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Oxidation Catalyst Effects on Natural Gas Transit Bus Ultrafine Particle Emissions

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* The statements and opinions expressed in this paper 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.

ABSTRACT

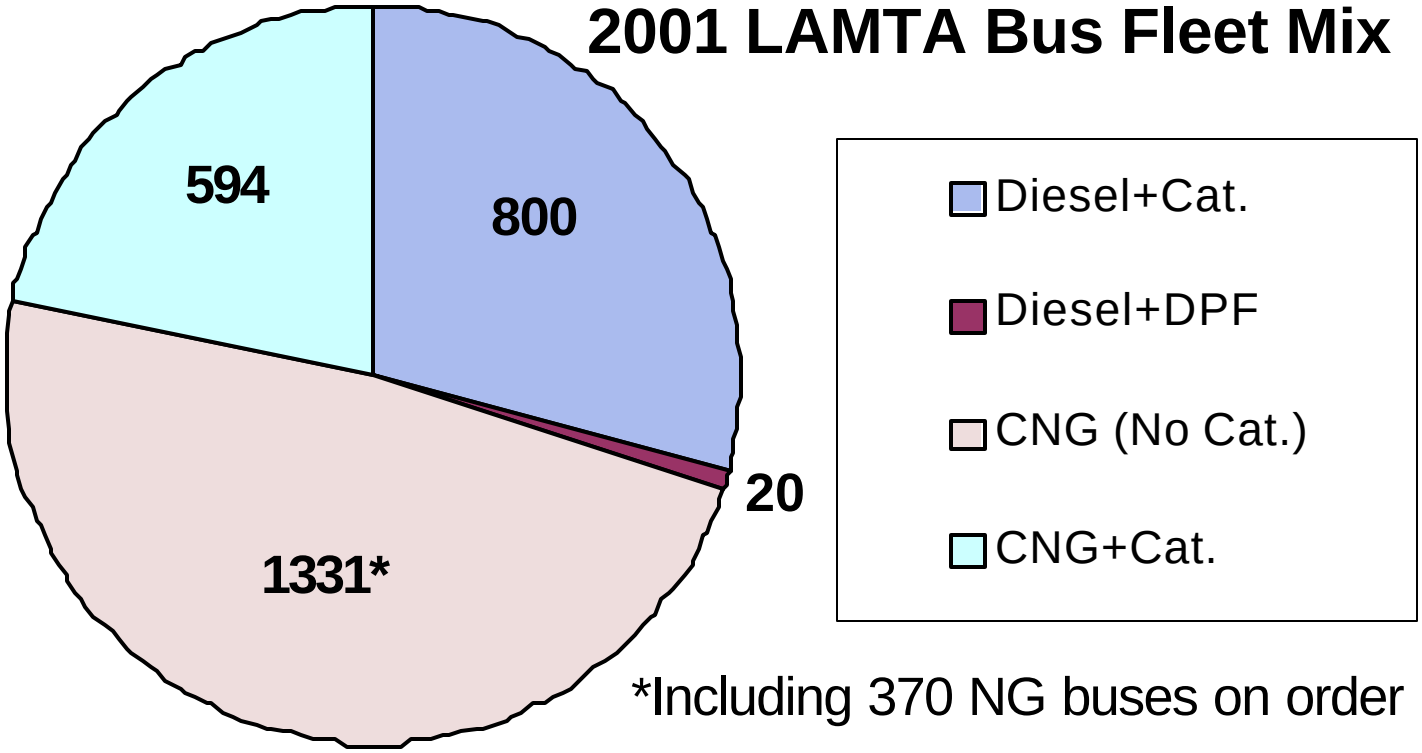
The majority (69%) of the compressed natural gas (CNG) transit buses operating in the Los Angeles, CA metropolitan area currently operate without oxidation catalysts. A series of laboratory chassis dynamometer tests was conducted to compare ultrafine (< 100 nm) particle emissions emitted by a CNG transit bus with and without an oxidation catalyst. Particle number distributions were measured with a TSI model 3936 Scanning Mobility Particle Sizer (SMPS) with a long DMA and ultrafine CPC and samples were collected simultaneously under two dilution conditions – a one-stage mini-dilution of raw exhaust and an EPA-approved constant volume sampler (CVS). Average idle mode ultrafine total particle emissions from the CNG bus were 40 – 180 times lower than a baseline diesel bus operating on ultra-low sulfur fuel and agreed within a factor of 2 under both dilution conditions. In contrast, during 55 MPH steady-state driving, the CNG vehicle number emissions were 20 times higher when measured in the CVS tunnel compared to the mini-diluter. Surprisingly, this relationship was unchanged by addition of an oxidation catalyst to the CNG vehicle. While the results of this study suggest CNG vehicles may emit significantly higher nanoparticle concentrations than trap-equipped diesel buses, the source of these particles has not been fully identified. It is suspected that oil composition and consumption rate may play a role and further investigation of more vehicles is warranted both in the laboratory and on the road.

Overview

- ARB's Transit Bus Emissions Study 2001
  - Preliminary findings published, accepted, or in draft
    - http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm
  - "snap-shot" of fleet: "toxicity" comparison
  - two late-model, similar-engine, in-use Los Angeles transit buses:
    - Diesel +/- DPF
    - CNG (no Oxidation Catalyst)
  - Steady-state and Transient cycles (CBD, NYB, UDDS)

- CNG +/- Oxidation Catalyst May 2002
- SMPS Particle Size Distributions
  - Idle and 55 mph Steady-State

LA Transit Bus Fleet (Nov. ’01)



