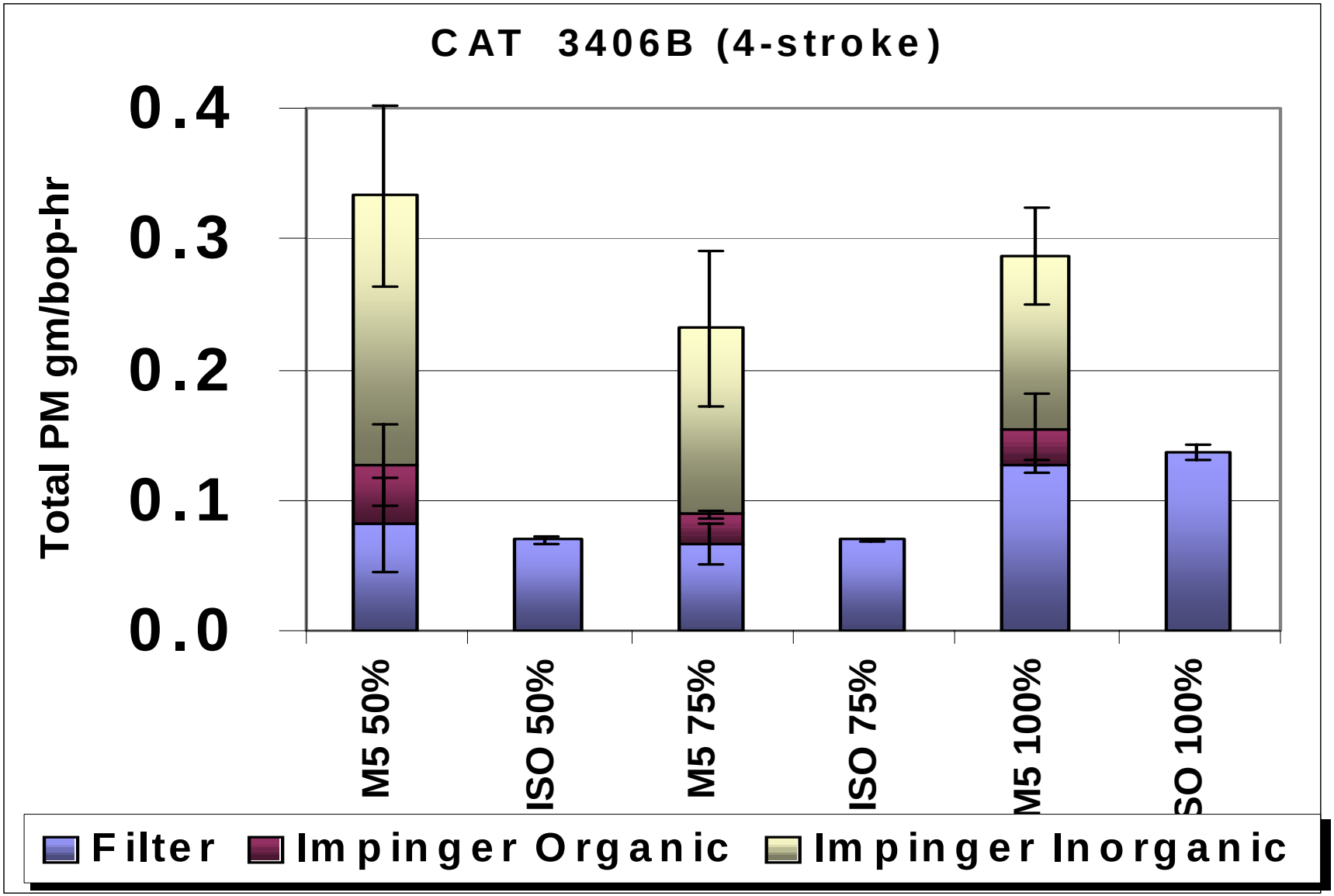
PM Emission Factors from Uncontrolled BUGs

