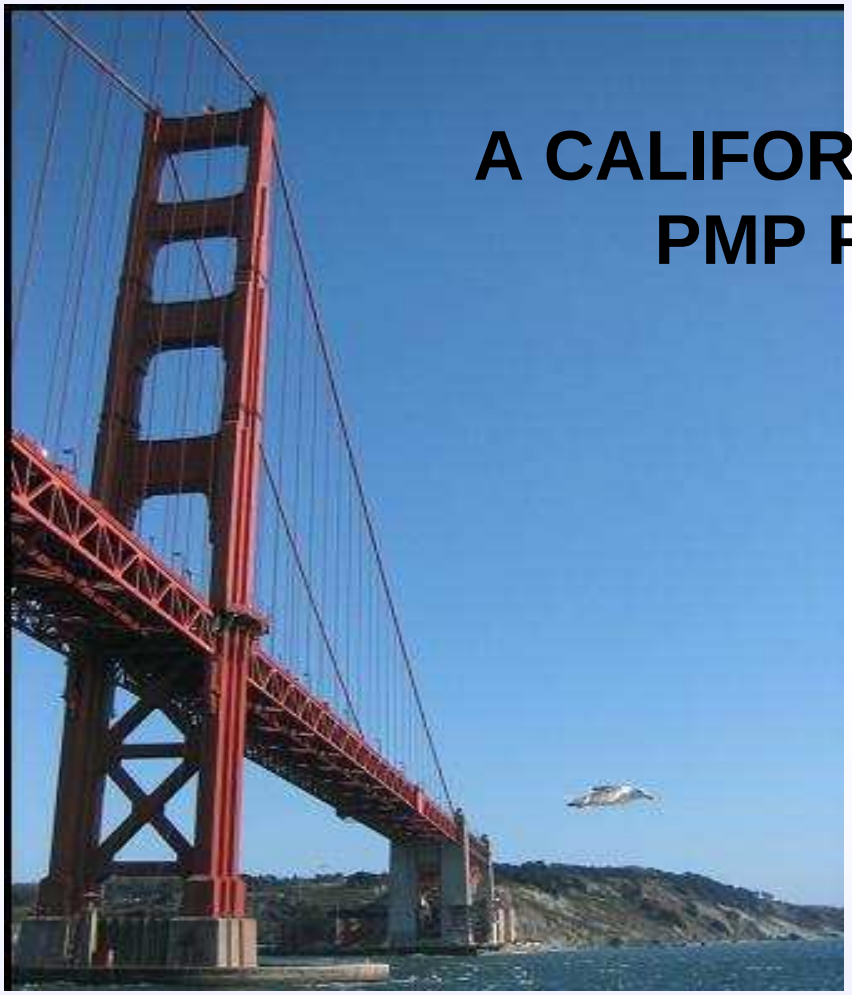
11th ETH International Conference on Combustion Generated Nanoparticles
August 12 –15 2007
Zürich, Switzerland



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

The statements and opinions expressed in this presentation are solely the authors' and do not represent the official position of the California Air Resources Board. The mention of trade names, products, and organizations does not constitute endorsement or recommendation for use.

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- Qiang Wei & Horiba for SPCS loan

HORIBA

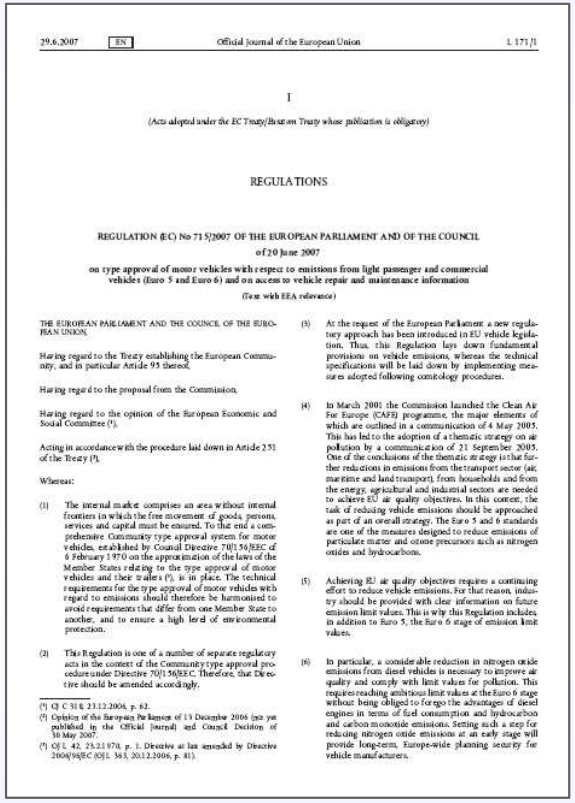
- European Commission, Directorate-General, Joint Research Centre (JRC)

- 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



29.6.2007 EN Official Journal of the European Union L 171/1

I

(Acts adopted under the EC Treaty/Euratom Treaty whose publication is obligatory)

REGULATIONS

REGULATION (EC) No 715/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 20 June 2007
on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information
(Text with EEA relevance)

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty establishing the European Community, and in particular Article 95 thereof,

Having regard to the proposal from the Commission,

Having regard to the opinion of the European Economic and Social Committee (1),

Acting in accordance with the procedure laid down in Article 251 of the Treaty (2),

Whereas:

(1) The internal market comprises an area without internal frontiers in which the free movement of goods, persons, services and capital must be ensured. To that end a comprehensive Community type approval system for motor vehicles, established by Council Directive 70/156/EEC of 6 February 1970 on the approximation of the laws of the Member States relating to the type approval of motor vehicles and their trailers (3), is in place. The technical requirements for the type approval of motor vehicles with regard to emissions should therefore be harmonised to avoid requirements that differ from one Member State to another, and to ensure a high level of environmental protection.

(2) This Regulation is one of a number of separate regulatory acts in the context of the Community type approval procedure under Directive 70/156/EEC. Therefore, that Directive should be amended accordingly.

(3) At the request of the European Parliament, a new regulatory approach has been introduced in EU vehicle legislation. Thus, this Regulation lays down fundamental provisions on vehicle emissions, whereas the technical specifications will be laid down by implementing measures adopted following comitology procedures.

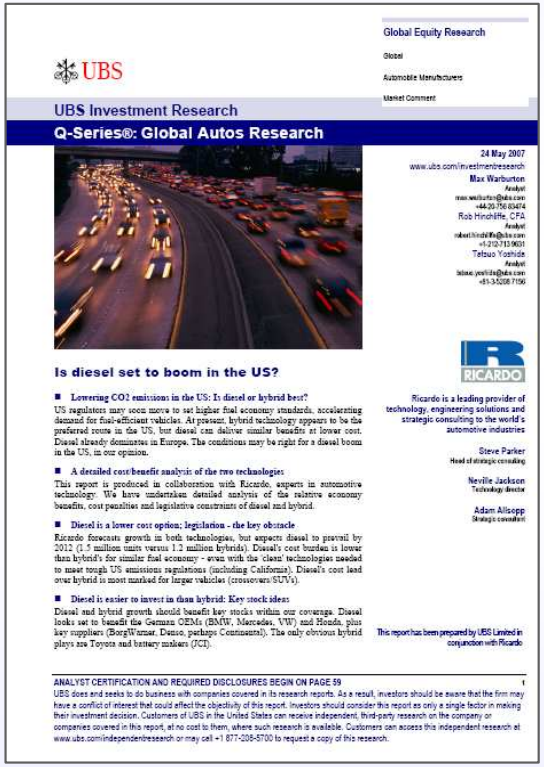
(4) In March 2001 the Commission launched the Clean Air For Europe (CAFE) programme, the major elements of which are outlined in a communication of 4 May 2005. This has led to the adoption of a thematic strategy on air pollution by a communication of 21 September 2005. One of the conclusions of the thematic strategy is that further reductions in emissions from the transport sector (air, maritime and land transport), from households and from the energy, agricultural and industrial sectors are needed to achieve EU air quality objectives. In this context, the task of reducing vehicle emissions should be approached as part of an overall strategy. The Euro 5 and 6 standards are one of the measures designed to reduce emissions of particulate matter and ozone precursors such as nitrogen oxides and hydrocarbons.

(5) Achieving EU air quality objectives requires a continuing effort to reduce vehicle emissions. For that reason, industry should be provided with clear information on future emission limit values. This is why this Regulation includes, in addition to Euro 5, the Euro 6 stage of emission limit values.

(6) In particular, a considerable reduction in nitrogen oxide emissions from diesel vehicles is necessary to improve air quality and comply with limit values for pollution. This requires reaching ambitious limit values at the Euro 6 stage without being obliged to forego the advantages of diesel engines in terms of fuel consumption and hydrocarbon and carbon monoxide emissions. Setting such a step for reducing nitrogen oxide emissions at an early stage will provide long-term, Europe-wide planning security for vehicle manufacturers.

(1) OJ C 318, 23.12.2006, p. 62.
(2) Opinion of the European Parliament of 13 December 2006 (not yet published in the Official Journal) and Council Decision of 30 May 2007.
(3) OJ L 42, 23.2.1970, p. 1. Directive as last amended by Directive 2006/96/EC (OJ L 363, 20.12.2006, p. 81).

In California, diesel "means" heady-duty vehicles, but light-duty ones are coming



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Global
Automobile Manufacturers
Market Comment

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Max Warburton
Analyst
+44-20-7568-8474

Rob Hinchliffe, CFA
Analyst
+1-212-713-9031

Tetsuo Yoshida
Analyst
+81-3-5208-7156

Is diesel set to boom in the US?

RICARDO

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

Steve Parker
Head of strategic consulting

Neville Jackson
Technology director

Adam Allsopp
Strategic consultant

■ 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 benefits, 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 (1.7 million units versus 1.2 million hybrids). Diesel's cost burden is lower than hybrid's for similar fuel economy - even with the 'clean' 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, perhaps Continental). The only obvious hybrid plays are Toyota and battery makers (JCI).

