

A photograph of the Golden Gate Bridge in San Francisco, California, showing the red suspension bridge structure against a clear blue sky and the water below.

A CALIFORNIA *Preliminary* ASSESSMENT OF PMP FOR DETERMINATION OF DIESEL PARTICLE EMISSIONS

**Alberto Ayala^{a,b}, Sherry Zhang^a, Jorn Herner^a and
William Robertson^a**

^a California Air Resources Board
California, USA

^b Department of Mechanical and Aerospace Engineering
West Virginia University, USA



California Environmental Protection Agency

Air Resources Board

Acknowledgments

- CARB Heavy Duty Lab: James Shears, Keshav Sahay, John Karim, Ralph Rodas, George Gatt
- CARB Light Duty Lab: Bruce Frodin, Ronald Haste, Wayne McMahan, Sharon Lemieux
- Tom Durbin and colleagues at Univ. of CA, Riverside/CE-CERT
- TSI Inc. for loan of particle counters
- Qiang Wei & Horiba for SPCS loan
- European Commission, Directorate-General, Joint Research Centre (JRC)
- Markus Kasper, Matter Engineering AG
- Jon Andersson, Ricardo UK Ltd
- David Kittelson, UMN
- Andreas Mayer, TTM



Project Drivers

- Clean air for health protection is CARB's number one mission
 - Potential health concerns associated with ultrafine PM emissions

- CARB-JRC Memorandum of Understanding for Research
 - Key topics: PMP & PEMS

- Need to enhance our understanding of the European PMP proposal

- Explore PMP utility for application in California

PMP entering EURO5/6 standards



In California, diesel “means” heavy-duty vehicles, but light-duty ones are coming

Global Equity Research

Global

Automotive Manufacturers

Market Comment

UBS Investment Research

Q-Series®: Global Autos Research

24 May 2007

www.ubs.com/investmentresearch

Max Warburton

Analyst

max.warburton@ubs.com

+44(0) 76 0454

Rob Hinchliffe, CFA

Analyst

rob.hinchliffe@ubs.com

+1 212 713 9011

Tatiana Kordina

Analyst

tatiana.kordina@ubs.com

+41 352 08 7156

Is diesel set to boom in the US?

Ricardo is a leading provider of technology, engineering solutions and strategic consulting to the world's automotive industries

Steve Parker

Head of strategy consulting

Neville Jackson

Technology director

Adam Allcock

Strategy consultant

This report has been prepared by UBS Limited in conjunction with Ricardo

Lowering CO₂ emissions in the US: Is diesel or hybrid best?

US regulators may soon move to set higher fuel economy standards, accelerating demand for fuel-efficient vehicles. At present, hybrid technology appears to be the preferred route in the US, but diesel can deliver similar benefits at lower cost. Diesel already dominates in Europe. The conditions may be right for a diesel boom in the US, in our opinion.

A detailed cost-benefit analysis of the two technologies

This report is produced in collaboration with Ricardo, experts in automotive technology. We have undertaken detailed analysis of the relative economy, benefit, cost penalties and legislative constraints of diesel and hybrid.

Diesel is a lower cost option; legislation – the key obstacle

Ricardo forecasts growth in both technologies, but expects diesel to prevail by 2012 (1.5 million units versus 1.2 million hybrids). Diesel's cost burden is lower than hybrid's for similar fuel economy – even with the diesel technologies needed to meet tough US emissions regulations (including California). Diesel's cost lead over hybrid is most marked for larger vehicles (crossovers/SUVs).

Diesel is easier to invest in than hybrid: Key stock ideas

Diesel and hybrid growth should benefit key stocks within our coverage. Diesel looks set to benefit the German OEMs (BMW, Mercedes, VW) and Honda, plus key suppliers (BorgWarner, Denso, paragon Components). The only obvious hybrid plays are Toyota and battery makers (TCL).

ANALYST CERTIFICATION AND REQUIRED DISCLOSURES BEGIN ON PAGE 59

UBS does not and seeks to do business with companies covered in its research reports. As a result, investors should be aware that the firm may have a conflict of interest that could affect the objectivity of this report. Investors should consider this report as only a single factor in making their investment decision. Customers of UBS in the United States can receive independent, third-party research on the company or companies covered in this report, at no cost to them, where such research is available. Customers can access this independent research at www.ubs.com/independentresearch or may call +1 877-208-8700 to request a copy of this research.



Reducing Emissions of a Known Toxic Air Contaminant

California's Diesel Risk Reduction Plan

New engine standards

2007-2010 engines are 90% cleaner for PM and NOx



Cleaner diesel fuel

To date on- and off-road, ship auxiliary engines

Stronger compliance programs

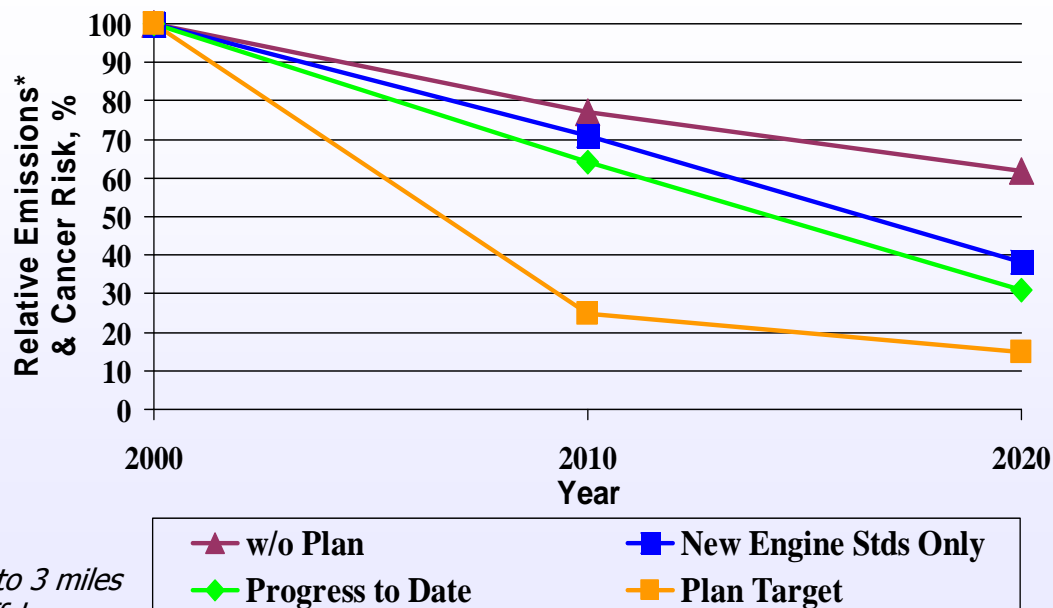
ensure in-use emissions maintained



In-use Emission Reductions

Clean up existing vehicles

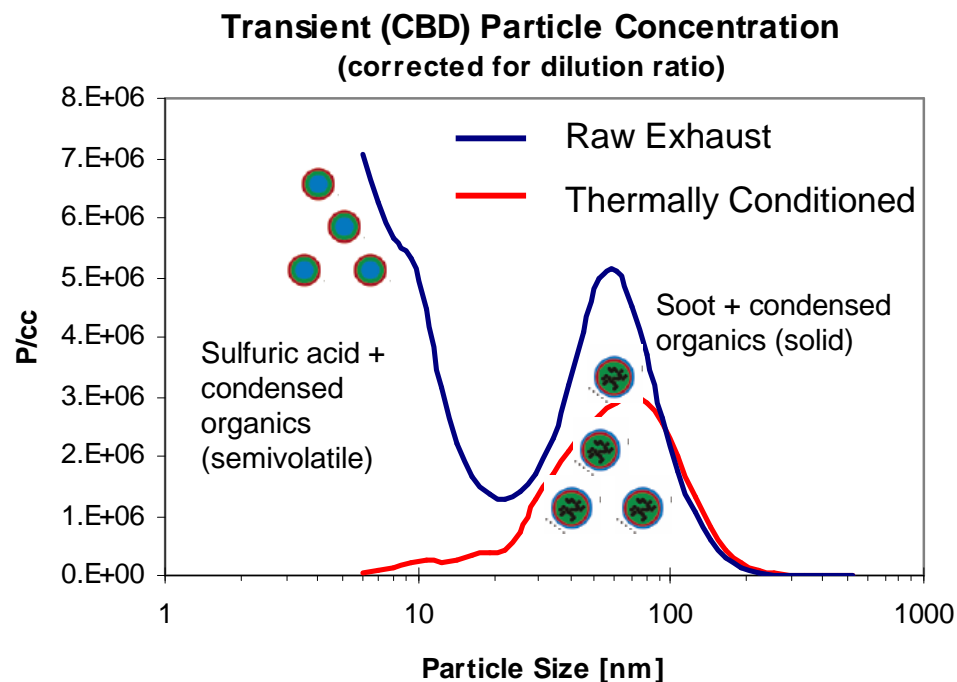
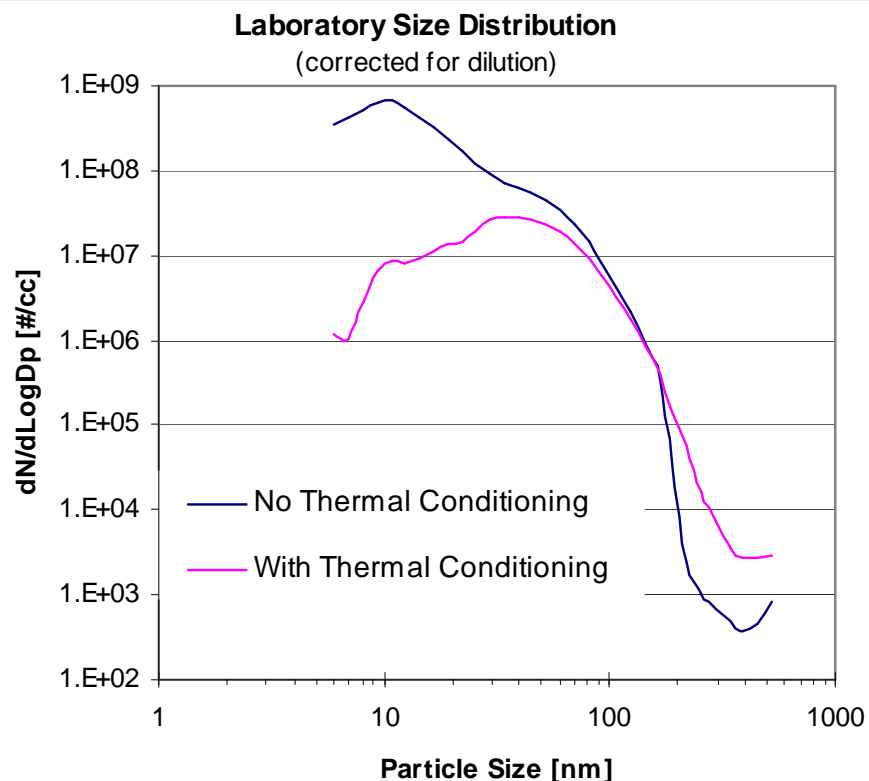
Requires Best Available Control Technology (retrofits, repower, replacement, retire)



- Multiple regulations already adopted (e.g., transit buses, refuse haulers, off-road fleets, OBD for trucks, etc)
- Several future measures (e.g., private on-road fleets, Bond \$ for port trucks and ships etc.)

