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A comparison of real-time on-road Diesel particulate emission with chassis dynamometer measurements

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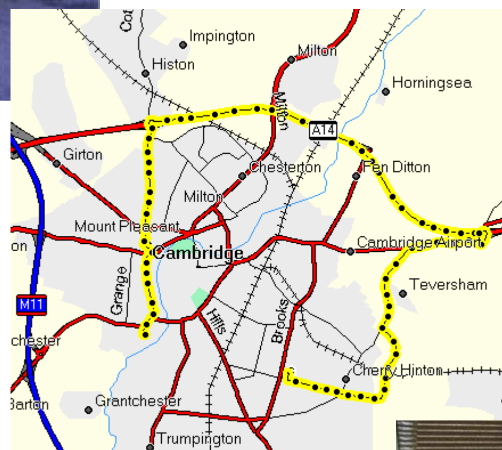
Overview

- Real-time particulate size spectrometer on-board Peugeot 406 2.2l Diesel car
- Diesel Particulate Filter (DPF) removed
- Log road speed and fuelling



- Reproduce drive on chassis dynamometer ("Rolling road")
- Additional spectrometer in standard *Constant Volume Sampler* (CVS) tunnel

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Aims

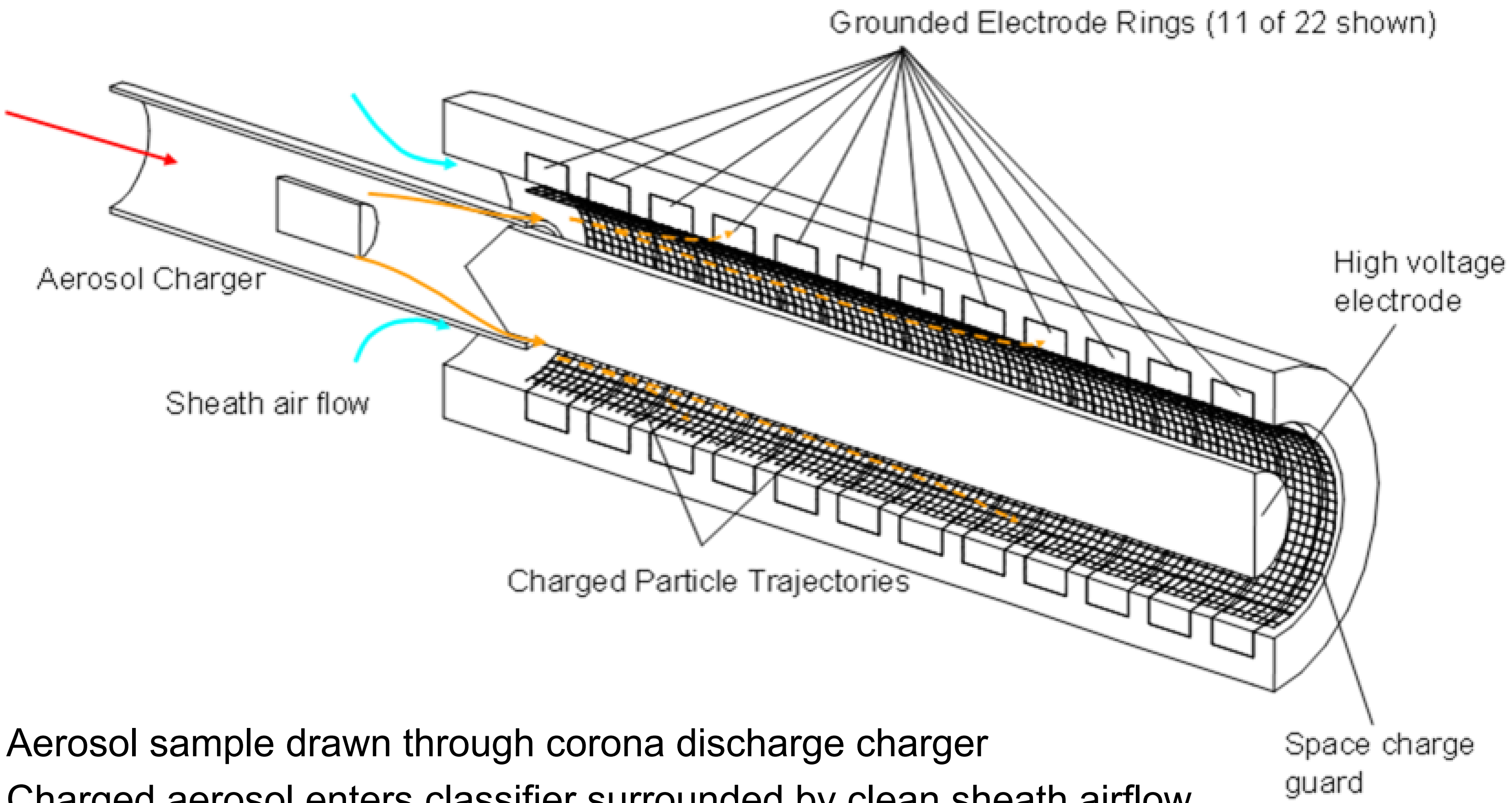
- Identify patterns of driving which cause most particulate pollution
- Can real-world driving be successfully reproduced in the "test cell" environment more often used for such tests?
- Compare direct sampling system of DMS50 with standard Constant Volume Sampler (CVS) system – observe effect upon nucleation.
- Legislative testing is performed under somewhat artificial standard drive cycles; can the vehicle meet the standards on a real-world drive?

Instrumentation (1): DMS50

- Real time particle size spectrometer
- Based upon DMS*500* (Reavell *et al.*, Aerosol Soc AGM 2002)
- 5 – 560 nm
- 10 Hz data rate, ~500 ms T_{10-90} response time
- Built-in rotating disc diluter
- 12 V operable for mobile use

- *DLC50* controls primary dilution at sampling point and drives heated line

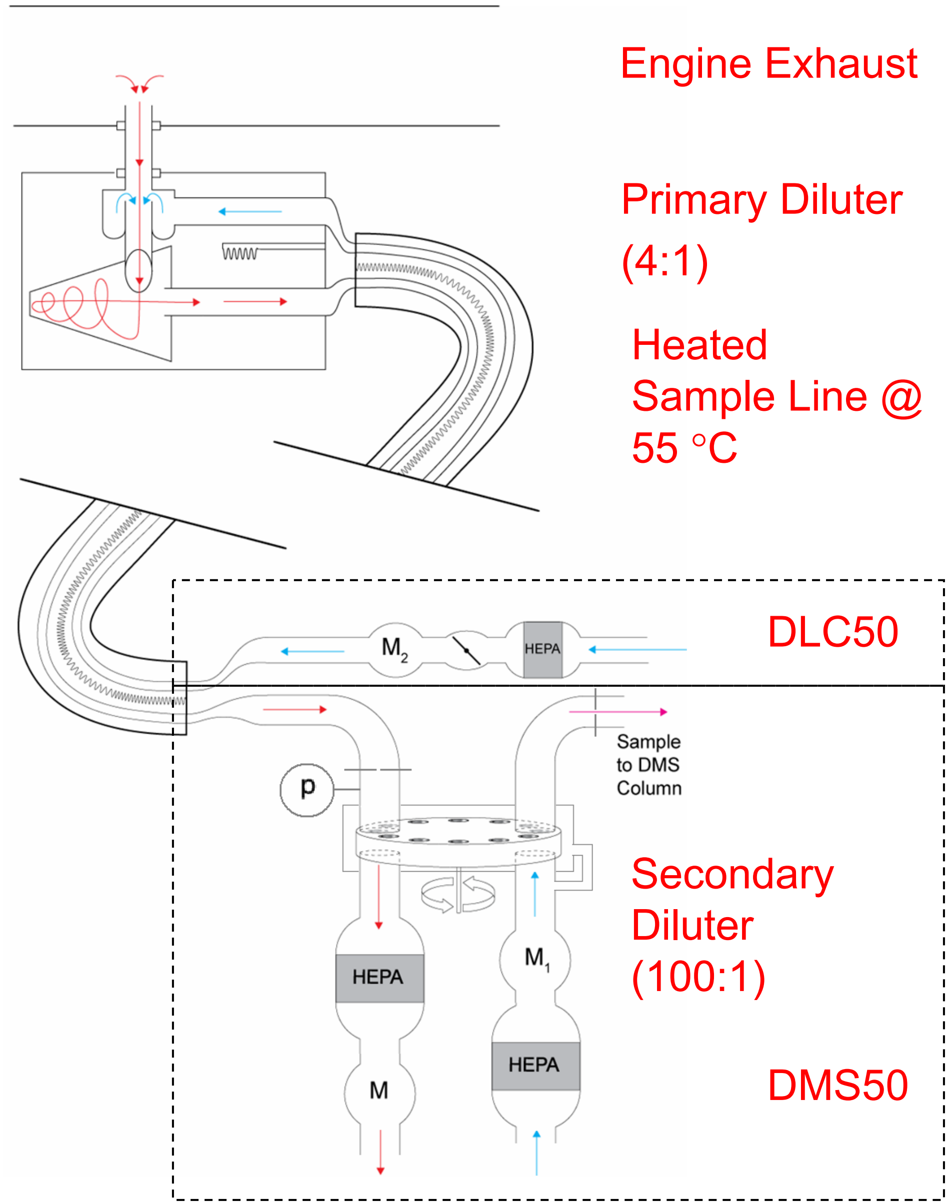
Instrumentation (2): Operating Principle



- Aerosol sample drawn through corona discharge charger
- Charged aerosol enters classifier surrounded by clean sheath airflow
- Strong electric field causes particles to drift towards sensitive electrometer detectors
- Larger particles with more drag drift more slowly and are detected further downstream
- Particle sizing on the basis of charge:drag ratio (electrical mobility)