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

ANALYST CERTIFICATION AND REQUIRED DISCLOSURES BEGIN ON PAGE 59

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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

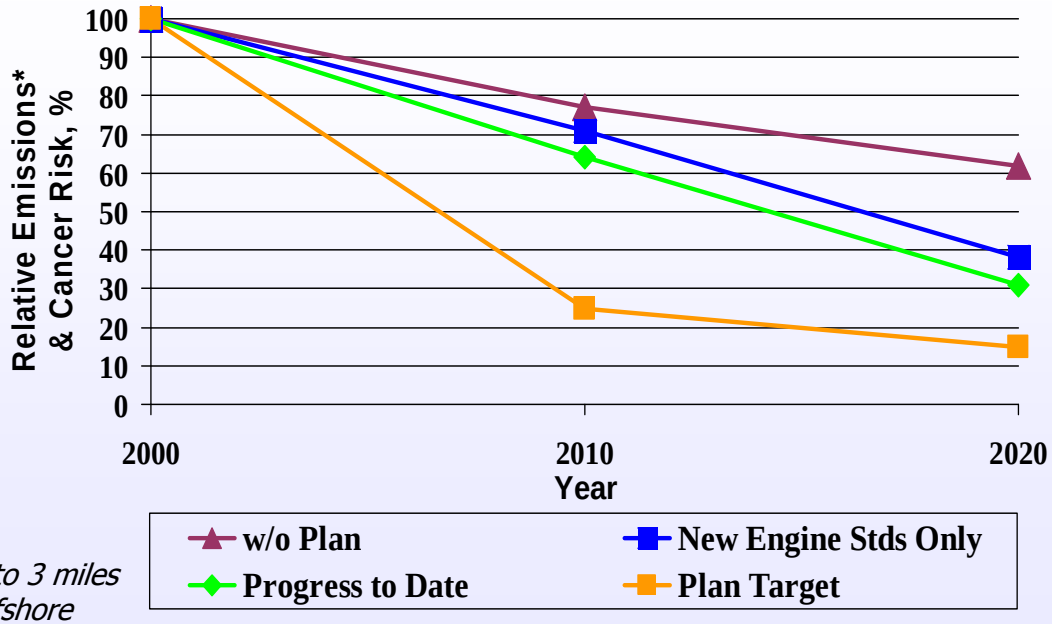
Stronger compliance programs

ensure in-use emissions maintained

In-use Emission Reductions

Clean up existing vehicles

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

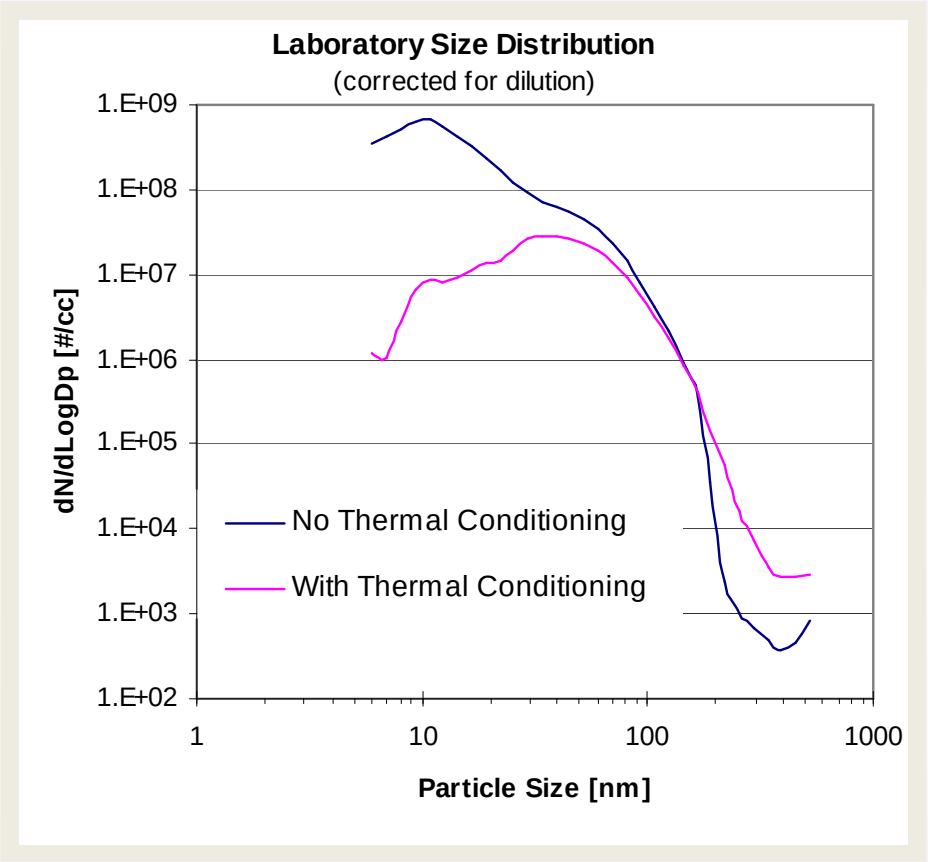


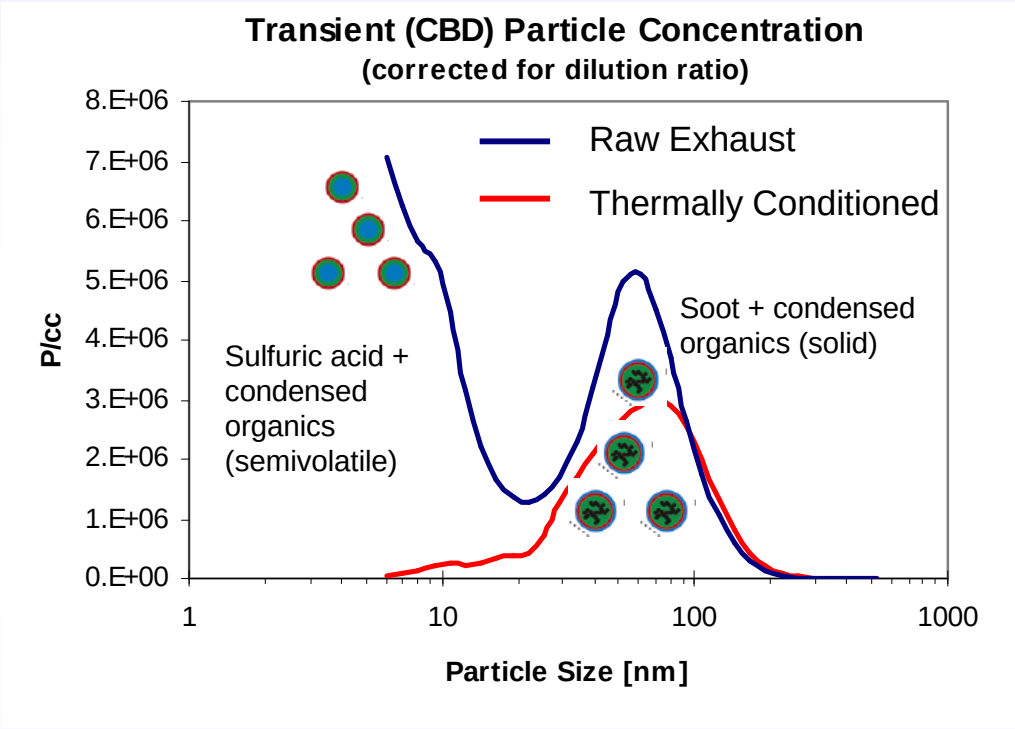
** to 3 miles offshore*

- 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)



