

Biodiesel and Renewable Diesel Emissions Study and Biodiesel Multimedia Evaluation

Real-Time Particulate Matter Emissions

Subhasis Biswas

**California Air Resources Board
Mobile Source Control Division/
Heavy Duty In-Use Strategies Branch**

INSTRUMENTS AND PARAMETERS MEASURED

1. **Differential Mobility Spectrometer (DMS 500, Cambustion Ltd)**
 - **Size distribution and number concentration** for C15 Caterpillar and MBE 4000 vehicles
 - Classifies particles (4.5 nm-1000nm) according to their electrical mobility
2. **Engine Exhaust Particle Sizer (EEPS 3090, TSI Inc)**
 - **Size distribution and number concentration** for 2006 Cummins ISM
 - Electrical mobility analyzer (6.04 nm-523nm)
3. **Electrical Aerosol Detector (EAD 3070A, TSI Inc)**
 - **Particle length/diameter concentration** (the total length of all the particles if placed in a line) for 2006 Cummins ISM and MBE 4000 vehicles
 - Diffusion Charger (10- ~1000nm)
4. **Photoelectric Aerosol Sensor (PAS 2000, Eco Chem)**
 - **Particle bound polycyclic aromatic hydrocarbons (pPAH)** for 2006 Cummins ISM and MBE 4000 vehicles
 - Photoionization of particle-bound PAH

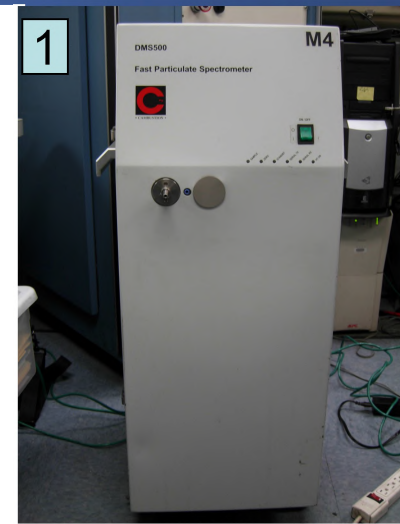


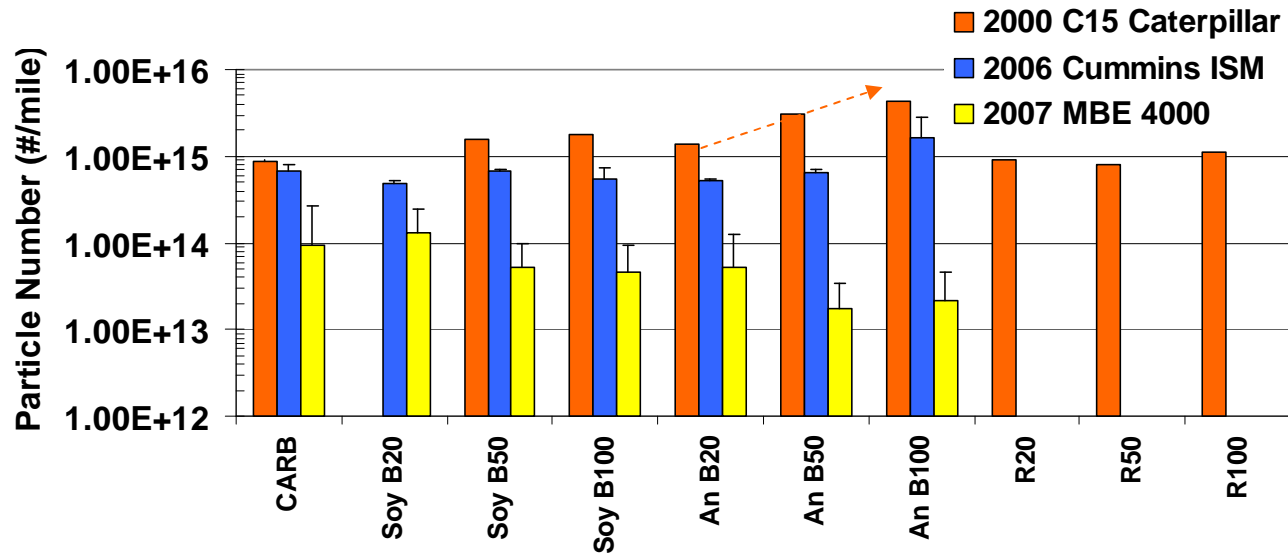
Table 1 Number of driving runs used for data analysis

