Physical Characteristics of PM from 2-Stroke and 4-Stroke Motorcycle Engines

G. Martini, P. Bonnel, C. Astorga-LLorens, A. Krasenbrink
Institute of Environment and Sustainability
European Commission – Joint Research Centre
ISPRA (Italy)

- ***Vehicle Emissions Laboratory (VELA) - Institute for Environment and Sustainability***

Background and objectives of the study:

- **Background:**
  - Amendment of the European Directive 97/24/EC
  - EURO3 stage for two and three-wheelers from 2006
  - Reduction of particulate emissions

- **Main Objectives:**
  - To evaluate particulate measurement techniques
  - To determine particulate mass emissions from 2-stroke engines
  - To assess particulate emissions for big four-stroke engines to check if they diverge significantly from passenger cars with similar engine sizes

Test Fleet:

Motos	Eng. (cc)	2S	4S	Remarks
MT001-50	50	X		Pre Euro1 Moped – No Cat
MT002-50	50	X		Direct Injection – No Cat
MT003-50	50	X		Conventional 2-stroke – With OxCat
MT004-125	125		X	Carburetor
MT005-125	125		X	Controlled TWC
MT006-200	200		X	Carburetor
MT007-500	500		X	SAI
MT008-1150	1150		X	Controlled TWC
MT009-1200	1200		X	Controlled TWC

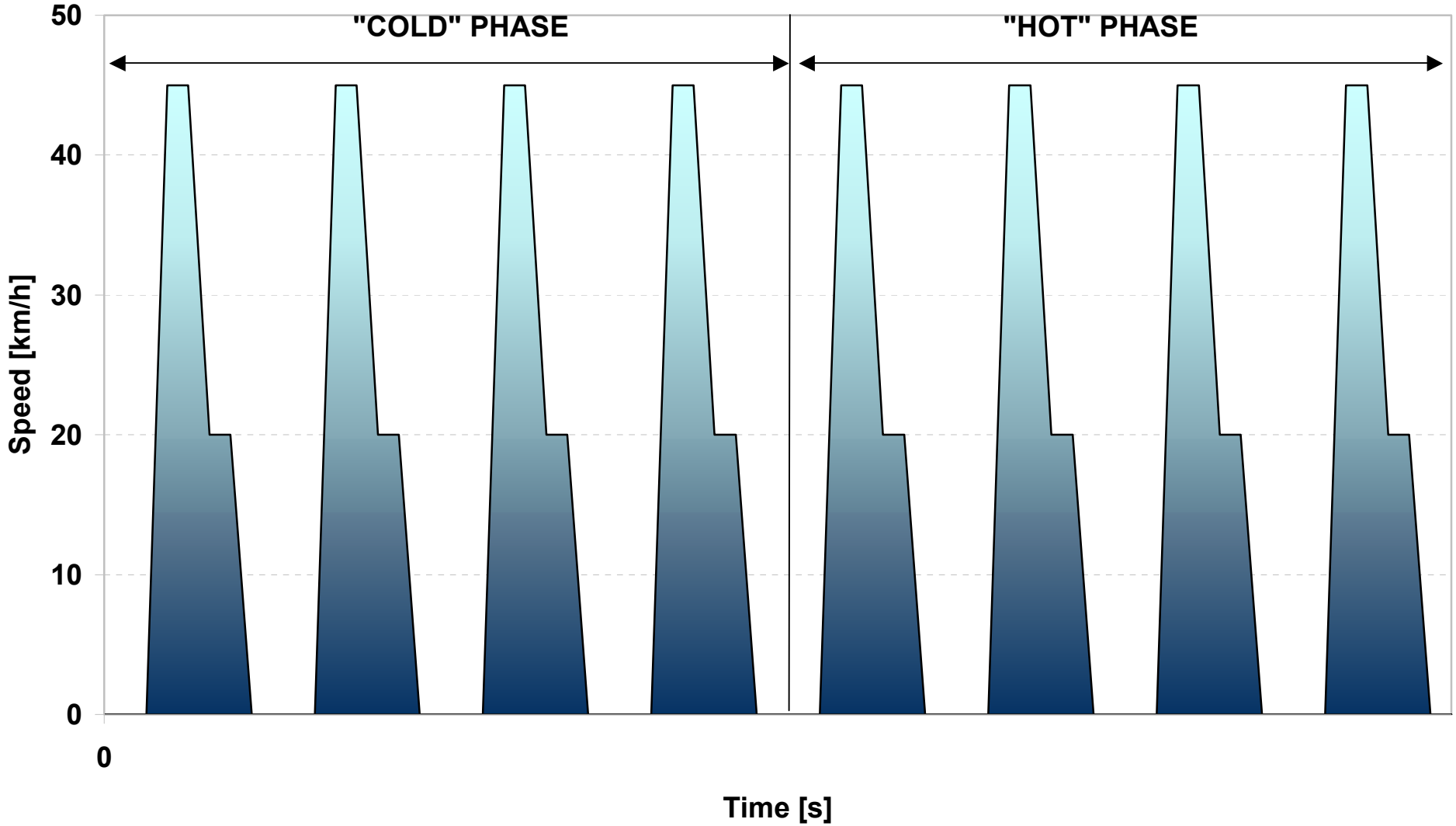
EFI = Electronic Injection
SAI = Secondary Air Injection
OC = Oxidation Catalyst
TWC= Three Way Catalyst