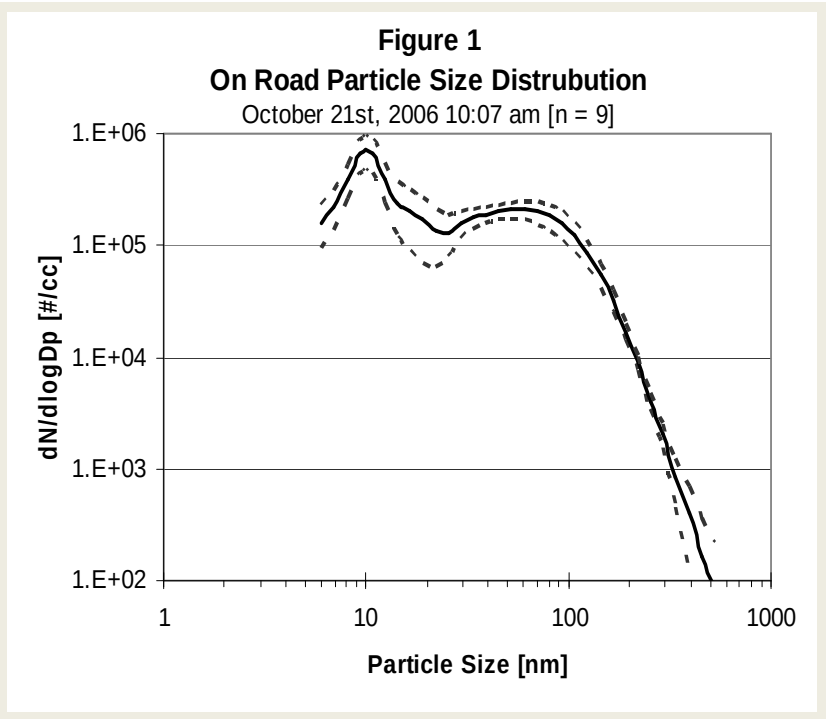


Within the ultrafine range, two modes exist in diesel emissions

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

Herner, Robertson, and Ayala, AAAR, Sept.2006

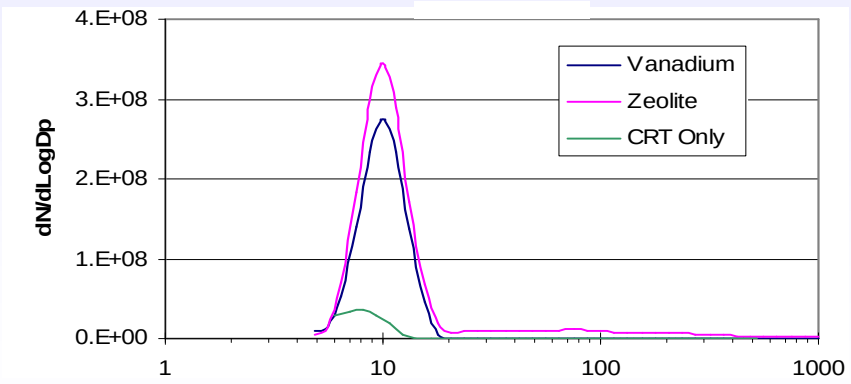
Effect of Heavy Duty Diesel Trucks

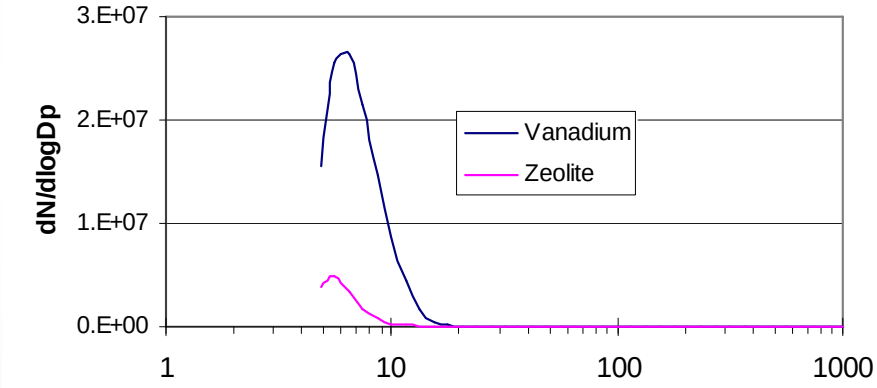


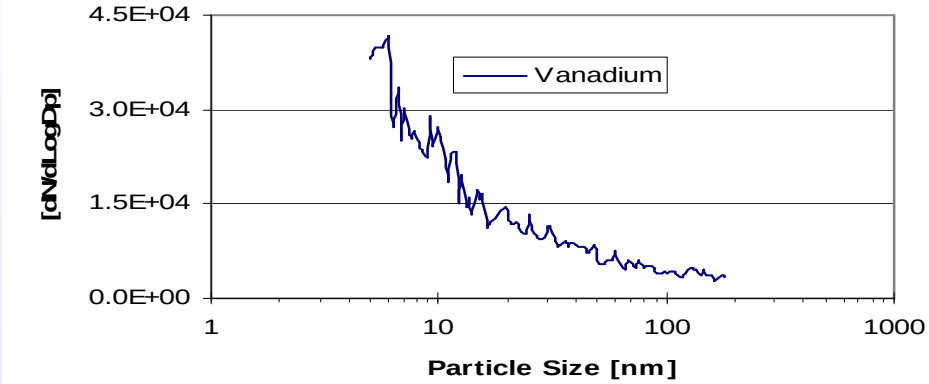
Kozawa et al. 2007, CRC, March 2007

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

Herner, Robertson, Ayala, and Sioutas, ETH, 2007.

California PMP

Heavy-Duty Vehicle Testing

Chassis dynamometer

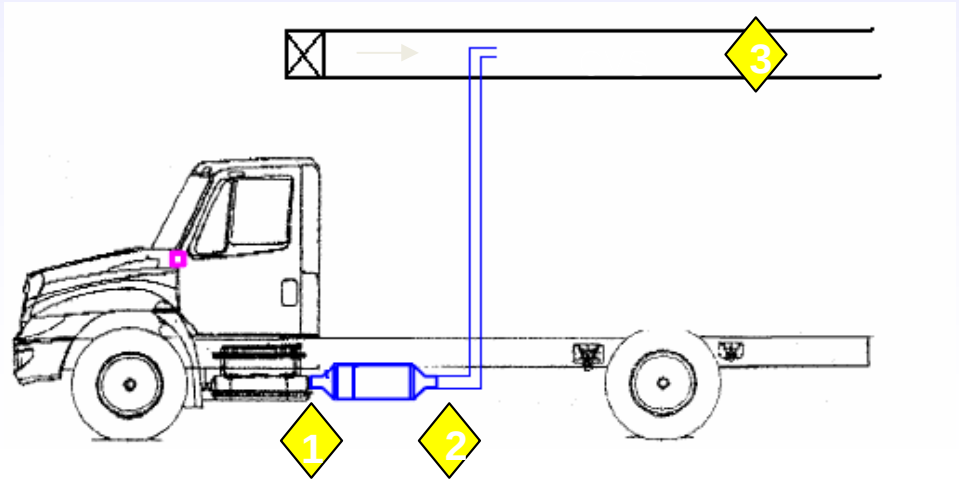
Over-the-road

UCR-CECERT-Mobile Emissions Laboratory

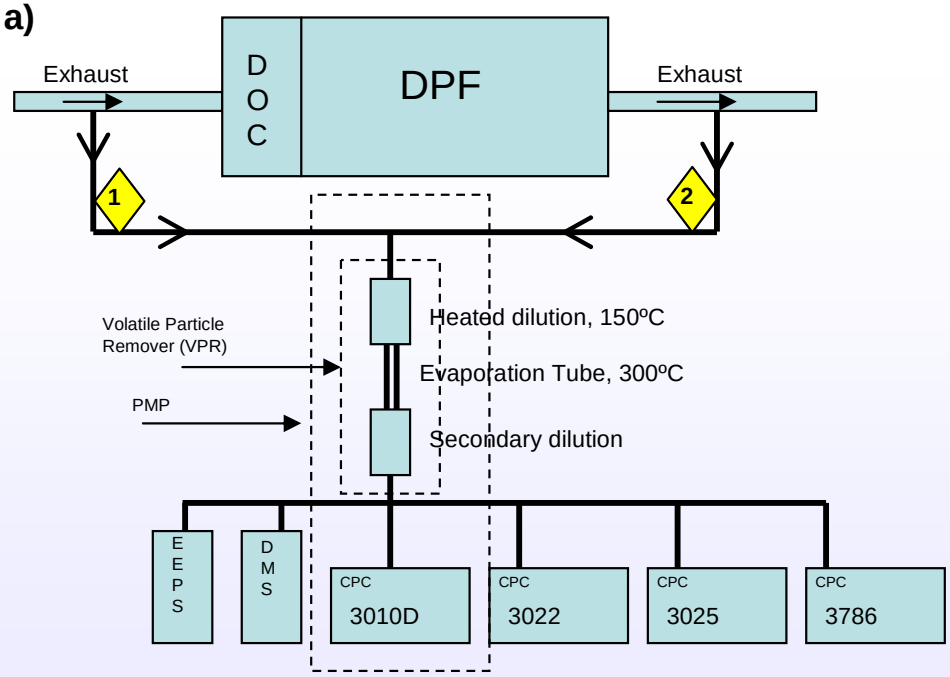
Light-Duty Vehicle Testing

Golden Vehicle

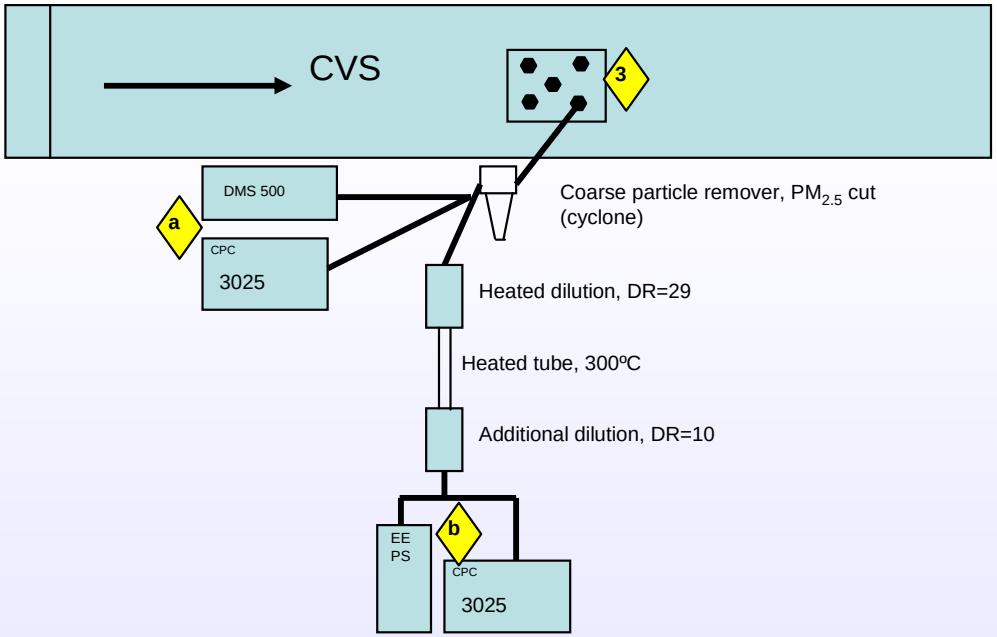
Experimental Setup for Heavy-duty Vehicle Experiments



a)

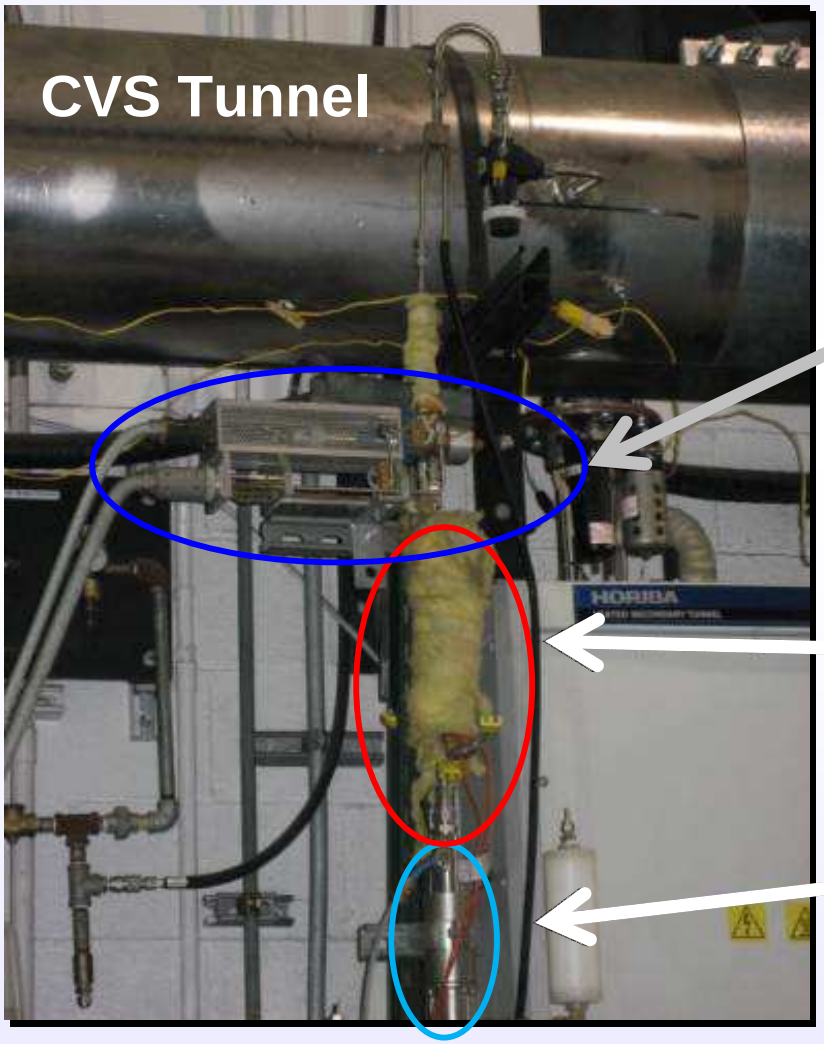


b)