	2000 C15 Caterpillar		2006 Cummins ISM				2007 MBE 4000							
	Particle Number/ Size Dist.		Particle Number/ Size Dist.		Particle Length (PL, EAD)		pPAH (PAS)		Particle Number/ Size Dist.		Particle Length (PL, EAD)		pPAH (PAS)	
Fuel	Cruise	UDDS	Cruise	UDDS	Cruise	UDDS	Cruise	UDDS	Cruise	UDDS	Cruise	UDDS	Cruise	UDDS
CARB	2	2	6	6	6	6	6	6	6	12	6	12	6	12
Soy B20	NA	NA	3	3	3	3	3	2	3	8	3	8	3	8
Soy B50	1	1	3	3	3	3	3	3	3	9	3	8	2	8
Soy B100	1	1	3	3	3	3	3	3	3	7	3	9	3	9
AnB20	1	2	3	3	3	3	2	3	5	4(2)	4	4(2)	4	3(2)
An B50	1	NA	3	3	3	3	3	3	4	3	3	3	4	4(1)
An B100	1	1	3	3	3	3	3	3	4	4(1)	4(1)	4(1)	4	4(1)
R20	1	1	Renewable fuel was not tested for International and MBE 4000 trucks											
R50	1	NA												
R100	1	1												

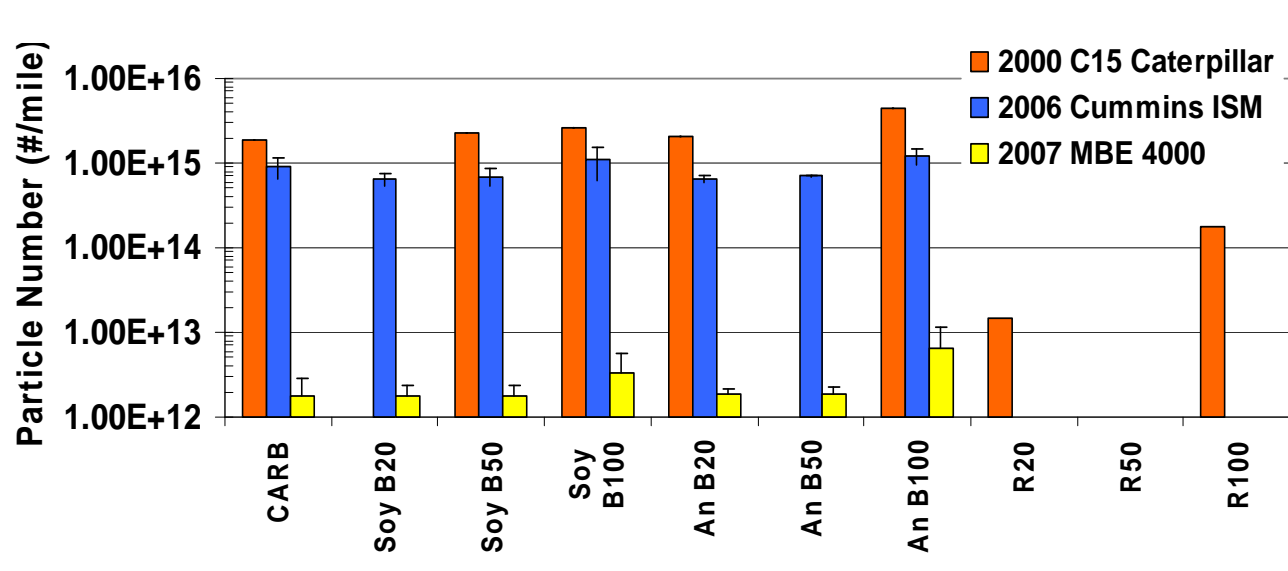
*A few single UDDS were run for MBE 4000 while testing Animal based biodiesel. These are denoted by the numbers in brackets [()]. Rest of the UDDSs are composites of two single UDDS.

PARTICLE EMISSIONS IN TERMS OF NUMBER

Cruise: Total Particle Number



UDDS: Total Particle Number



•C15 Caterpillar:

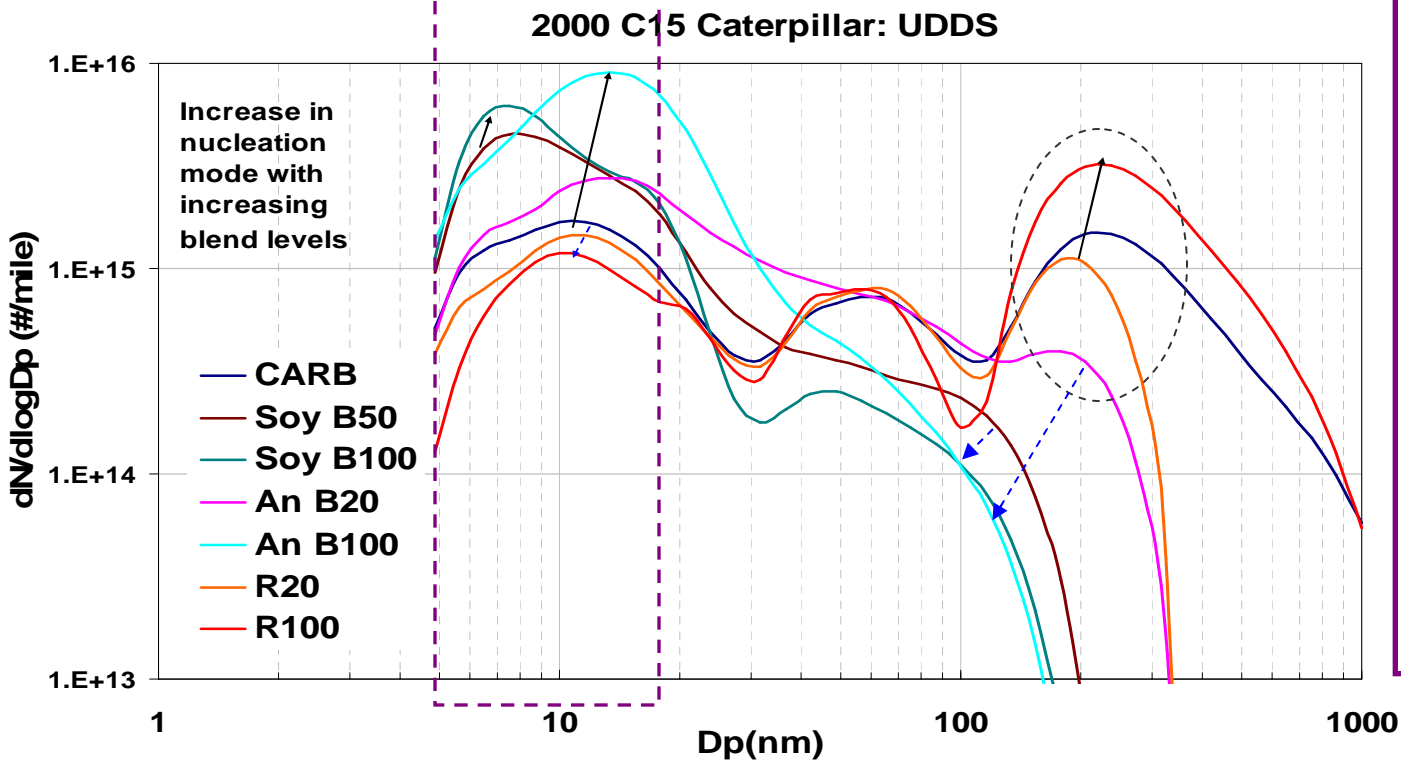
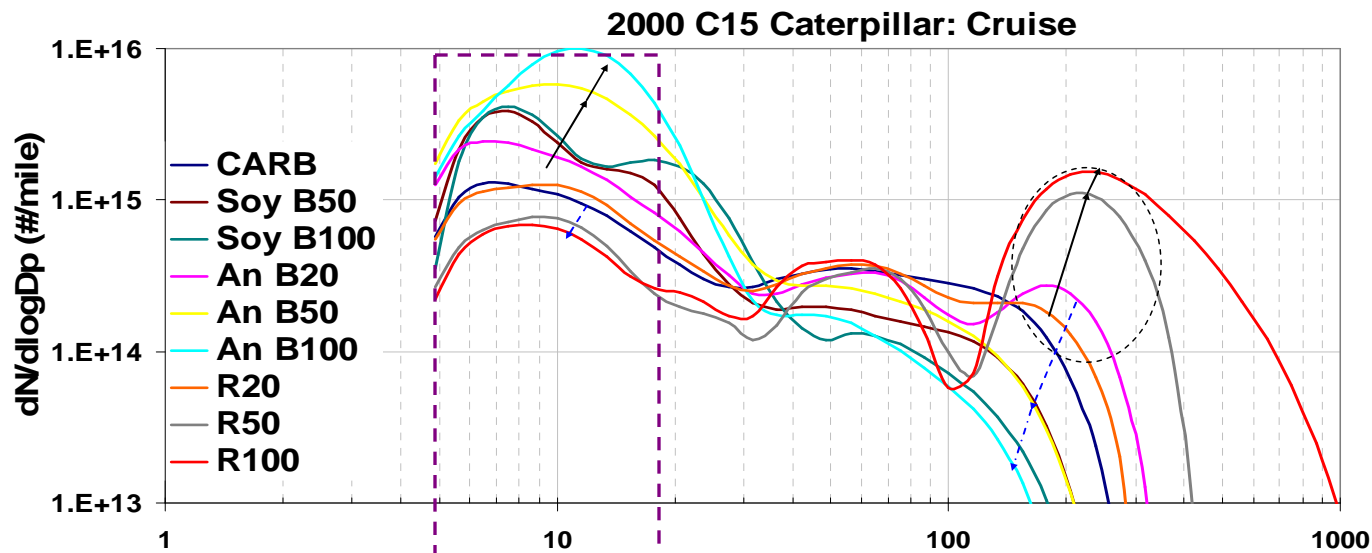
- PN varied between 1.4×10^{13} - 4.2×10^{15} #/mile
- An B100 highest particle number (PN) (4.2 - 4.4×10^{15} #/mile)
- Increase in PN with the progressive enrichment in fuel blends for Animal based biodiesel

Cummins ISM: Particle number concentration varied between $\sim 4.8 \times 10^{14}$ - 1.65×10^{15} #/mile for cruise and 6.52×10^{14} - 1.19×10^{15} for UDDS cycle.