AP-42= 1.34 & 0.43 g//kW-hr

Certification: T1 = 0.54, T2= 0.20

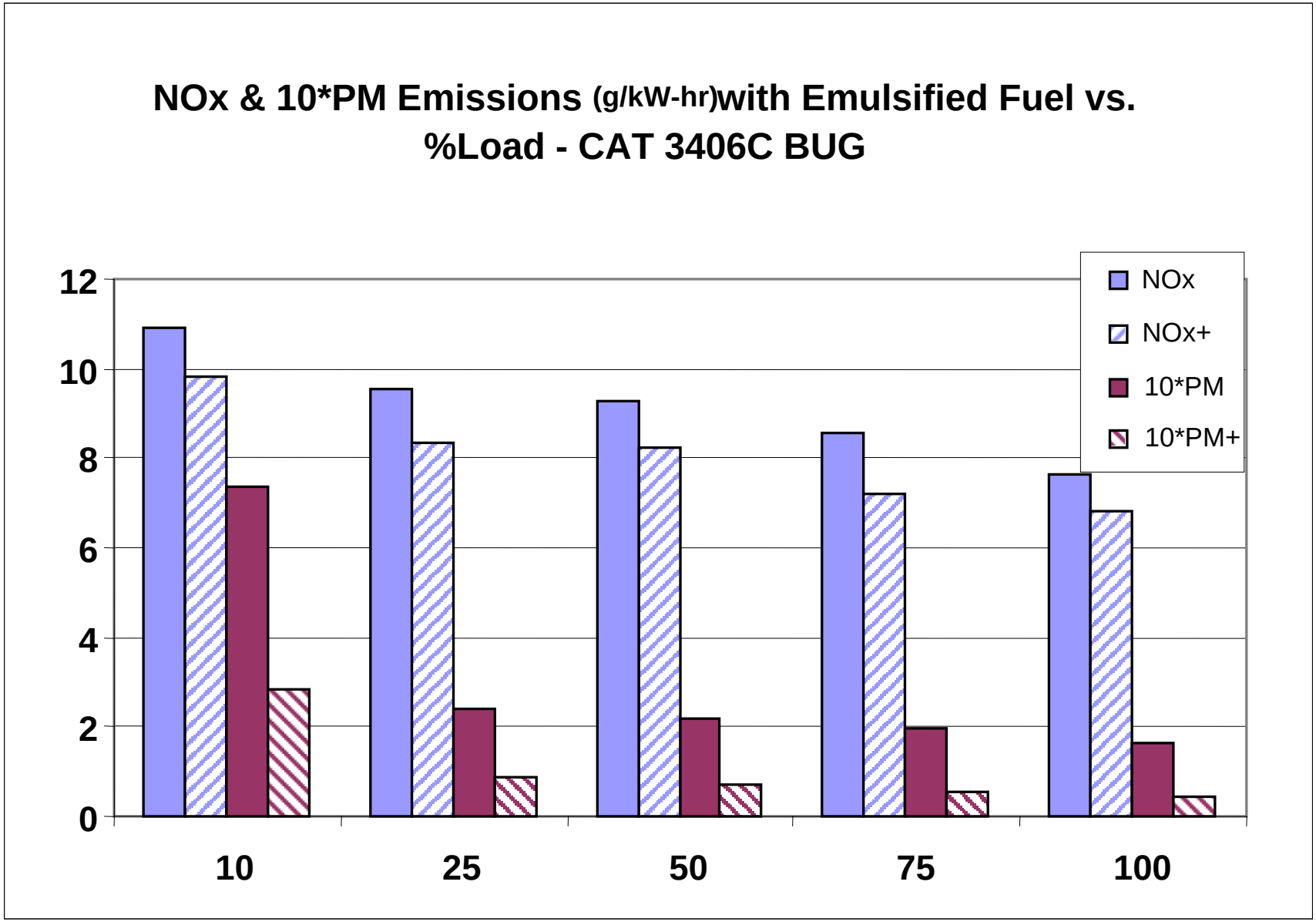


Comparison of Filter Mass by ISO & M5 Methods

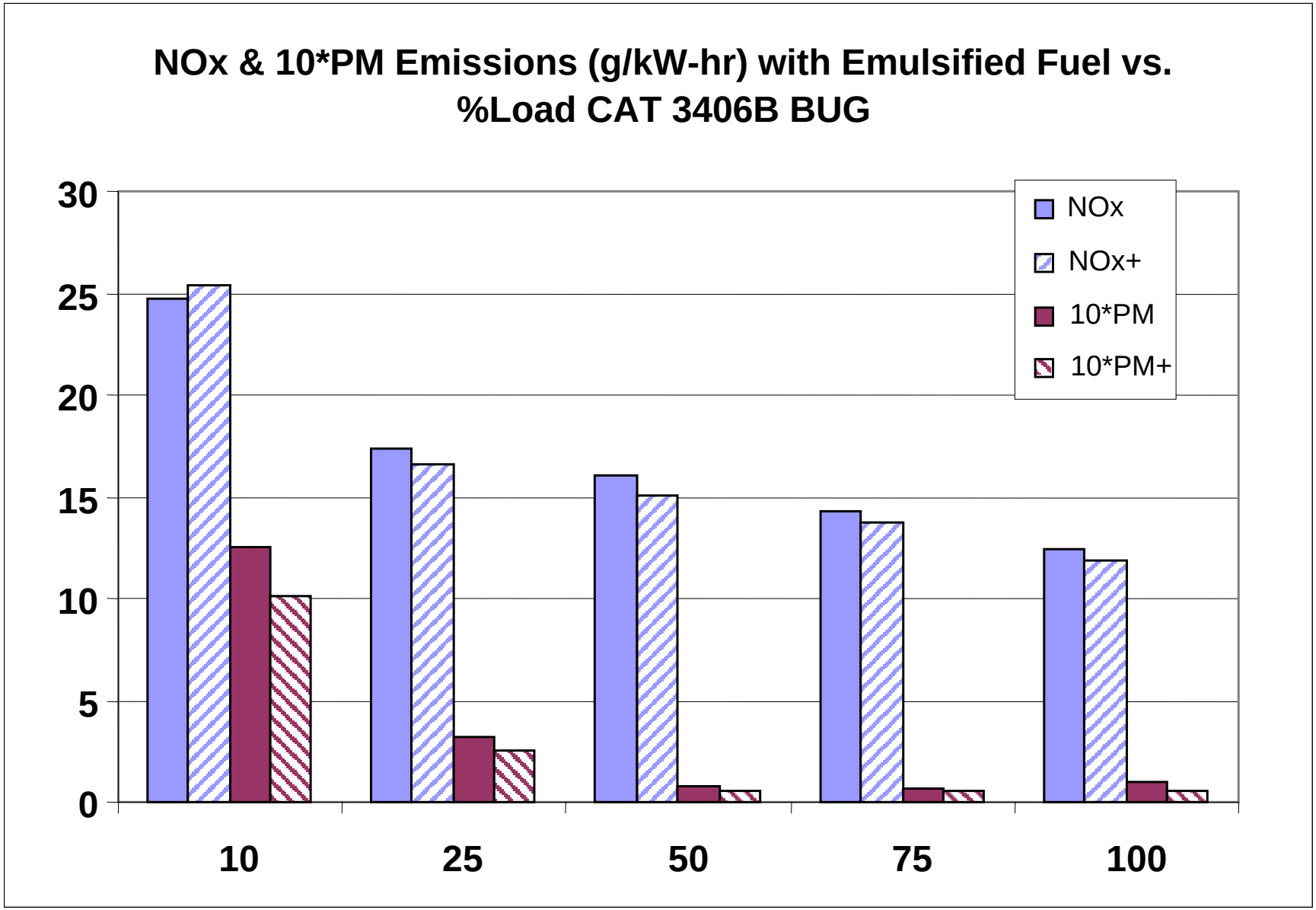


BUG Emissions with Fuel Change

Reducing PM Emissions for a CAT-3406C with a Diesel-water Emulsion



Reducing PM Emissions for a CAT-3406B with a Diesel-water Emulsion



Emissions with Control Device and Durability Testing

Recommended Durability Test Cycle for an Emergency Standby Generator

- **Part 1: Simulated Maintenance for Emergency Standby Generator**
  - ✓ **Cold-start engine and run engine at no-load for no more than 1 hour.**
  - ✓ **Shutdown engine and cool until engine reaches cold-start conditions**
  - ✓ **Run these tests consecutively and repeat 24 times.**