Herner, Robertson, and Ayala, SAE Tech. Paper 2007-01-1114

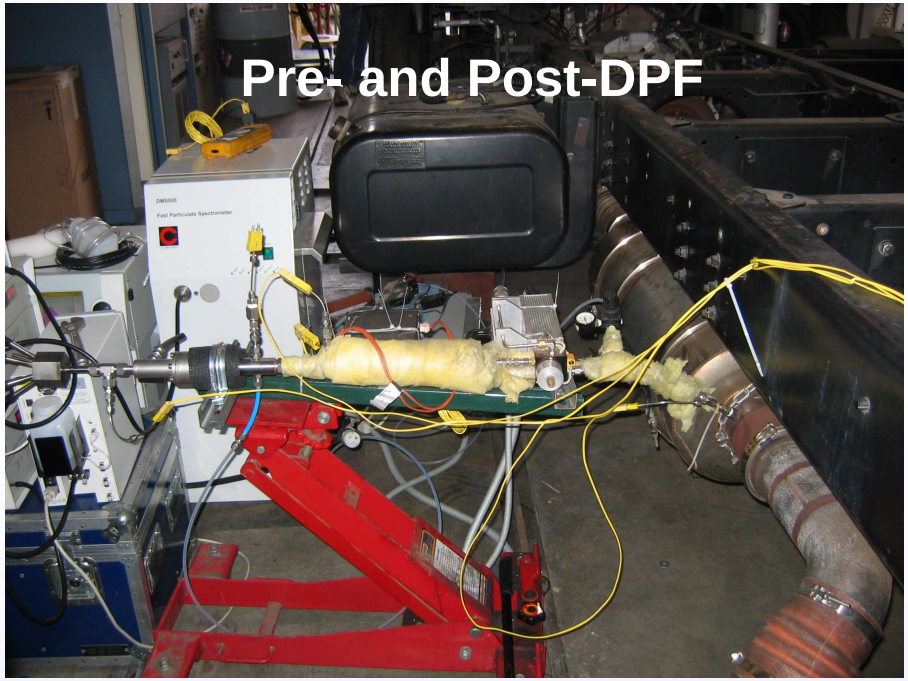
PMP implementation @ chassis dynamometer lab