MBE 4000: Higher PN emissions for Cruise cycles (1.76×10^{13} - 1.31×10^{14} #/mile) than UDDS (1.76 - 6.41×10^{12} #/mile)

- **Highest PN for C15 closely followed by Cummins ISM; MBE 4000 reduced PN significantly**

PARTICLE SIZE DISTRIBUTION

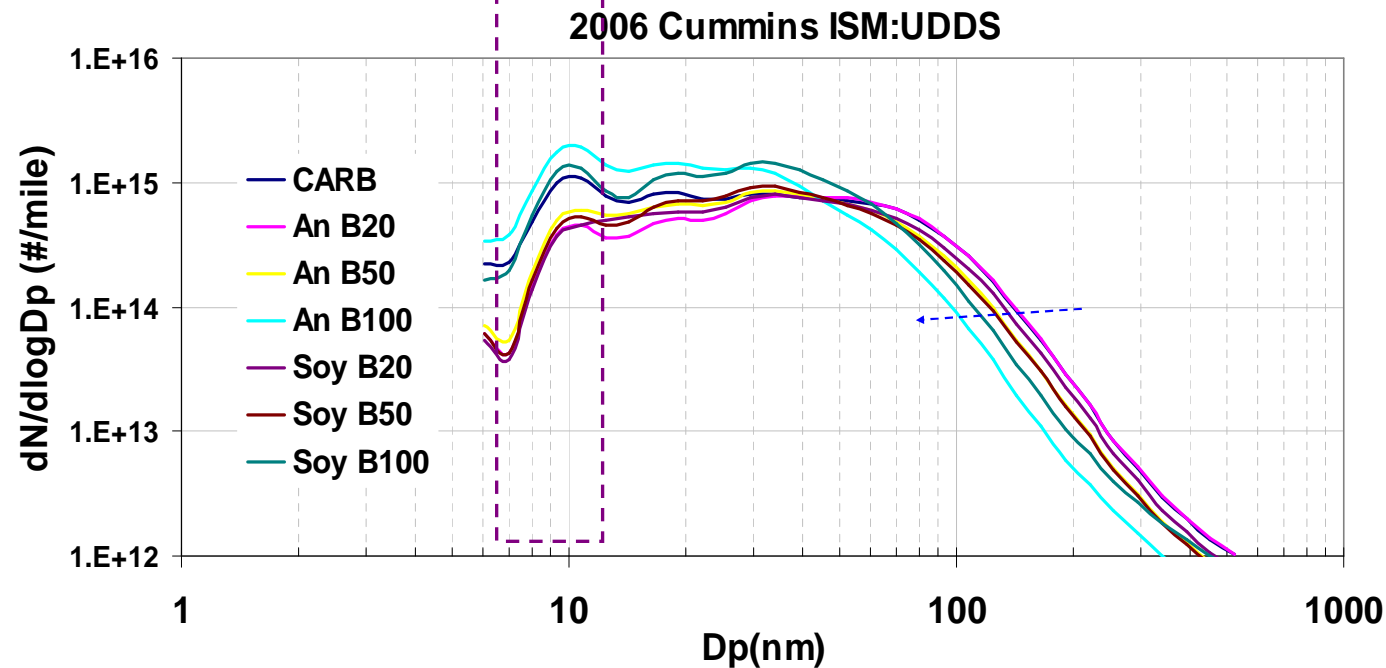
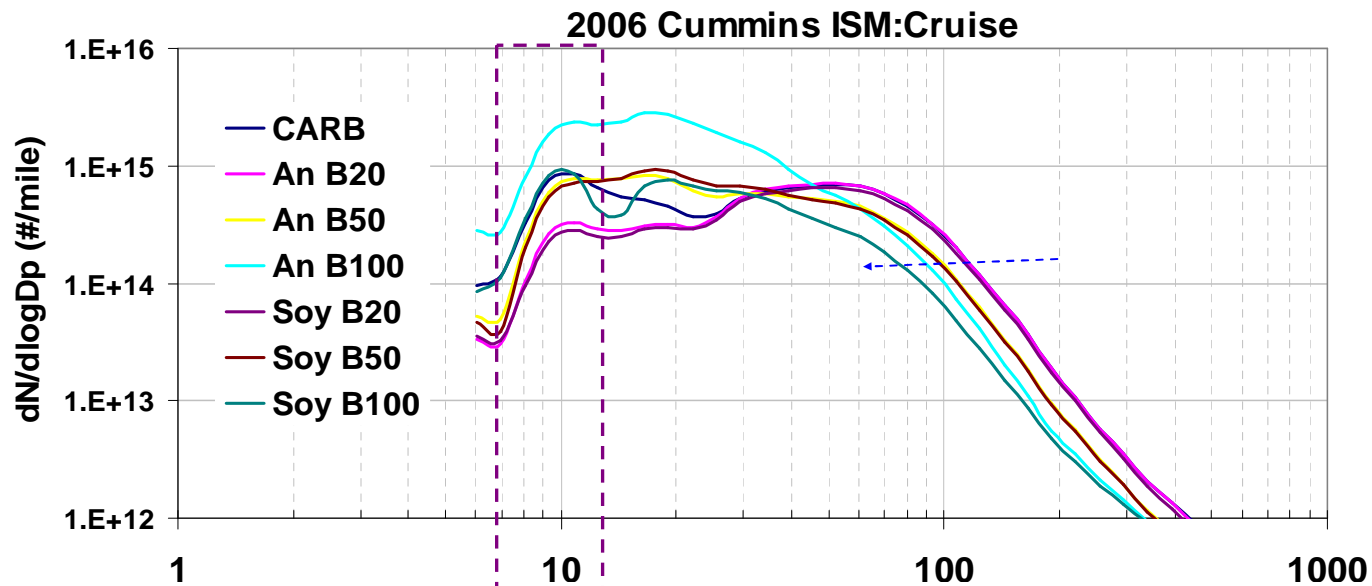