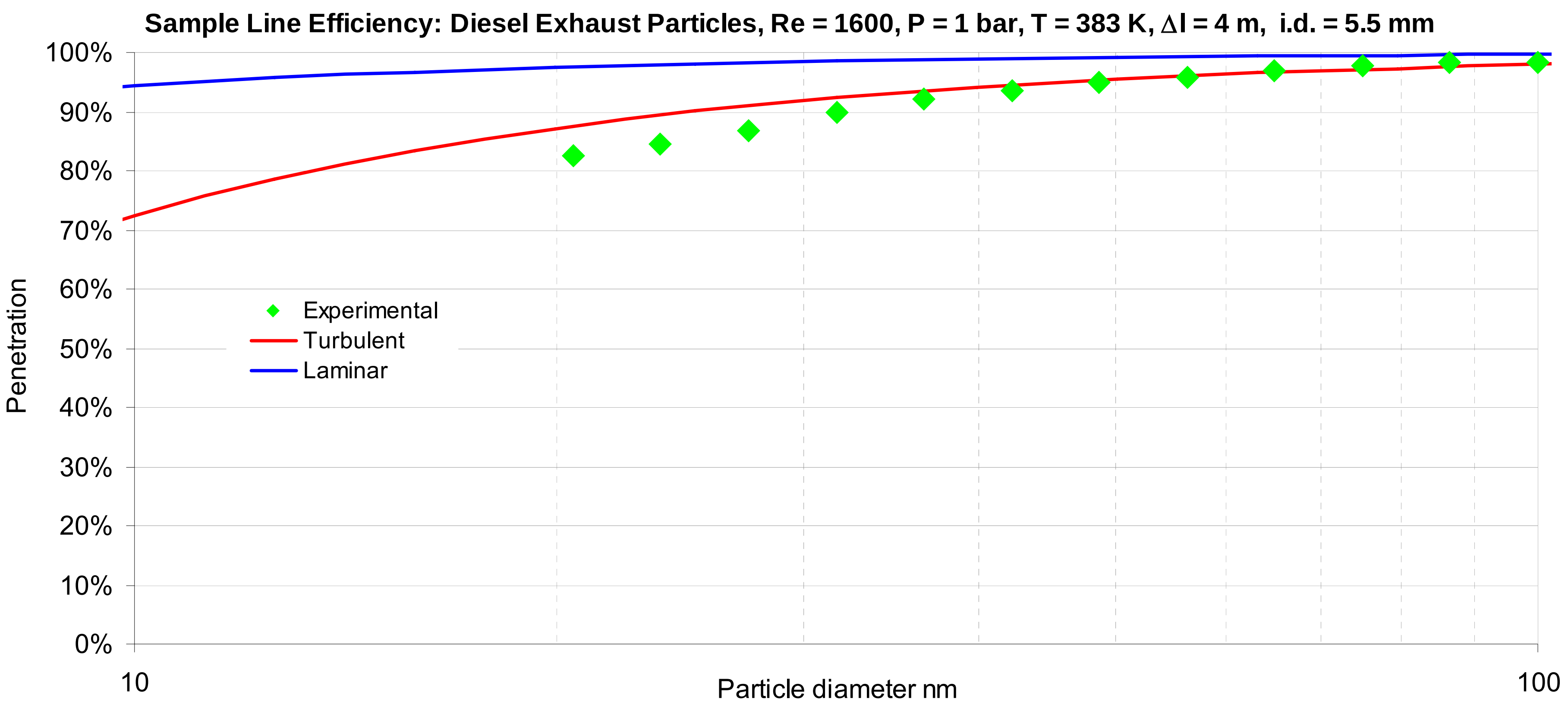
Sampling and Dilution System

- DMS50 has built-in rotating disc diluter
- DLC50 adds primary dilution and heated line control – dilution correction feedback provided to DMS
- Primary dilution
  - Inhibits agglomeration and condensation
  - Mass flow controlled HEPA filtered compressed air.
  - 4:1 dilution ratio used here
  - Heated to 55°C by sample line
- Secondary high ratio diluter
  - Extends instrument cleaning interval
  - Rotating disc type
  - Dilution used: 100:1
- **Total dilution 400:1** used here



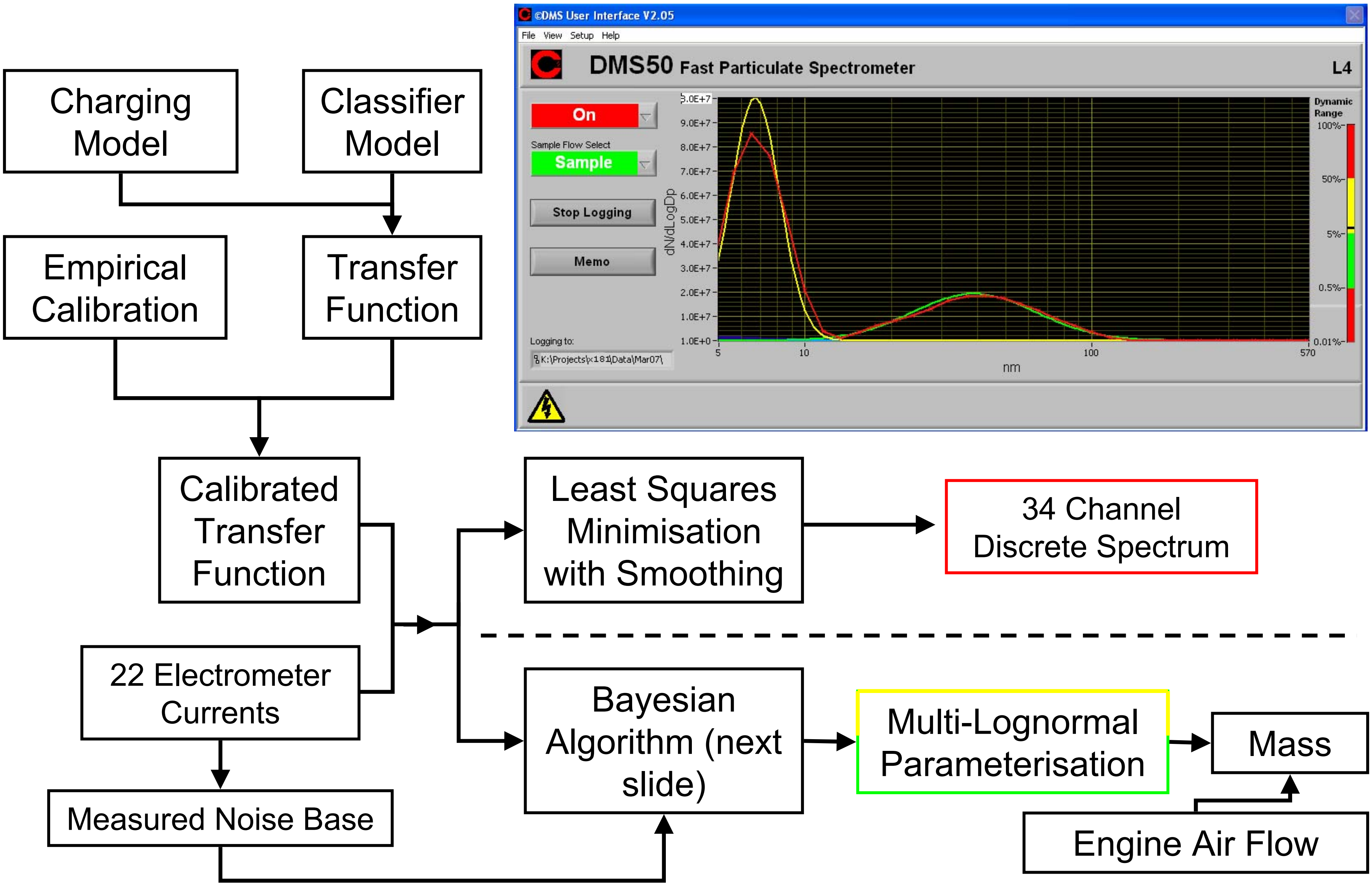
Aside: Sample Line Penetration

- DMS Used to measure sample line losses:



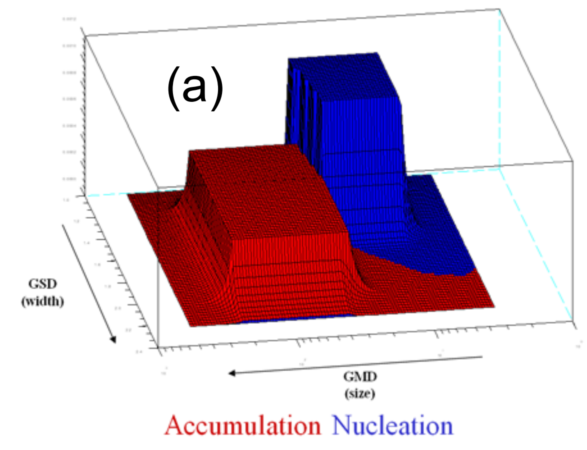
- Similar results with NaCl: at 1 atm with SMPS and at 250 mbar with DMS

Data Processing (1): Size Spectrum

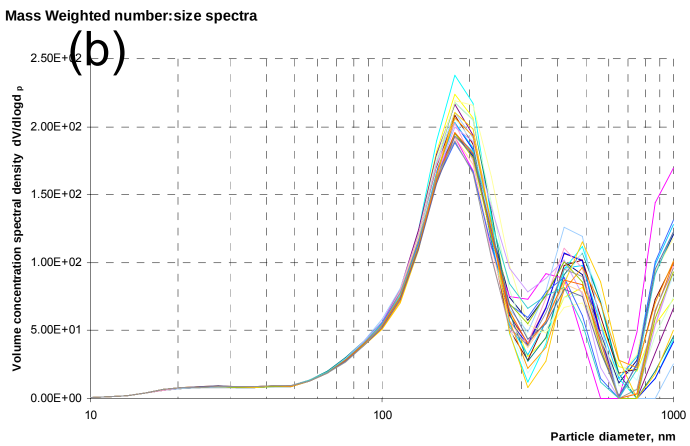


Data Processing (2): Lognormal Parameterisation

- Bayesian statistical algorithm
- Multi lognormal functions optimised
- Probability map of CMD and GSD used to determine whether peak is **nucleation** or **accumulation** **(a)**:
- Determine which modes (if any) are actually significant, only return these.