Primary Diluter
High Ratio Rotating Disk

Evaporation Tube

Secondary Diluter
9:1 Ejector



Instrumentation

Particle Counters

TSI 3786
2.5nm

TSI 3025A
3nm

TSI EEPS, 5.6nm

TSI 3022A
7nm

TSI 3010D
23nm

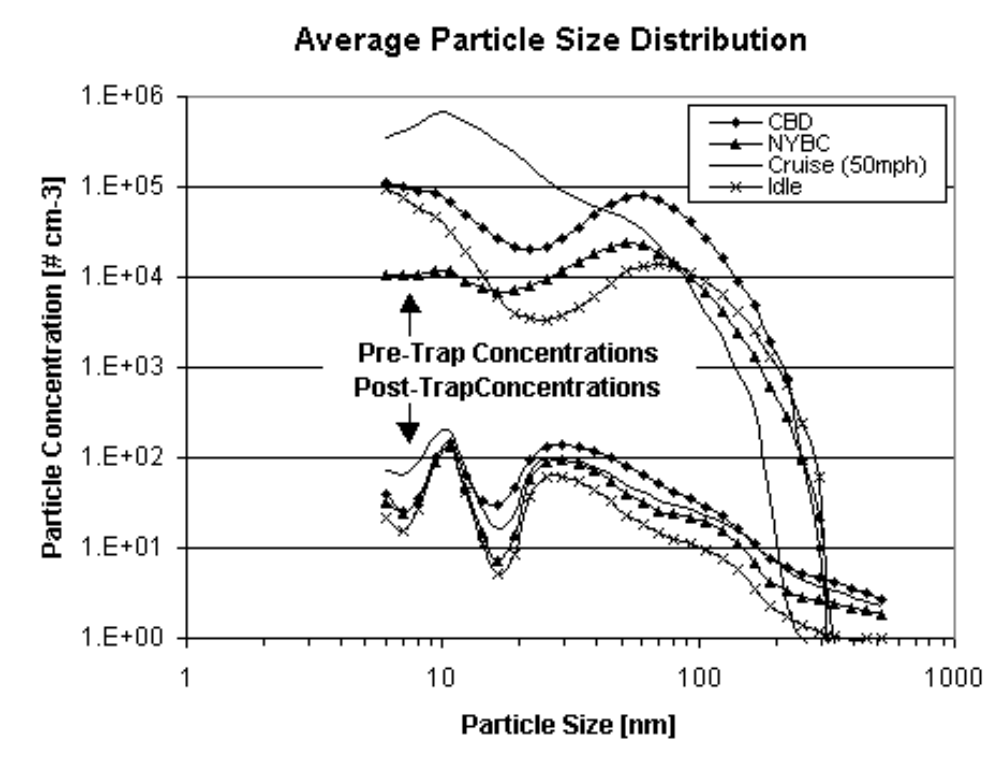
Cambustion DMS-500
5.6 nm

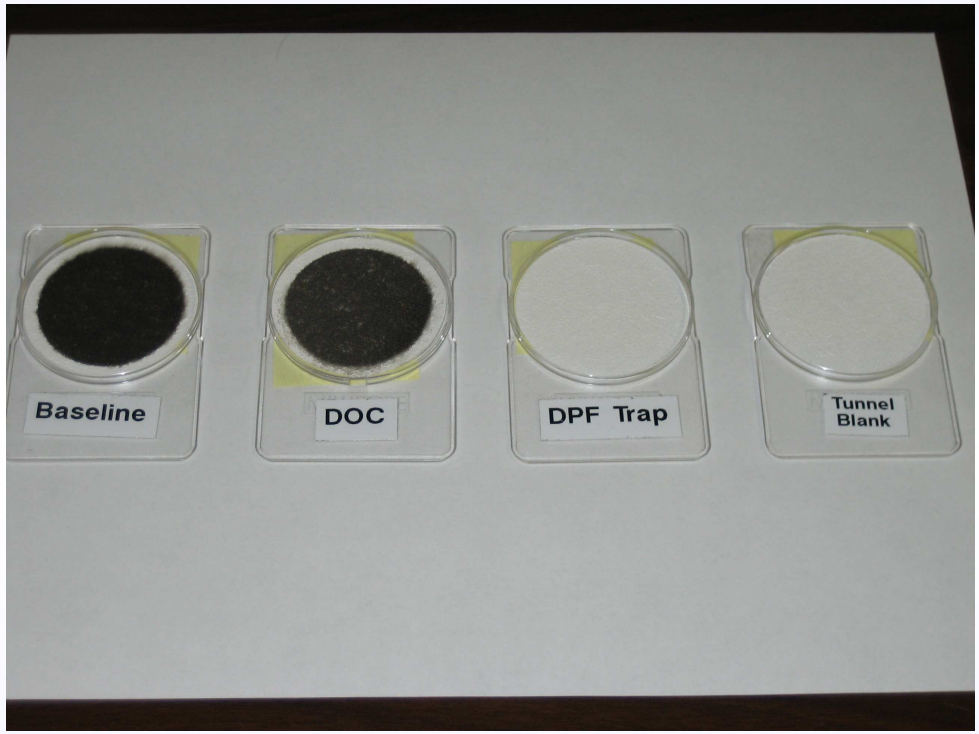
Diluters

Matter Engineering MD-19

Dekati DI 1000

DPF PM reduction effectiveness is confirmed

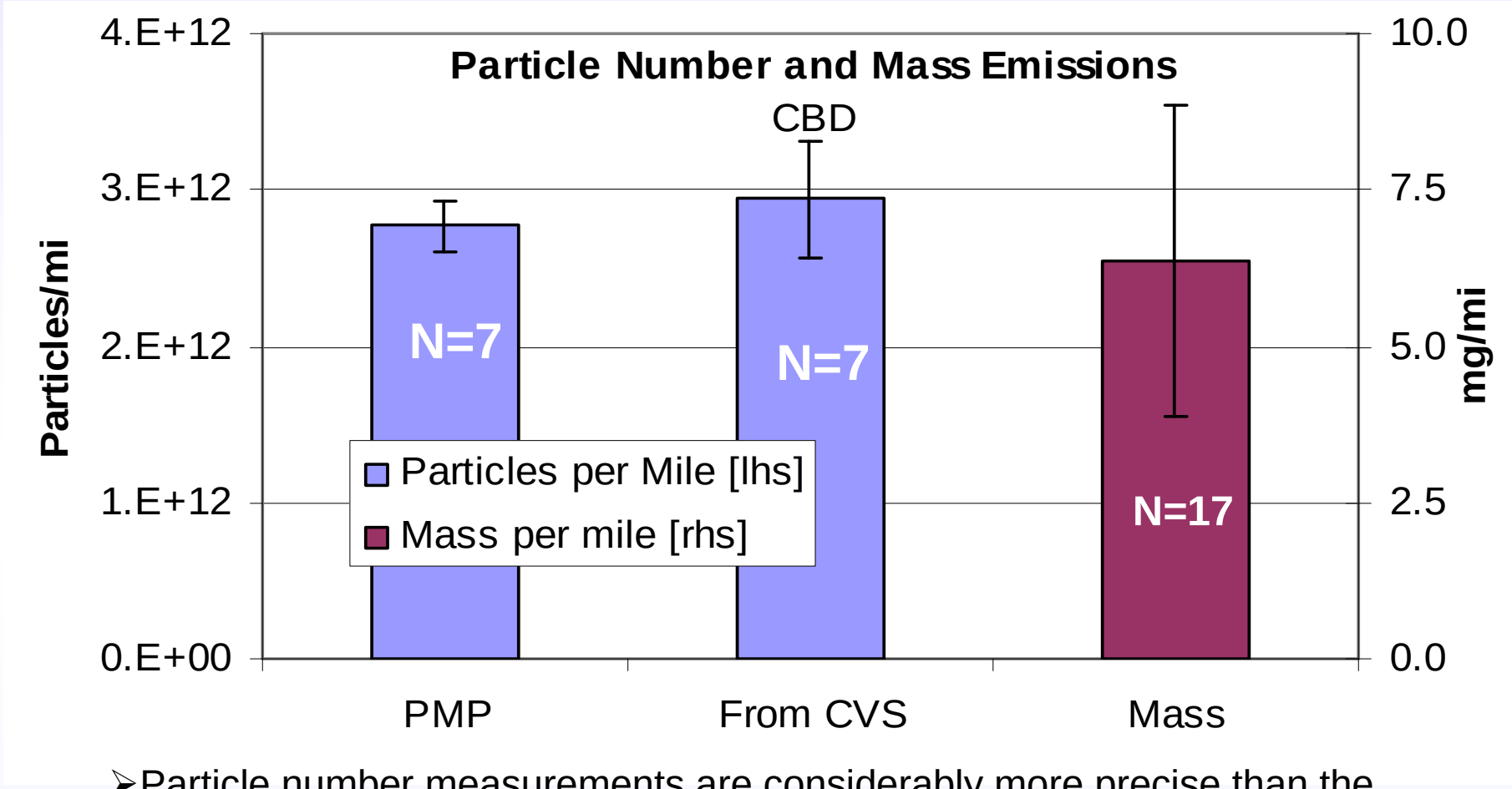




Average particle concentration measured with the EEPS pre and post trap for CBD, NYBC, Cruise and Idle. The trap effectively reduces total particle concentration by approximately 100 X. *No DR correction.*

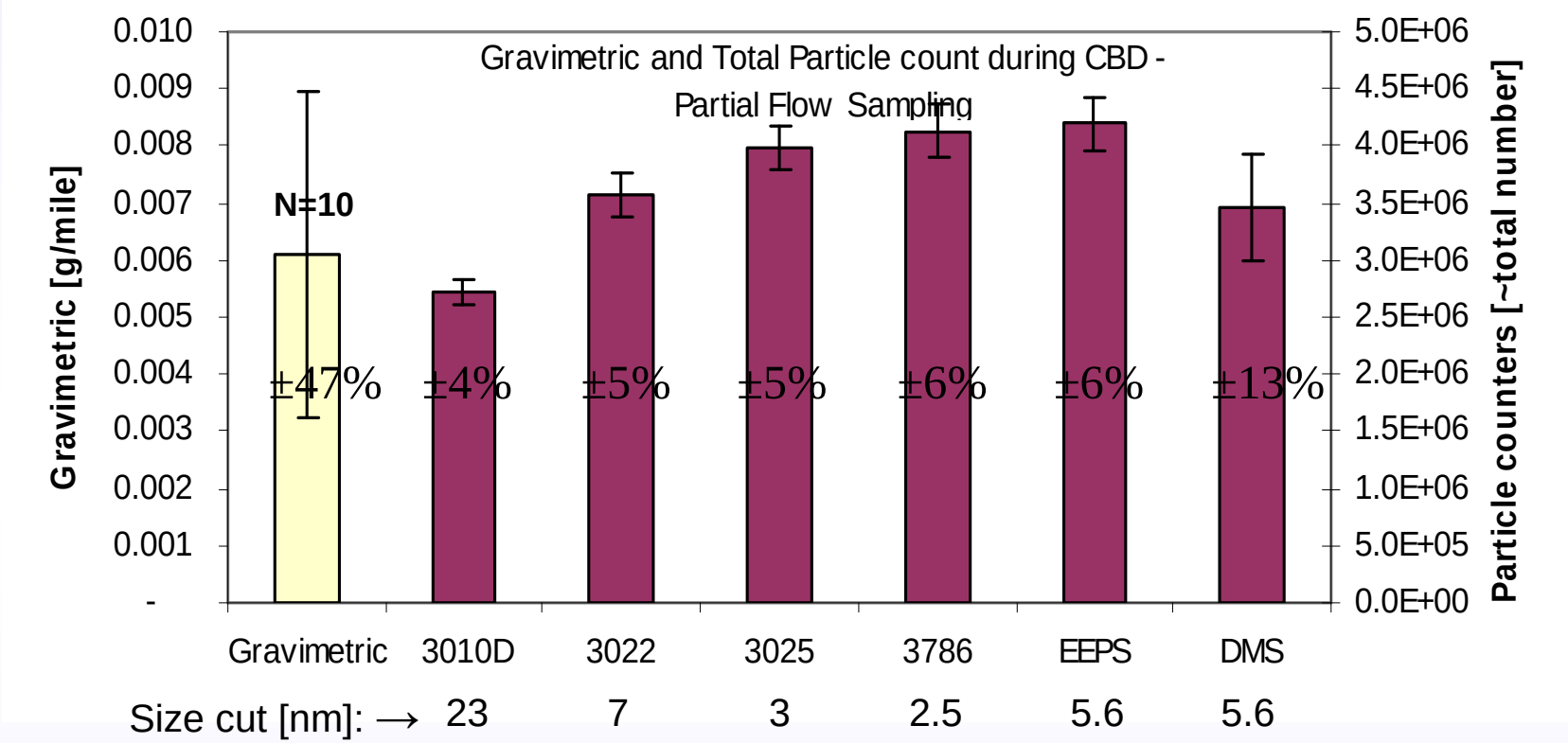
Ayala and Herner, *J. of Lubricants and Fuels*, SAE Transactions, 2005 (Also SAE Technical Paper 2005-01-3800)

Emission Measurement Comparison



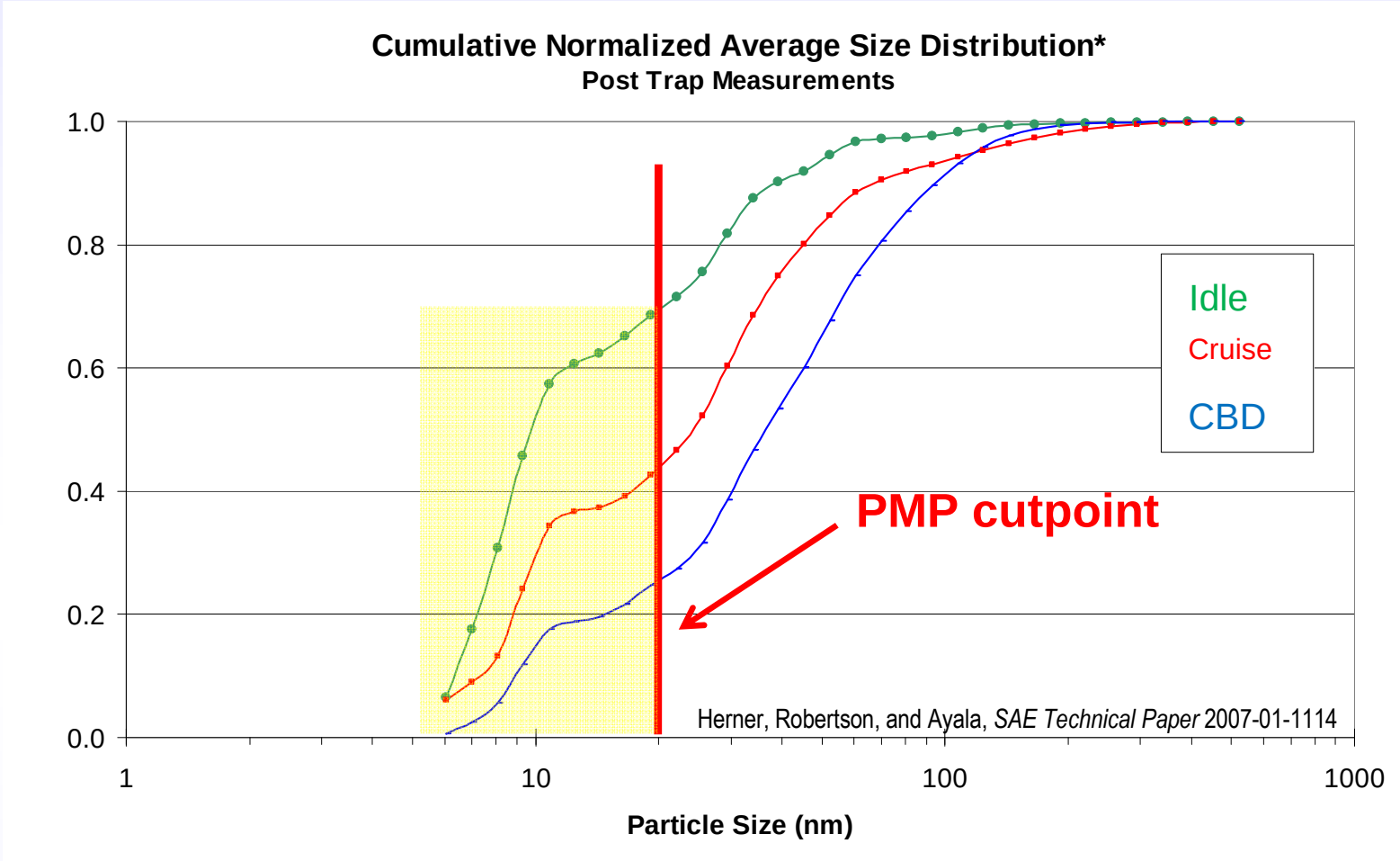
- Particle number measurements are considerably more precise than the mass measurement in the current study.
- Upcoming improvements in gravimetric measurements at CARB labs are expected to get closer to new US07 1065 Rule.