Presence of semi-volatile and volatile material

Diesel size distribution measured in the laboratory (50mph)



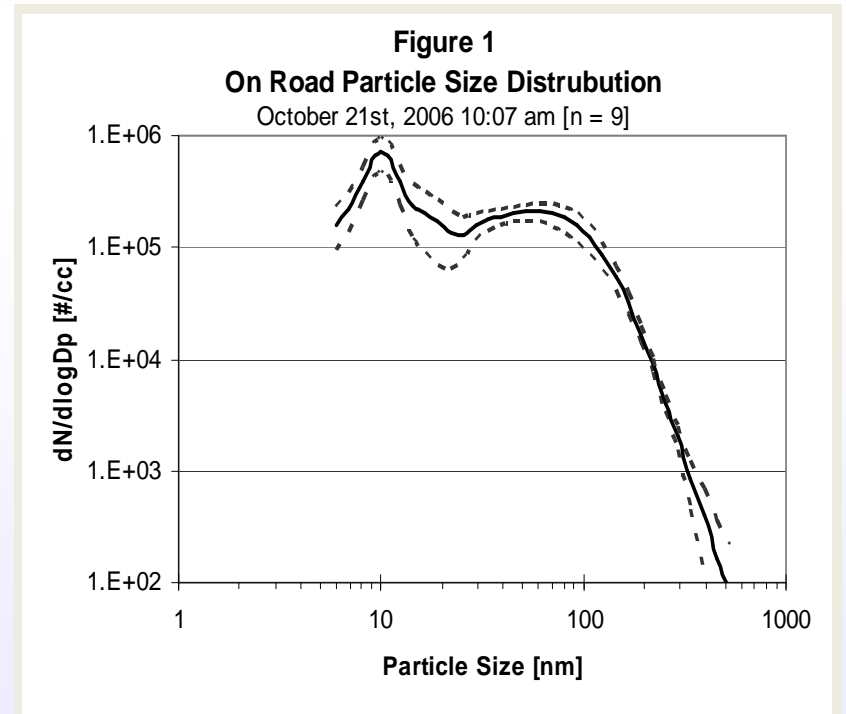
Within the ultrafine range, two modes exist in diesel emissions

1. Semivolatile nucleation mode (nanoparticles)
2. Solid soot particles in the accumulation mode

Effect of Heavy Duty Diesel Trucks



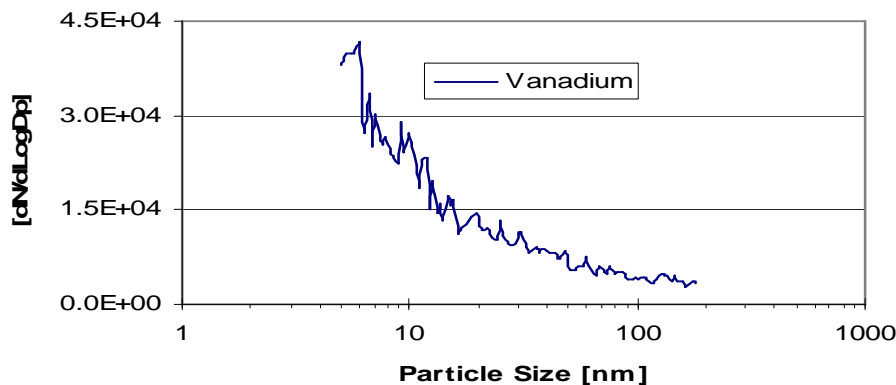
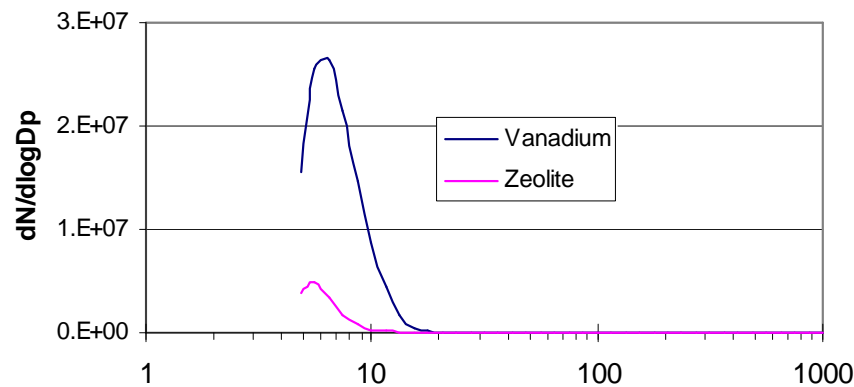
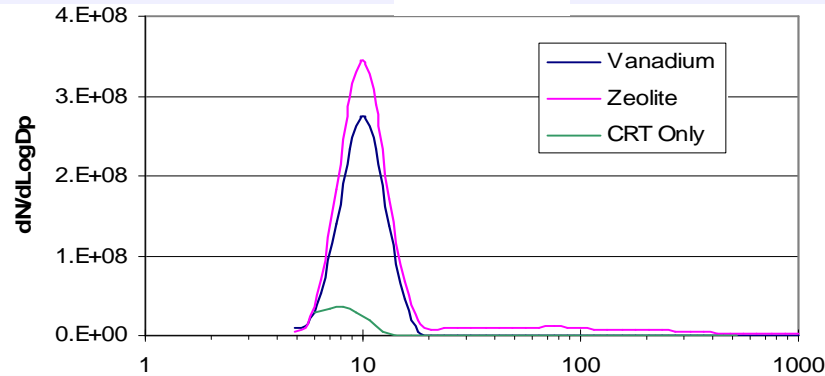
No diesel aftertreatment, ULSD



Kozawa et al. 2007, CRC, March 2007

DOC + DPF + SCR Results

Average Particle Size Distribution



50mph Cruise

- Size distribution similar

UDDS

- Vanadium particle emissions higher due to lower nucleation activation temperatures

Idle

- Particle count comparable to particle count of tunnel blanks
- Similar for vanadium and zeolite