- Advantages:
  - Simplification of data analysis
  - Automatic separation of modes
  - Increased spectral resolution
  - Reduced noise, esp. for mass weighting (b):



Data Processing (3): Mass Calculation

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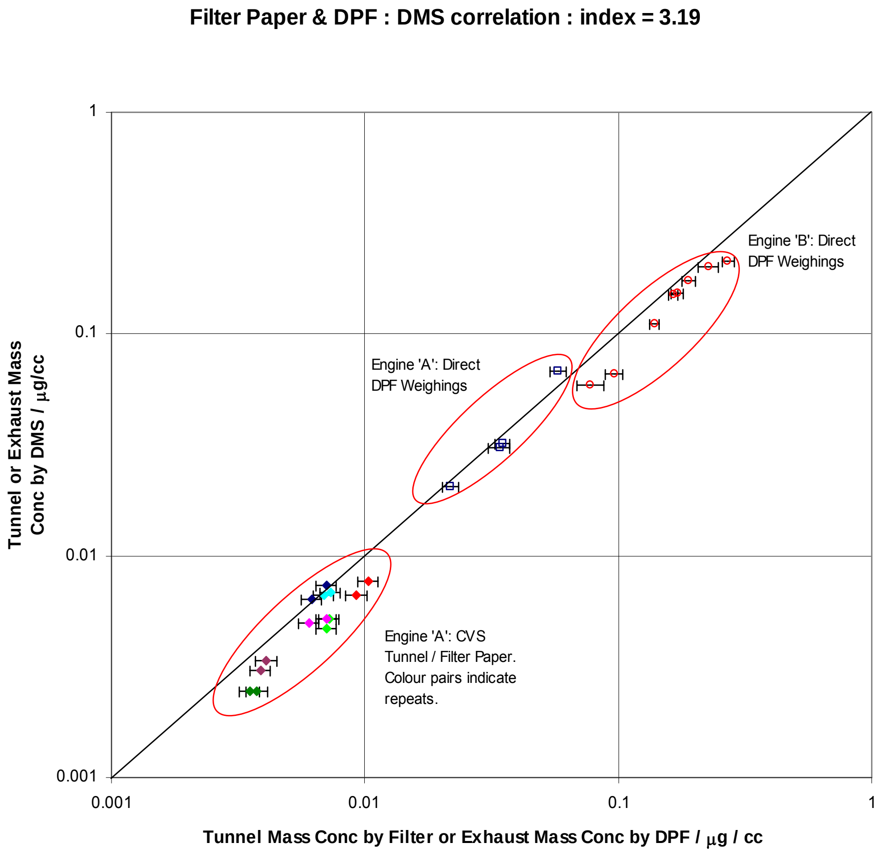
- Lognormal algorithm allows modes to be weighted by different functions (spherical vs. agglomerates) and reduces noise in tails of spectrum.
- Volume relationship for agglomerates sampled with DMS-type instruments:

$$\textbf{volume} \propto \mathbf{D^{3.19}}$$

- Validation data (Symonds *et al.* 2007) cf. Diesel Particulate Filter and Filter paper weighings:



Experimental

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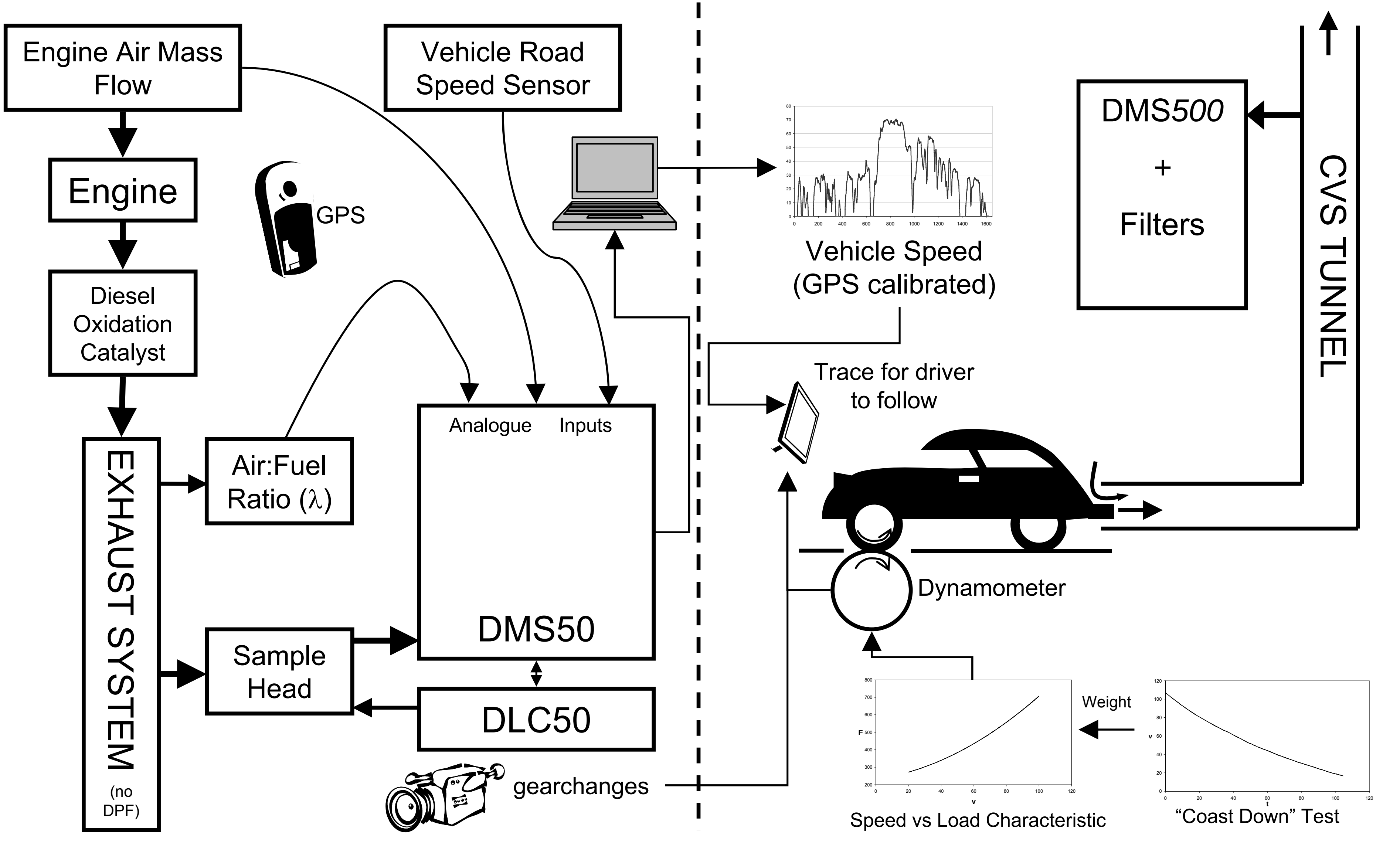
In Vehicle (Road & “Rolls”) | Dynamometer (“Rolls”)



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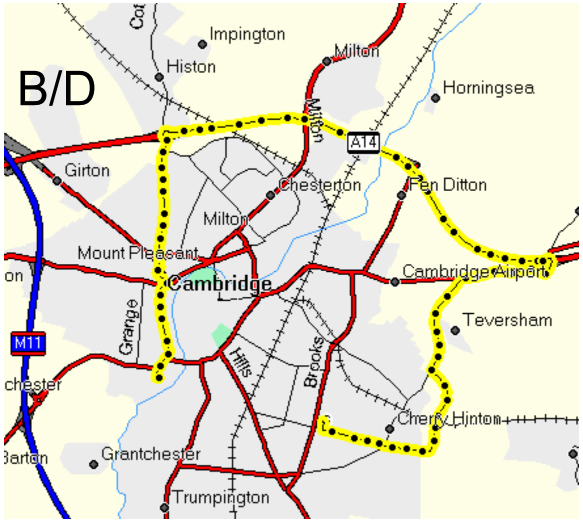
Routes

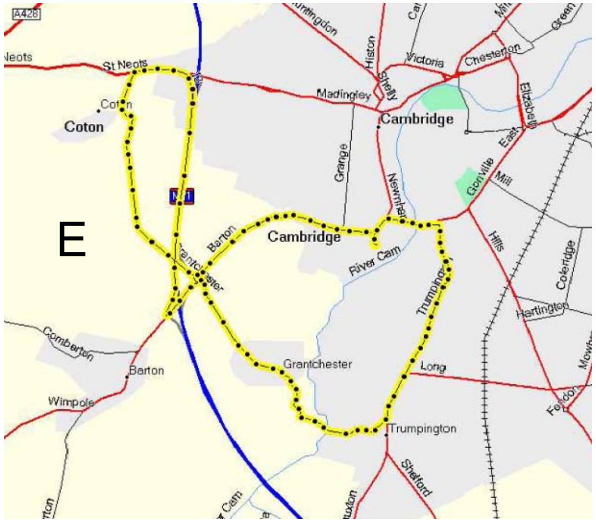
- Day 1:
  - A: Warmup
  - B: Newnham →“The Backs” → A14 → Newmarket Road → Cherry Hinton

    Both urban and extra urban driving. Wind: 6.2 mph, S.E. (head)
- Day 2:
  - C: Warmup
  - D: As B but slightly longer at start.