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.

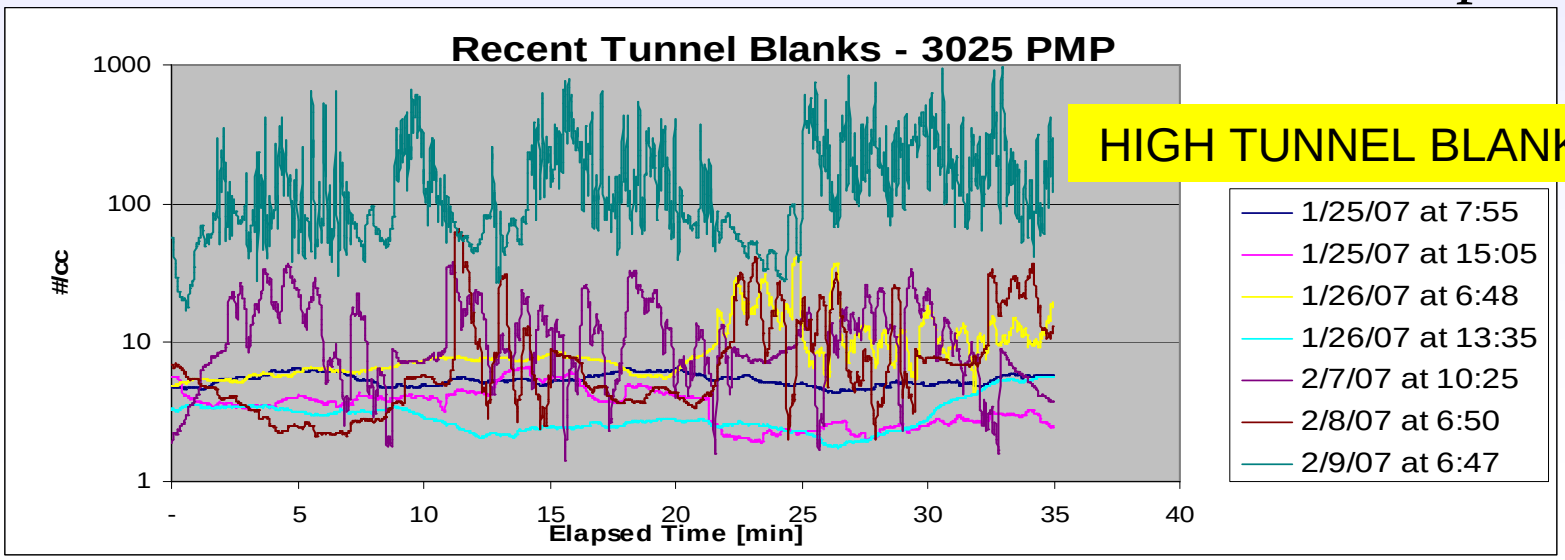
Herner, Robertson, and Ayala, *SAE Technical Paper* 2007-01-1114



- 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 ware 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