Test Matrix:

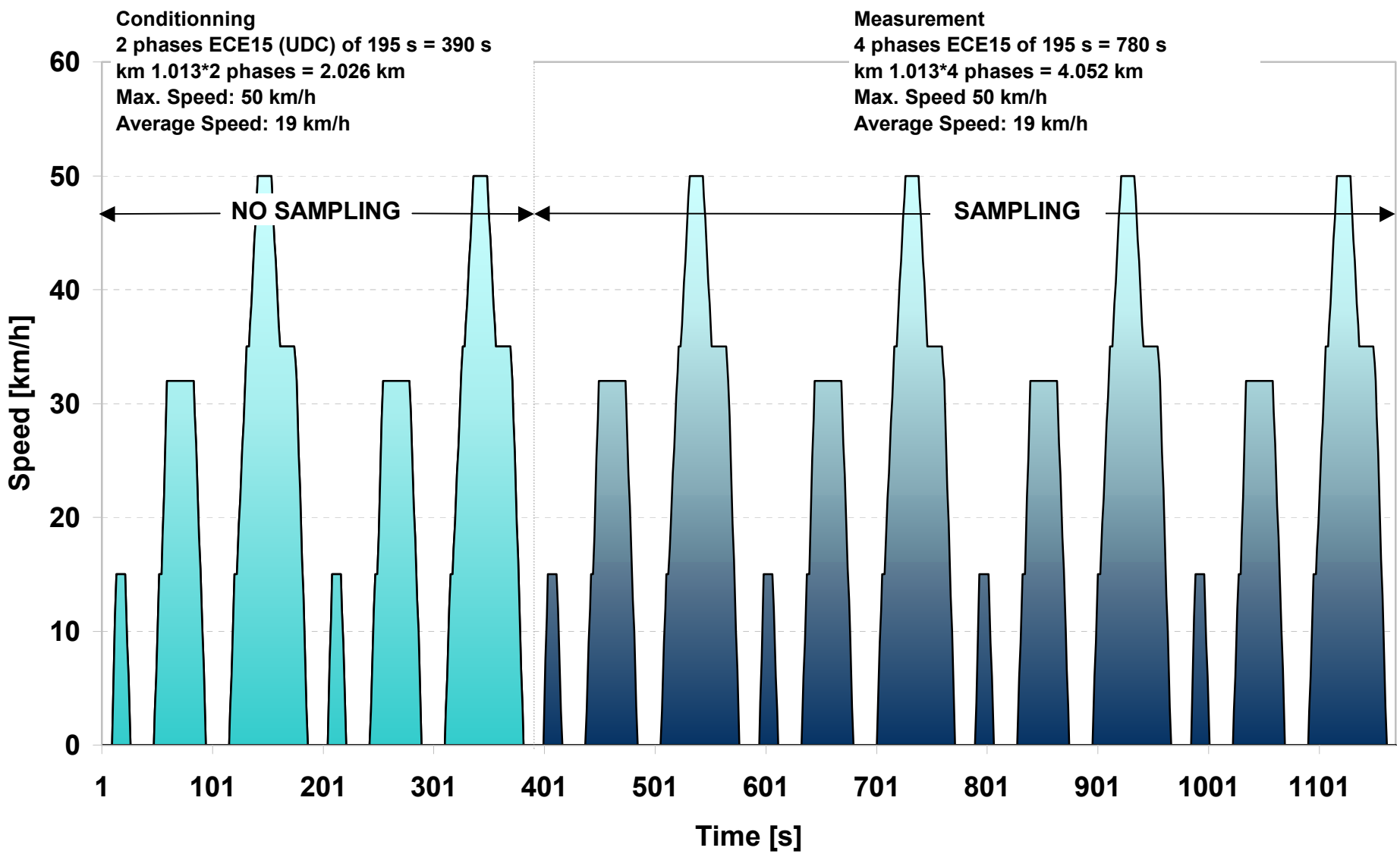
Motos		EURO2	EURO3		WMTC
	ECE47	ECE 40	6UDC	6UDC+EUDC	(*)
MT001-50	X	X	X		
MT002-50	X	X	X		X
MT003-50	X	X	X		
MT004-125		X	X		X
MT005-125			X		X
MT006-200			X		X
MT007-500		X		X	X
MT008-1150				X	X
MT009-1200				X	X