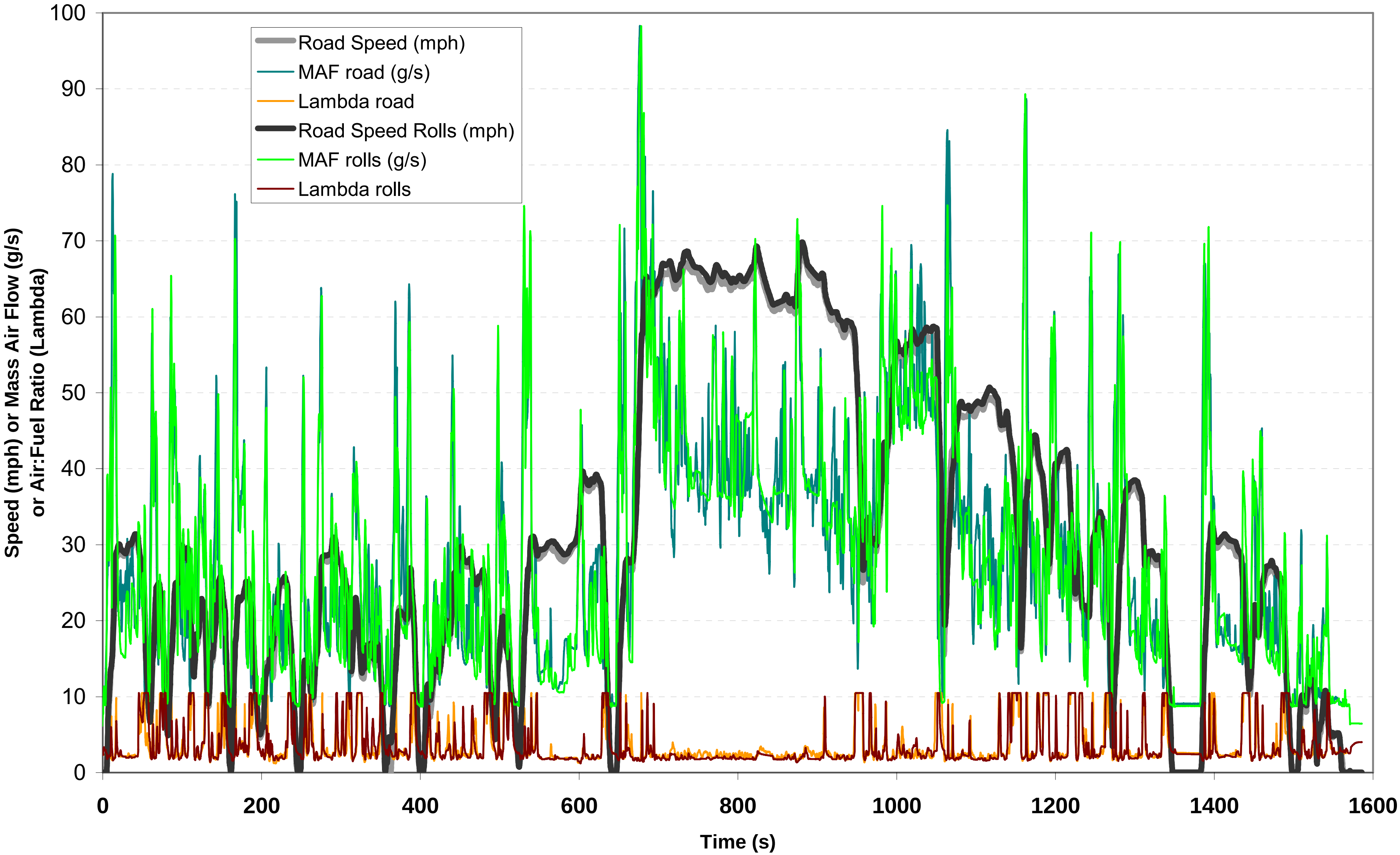
    Wind: 10 mph, W (tail)
- Day 3:
  - E: Sampling **pre-DOC**