California PMP

Heavy-Duty Vehicle Testing

Chassis dynamometer



Over-the-road



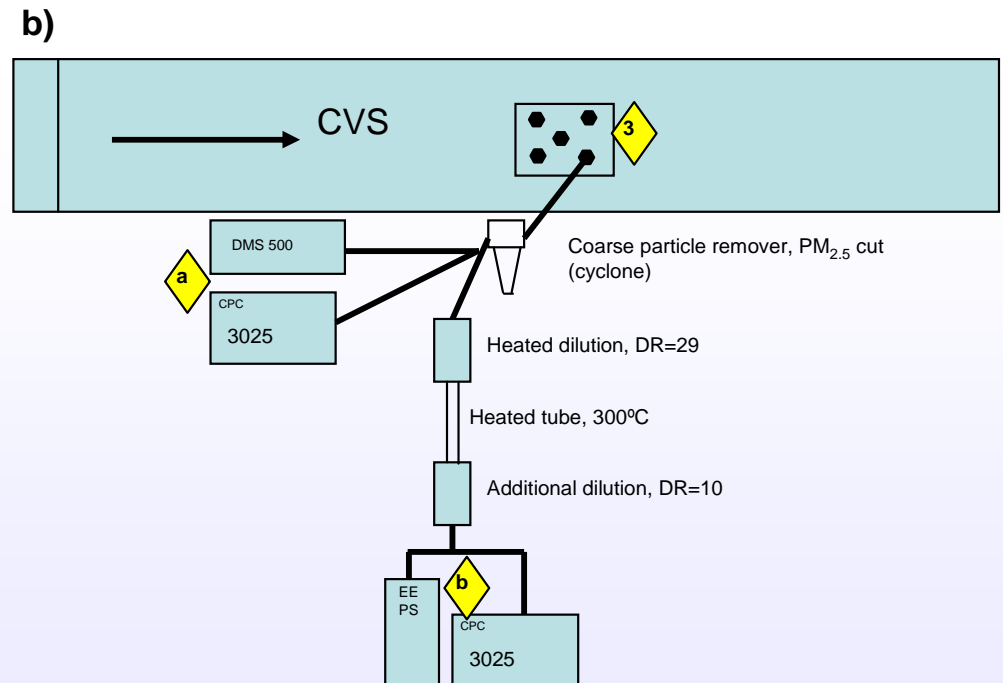
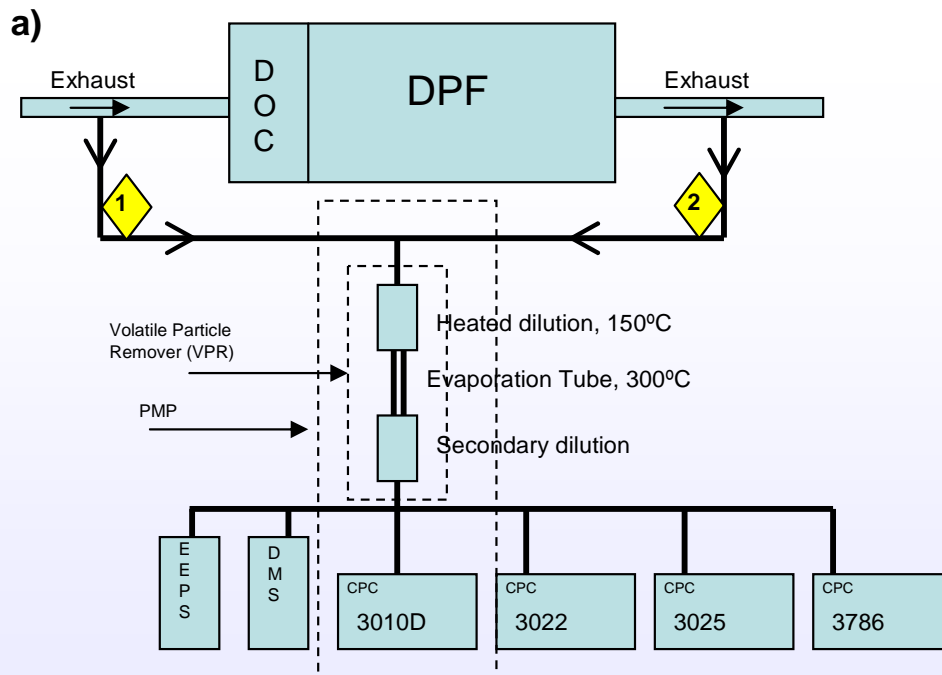
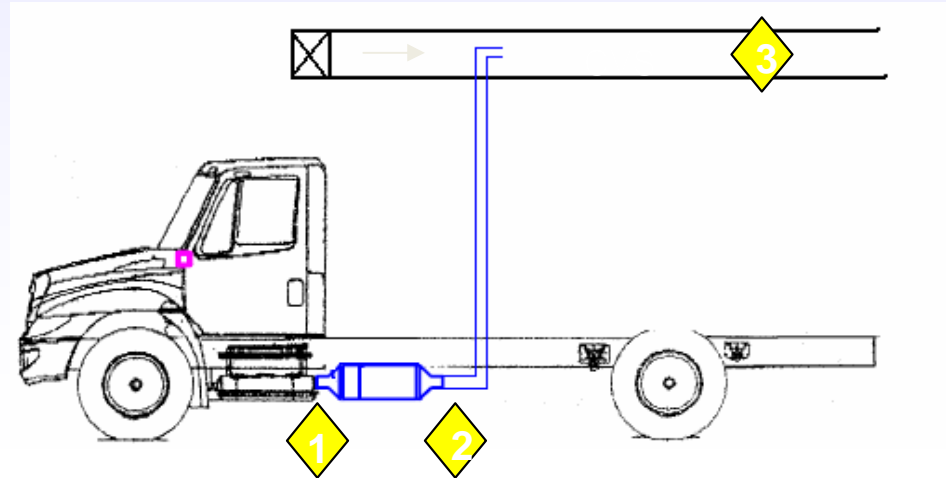
UCR-CECERT-Mobile Emissions Laboratory

Light-Duty Vehicle Testing

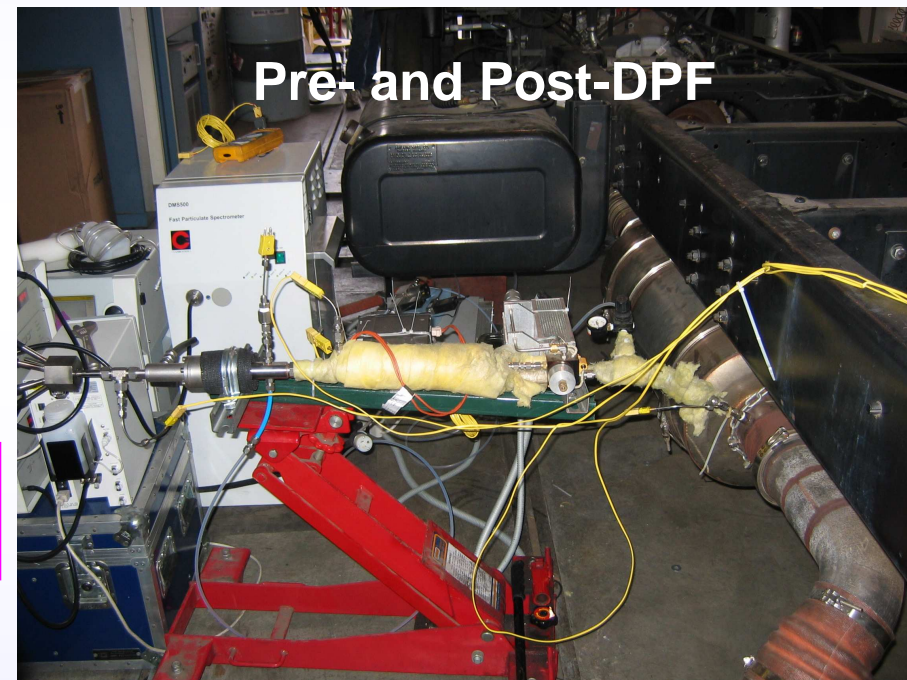
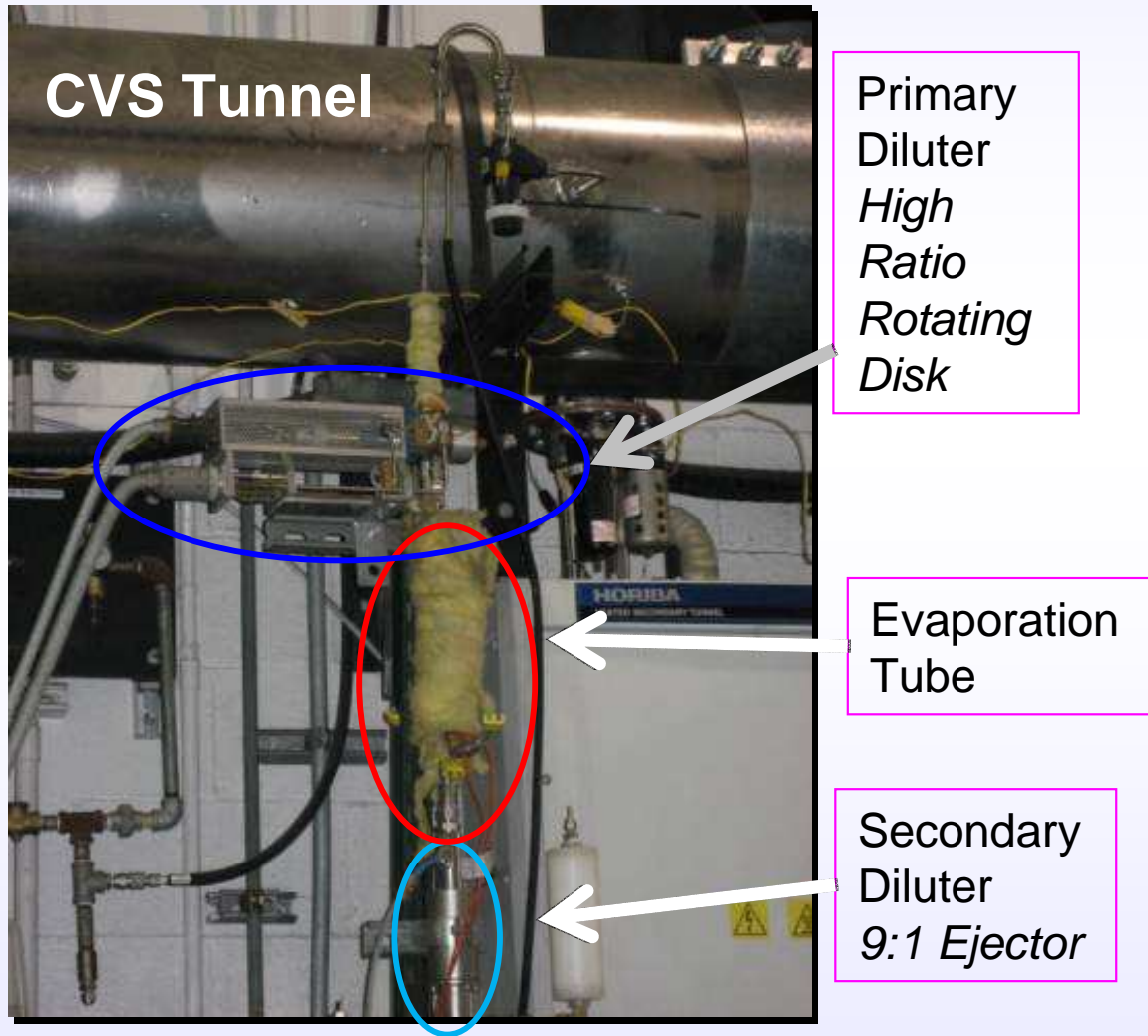
Golden Vehicle