- **Part 2: Simulated Operation**

  A. Low-Load Operation

    A. Run engine at low-load (25%) for a total of 24 hours.

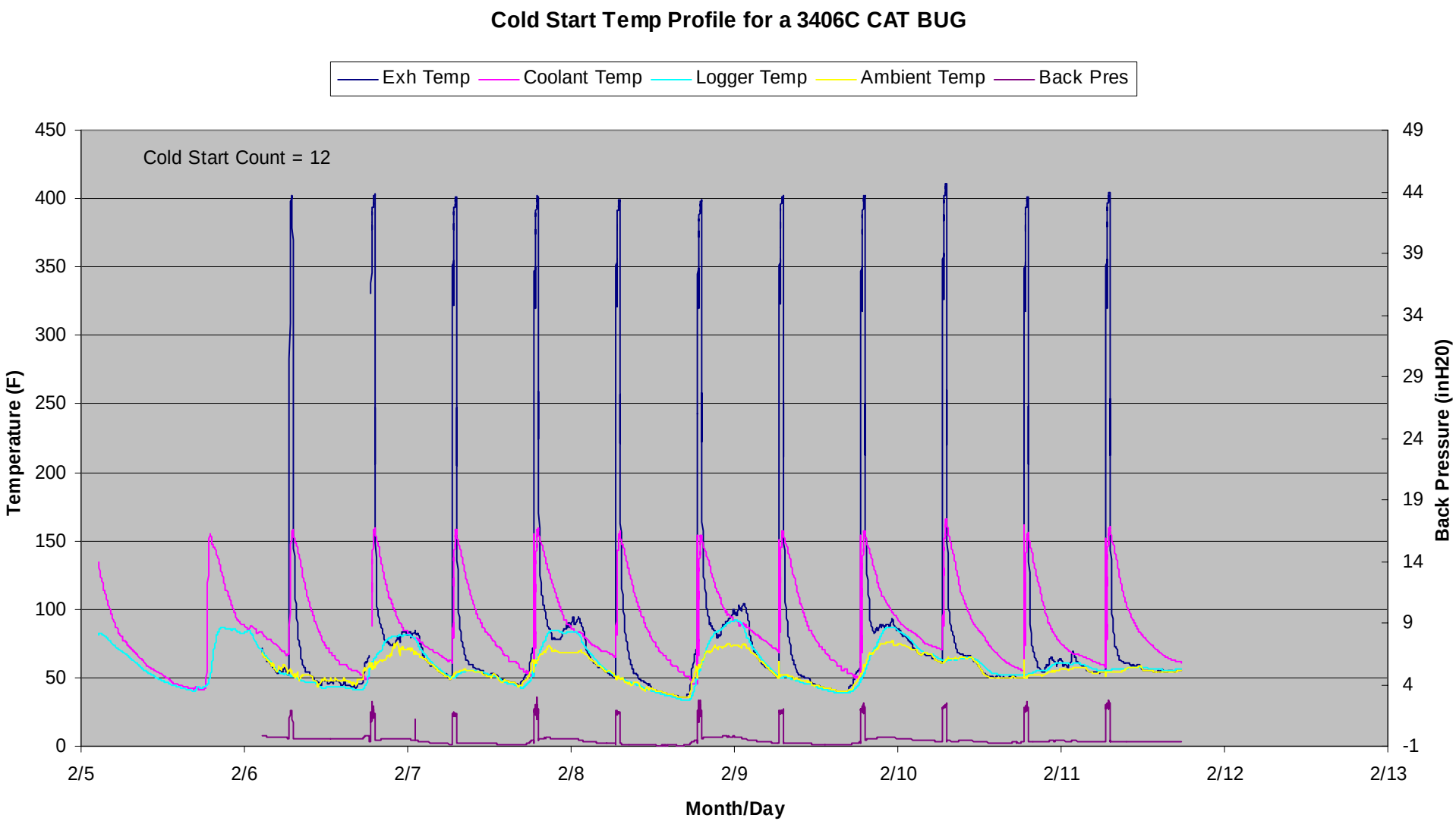