    Newnham → M11 → Coton → Granchester → Trumpington

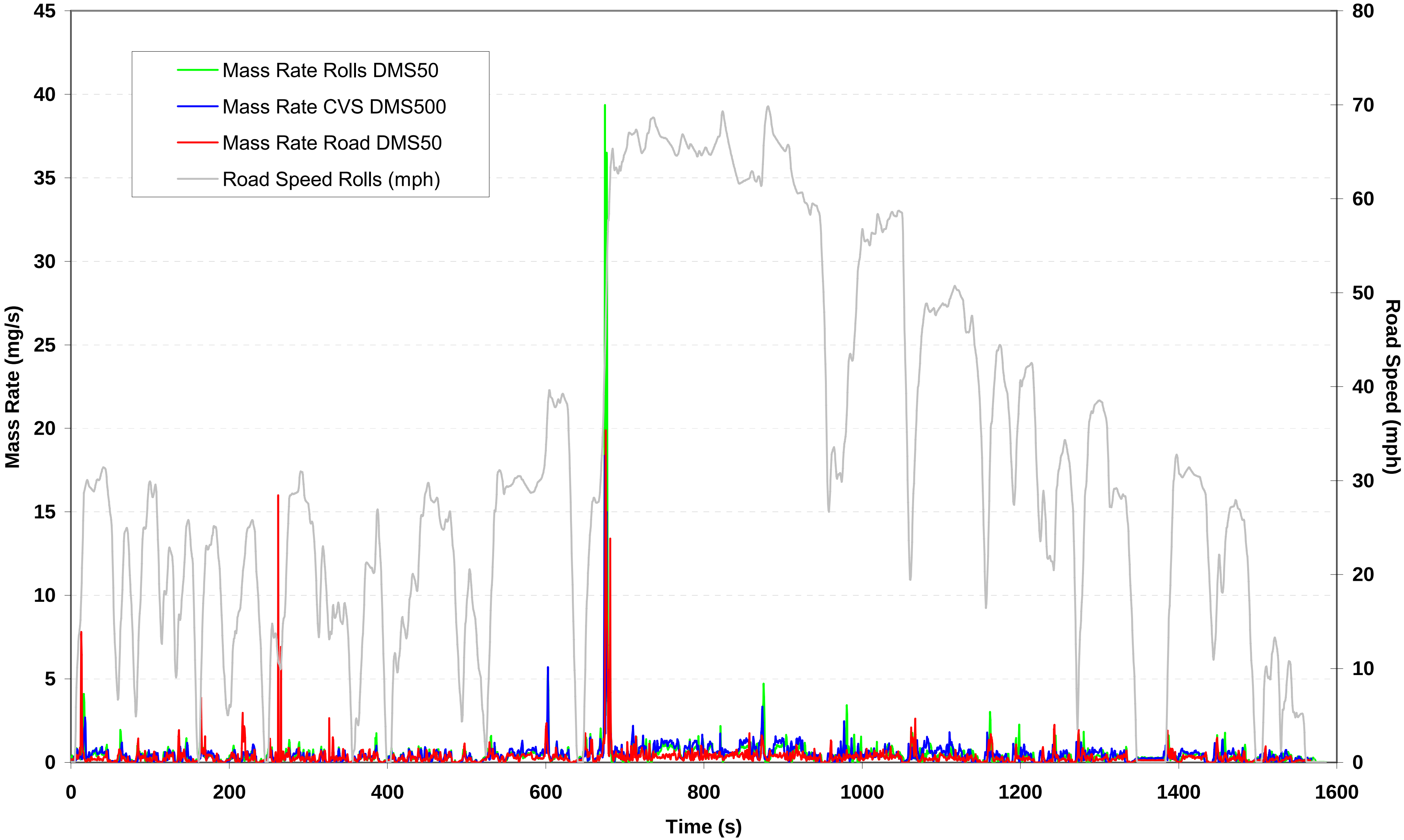




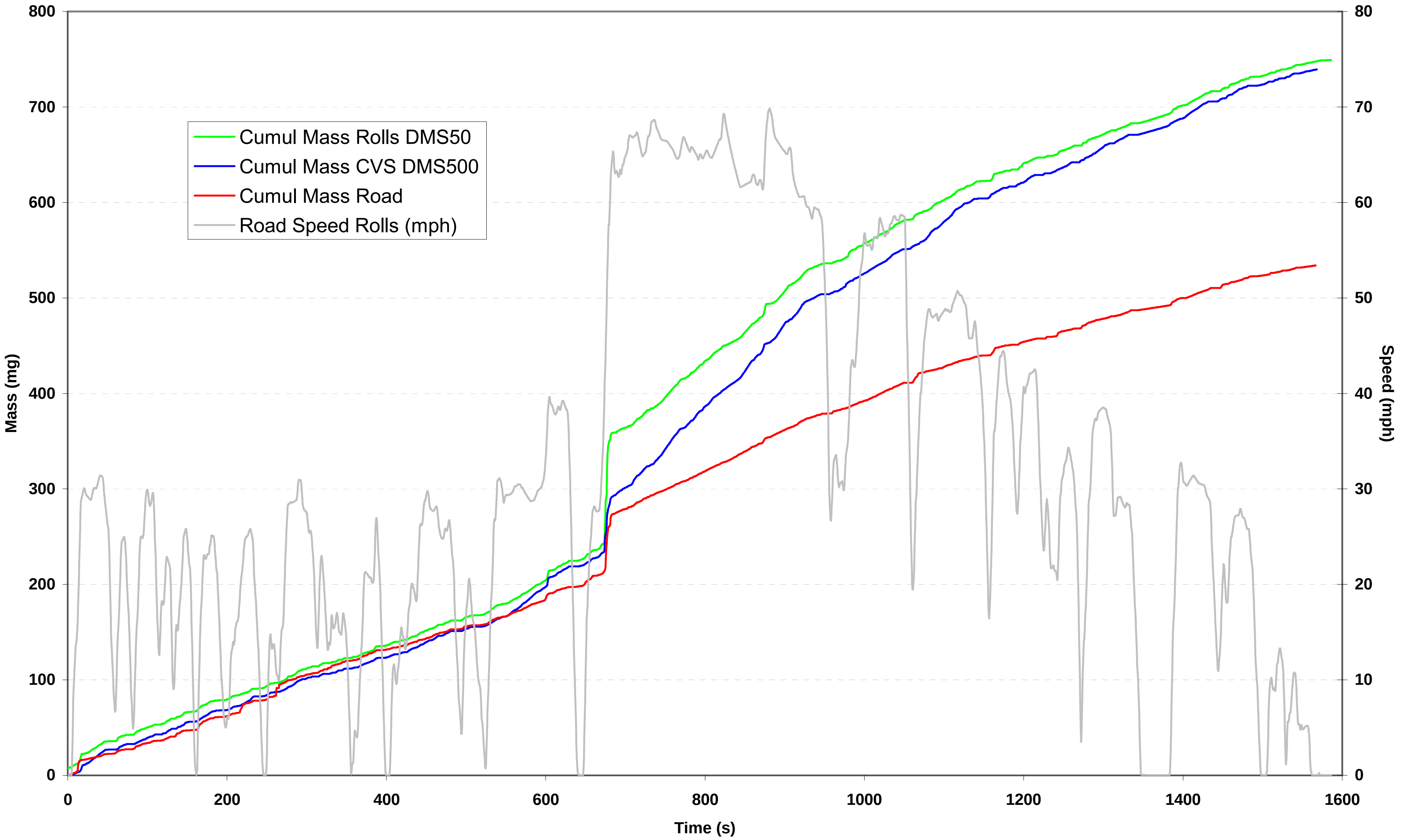
Drive D: Repeatability



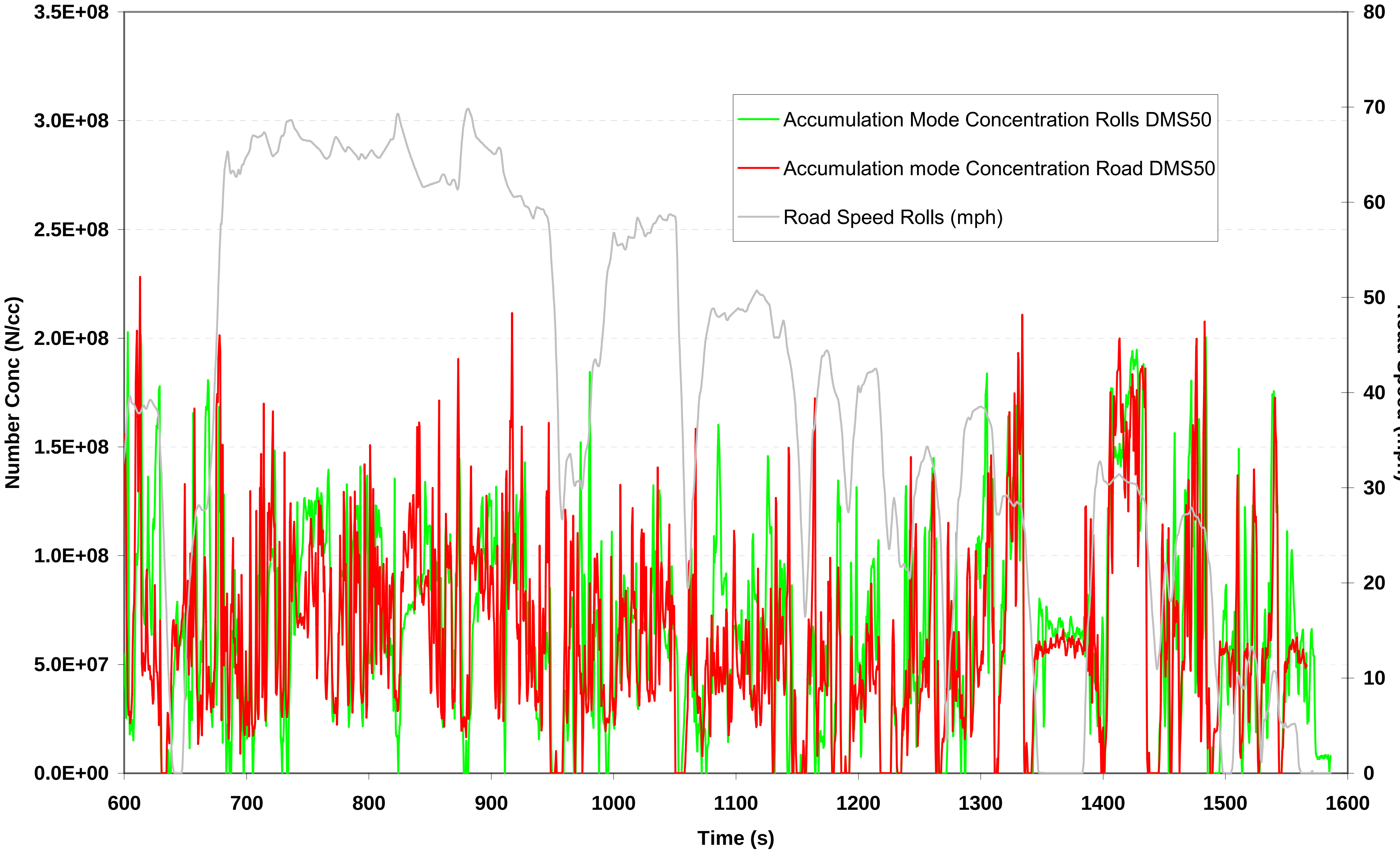
Drive D: Soot Mass Rate



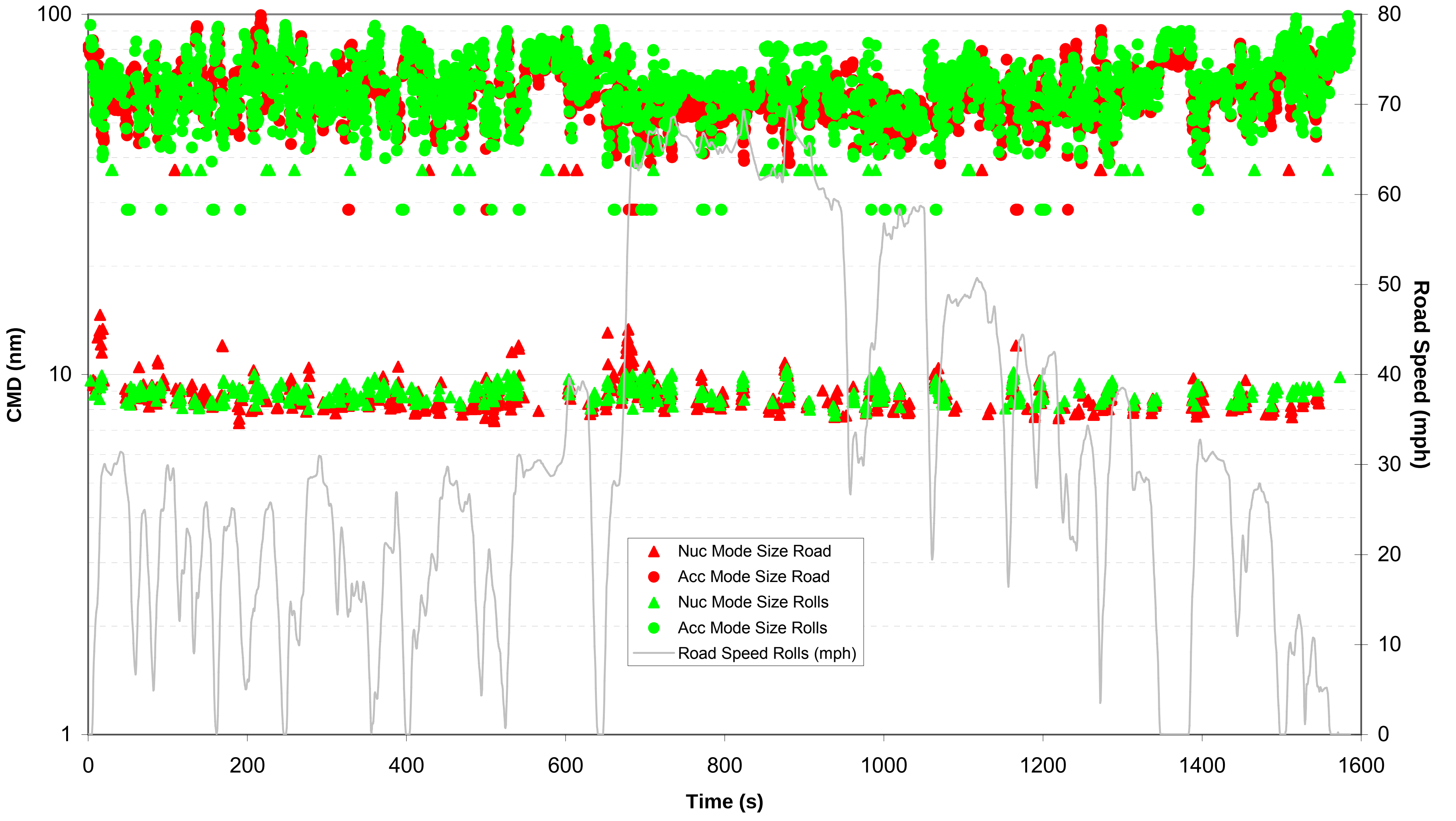
