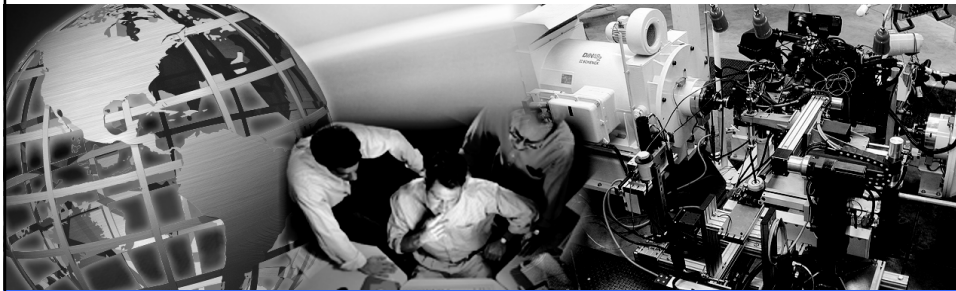


Recent Topics in Diesel Engine Emission Measurement

*International Seminar on Low Emission Aspect and Combustion Control for Engine Systems
Doshisha University, Energy Conversion Research Center*

July 12, 2006

*Masayuki Adachi, Dr. Eng.
General Manager, HORIBA Automotive Test Systems*



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Contents

1. PM Measurement dilemma
2. Enhanced gravimetric techniques
3. PM counting method
4. Conclusion

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PM Measurement Dilemma 1

- Conventional method is facing a limit of precision
 - Current measurement methods are based on “old dirty” diesel engines
 - Advanced diesel engine systems generate significantly low emission
- Nuclei-mode particle controversy
 - Need to measure due to health hazard
 - Mostly heavy hydrocarbon particles?
 - Sulfur mist as core??
 - Extremely high variability depending on sample condition
 - Dilution ratio, temperature, residence time, etc...

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PM Measurement Dilemma 2

- Scientific vs. Industrial
 - Thorough scientific characterization of particle emission needs highly skilled PhDs
 - Regulatory procedure (industry protocol) must be reproducible for everyone in the industry
- PM definition in gravimetric method
 - Exhaust gas is diluted and controlled at lower than 52 degC
 - Filter (0.3u, >99%) is used for collection
 - After PM collection, filter is soaked for 8(LDD) / 1-80(HDD) hours, 23 degC w/ defined humidity
 - Weigh everything on the filter as PM
 - Gas absorption. PM mass being much less than 1/1000 of filter.

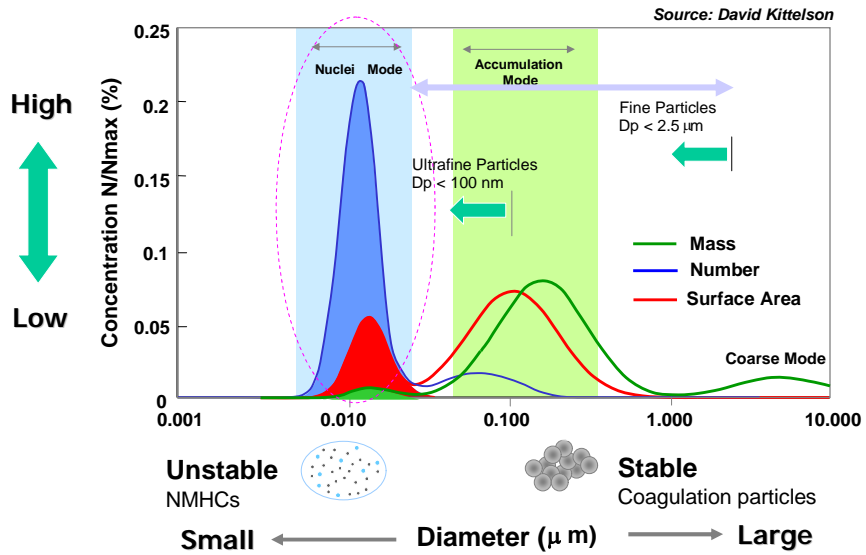


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The "well known" diesel PM size distribution



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Enhanced Gravimetric Techniques