Cat = oxidation catalyst

DPF = diesel particulate filter

2001 Test Vehicles

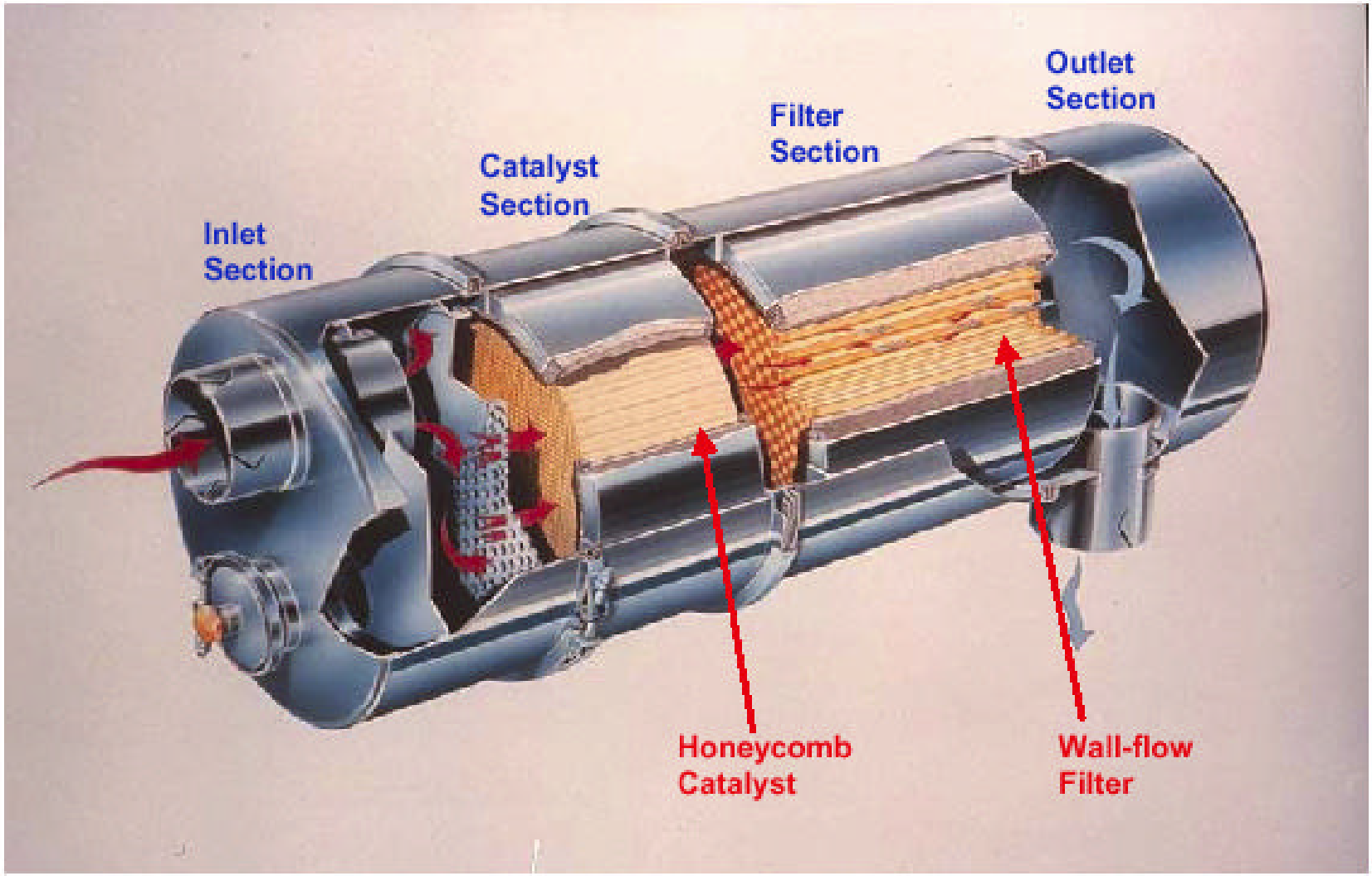
	Natural Gas** "CNG"	Baseline Diesel*** "diesel OEM"	Trap Diesel*** "CRT"
Fuel:	Compressed natural gas	Ultra-low sulfur BP/ARCO ECD-1	Ultra-low sulfur BP/ARCO ECD-1
Mileage at start:	19,629	15,169	15,569
MTA Bus#*	5300	3007	3007
Type & Weight	New Flyer Transit 33,150 lbs	New Flyer Transit 30,510 lbs	New Flyer Transit 30,510 lbs
Model Year:	2000	1998	1998
Engine Manufacturer:	Detroit Diesel	Detroit Diesel	Detroit Diesel
Engine Model:	Series 50G	Series 50	Series 50
Displacement/Type:	8.5L/4 cyl/4 stroke	8.5L/4 cyl/4 stroke	8.5L/4 cyl/4 stroke
After-treatment	None	Catalyzed muffler	Johnson-Matthey Continuously Regenerating Trap (CRT™)