- High concentrations of small particles (<20nm) were formed; distinct peak ~10nm for all fuel types and cycles

- Nucleation increased while accumulation mode decreased with increasing blend levels for Animal and Soy biodiesel.

- Renewable fuel, tri-modal distributions with peaks of ~10, 60, 230nm.

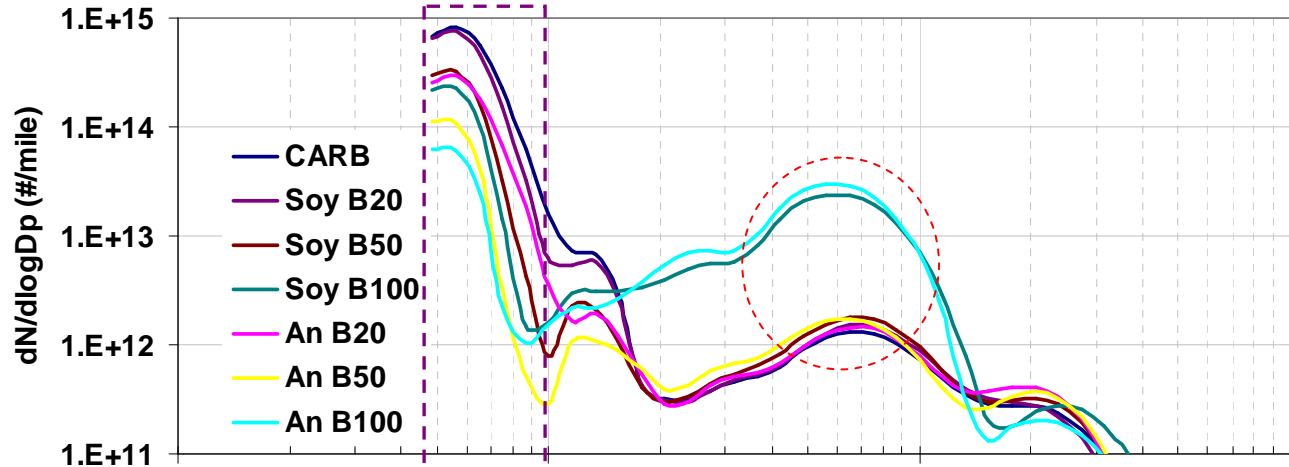
- Larger particles (230nm) increased with increasing blends for Renewable fuels