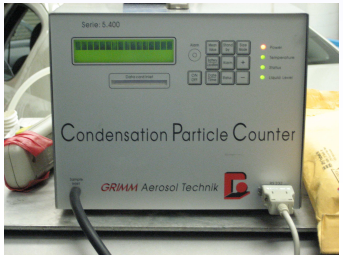
3) FTIR for NH3, N2O, NO2

Golden Vehicle Testing - Instrumentation

Particle Counters

TSI 3790

TSI 3010D



Grimm CPC

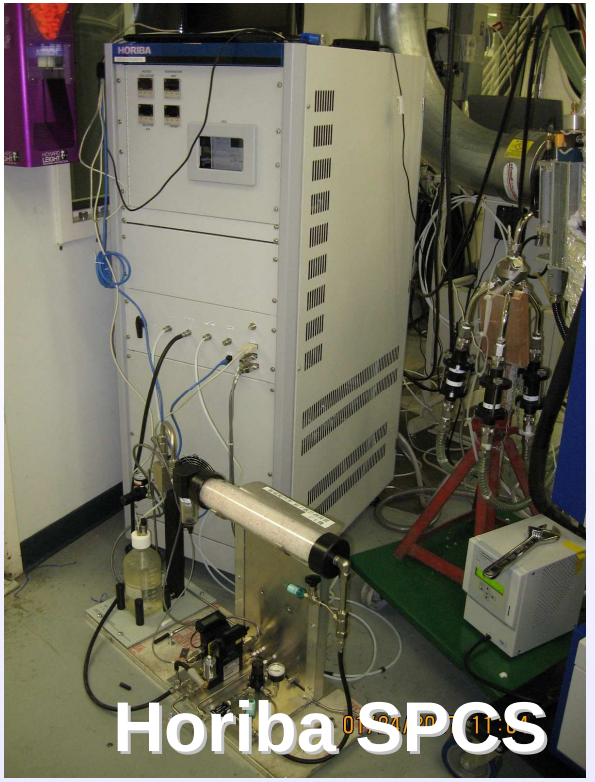
TSI EEPS

EcoChem PAS2000

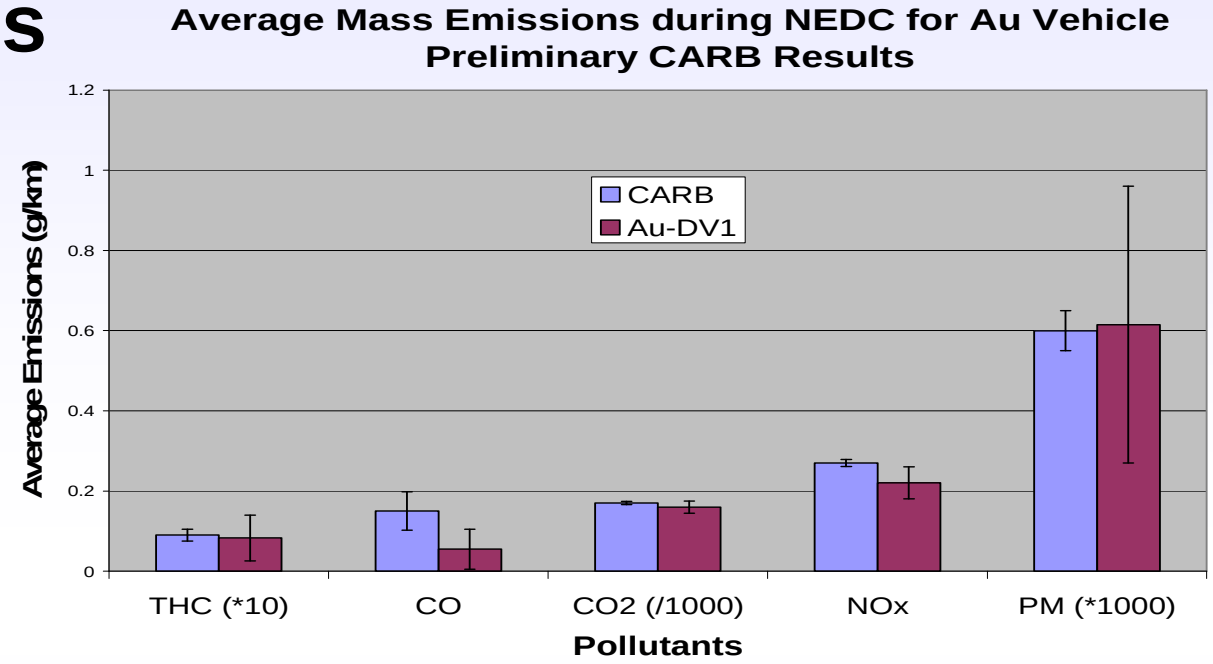
Matter Engineering LQ1-DC

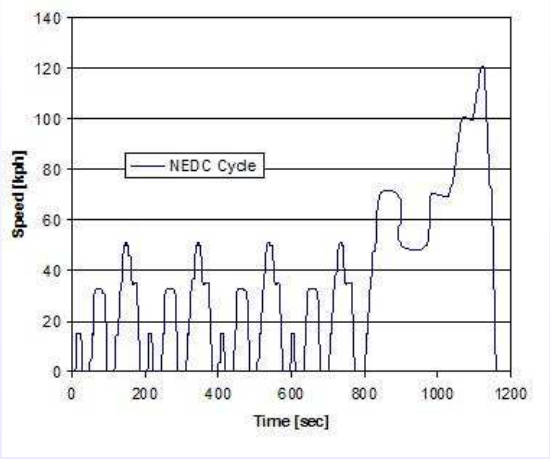
Diluter

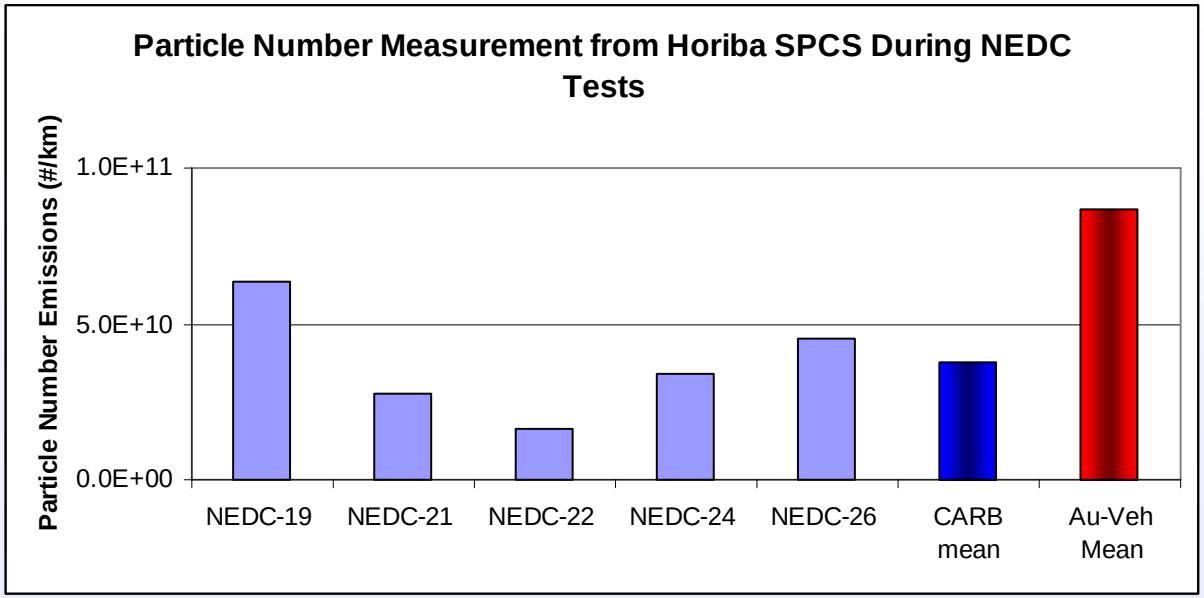
Matter Engineering MD-19



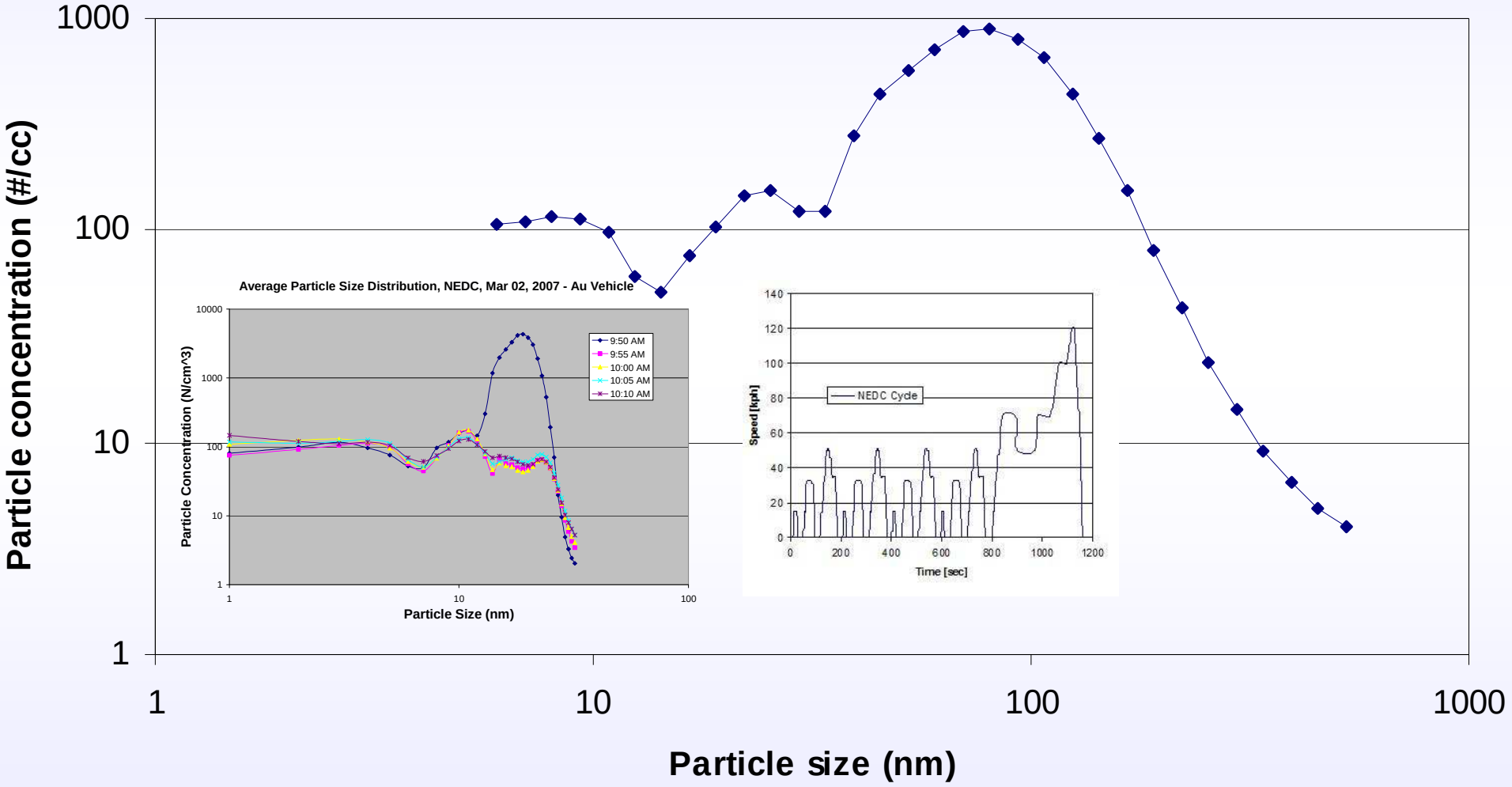
Comparison of Emissions Results for CARB lab and PMP labs





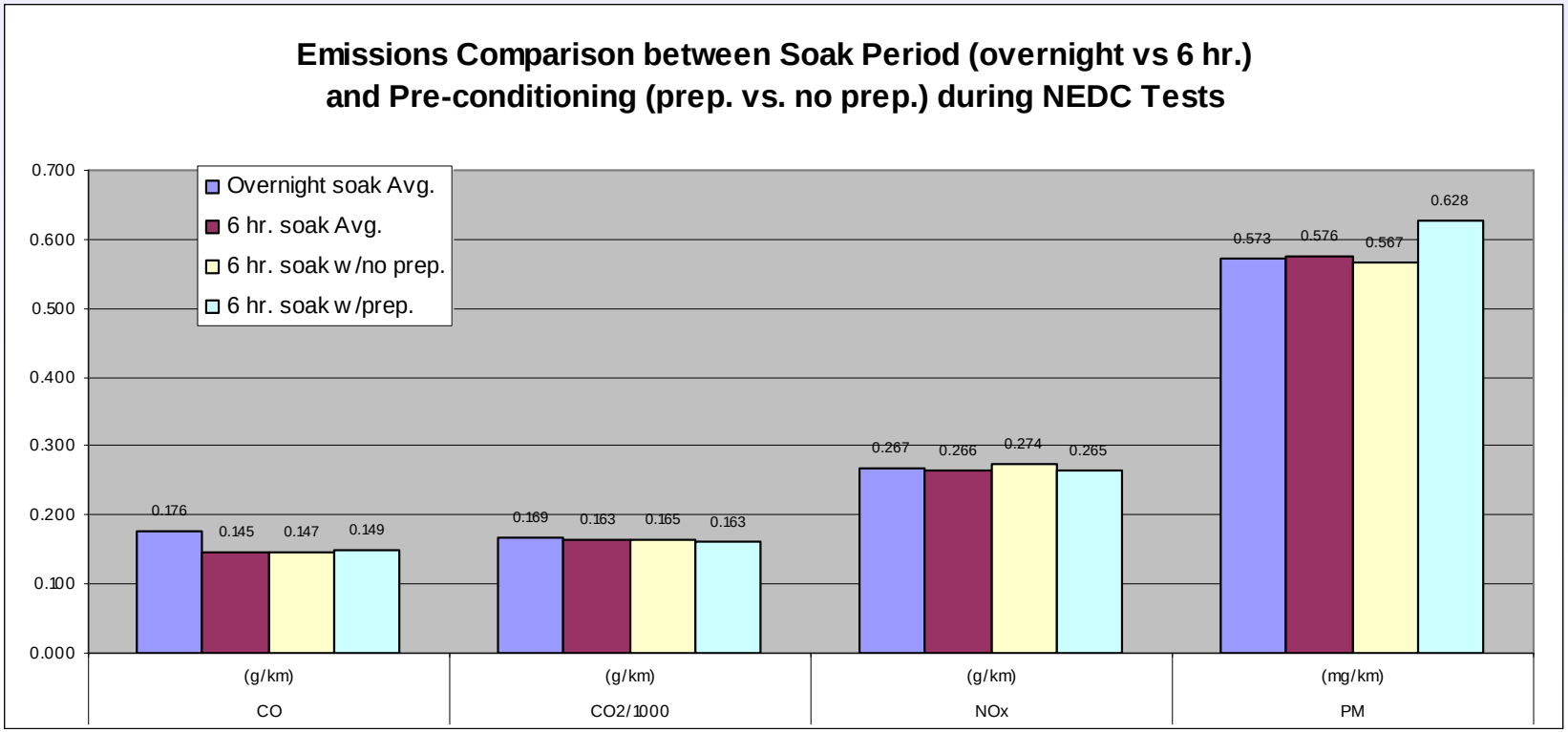


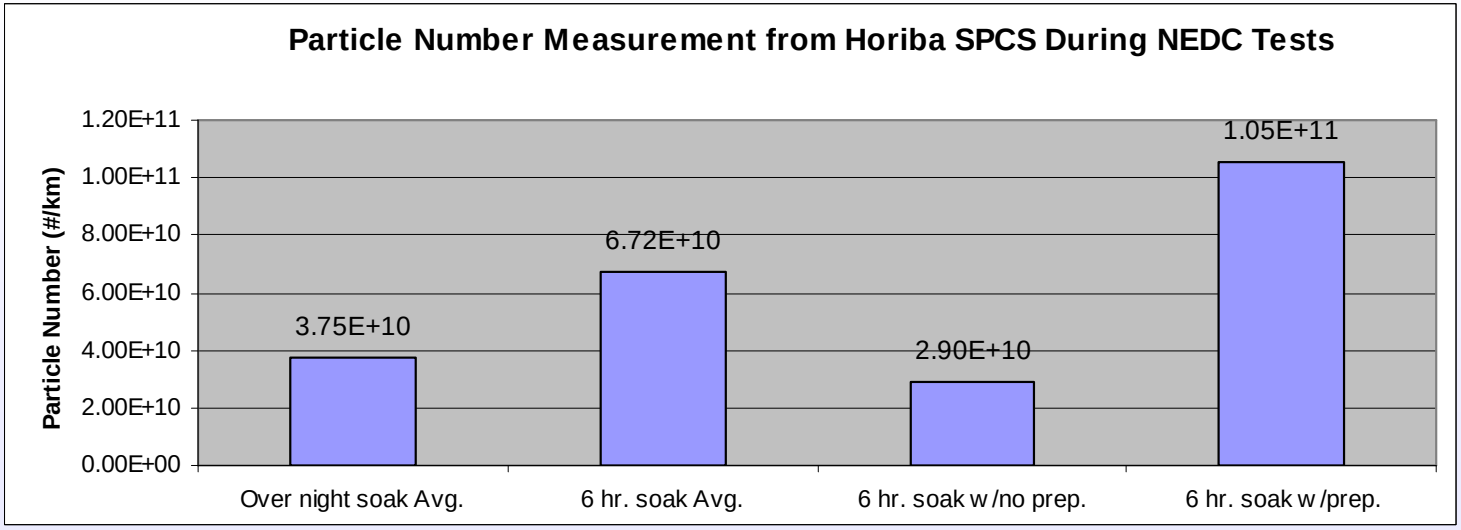
Particle Size Distribution (1-NEDC-10, 02MAR07)*
Au Vehicle