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EPA 2007 HDD Regulation 1

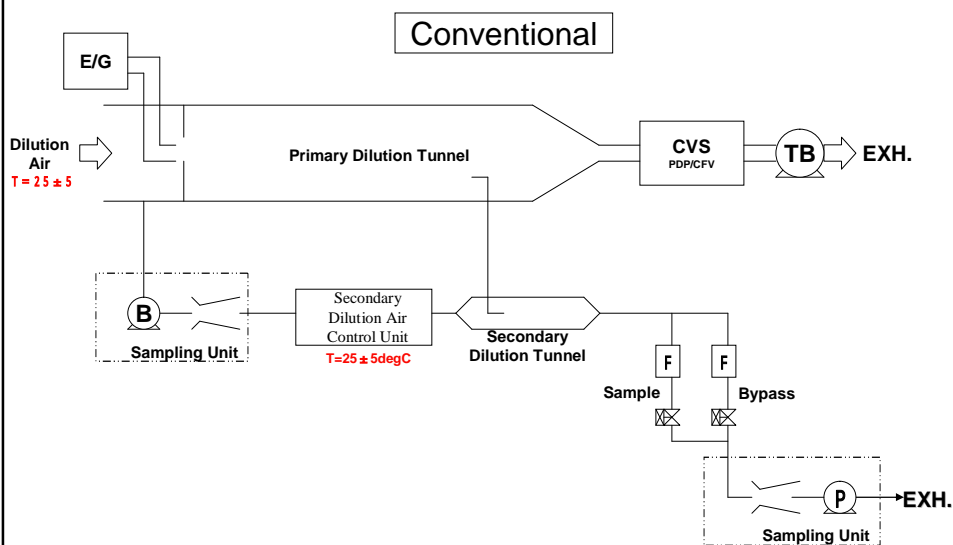
- First proposal in the world to enhance precision of the HDD measurement
 - Revised standards:
NOx: 0.20g, NMHC: 0.14g, CO:15.5g, PM:0.01g /bhp-hr
 - Use of sub-sonic venturi for CVS
 - Dilution air: >15degC, HEPA filtered
 - Filter temperature: within 5 degC from 47degC, TX40 or Teflo
 - Use cyclone to cut 50% of 2.5-10u and bring 99% of 1.0u
- Recent USEPA/CRC study at SwRI E-66
 - Study evaluated filter media
 - Residence time effects
 - DPF equipped 2007 compliant engines with controlled DPF bypass
 - Partial flow systems
 - Study complete and final report due soon