* Buses from Los Angeles County Metropolitan Transit Authority fleet

** The CNG bus was re-tested after an additional two months (~1500 miles) of fleet use ("CNG retest").

*** Baseline diesel and trap diesel were the same vehicle.

CRT® Particulate Filter

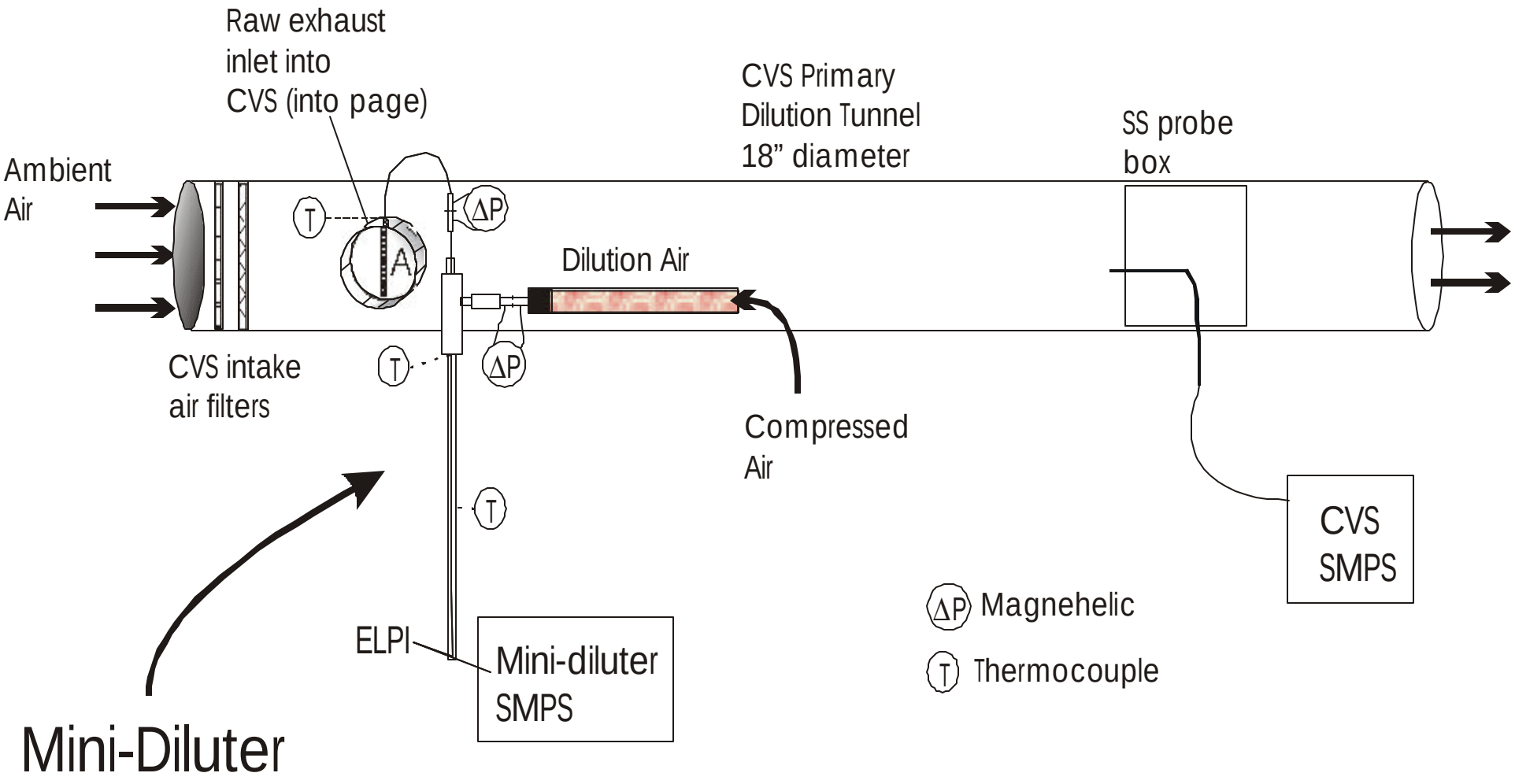


Unique Patented Johnson Matthey System

J-M Continuously Regenerating Technology (CRT®)

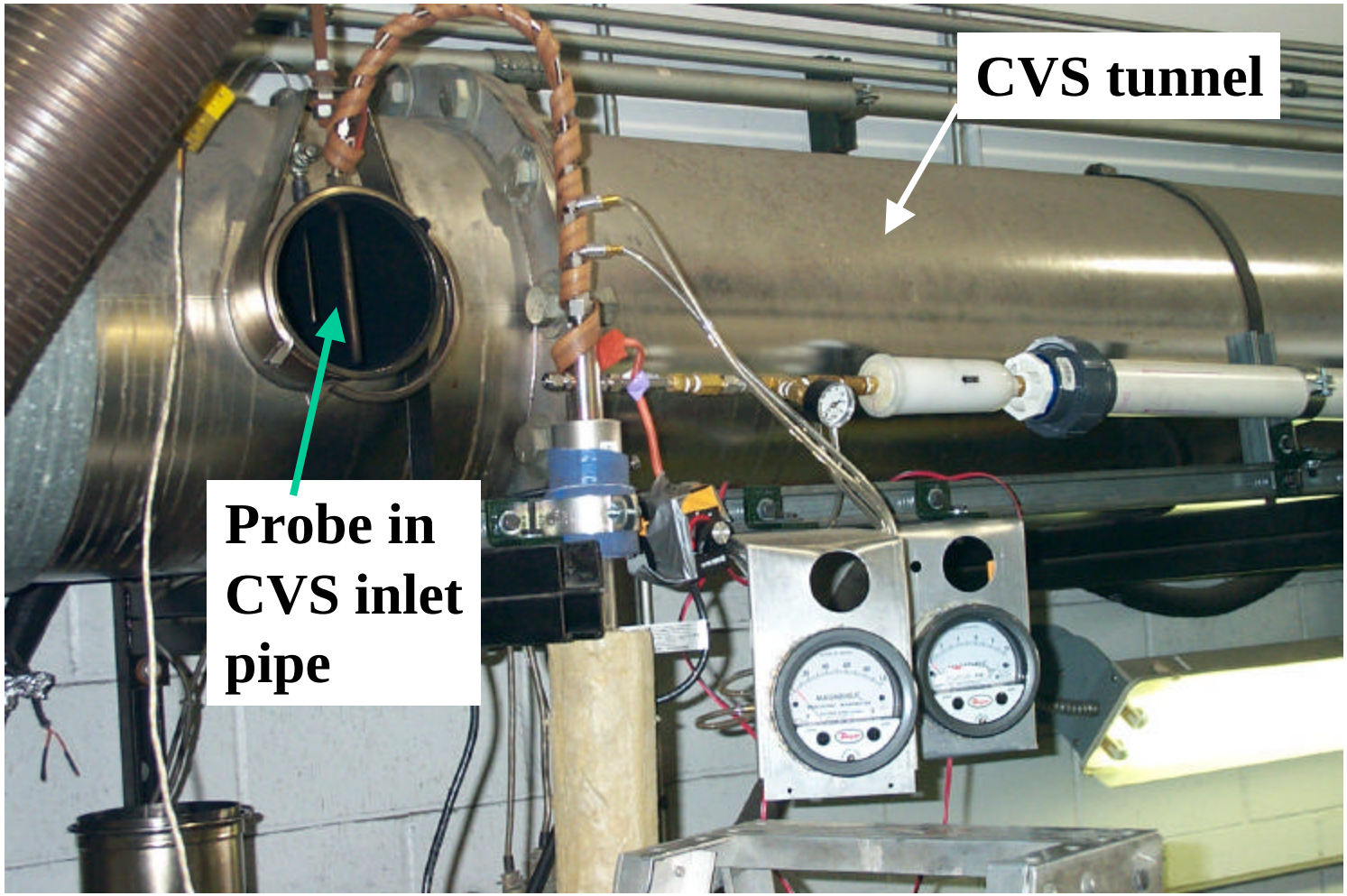
- Passive aftertreatment
- Requirements:
  - Ultra low S fuel <15 ppm
  - exhaust T 275 ^{o}C (40-50% of time)
  - NOx/PM ratio 8 (20 better)
  - Engine should be well-maintained
- One of 2 DPF's verified by ARB in California
  - > 85% PM emission reduction (Level 3)
- Retrofit for >1994 model years