(*) Worldwide Motorcycle Test Cycle

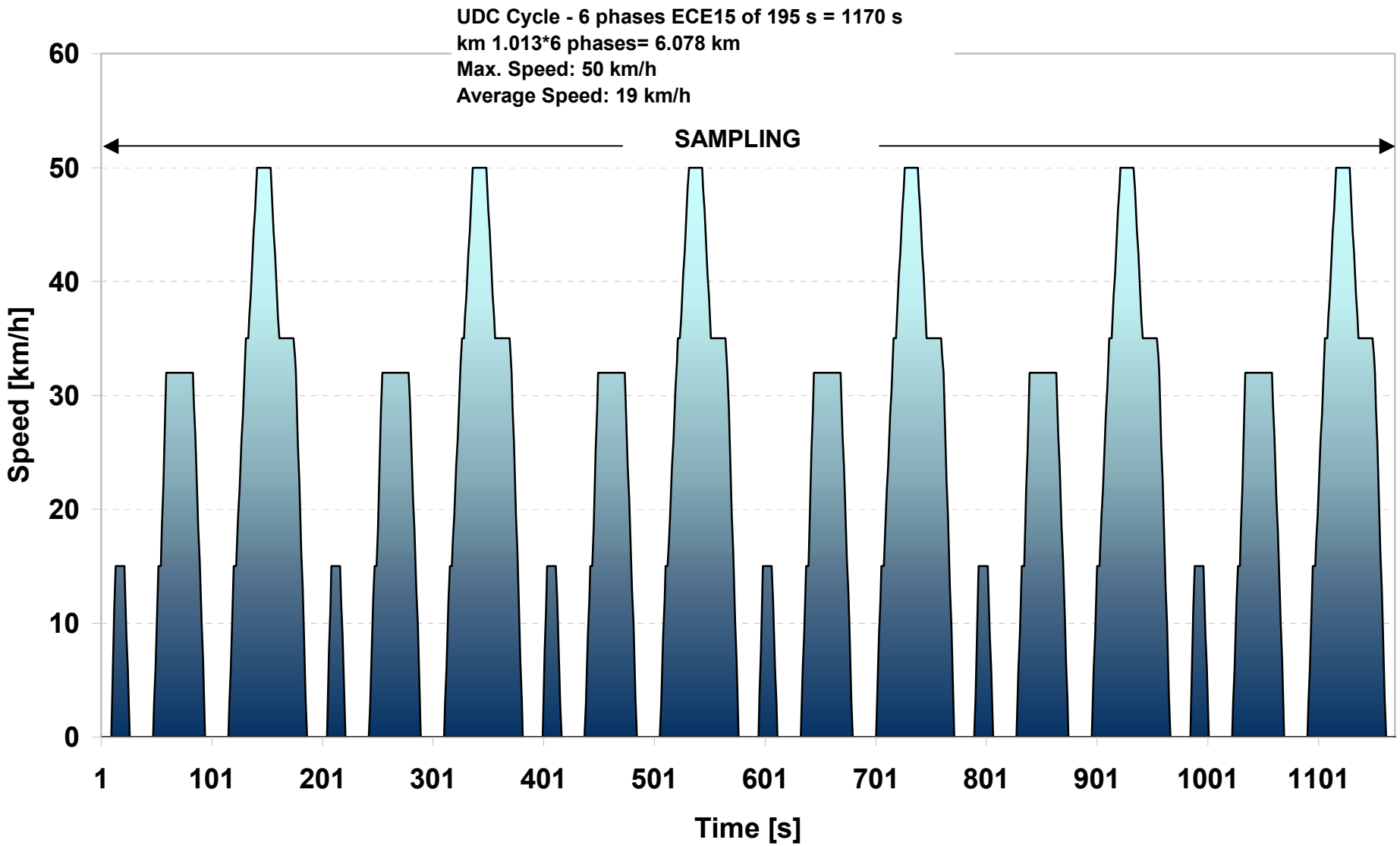
Test Procedure: *1a. ECE 47 Test Cycle (Mopeds only)*