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EPA 2007 HDD Regulation 2

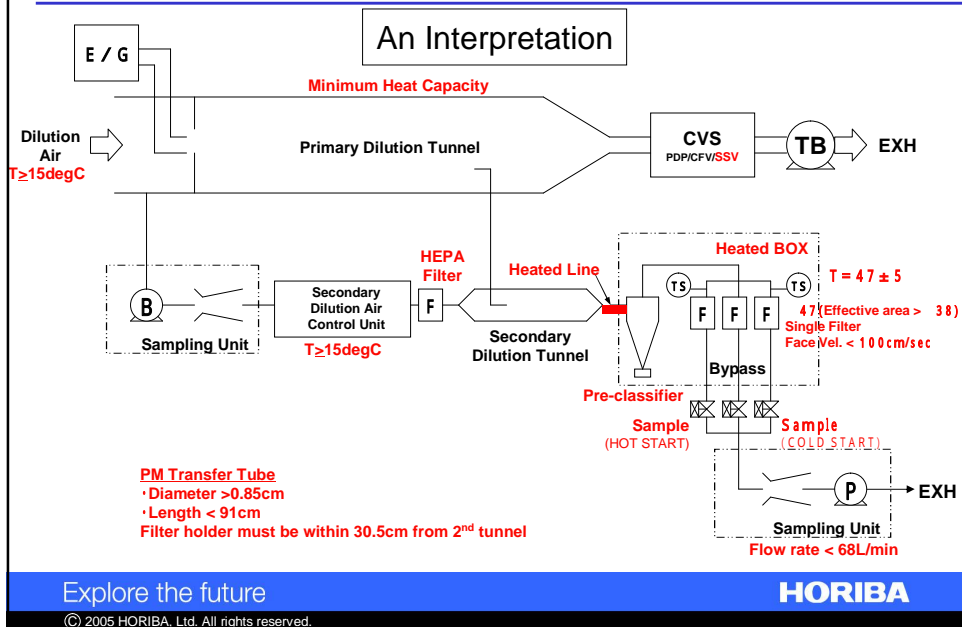


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EPA 2007 HDD Regulation 3

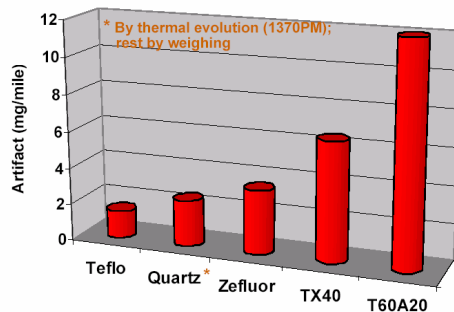


Discussions for filter material 1

■ Gaseous HC conversion to PM mass

- Mass collected can be overwhelmed by absorption of gaseous hydrocarbons

Organic Vapor Artifact: Current Estimates (FTP)



Teflo artifact is *not* zero, but it is the lowest thus far.

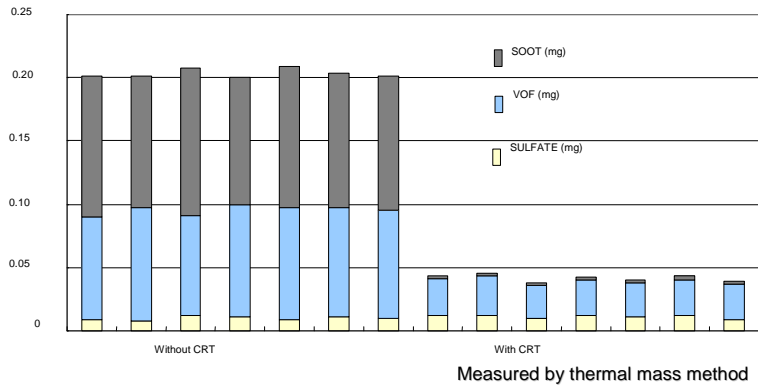
Vogt, Chase, Maricq, Ford Motor company, <http://ies.jrc.cec.eu.int/Units/eh/events/EURO5/>

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Soot removal by DPFs



**Hydrocarbon is becoming as a major constituents of PM
Is this gaseous HC, non-gaseous HC, or both?**

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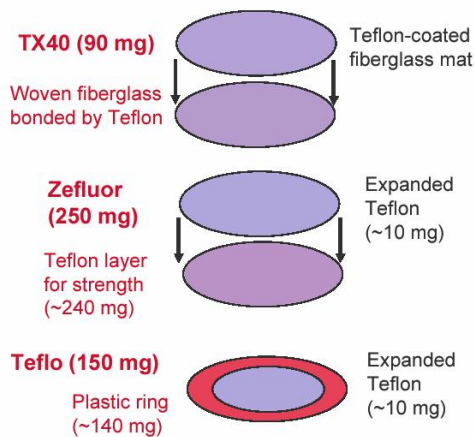
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Discussions for filter material 2

One reason why artifact is smaller for Teflo than TX40 & Zefluor

- TX40 & Zefluor have 2 layers
- 2nd layer adds no PM efficiency – it is for structural support
- T60A20 has high artifact from addition of backup filter



 Research and Advanced Engineering

Vogt, Chase, Maricq, Ford Motor company, <http://ies.jrc.cec.eu.int/Units/eh/events/EURO5/>

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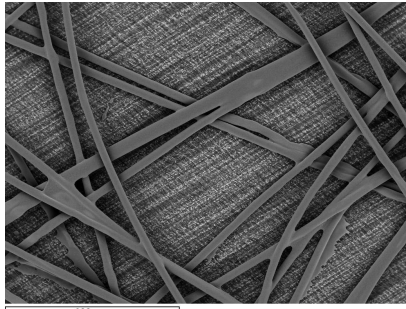
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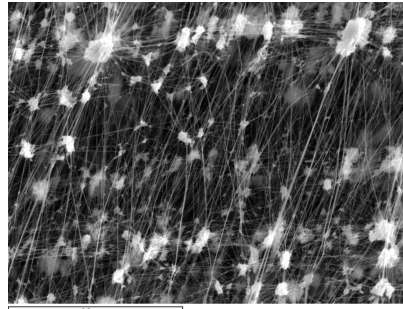
A proposal for new style filter