  B. Mid-Load Operation

    A. Run engine at mid-load (65%) for a total of 24 hours.

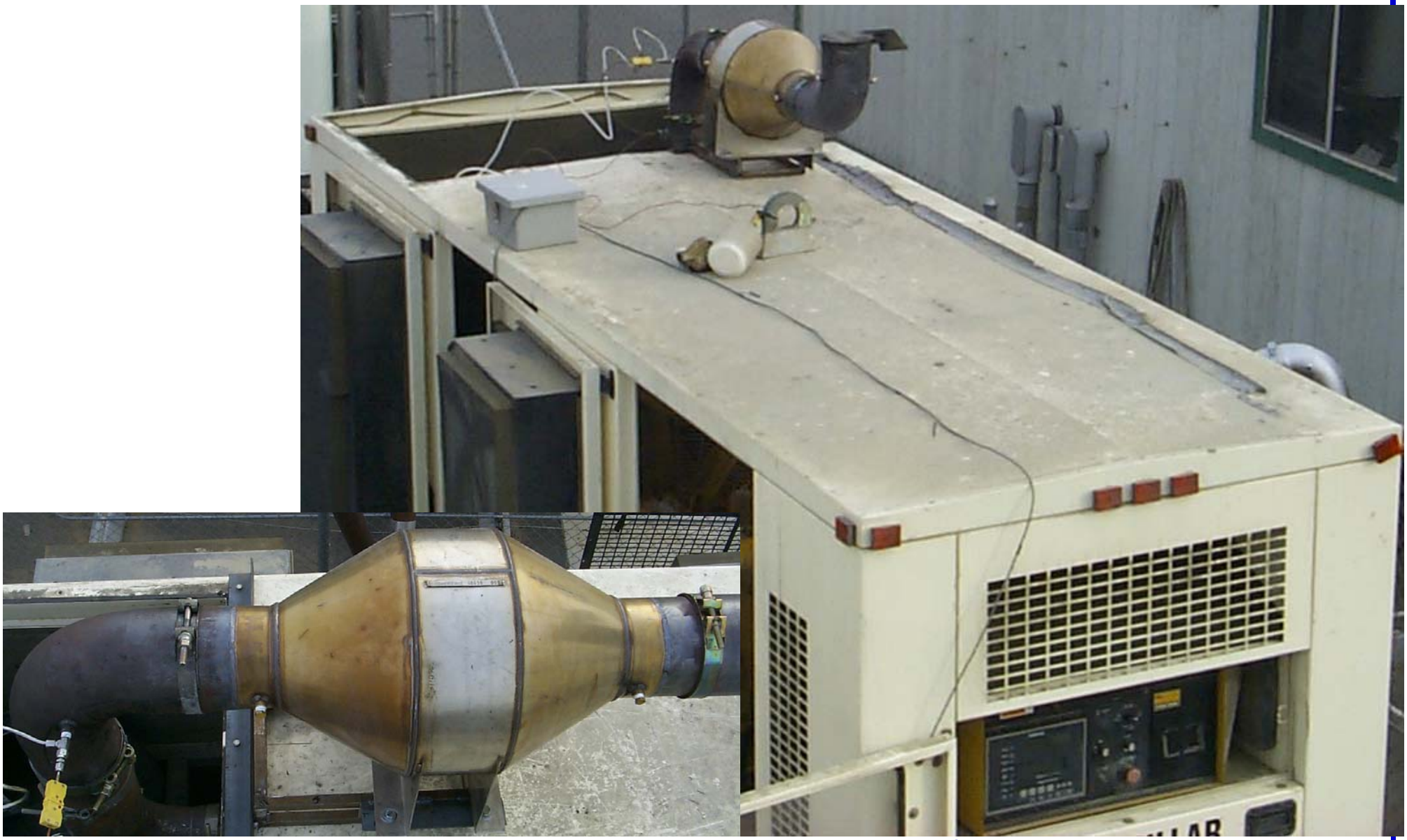
  C. High-Load Operation