Drive D: Cumulative Soot Mass Emission



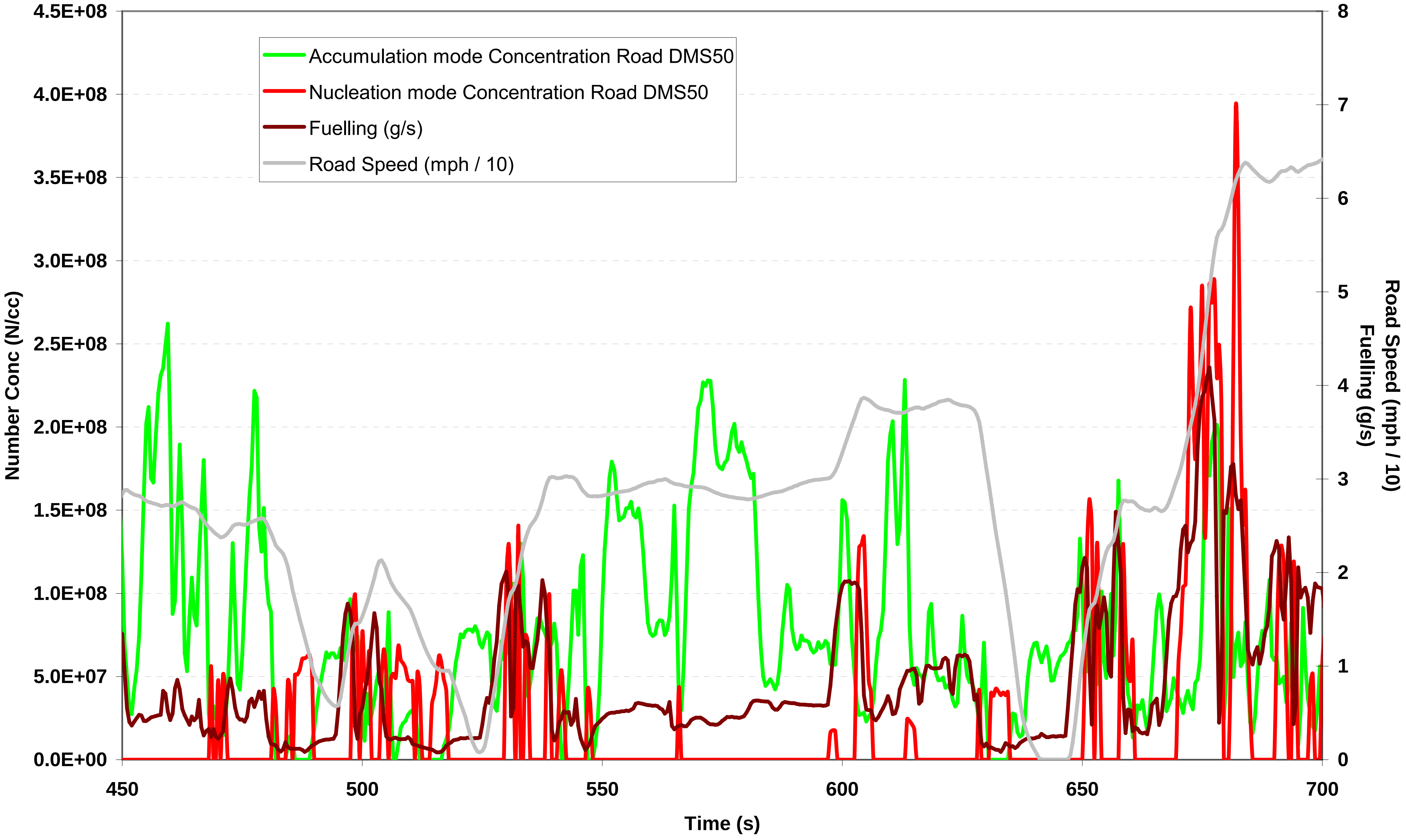
Drive D: Accumulation Mode Concentration Differences



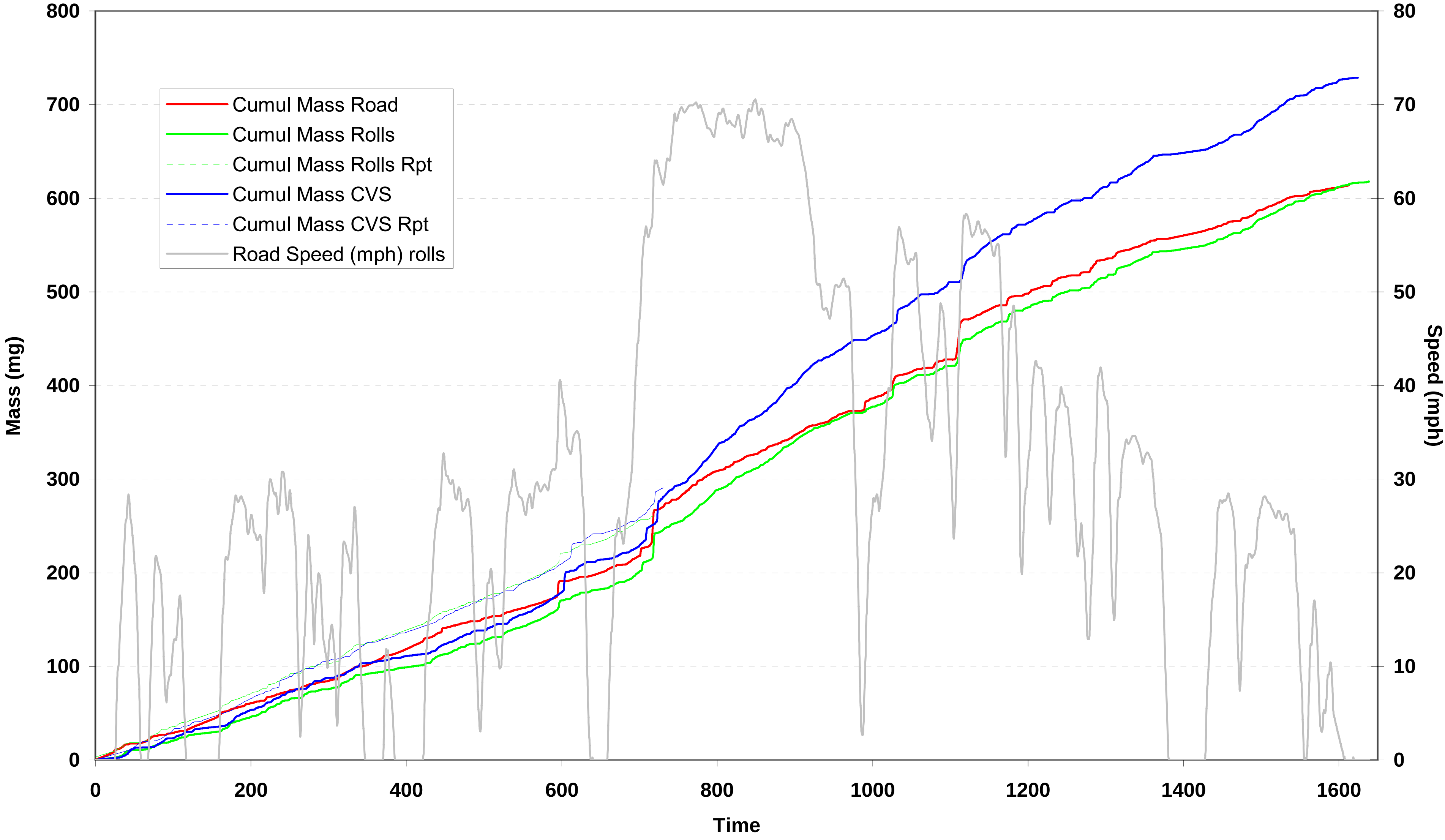
Drive D: Size Differences



Drive D: Effect of Fuelling on P.M.