■ A new concept filter material

- Teflon membrane w/ unwoven PET backing
- Developed primarily for ambient PM component speciation
- Evaluations to be made for automotive applications



PET backing



Teflon membrane

Shinohara, et.al., European Aerosol Conference 2004 and 2005

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Particle Counting Technique

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GRPE - Particulate Measurement Program

■ The PMP program is organized under the UNECE WP29/GRPE Group

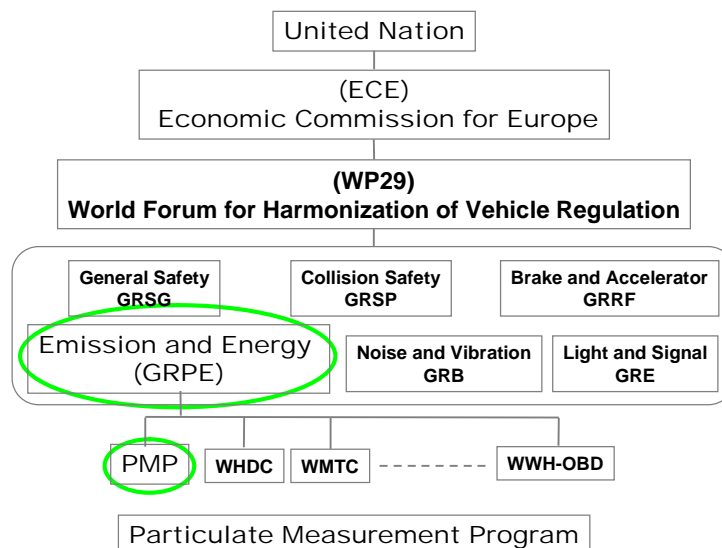
- Aim is to develop a new system of PM measurement (instrument, sampling and procedures) to complement or replace the existing gravimetric method
- PMP is open to governments or industry who are members of GRPE.
- Each contributor funds their own research
- All results are shared and will be published during and at the end of the two year program

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PMP positioning



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GRPE-PMP activity

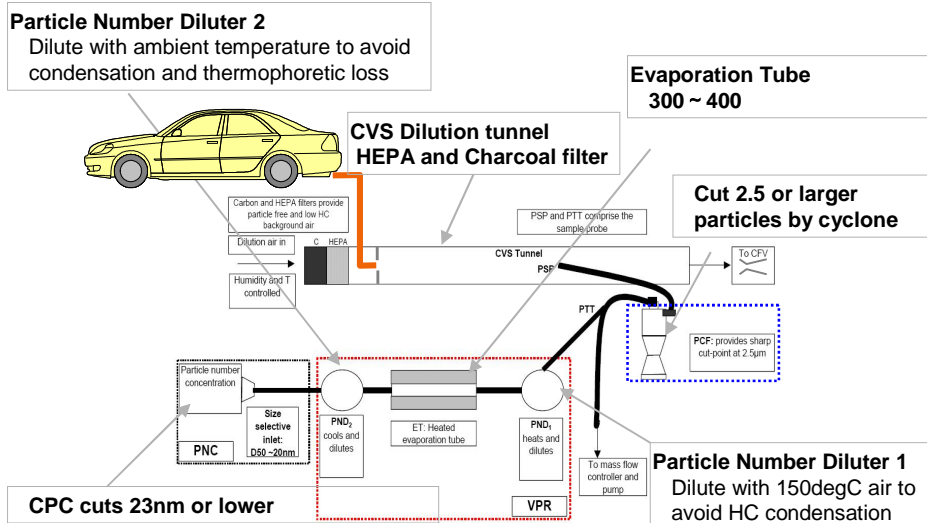
- Besides the conventional gravimetric filter technique, many alternative methods have been developed
- Development has been accelerated by the GRPE-PMP activity
 - **CPC/CNC - Condensation Particle Counter**
 - DCS - Diffusion Charging Sensor
 - EDB - Electrical Diffusion Battery
 - PASS - Photo Acoustic Soot Sensor
 - ELPI - Electrical Low Pressure Impactor
 - LII - Laser Induced Incandescence
 - PAS - Photoelectric Aerosol Sensor
 - TEOM - Tapered Element Oscillating Microbalance
 - QCM - Quartz Crystal Microbalance
 - DMS - Differential Mobility Spectrometry
 - MEXA -MEXA 1370PM : PM mass by gas analysis
 - **EPA-2007 "style" GRAVIMETRIC as a reference method**