Experimental Setup for Heavy-duty Vehicle Experiments



PMP implementation @ chassis dynamometer lab



Instrumentation

Particle Counters



TSI 3786
2.5nm



TSI 3025A
3nm



TSI EEPS, 5.6nm



TSI 3022A
7nm

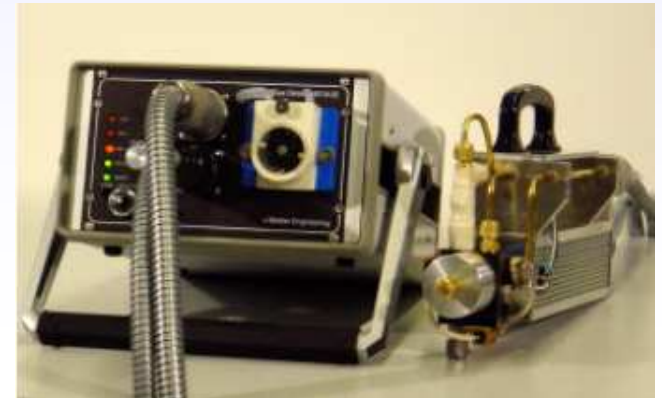


TSI 3010D
23nm



Cambustion DMS-500
5.6 nm

Diluters

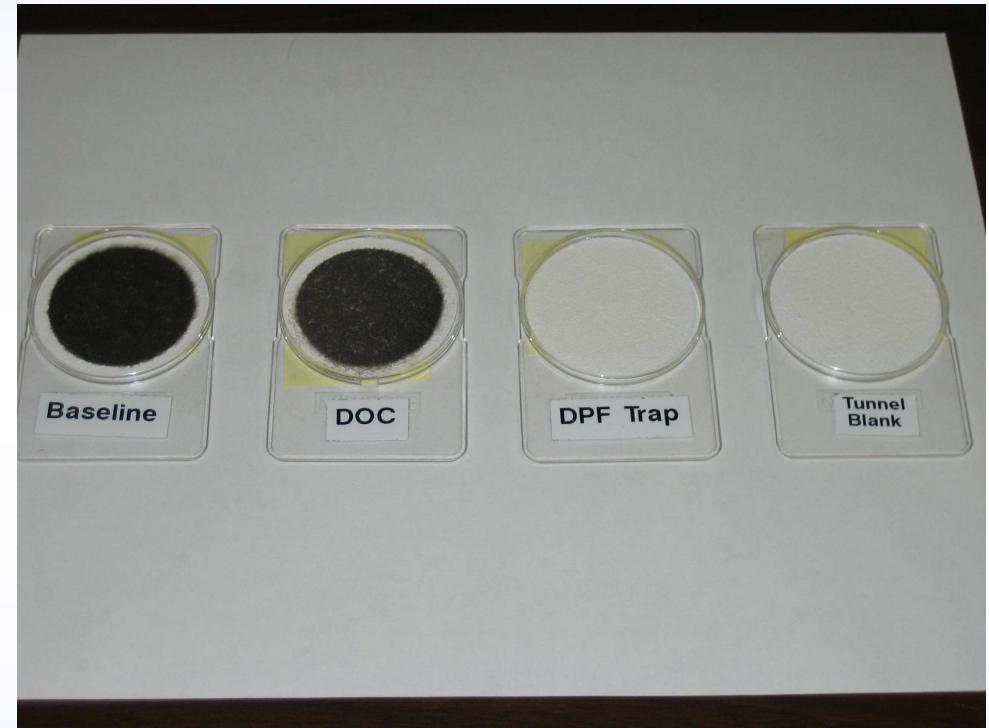
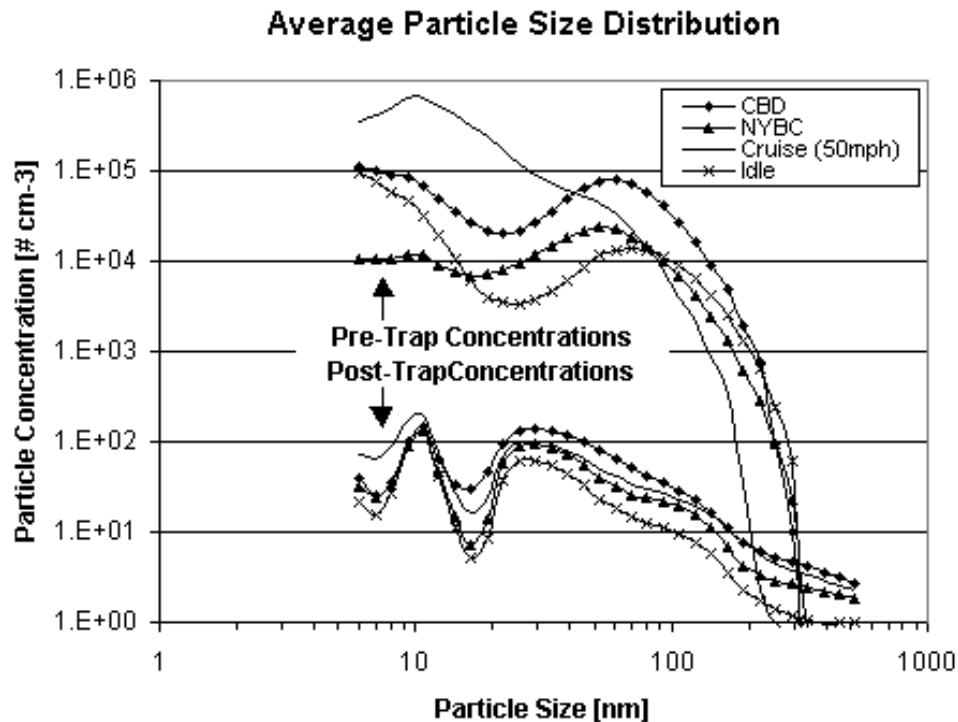