    A. Run engine at high-load (80%) for a total of 24 hours.

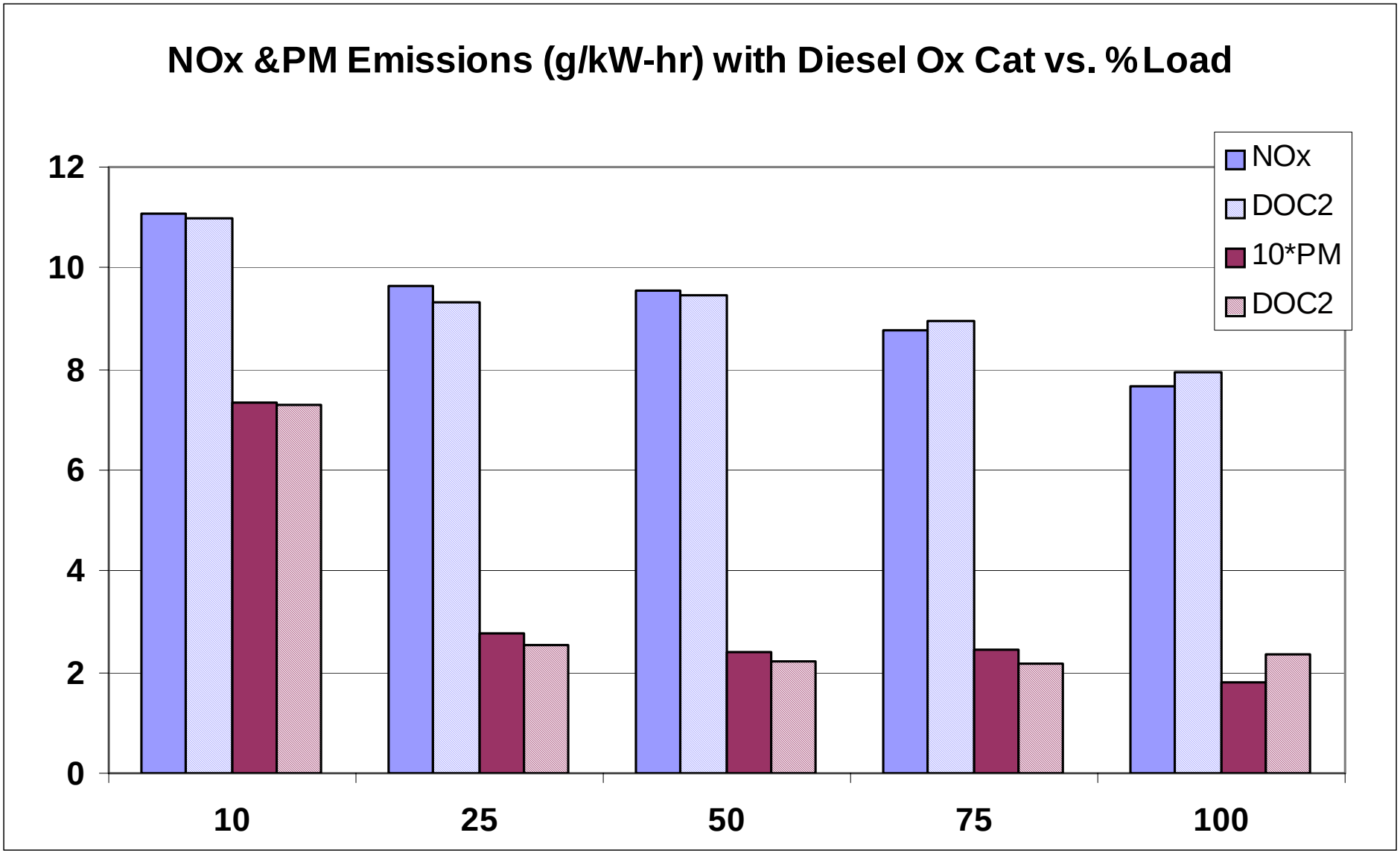
Temperature Profiles for a Maintenance Cycle