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PMP Recommendation for counting



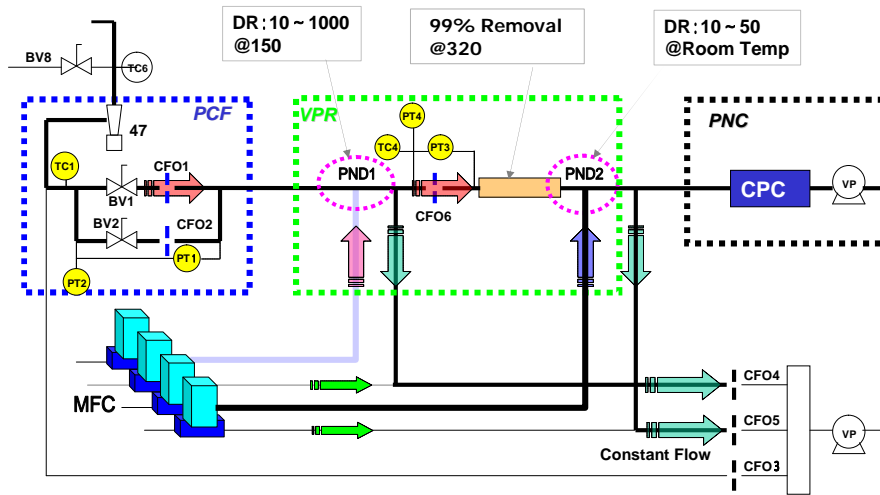
GRPE Informal Document: GRPE-48-11-Rev.1

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A prototype flow schematics



Wei, et al., SAE2006-01-0865

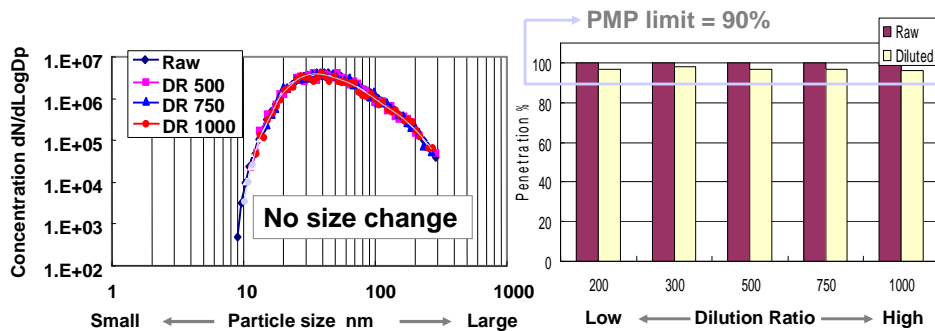
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SPCS particle penetration

$$\text{Penetration} = \frac{\text{Concentration after SPCS} \times \text{DR}}{\text{Raw Concentration Before SPCS}} \times 100$$



Raw concentration
 ↓↓
 Diluted concentration

Penetration > 98%
 Particle Loss < 2%

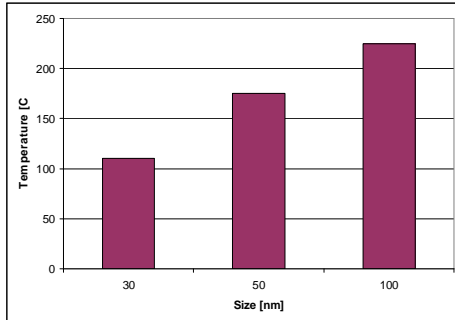
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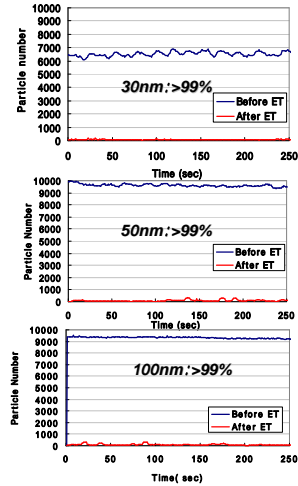
C40 (Tetracontane) Particle Removal Efficiency