Dual Dilution Setup

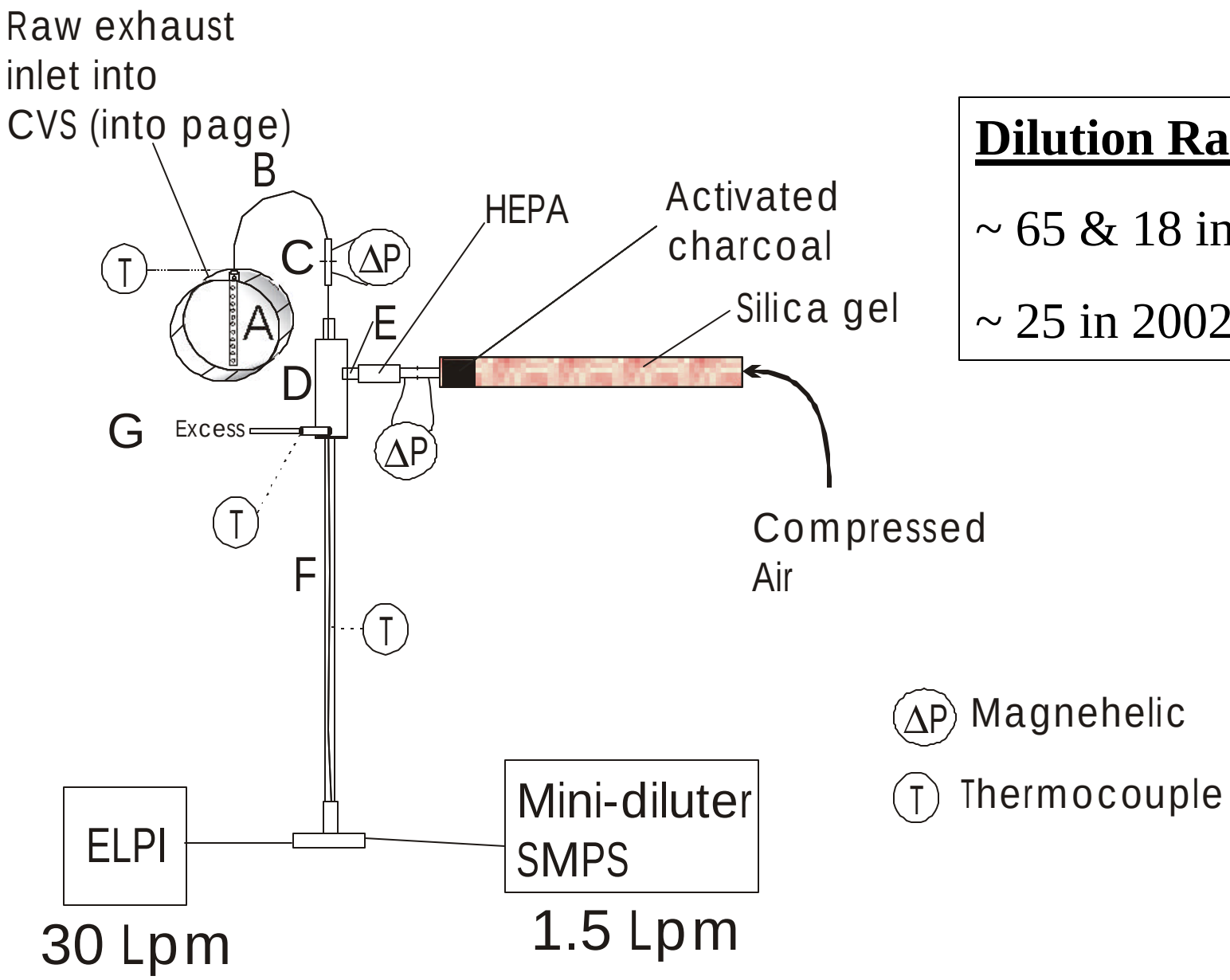


ARB's Dynamometer Lab

Mini-Diluter at CVS Exhaust Inlet



Mini- Diluter



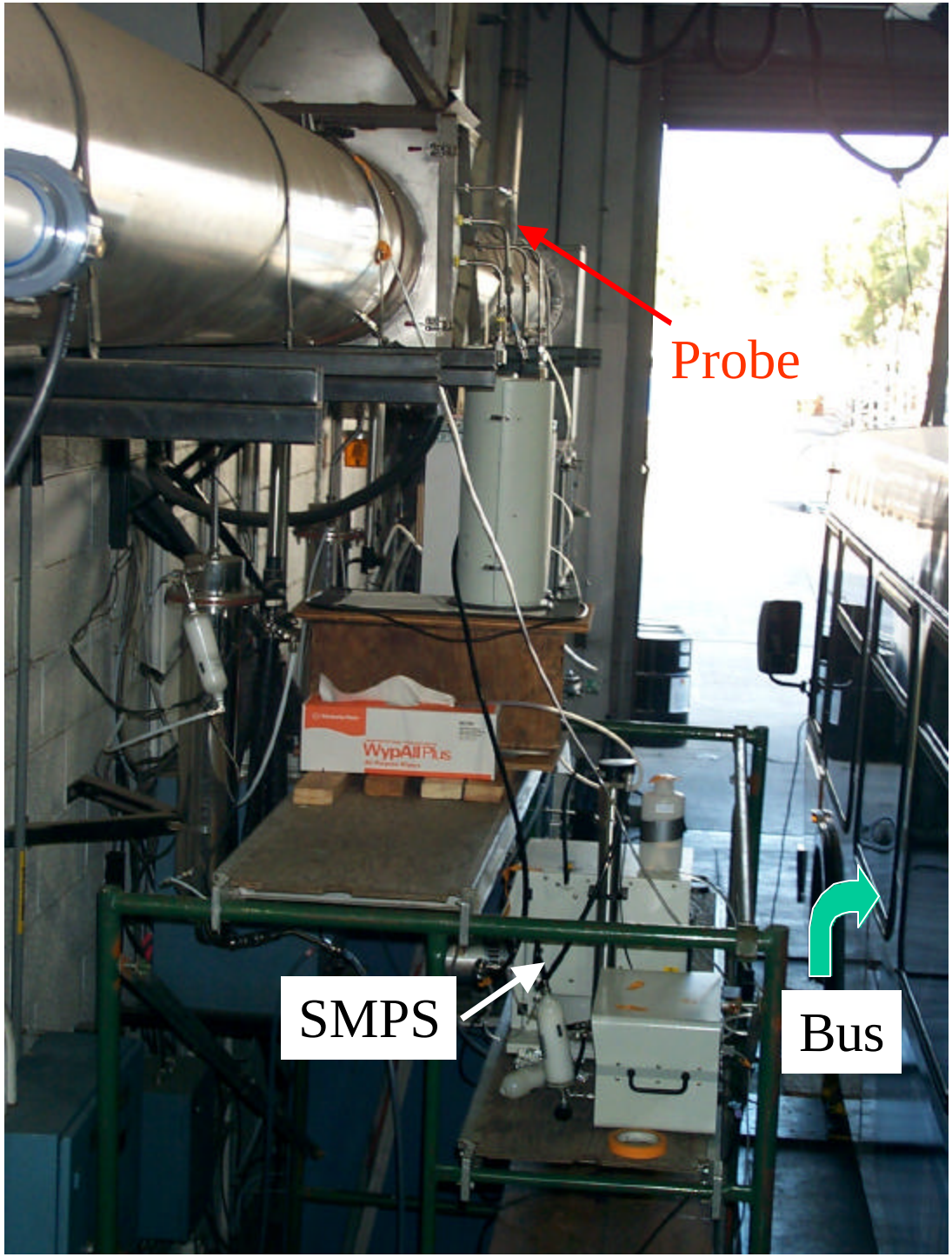
Dilution Ratios

~ 65 & 18 in 2001

~ 25 in 2002

CVS Sampling Station

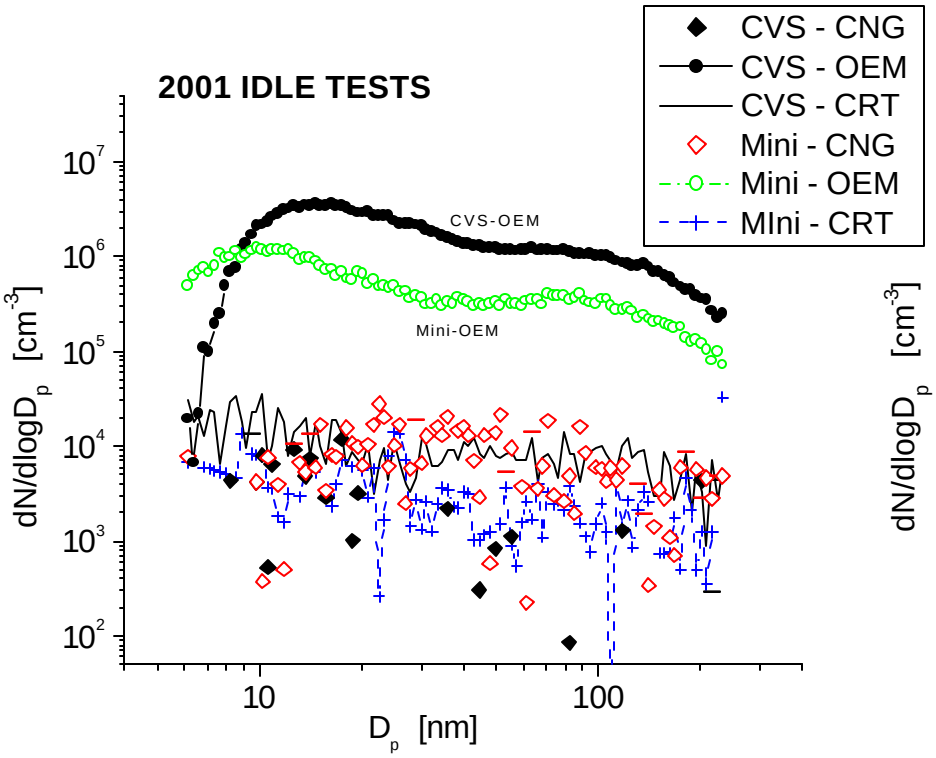
Dilution Ratios ~ 8 to 25
(cycle & bus dependent)

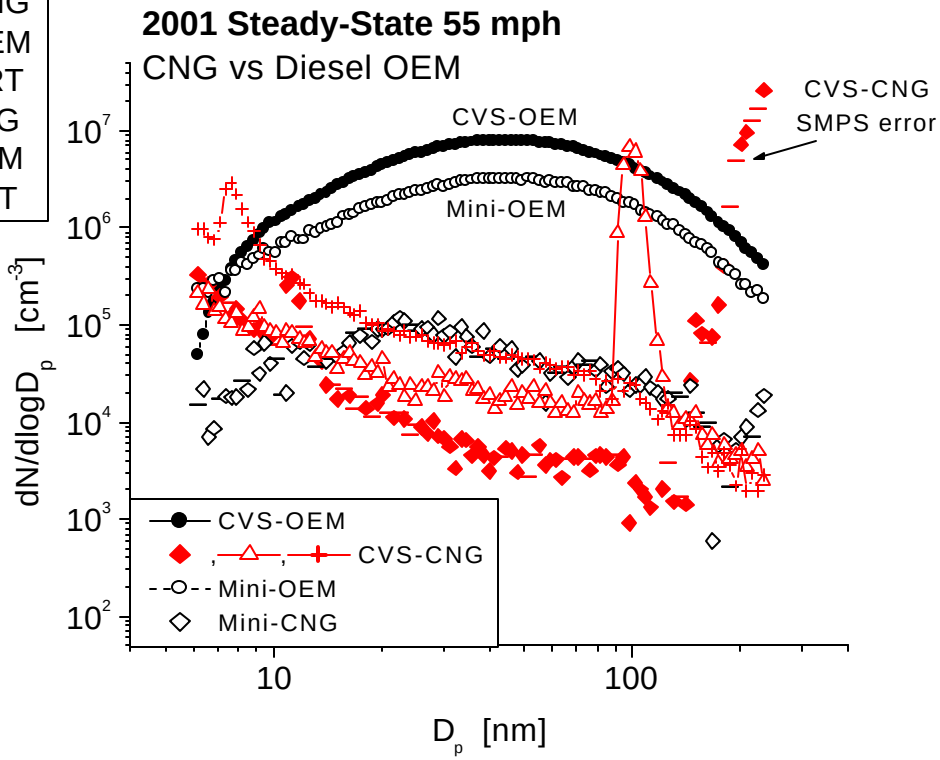


Scanning Mobility Particle Sizer

- TSI 3080 Classifier, 3025A CPC
- 1.45 Lpm aerosol flow rate (14.5 Lpm sheath)
- 2-min up-scans &
  30-sec retrace
- 6 – 225 nm
- dN/dlogDp (AIM ver4.3)
- TB and DR-corrected

2001 IDLE & SS 55





2001 Data Summary

- Both CNG & CRT configurations reduced number concentration by 10 –100x compared to Diesel Baseline.
- Cycle effects: SS55 and NYB highest Total N.
- CRT had lowest Total N on all cycles except UDDS.
- CVS dilution artifacts hinder interpretation of real-world ultrafine distributions.
- CNG bus high NP mode may reflect higher nucleation of semi-volatile gas species due to lack of oxidation catalyst.
- Need to test CNG with oxidation catalyst…

2002 Test Vehicles

	Cummins	DDC
Data label	Cummins w/Oxi Cat	DDC CNG-3
Vehicle	#134	#5300
Fleet	Omnitrans	Los Angeles MTA
Chassis	New Flyer	New Flyer
Capacity	40 passenger	40 passenger
Fuel	CNG	CNG
Engine	C 8.3 G-plus	Series 50 G
Model year	2001	2000
Mileage at start:	18,700	56,600
After-treatment	Oxidation Catalyst (OC)	OEM* and OC**
Total miles on OC	18,700	4,300