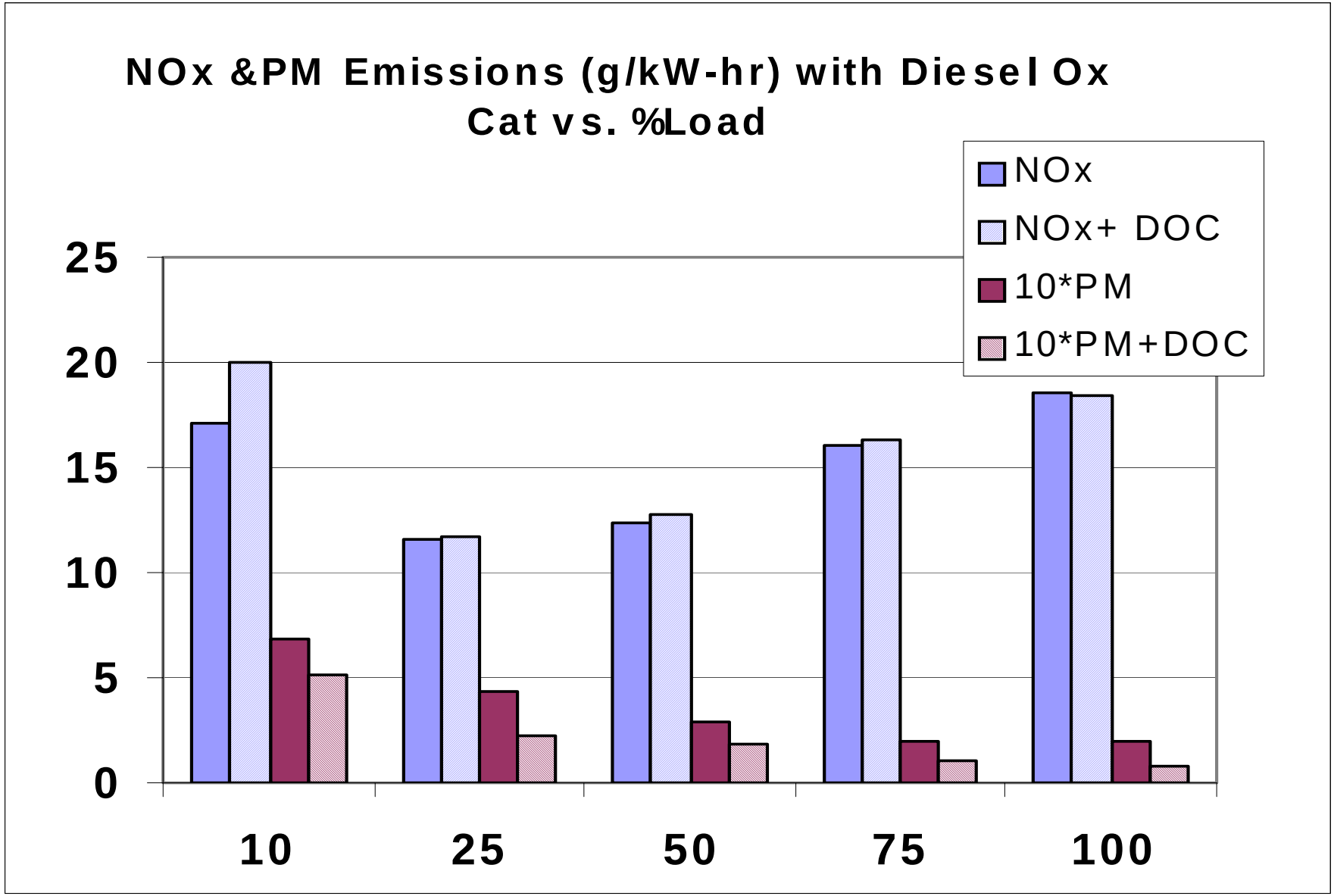
Diesel Oxidation Catalyst



Reducing PM & NOx Emissions for a CAT 3406C Engine with a Diesel Oxidation Catalyst