Matter Engineering MD-19



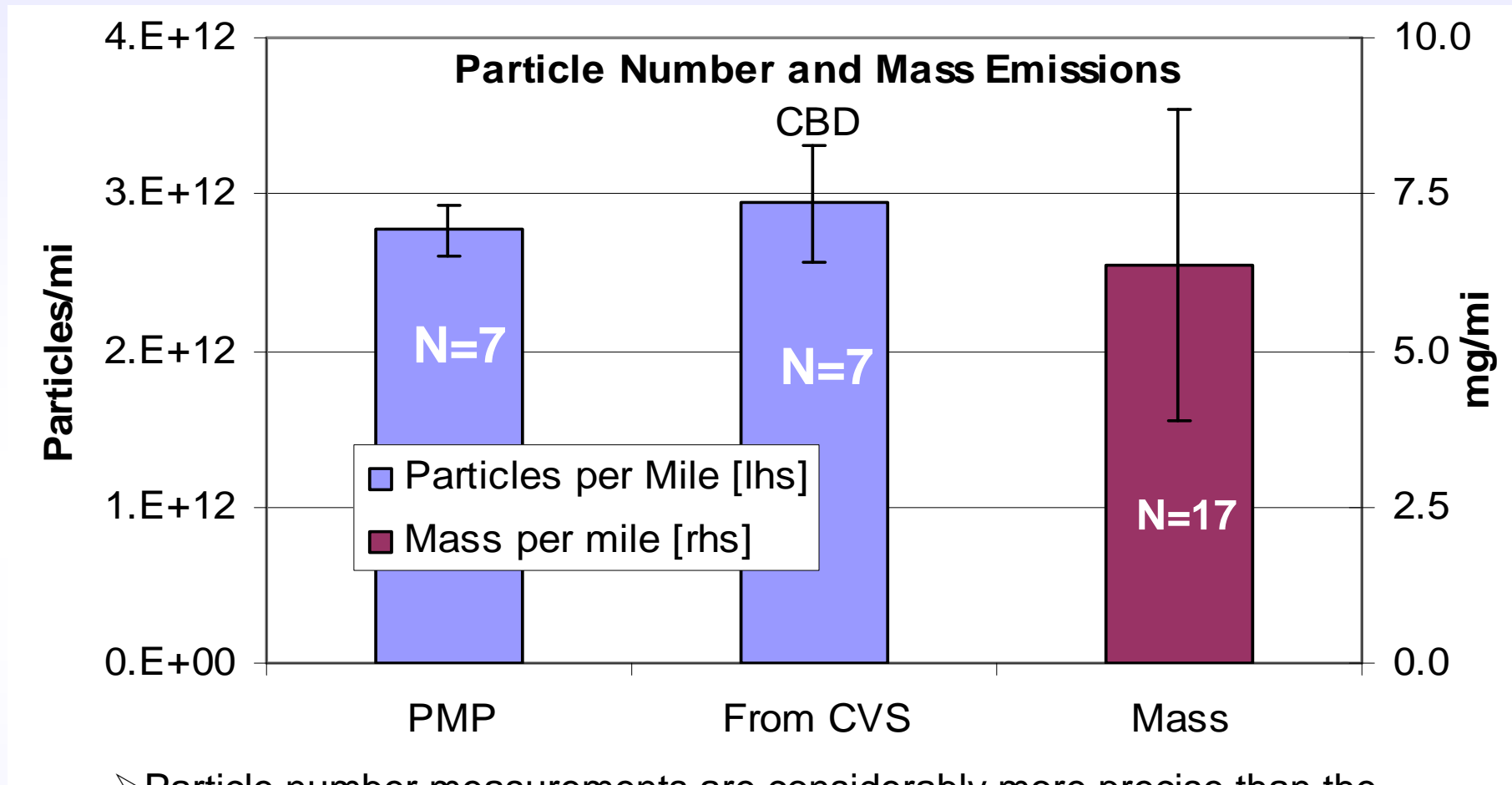
Dekati DI 1000

DPF PM reduction effectiveness is confirmed



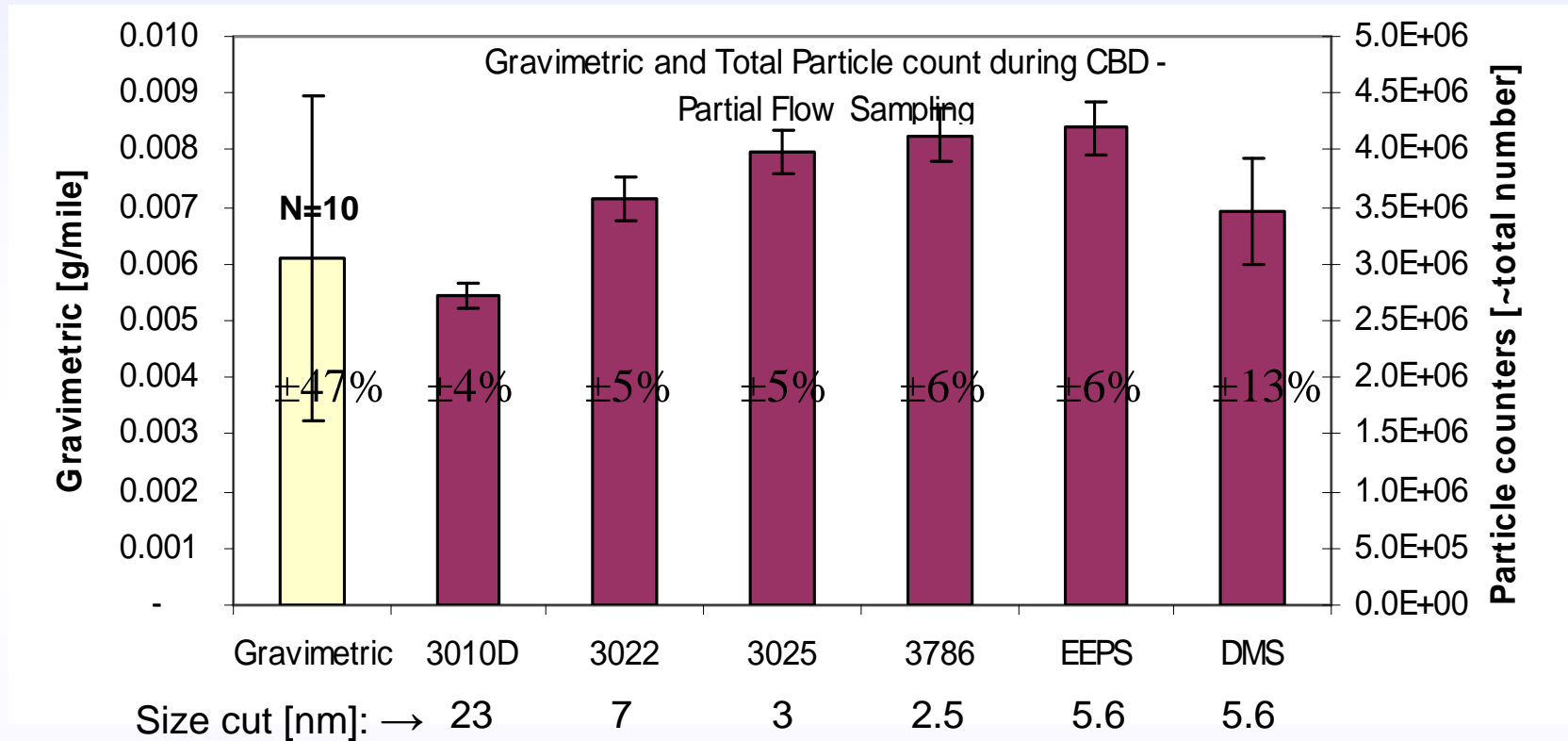
Average particle concentration measured with the EEPS pre and post trap for CBD, NYBC, Cruise and Idle. The trap effectively reduces total particle concentration by approximately 100 X. *No DR correction.*

Emission Measurement Comparison

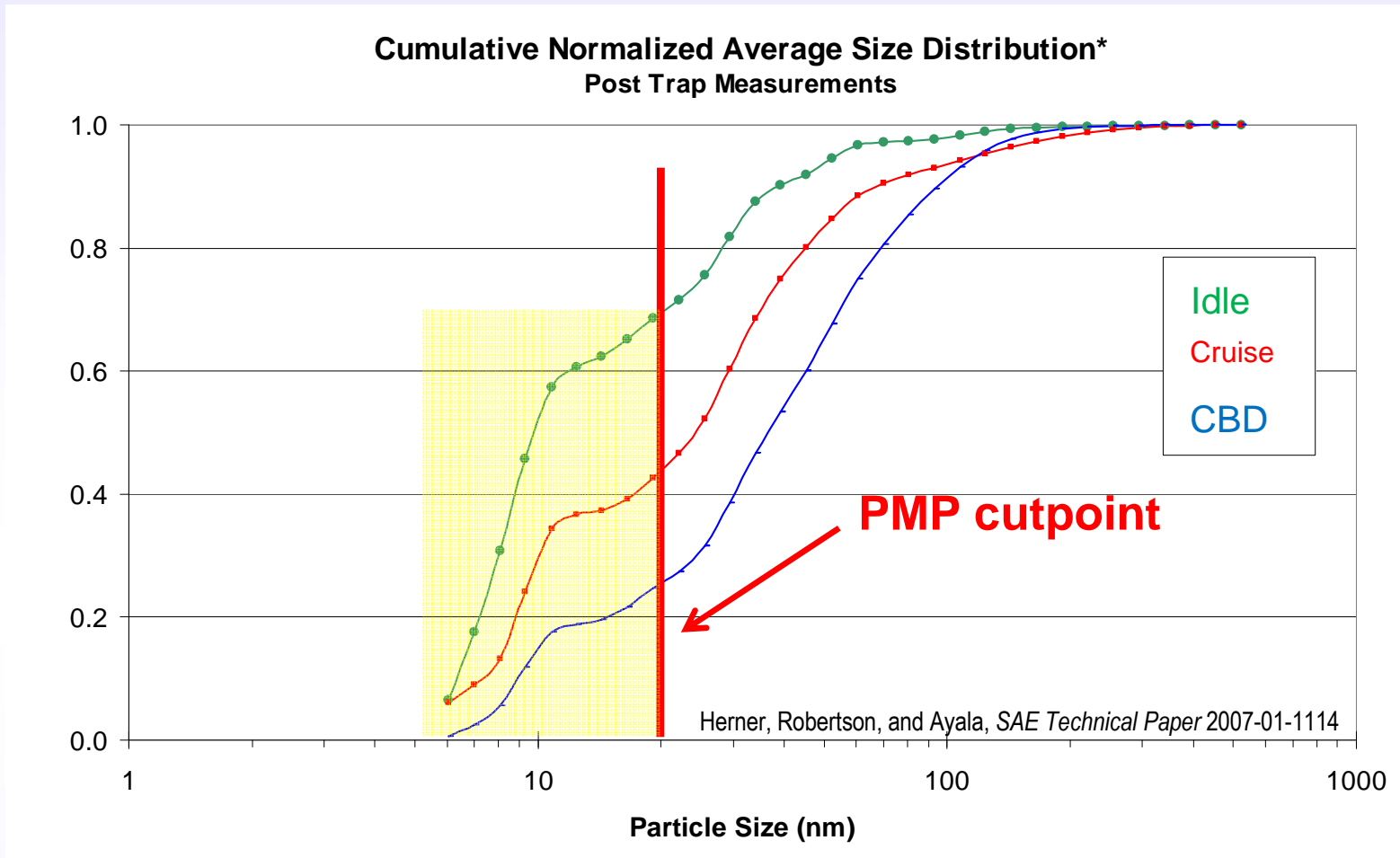


- Particle number measurements are considerably more precise than the mass measurement in the current study.
- Upcoming improvements in gravimetric measurements at CARB labs are expected to get closer to new US07 1065 Rule.

Post-DPF Measurements



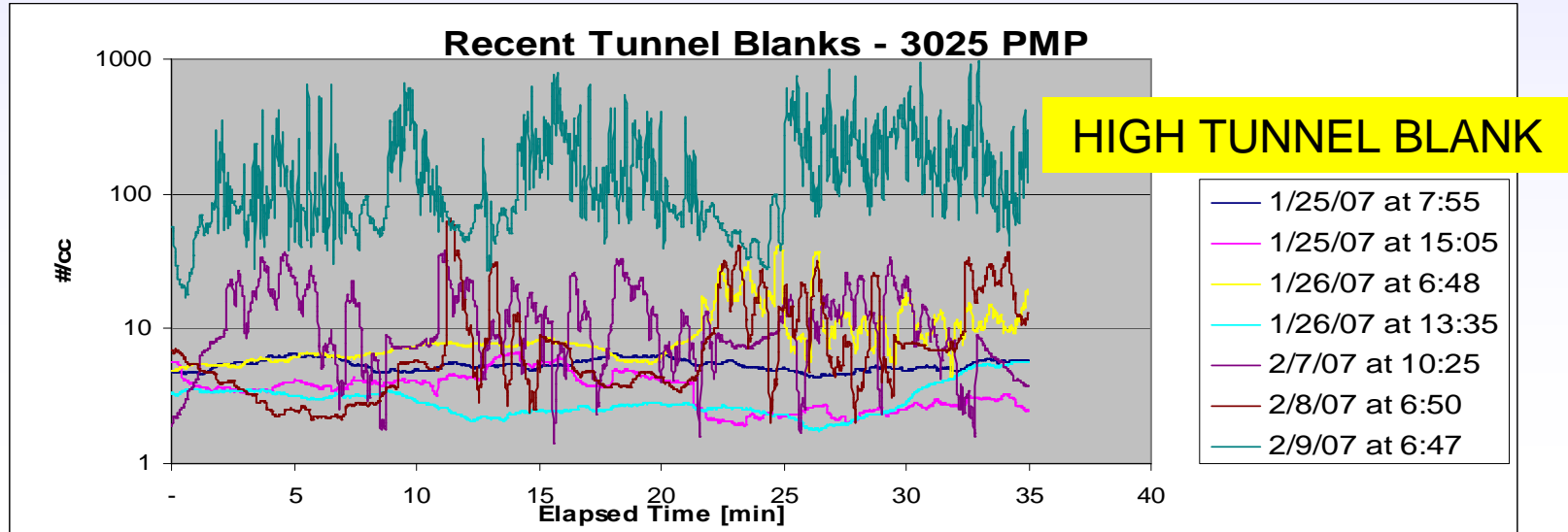
Gravimetric and post trap Partial Flow PMP particle number measurements. The particle number measurements are averages of total particle count for only three measurements, two with the ET heated and one with the ET unheated.