DDC is same bus as 2001

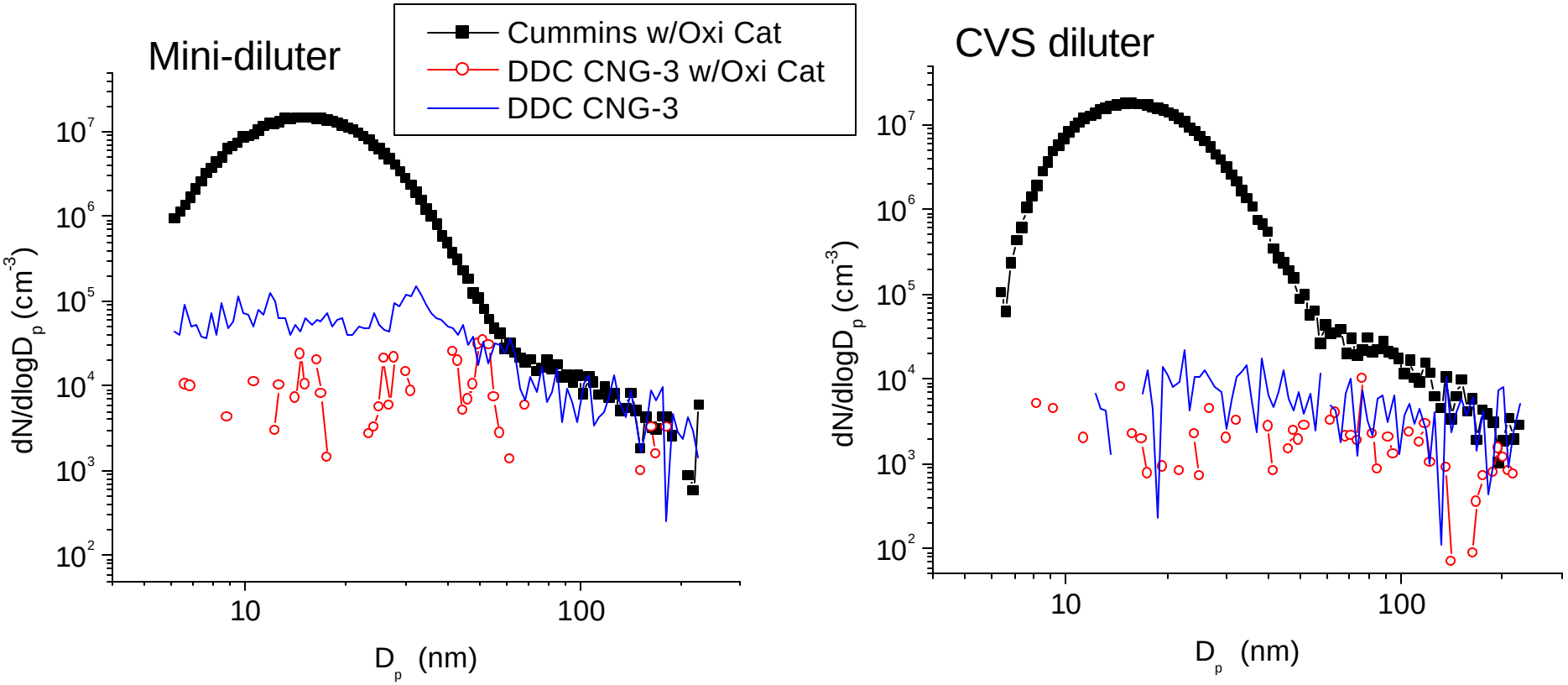
**OEM configuration is with no controls*

***1st DDC 50G w/Oxi Cat on New Flyer chassis*

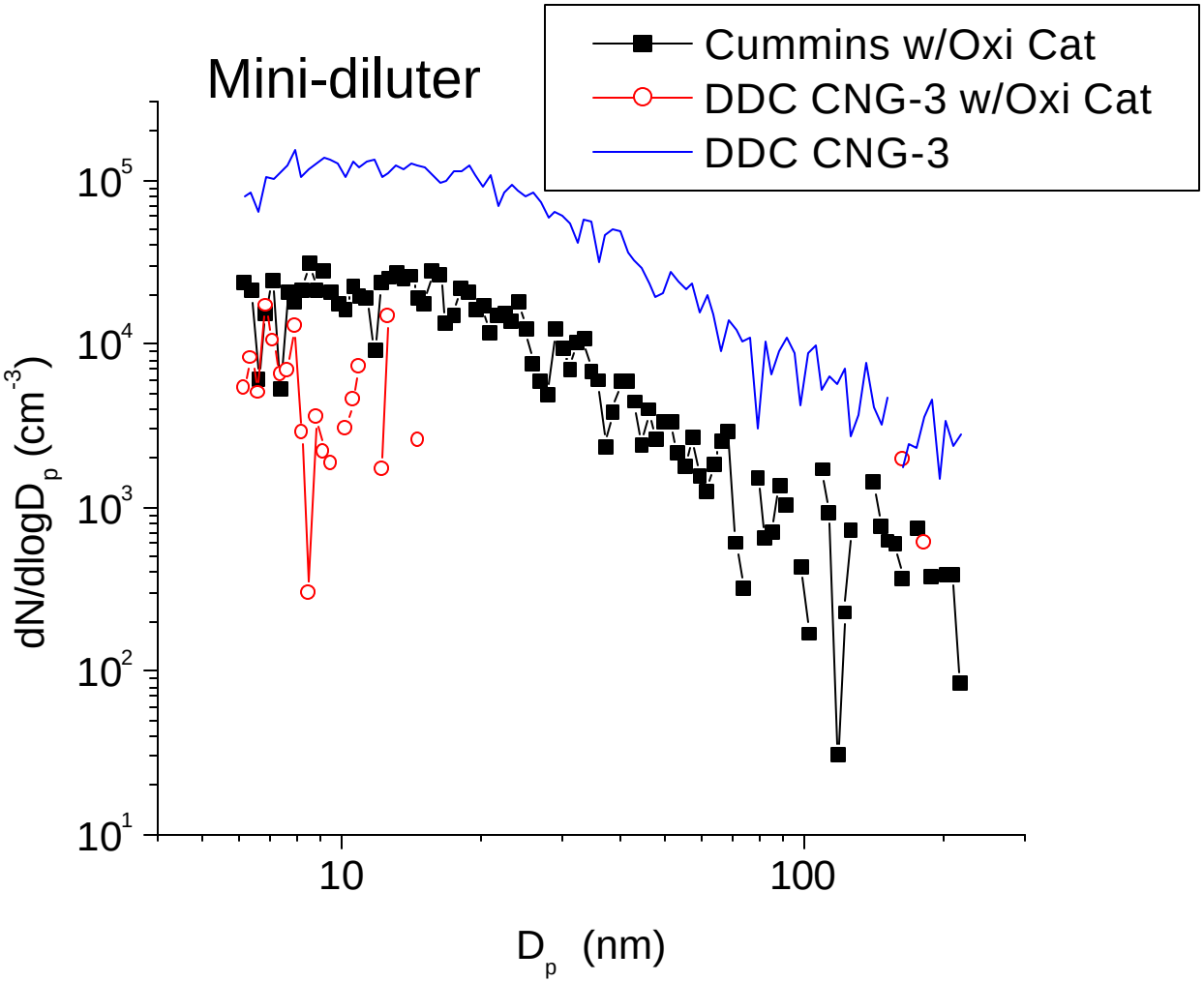
CNG buses: Fuel and Lube Oil

	Cummins	DDC
Fuel (3 samples)	Methane No. > 100	Methane No. > 100
Oil:		
Additives	Normal	Normal
Wear Metals	Normal	Normal
Chlorine	25 ppm	12 – 22 ppm
Copper	73 ppm	Normal