Drive B: Cumulative Soot Mass Emission



Drive B: Total Concentration

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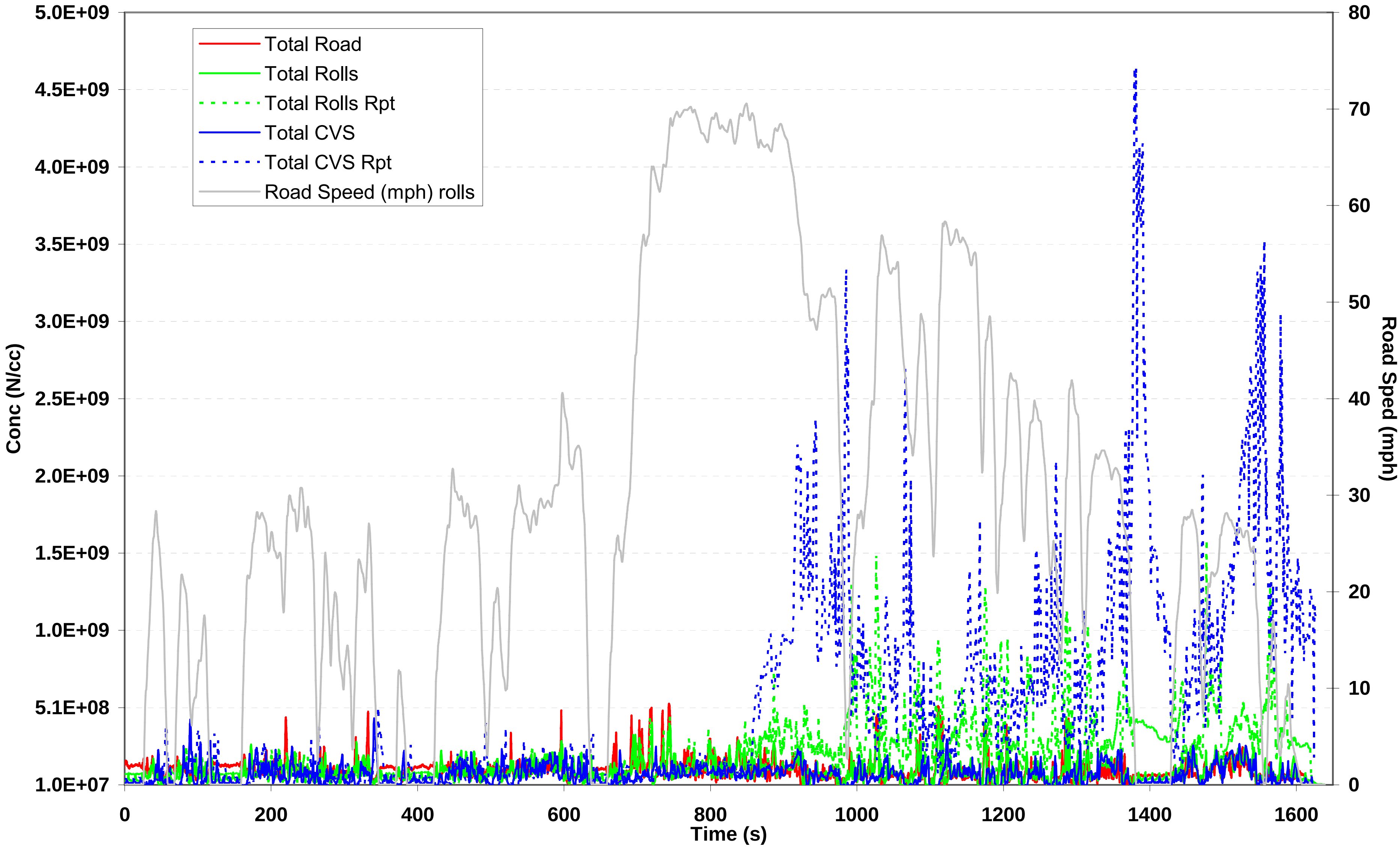
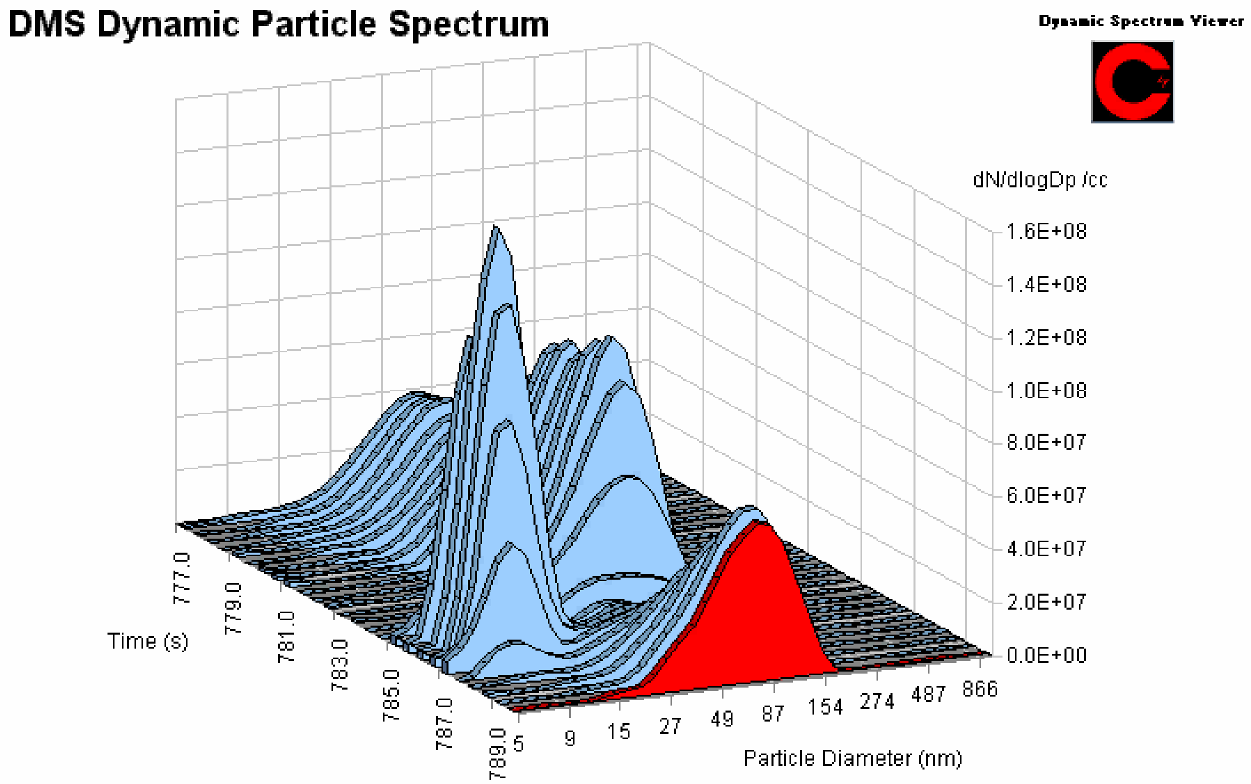
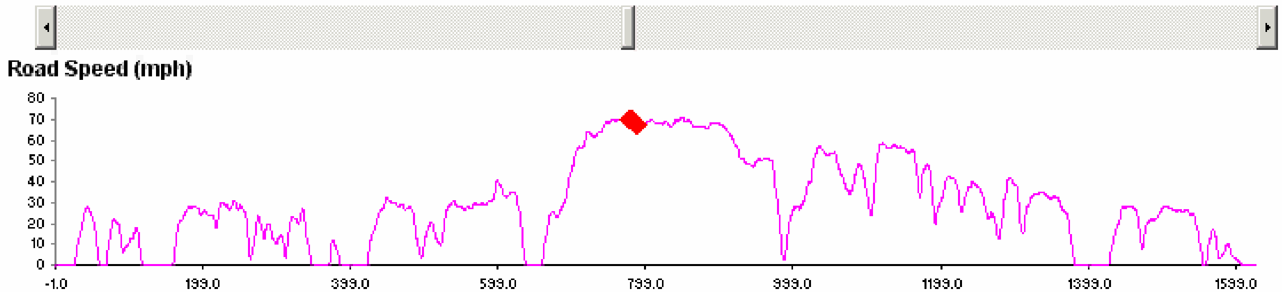
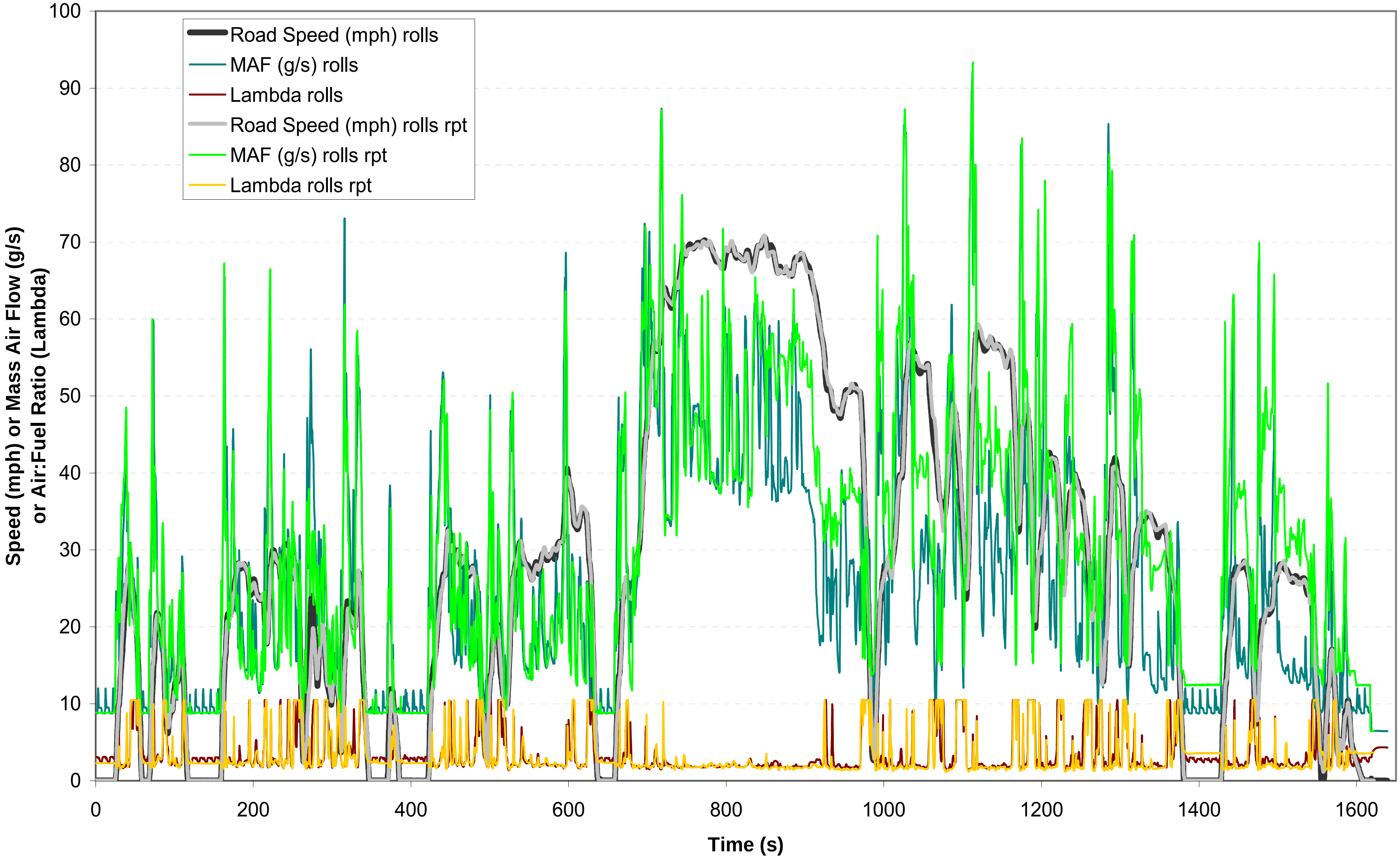


Drive B: Animation, CVS Repeat



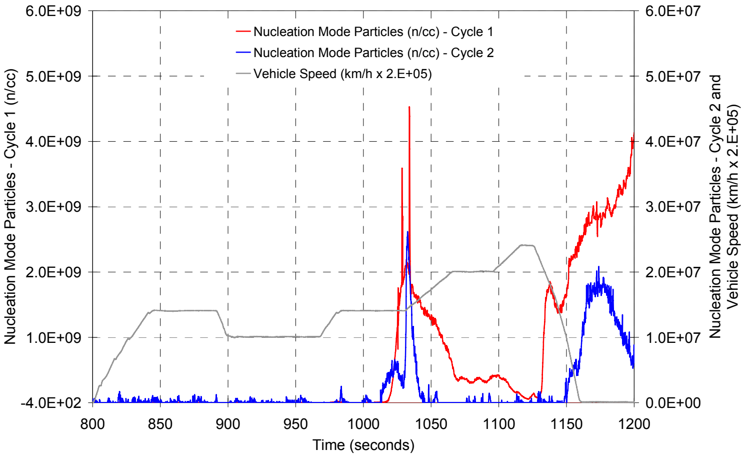


Drive B: Change in Vehicle on Repeat



DPF Regeneration Event

- Although DPF not fitted, ECU can attempt to regenerate after a period of driving.
- “Post-injection” of extra fuel causes high temperature in exhaust system $\Rightarrow$ soot oxidation.
- Large nucleation mode also seen *with DPF fitted*, post-DPF (Campbell *et al.* 2006):



- This suggests that nucleation precursor is emitted from DOC when hot, nucleation then occurring in exhaust system or CVS.
- Chemical analysis by Campbell *et al.* suggested Sulphate to be the major constituent.
- Sulphate (from sulphur in fuel) known to adsorb on DOC substrate.