C40 conc. $\cong 10^4$ #/cc
 $DR_{PND_2} = 24.5$
 $RE > 99\%$



Minimum Temp. to remove C40 particles

ET Temp: 320

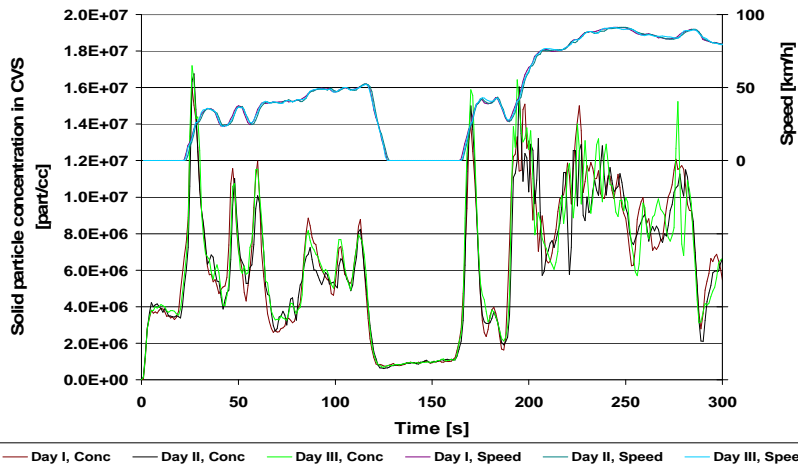


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Consecutive measurements of diesel vehicle

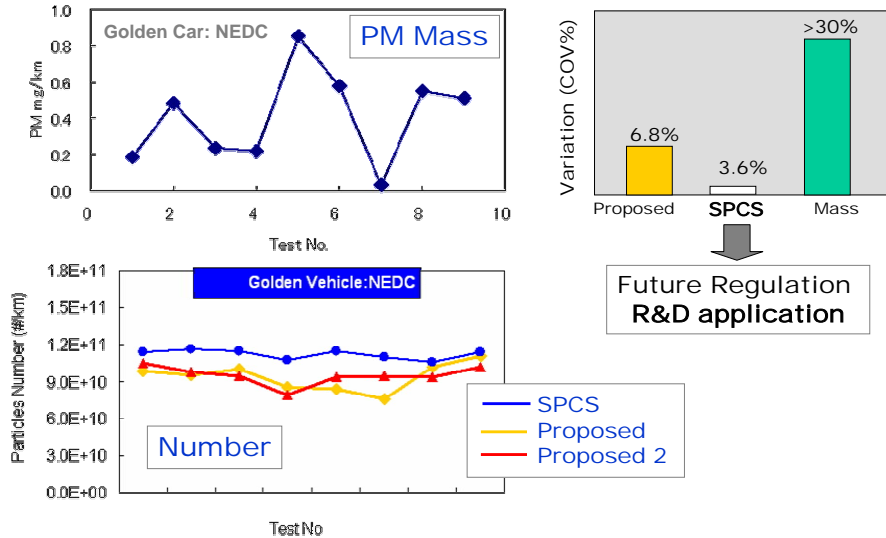


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Mass vs. Number



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Conclusion

- Gravimetric techniques continue to be employed in the industry
 - However, subject to issues related to ultra-low mass measurement
 - Gas HC artifact, electro static force, etc.
- Particle counting method is very promising as highly reproducible technique
 - Can be a good tool for diesel R&D !!
Not only for regulatory purpose.
 - Standard calibration method still to be established
 - Hydrocarbon is becoming dominant PM constituent for DPF diesel. But eliminate it?

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