- 25-75% of apparently **solid** particle counts can be below PMP cutpoint
- Possible importance of sub 20nm particles dependent on composition

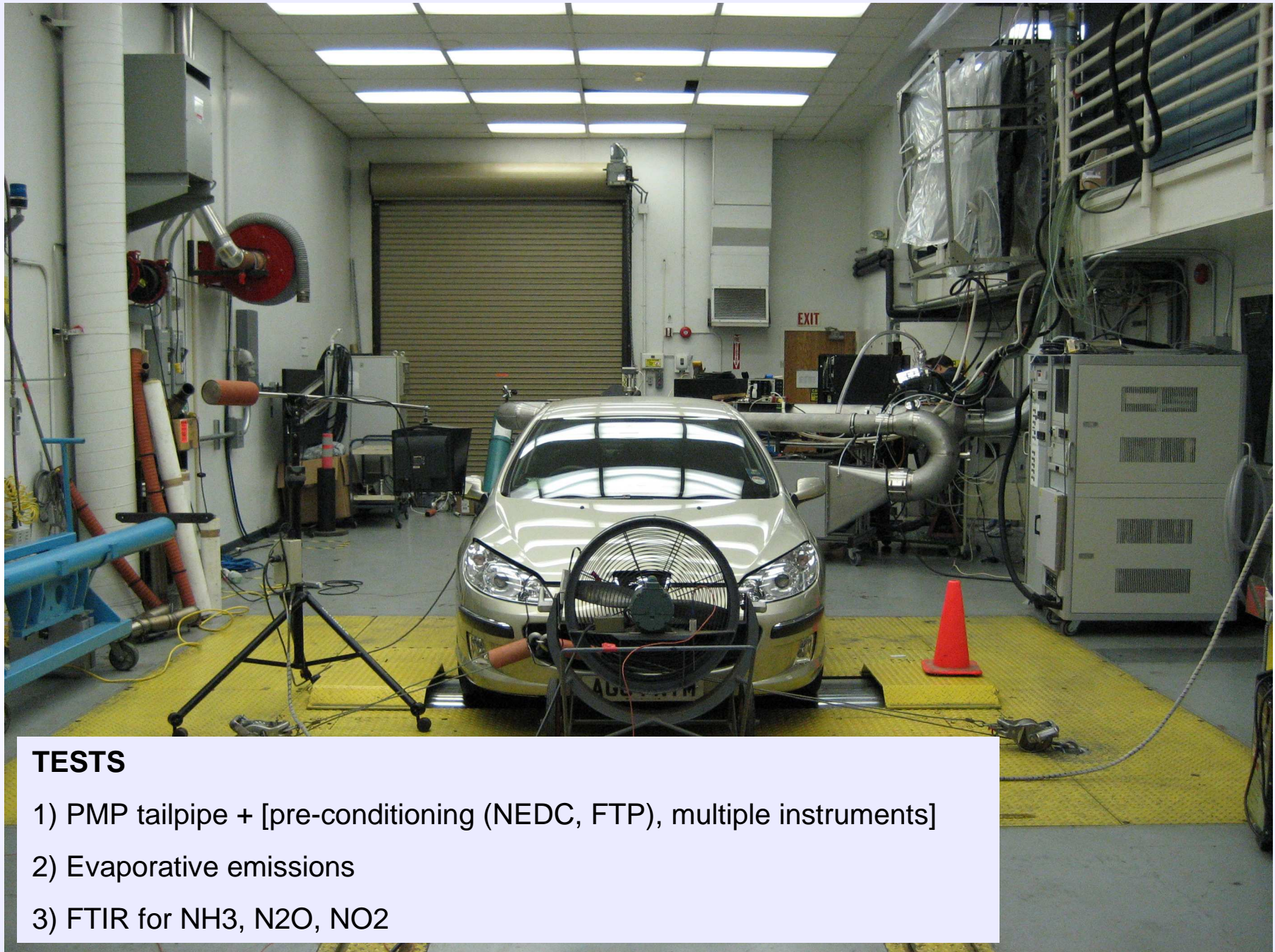
Testing has not been problem-free

One example



- Lubricating coating on rotating disk and diluter head can quickly degrade and wear off
- Once the coating starts to break apart, the instrument appears to generate particles
- It may be preferable to operate the instrument at 80°C or 120°C to avoid wearing off the coating which seems to happen when operating at 150°C





TESTS

- 1) PMP tailpipe + [pre-conditioning (NEDC, FTP), multiple instruments]
- 2) Evaporative emissions
- 3) FTIR for NH_3 , N_2O , NO_2

Golden Vehicle Testing - Instrumentation

Diluter



Matter Engineering MD-19

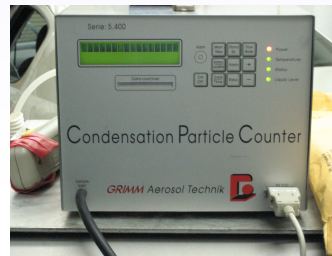
Particle Counters



TSI 3790



TSI 3010D



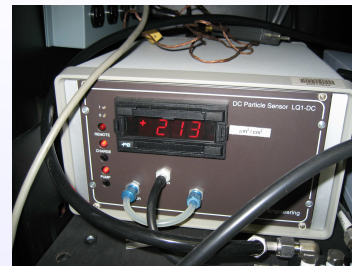
Grimm CPC



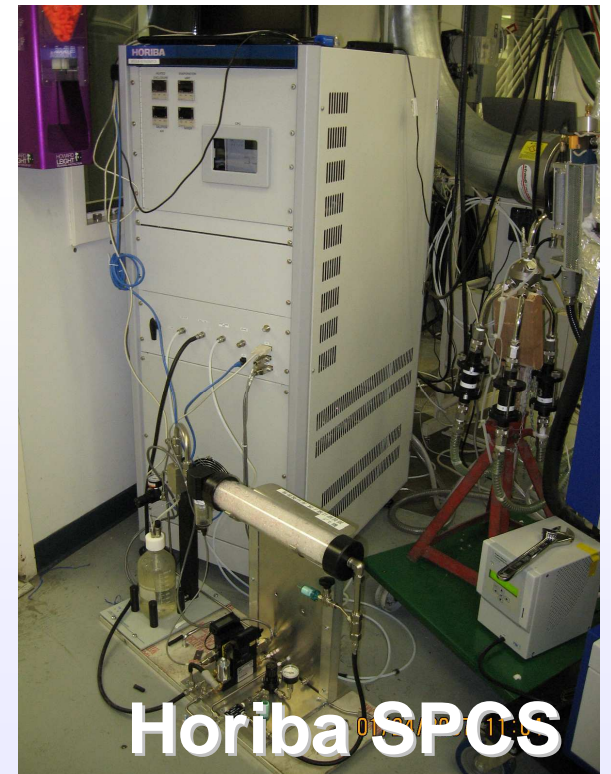
TSI EEPS



EcoChem PAS2000



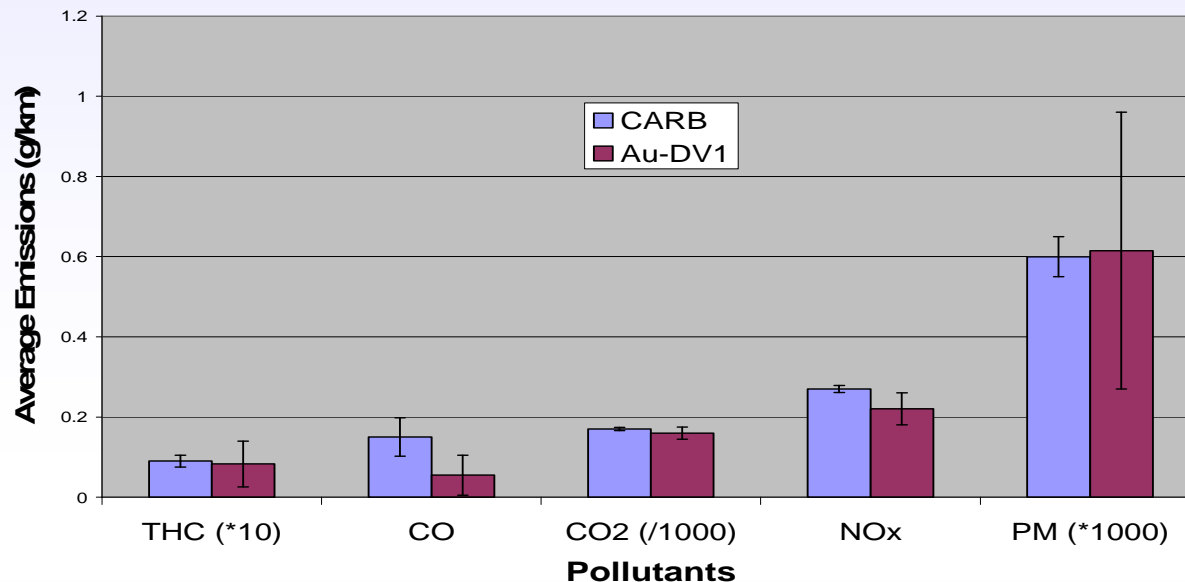
Matter Engineering
LQ1-DC



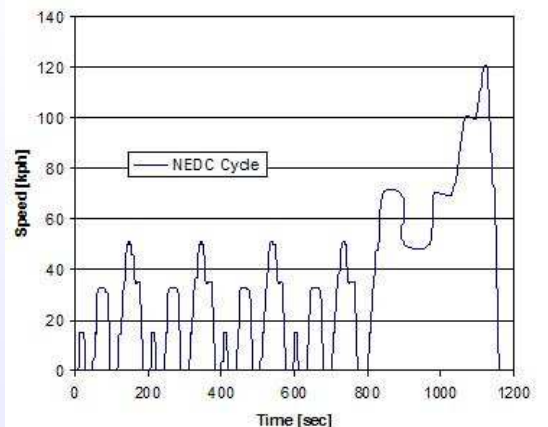
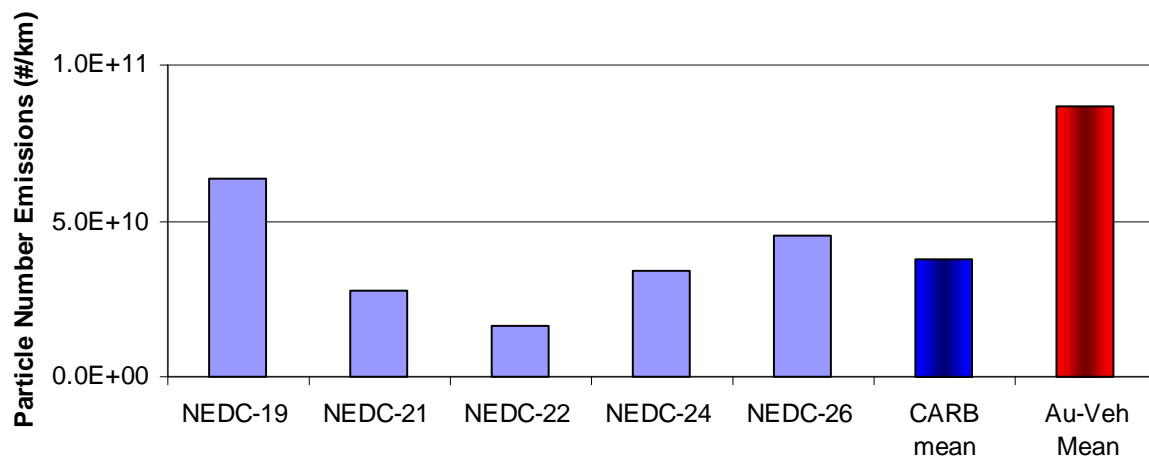
Horiba SPCS