Nucleation Material

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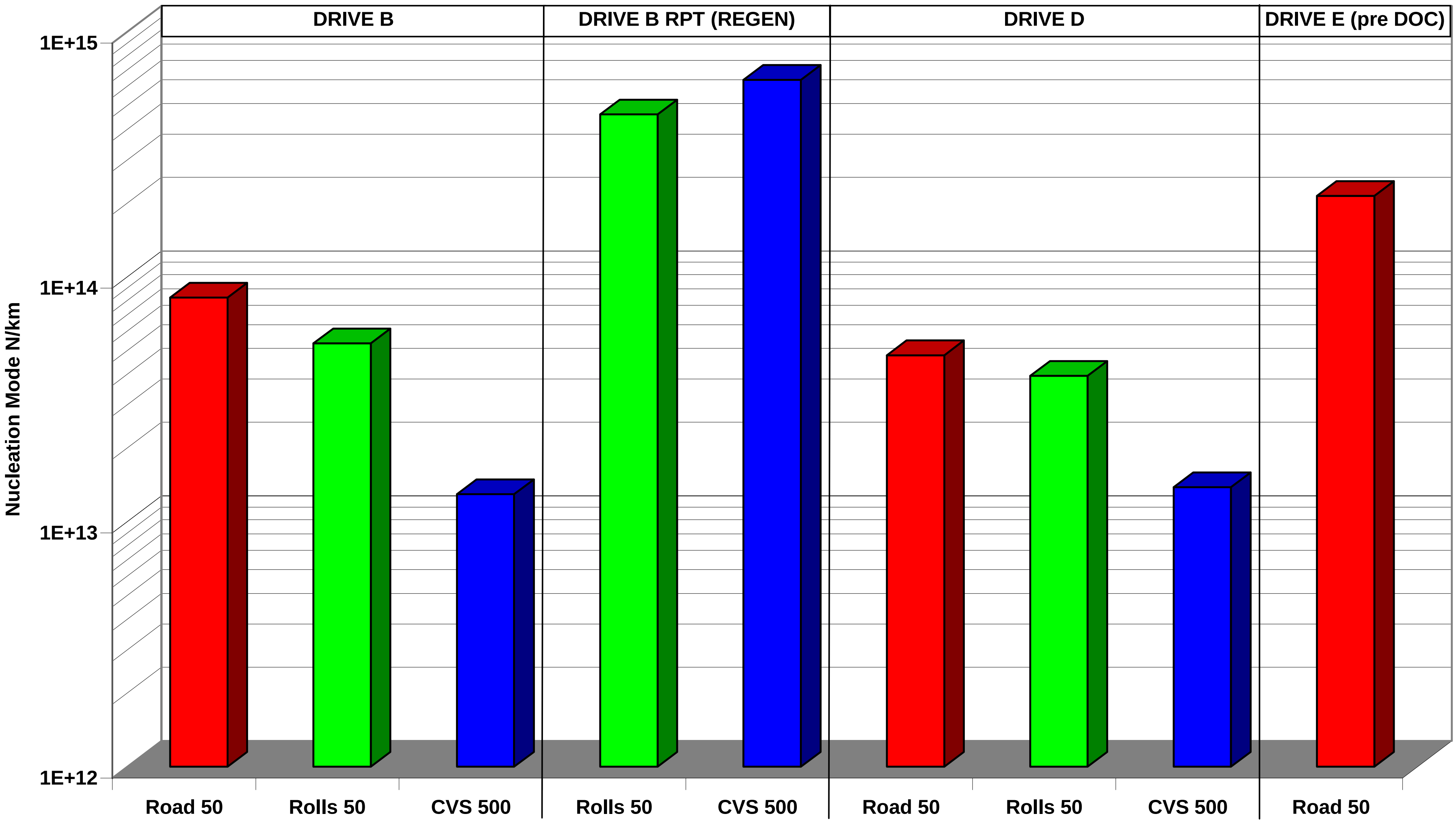
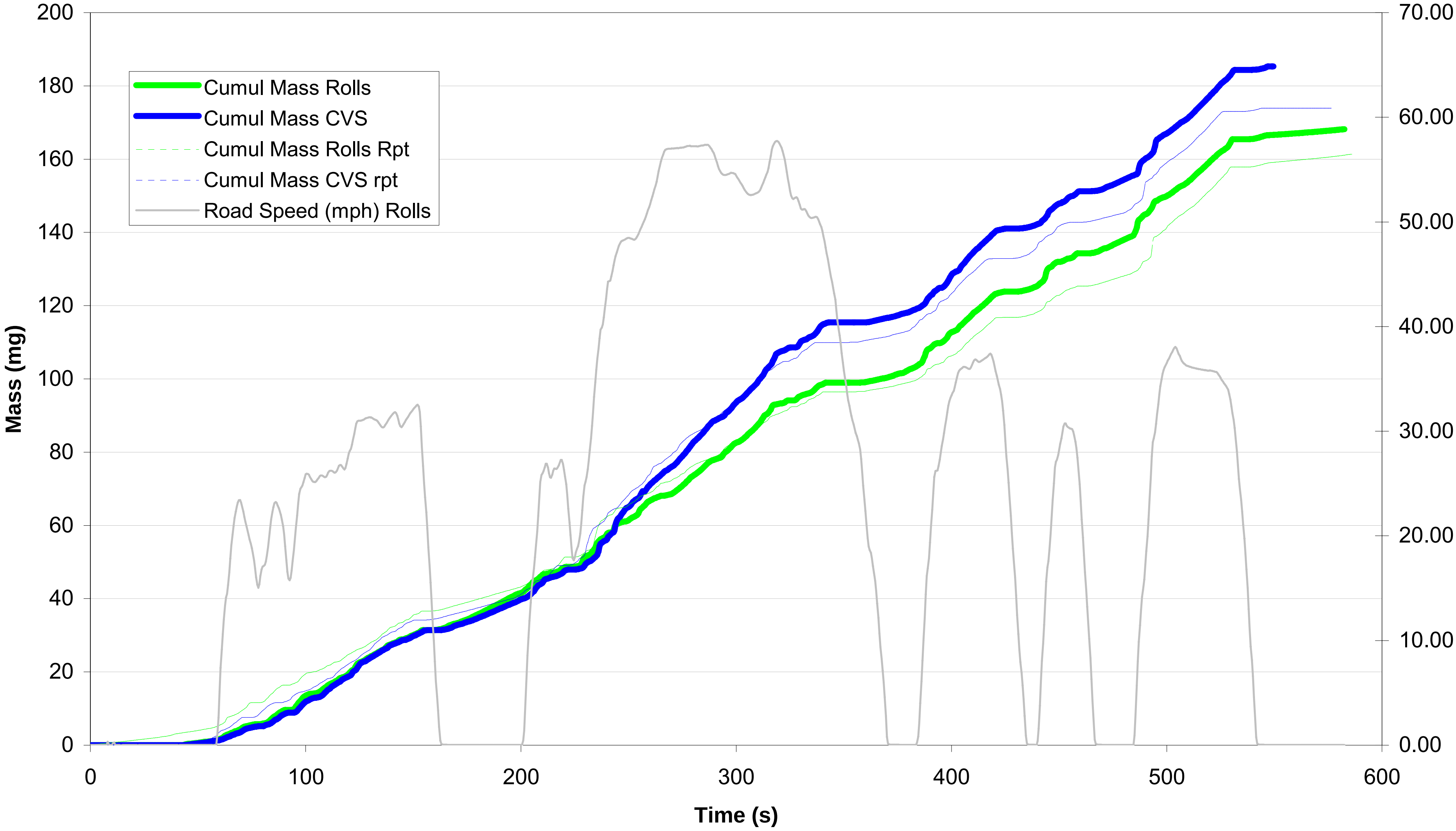
N / km; corrected to tailpipe



FTP75, 1st 505s: Cumulative mass



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Specific Emissions

Test	Filter Paper	DMS50 Rolls	DMS500 Rolls	DMS50 Road	Euro Stage III Limit
Drive "D"	0.047 g/km	0.034 g/km	0.033 g/km	0.024 g/km	0.05 g/km
FTP75, 1st 505 s	0.042 g/km	0.027 g/km	0.029 g/km	n/a	

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Conclusions

- Acceleration and Deceleration responsible for much P.M. emission: Slip road to A14 gives ~10% of the mass of a half-hour drive.
- Correlation between peaks and troughs in fuelling and peaks in nucleation mode emission
- Less correlation between fuelling and accumulation mode emission – unknown factor introduced by Exhaust Gas Recirculation.
- DPF regeneration produces large amount of (probably) desorbed sulphate from the DOC, which forms a large (ca. 50 nm, 4×10^9 cc^{-1}) nucleation mode.
- However, DOC reduces nucleation material during normal driving, by oxidising un-burnt hydrocarbons.
- Vehicle easily meets Euro III emissions standards, even without a DPF, even “off-cycle”.
- Remarkable how closely on-road tests can be reproduced under laboratory conditions.

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Acknowledgements

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