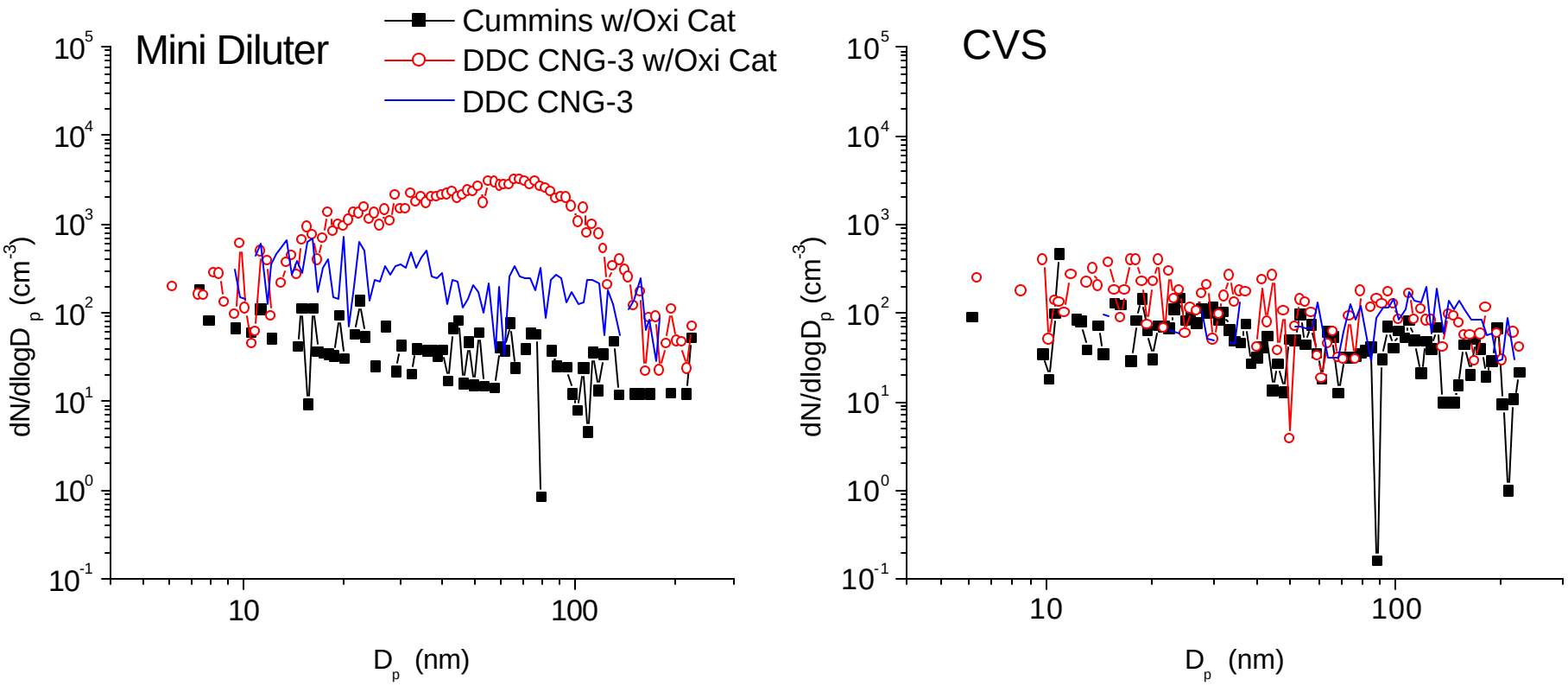
CNG buses: Idle



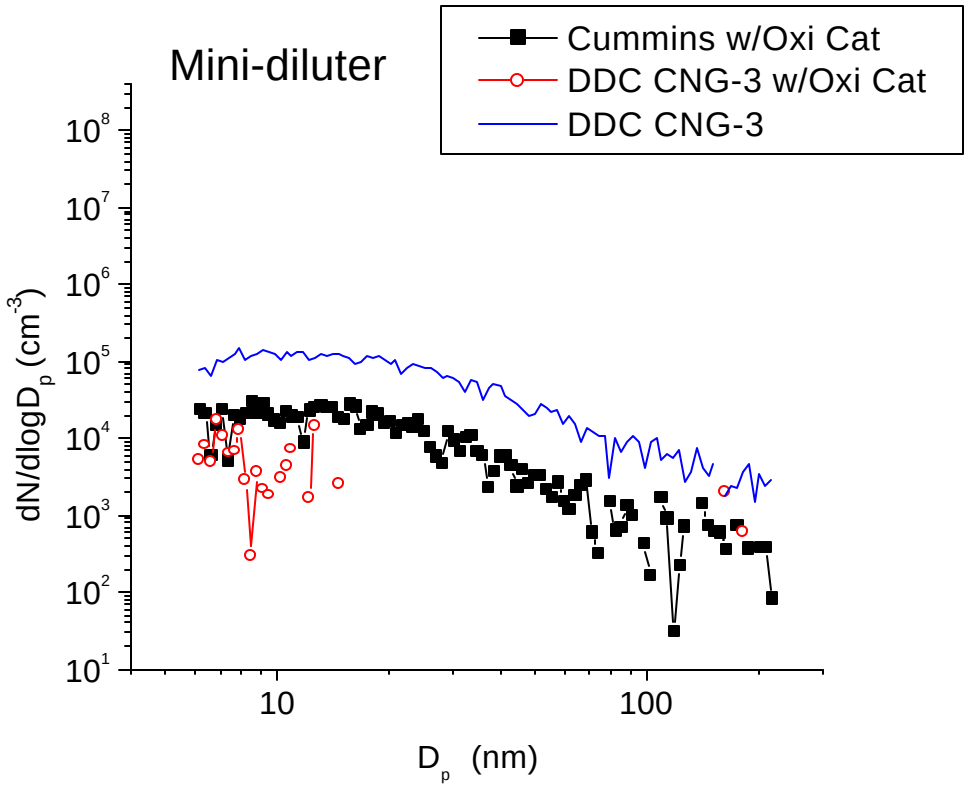
CNG buses: Steady-State 55 MPH

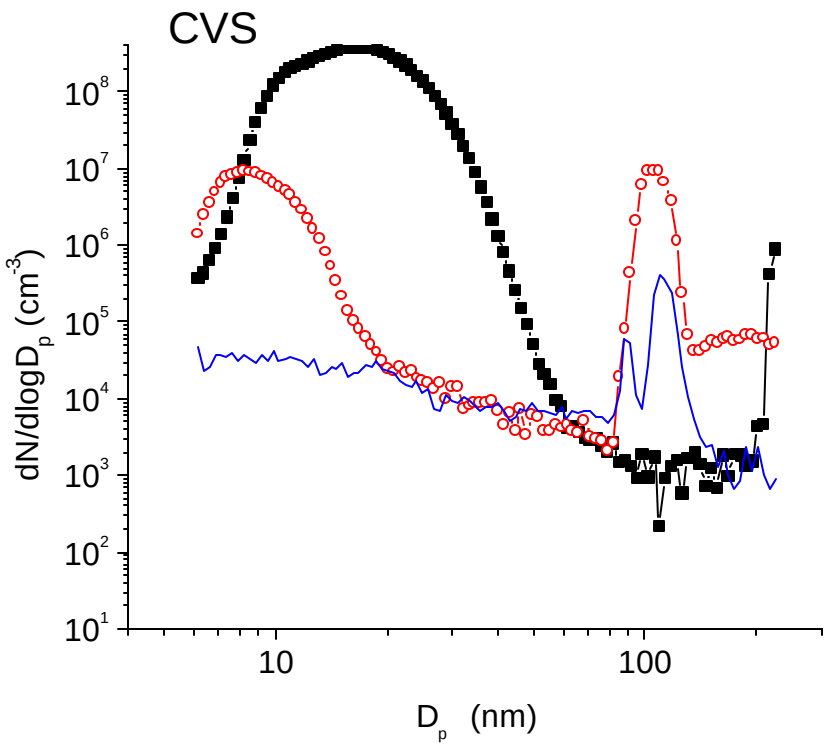


CNG buses: Tunnel Blanks

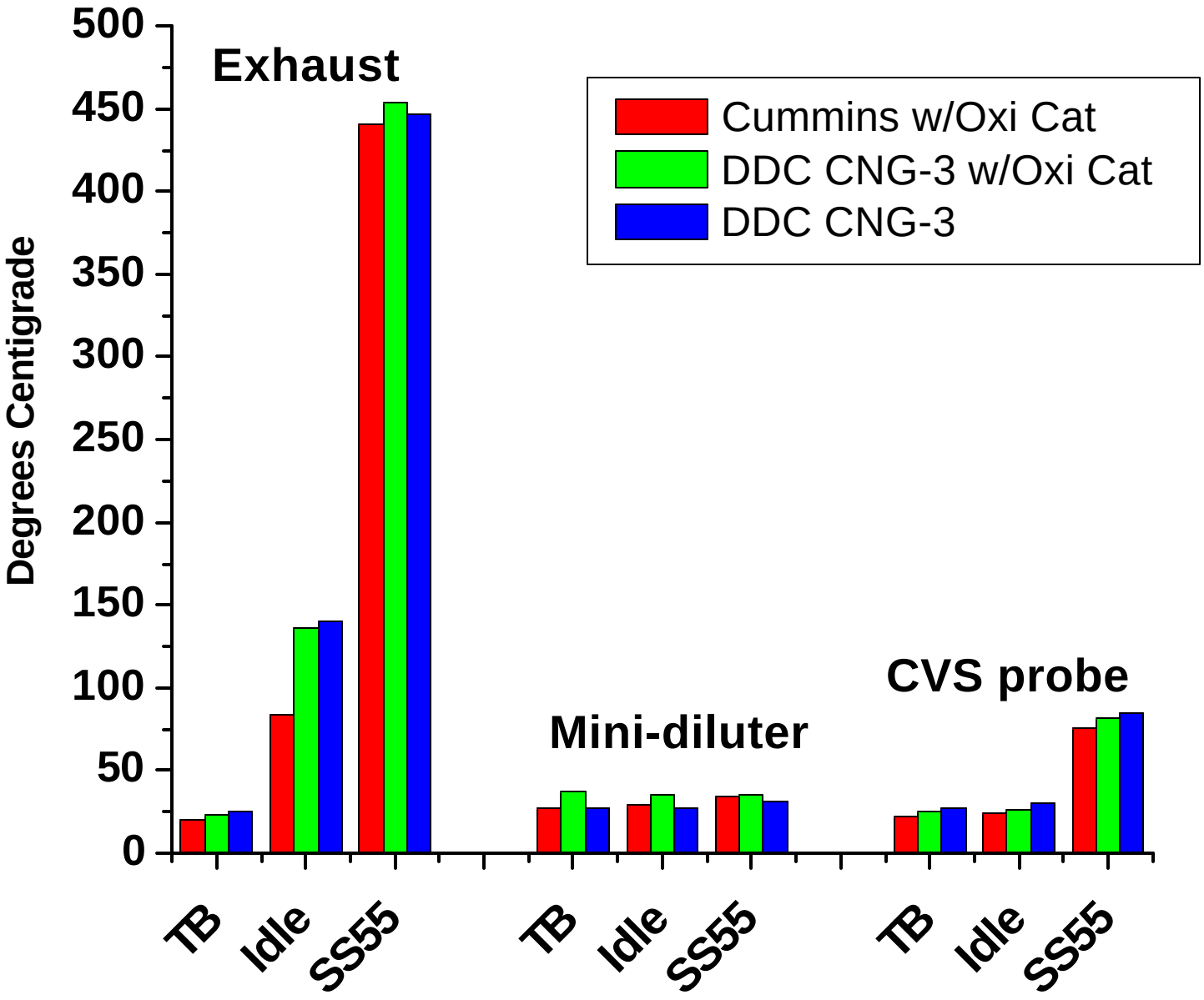


CNG buses: Steady-State 55 MPH





Temperatures °C



Observations 1

- At low-load (IDLE), Cummins engine emits very high nanoparticle concentrations, independent of dilution conditions.

- On mini-diluter, at high-load (SS55) Cummins 100x lower than IDLE; DDC +/- Oxi. Cat. small change IDLE to SS55.

- Mini-diluter gives more reproducible particle size distributions on all steady cycles examined, compared to CVS tunnel.

Observations 2

- CNG nanoparticle mode (~ 20 nm) can exceed diesel OEM emissions.
  - ?what is source of NP mode when have Oxi.Cat.?

- Evidence for possible nucleation in CVS under high-load (SS55) only for CNG buses equipped with oxidation catalysts.

- Tunnel blank role/subtraction very important for low-emission vehicles.
  - Temperature effects on TB vs. cycle

Thank You!

- California Air Resources Board
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- Kathy Nanzetta, Terry James, and Mark van deWater (UC Davis)