Comparison of Emissions Results for CARB lab and PMP labs

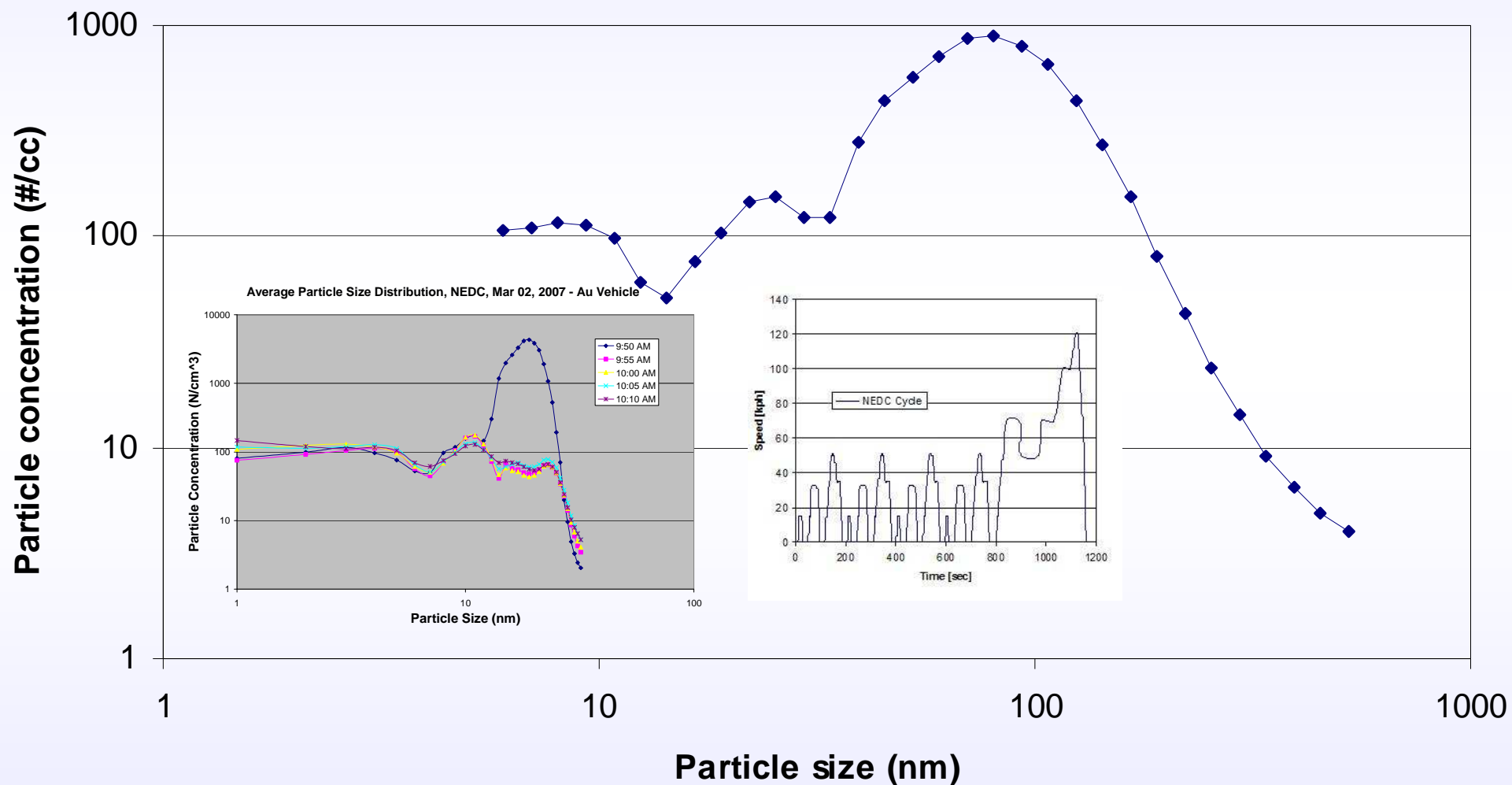
Average Mass Emissions during NEDC for Au Vehicle
Preliminary CARB Results



Particle Number Measurement from Horiba SPCS During NEDC Tests



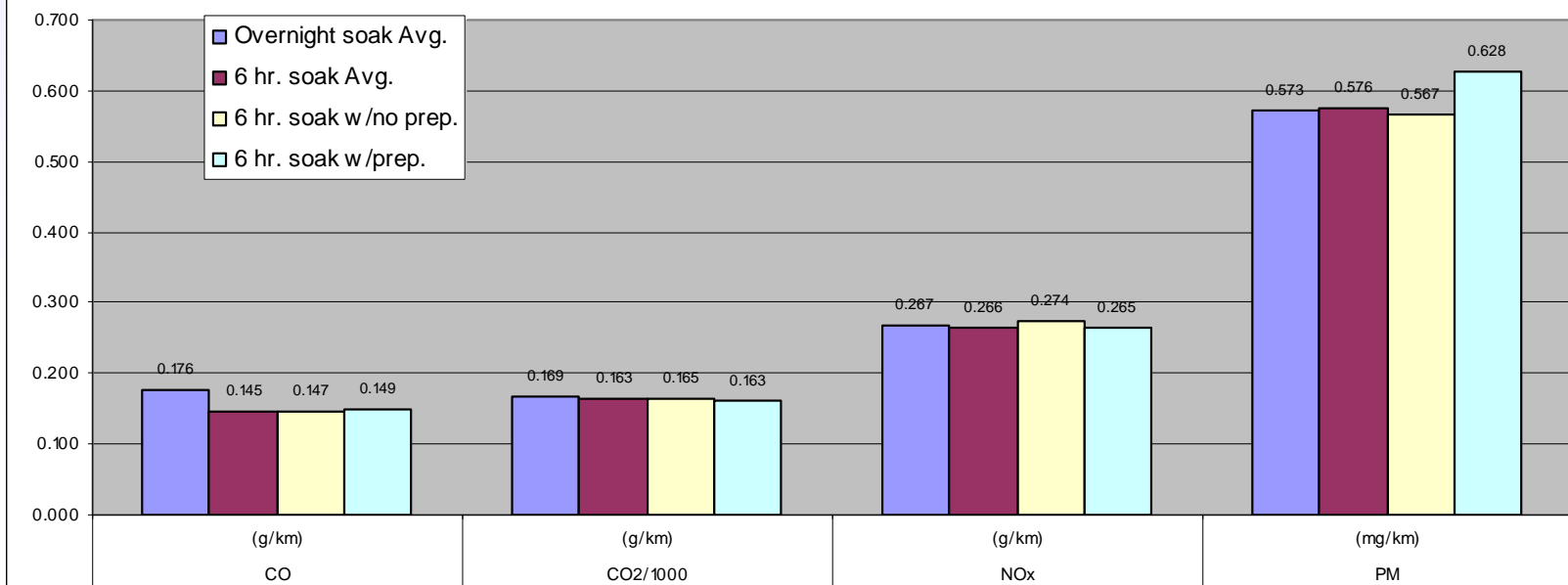
Particle Size Distribution (1-NEDC-10, 02MAR07)* Au Vehicle



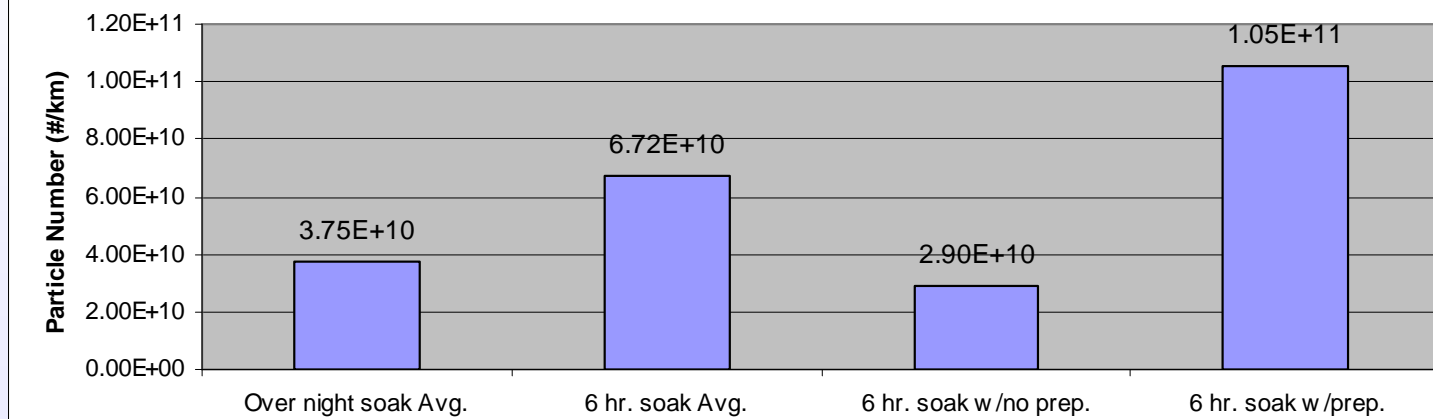
*EEPS average over entire NEDC. EEPS post-cyclone, pre-PND1