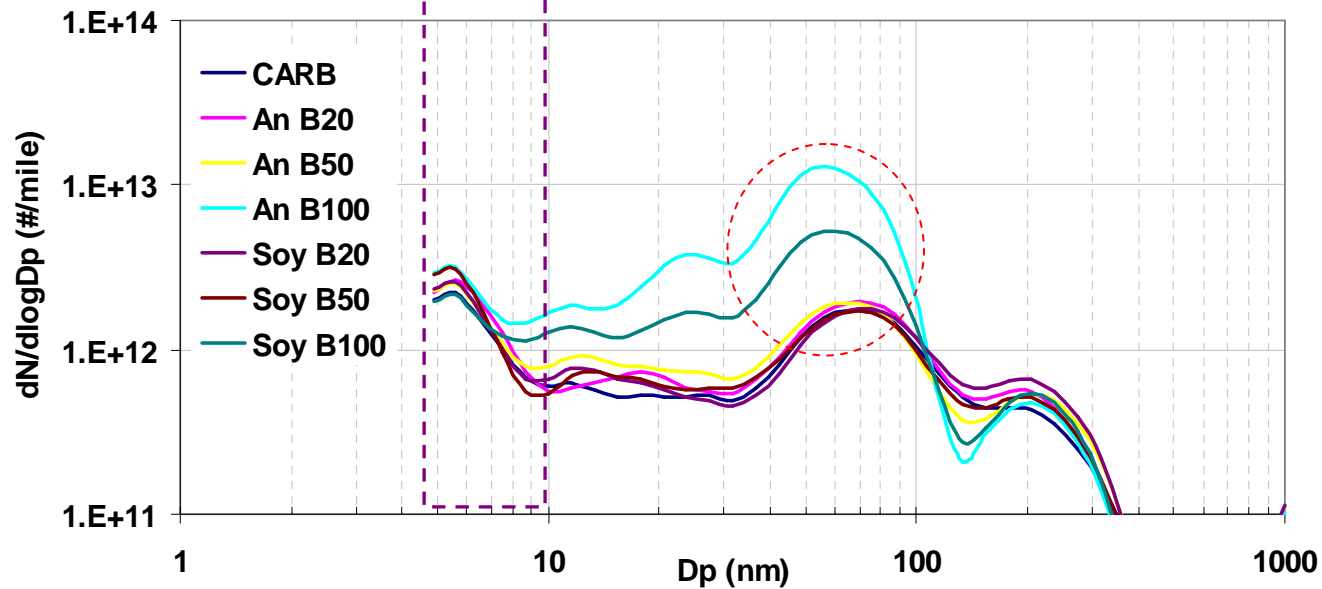
- Distinct peak at ~10 nm and a broad peak at ~50-60 nm
- No Particulate trap; second mode (~50 nm) likely generated from elemental carbon emissions

- With higher content of biodiesel (B50, B100) the size of larger mode (~50nm) has decreased (shift towards smaller modes), while the small nucleation mode (10-20nm) is increased especially for B100.