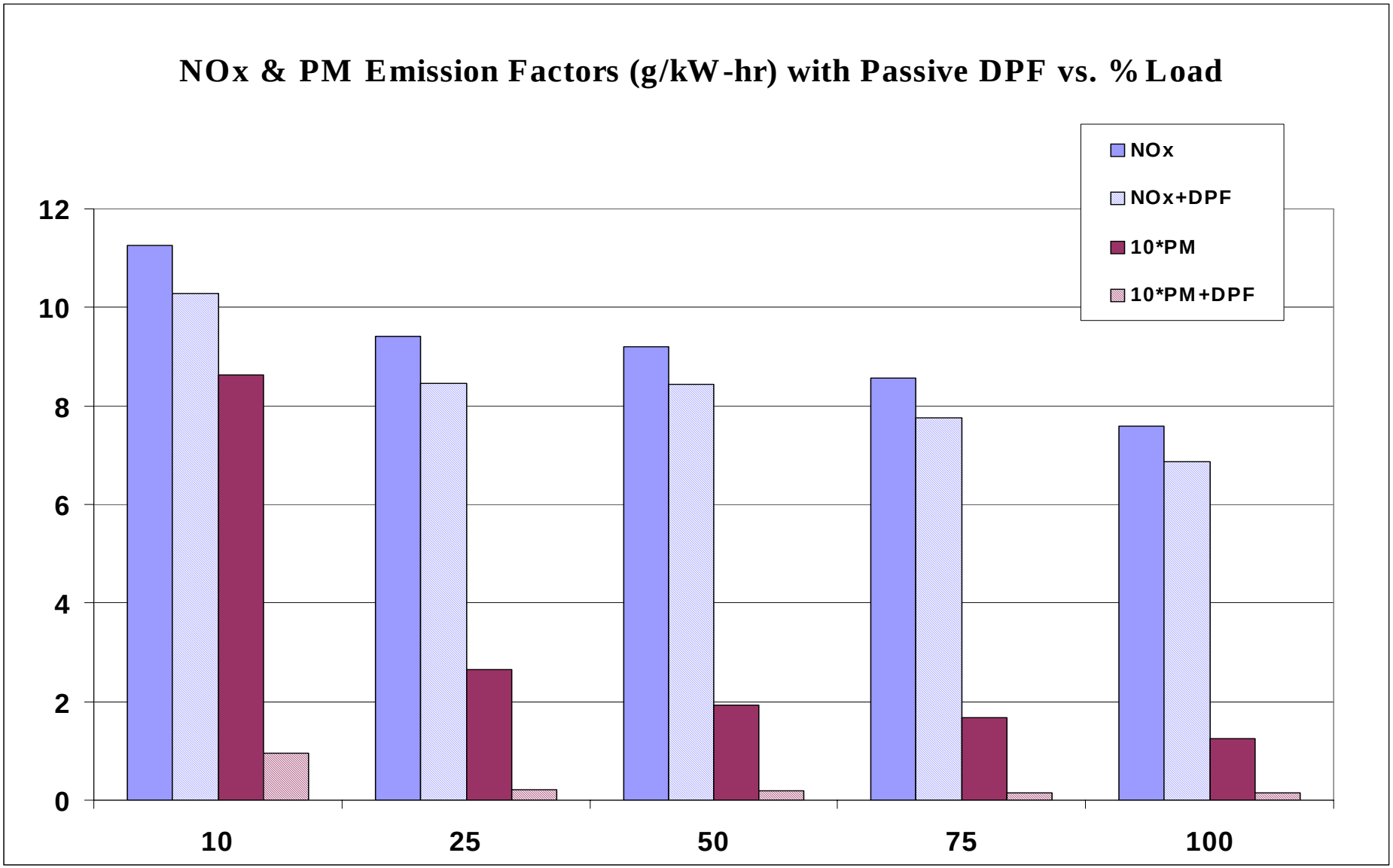


Reducing PM & NOx Emissions for a 2-Stroke Engine (6V92) with a Diesel Oxidation Catalyst



Passive Diesel Particle Filter

Control of a CAT 3406C with a Diesel Particulate Filter(DPF)



Active Diesel Particle Filter System

Overview of Control Technology

- ***Fuel emulsions*** **reduced PM ~ 70% and NO_x by 13% for newer engines. PM was reduced 25% and NO_x by 4% for older engines.**
- ***Diesel oxidation catalysts*** **(DOC) removed 5-20% of the PM for a model year 2000 engine with "dry soot" and up to 45% for a 1980's 2-stroke engine.**
- ***Passive diesel particulate filters*** **(DPF) removed over 91% of the PM but increased NO_2 levels.**
- ***Active traps*** **removed up to 98% PM without generating NO_2.**
- **A *fuel borne catalyst* plus DOC removed 44% of the PM with a 2-stroke engine and 99.7% of the PM from a new engine with a lightly loaded DPF.**

Conclusions

- **Results showed that in-use NO_x and PM emission factors for the uncontrolled BUGs were less than in the AP-42 tables.**
- **BUGs from the same engine family had the same emission values in the field tests.**
- **With control technology, PM emissions can be reduced from 5% to 99.8+%. Selection depends on a number of factors, including PM characterization.**
- **On-going: we are working with EPA to transfer the BUGs results to AP-42.**

Thank You Sponsors!

- US Environmental Protection Agency (US EPA)
- California Air Resources Board (CARB)
- California Energy Commission (CEC)
- South Coast Air Quality Management District (AQMD)
- Detroit Diesel Corporation
- International Truck & Engine
- Caterpillar
- Cummins
- Mack
- Volvo