Pre-conditioning effects

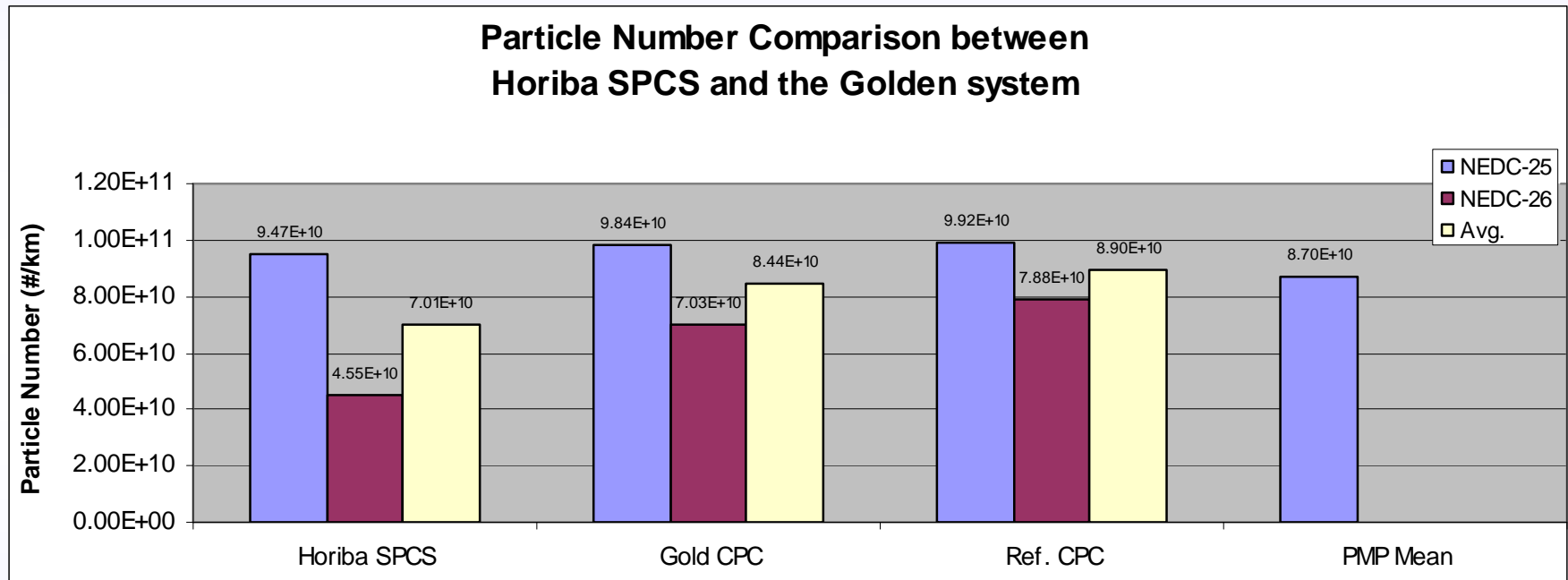
Emissions Comparison between Soak Period (overnight vs 6 hr.) and Pre-conditioning (prep. vs. no prep.) during NEDC Tests

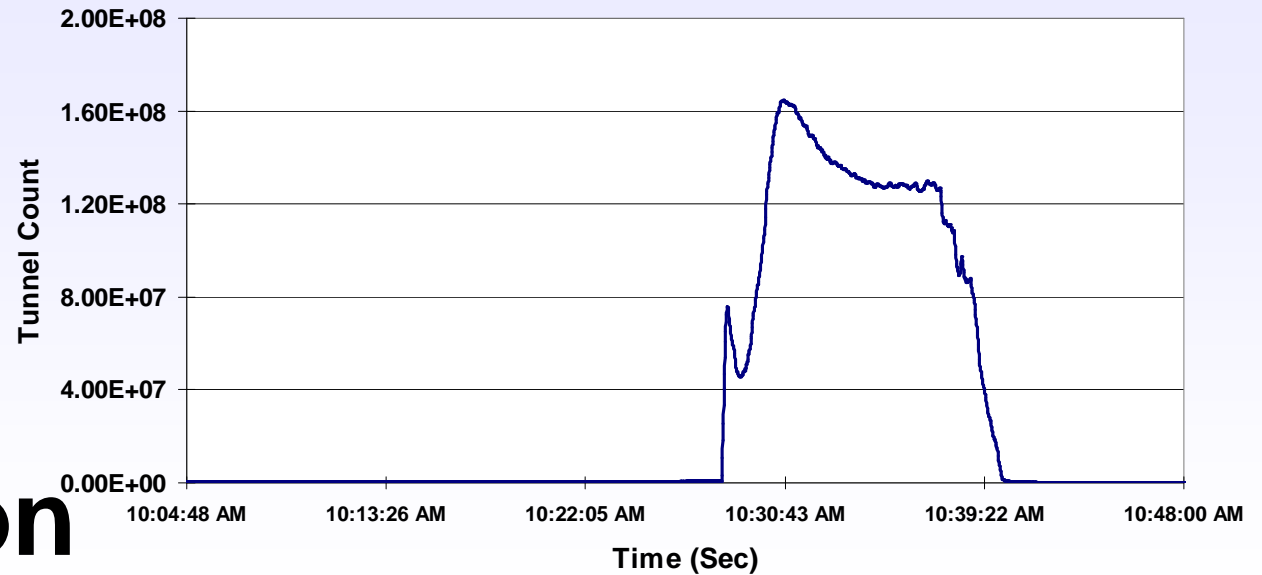


Particle Number Measurement from Horiba SPCS During NEDC Tests

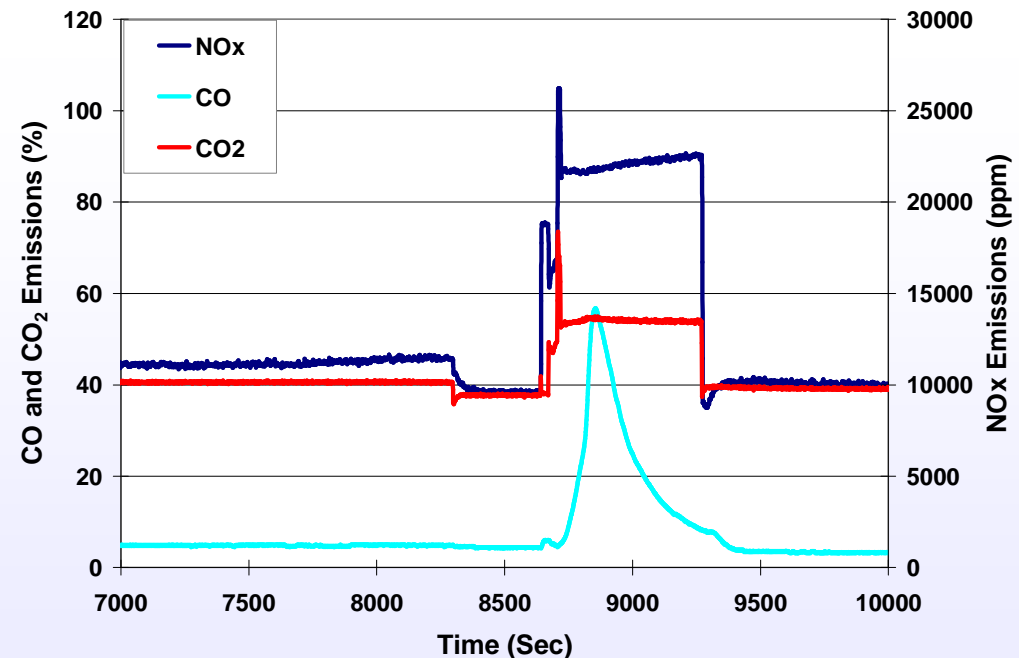


Instrument Comparison





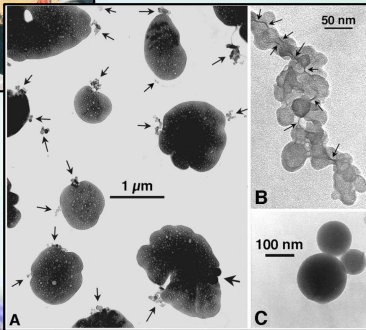
Regeneration achieved as expected



The Role of Aerosols in the Current Climate Picture



*Soot particles (arrows)
coated by ammonium
sulfate*



Global: Change radiative balance (<GHGs)

Regional: Change radiative balance (>>GHGs) & clouds

Soot particles: Most efficient aerosol species at absorbing solar radiation, could be as high as that of methane

Control of fossil-fuel soot (BC+OC) may be the fastest method of slowing global warming for a specific period

climate
CHANGE

Final Remarks

- PMP Protocol well suited for detection of soot aggregate particles in presence of nucleating semivolatiles
- Is adaptable to Heavy Duty applications
- Instrument refinement continuing
- Room for future work: Is PMP all we need?

Future Work

- Broader CARB study of HD PMP underway
 - Chassis testing completed
 - On-road testing in analysis phase
- CARB seeking continued involvement in European HD PMP evaluation
- CARB study of HD vehicle PM toxicity underway
 - Multiple analytical methods, aftertreatment technologies
 - Inform policy debate on volatile vs. solid particles
- Light-duty study of inter-laboratory “Golden Vehicle”
 - Testing completed
 - Findings being written up

California Air Resources Board



Thank you!

Alberto Ayala, Chief

Climate Change Mitigation and Emissions Branch

1001 I Street P.O.Box 2815

Sacramento, CA 95812. USA.

Phone +1 916.327.2952

aayala@arb.ca.gov

www.arb.ca.gov