2007 MBE 4000: Cruise



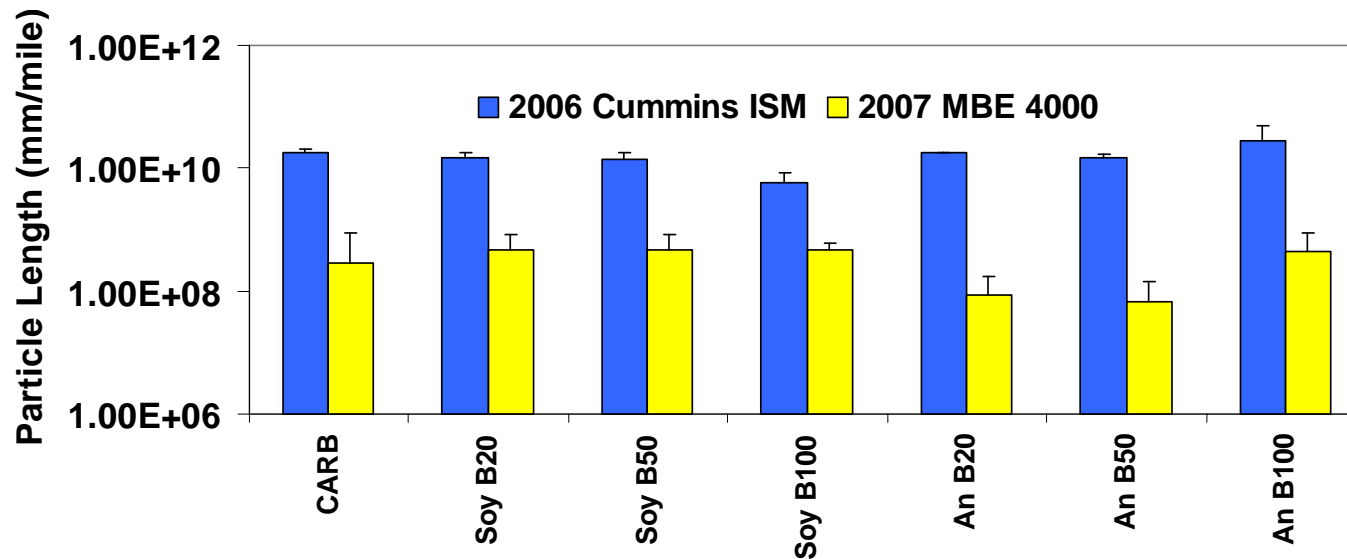
2007 MBE 4000: UDDS



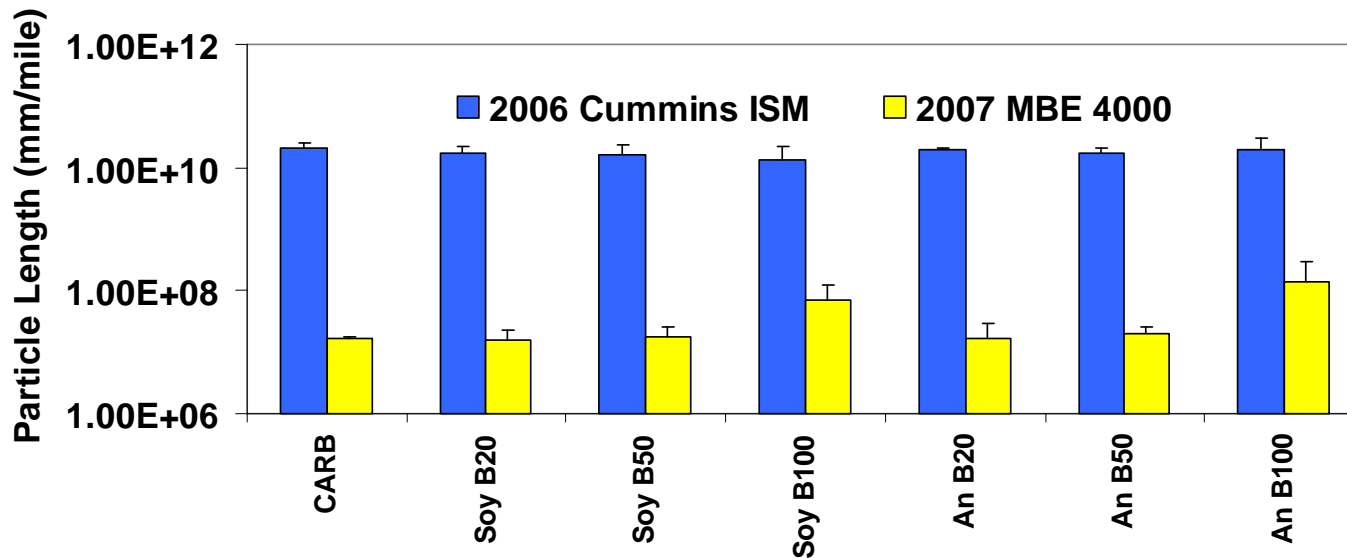
- Predominantly two modes: <10nm; ~50nm
- Cruise cycles were associated with high concentration of nucleation mode particles
- Pure biodiesels (animal and soy B100) showed the highest concentration in accumulation

PARTICLE LENGTH (PL) / DIAMETER CONCENTRATION

Cruise: Particle Length



UDDS: Particle Length



- **Cummins ISM**

PL is approximately in the range of $\sim 10^{10}$ mm/mile and is consistent over the whole spectrum of fuel types and driving conditions.

- **MBE 4000**

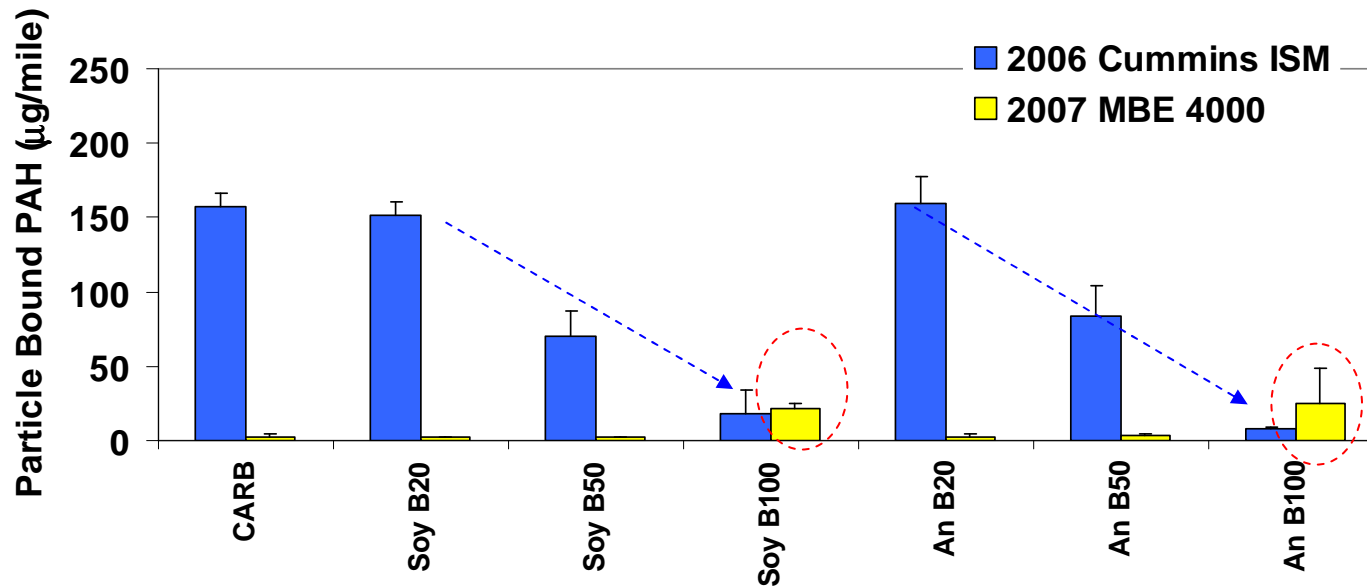
The PL did not change with higher blends of soy biodiesel during cruise operation.