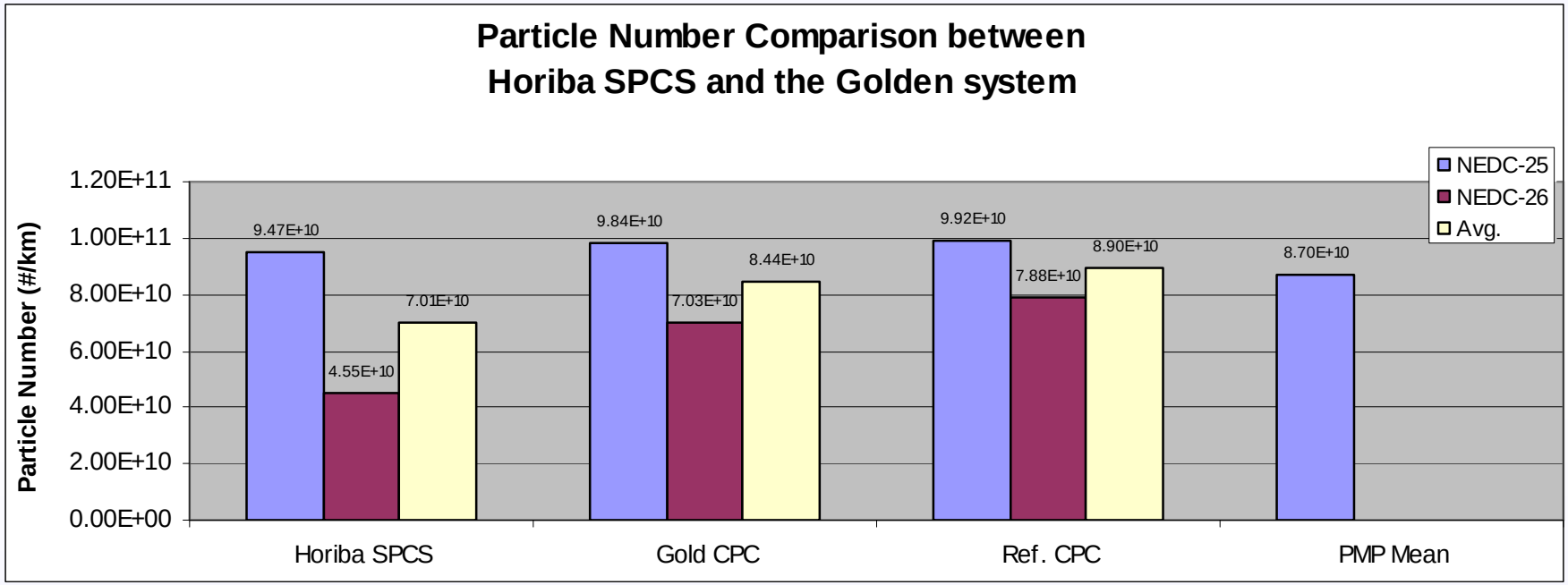
*EEPS average over entire NEDC. EEPS post-cyclone, pre-PND1

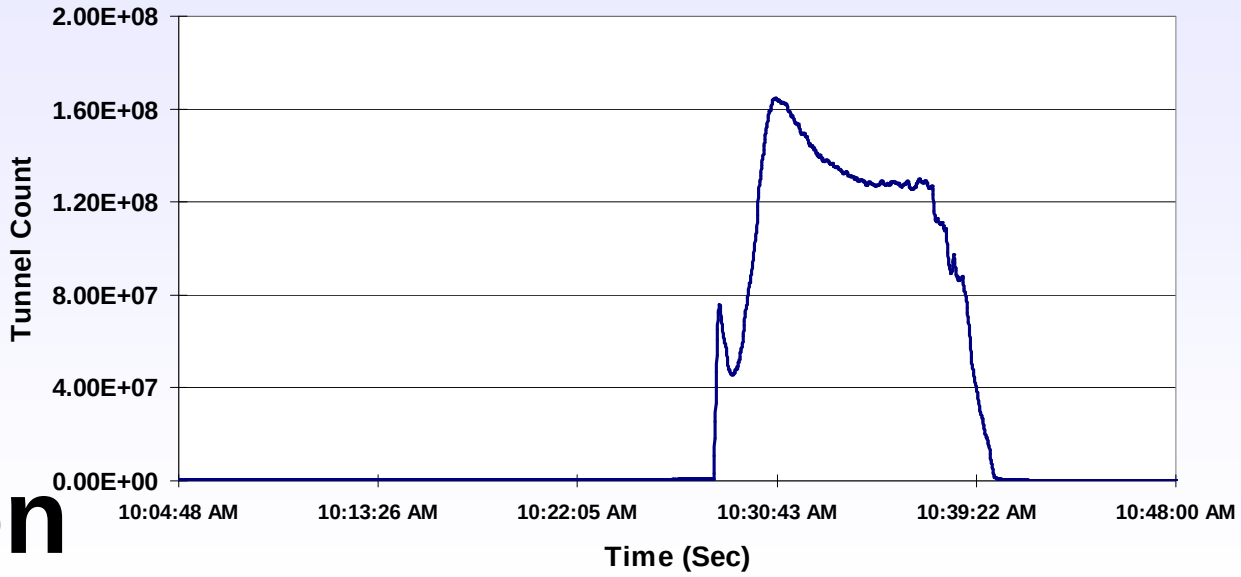
Pre-conditioning effects



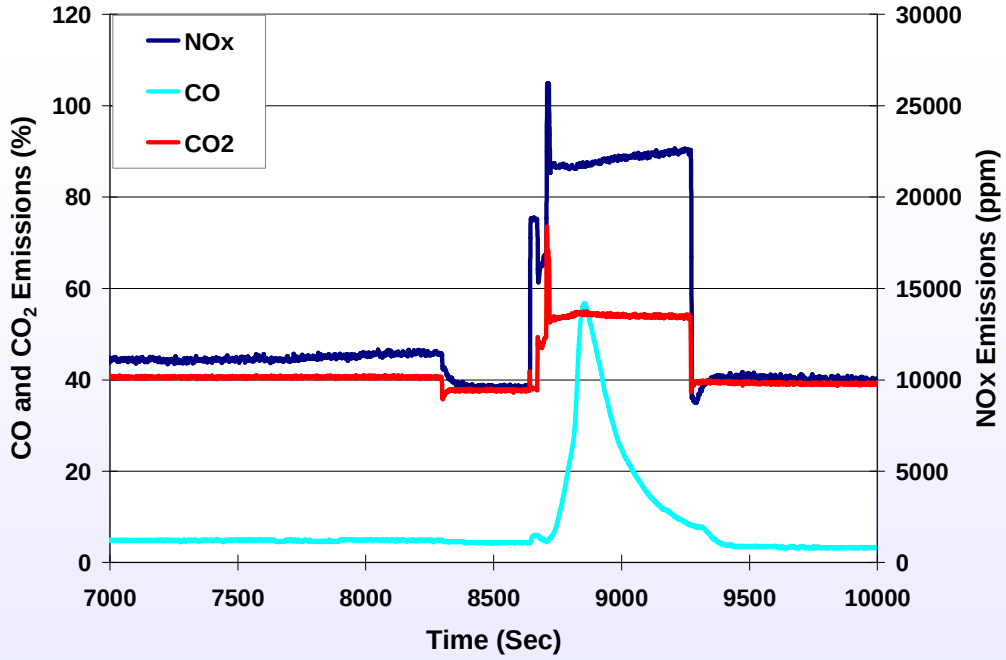


Instrument Comparison

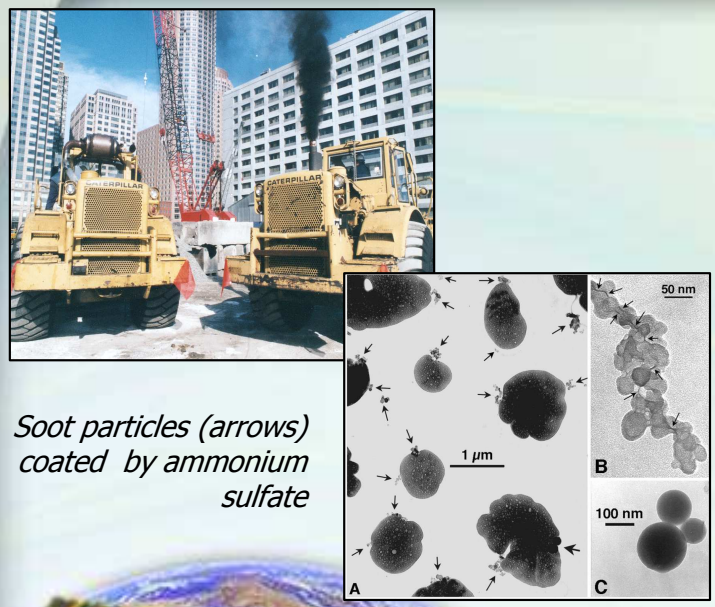




Regeneration achieved as expected



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

California Environmental Protection Agency
AIR RESOURCES BOARD

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