- Slightly higher signals observed for B100 for UDDS cycle

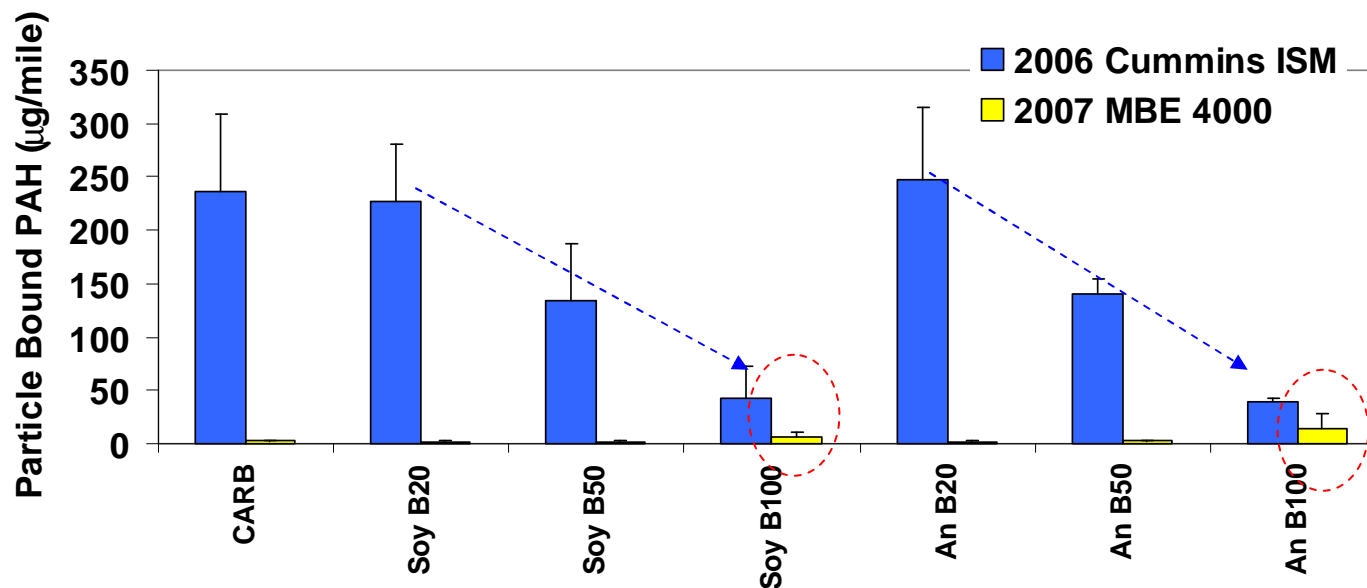
- The Cummins ISM truck produced almost one to two magnitude higher PL than the MBE 4000

PARTICLE SURFACE BOUND PAH

Cruise: Particle Bound PAH



UDDS: Particle Bound PAH



•Cummins ISM

- Higher pPAH in UDDS cycle (39-235 µg/mile) than Cruise (7.4-160µg/mile) cycle
- Higher Blend level(B50 and B100):significant and progressive reduction in pPAH

MBE 4000

- pPAHs are low, varied between 1.7-24.4 µg/mile
- pPAH emissions (µg/mile) were more in cruise than UDDS runs for B100.
- B100 pPAH increased: higher accumulation mode
- Significant improvement (two order of magnitude) in eliminating pPAHs for CARB, B20 and B50

SUMMARY

- Highest Particle number observed for C15 caterpillar closely followed by Cummins ISM
- Equipped with DPF and DOC, MBE 4000 reduced PN significantly compared to C15 Caterpillar and Cummins ISM
- Particle number did not follow the same trends as that of PM mass for different blend levels
- Size distribution showed mono, bi and tri -modal distributions. Significant nucleation observed for C15, Cummins ISM and MBE 4000 cruise
- For C15 and Cummins increase in nucleation was accompanied by decrease in accumulation mode particles for Animal and Soy based bio-diesel
- Higher particle length / diameter concentration observed for Cummins ISM than MBE 4000
- Progressive reduction in pPAH observed for uncontrolled emissions of Cummins ISM with increasing blends of biofuels
- Higher pPAHs correspond to higher accumulation mode particles