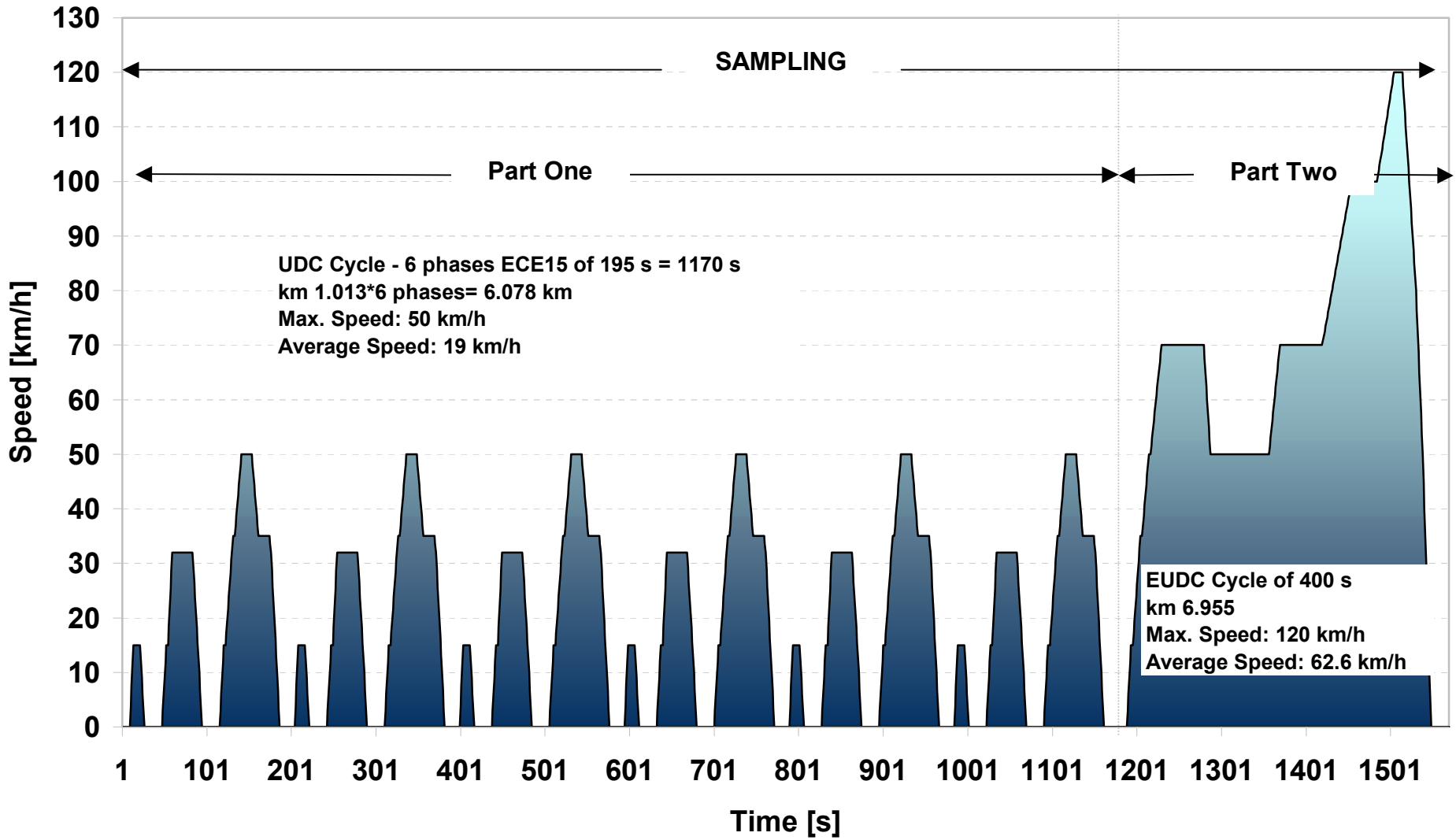
Test Procedure: *1b. EURO 2 Test Cycle*



Test Procedure: *1c. EURO 3 Test Cycle (<=150 cc)*



Test Procedure: *1d. EURO 3 Test Cycle (>150 cc)*



Test Procedure: *2. Test Set-up*

- Carried out at the JRC-VELA1 emissions test facility
- Roller bench 48” suitable for testing small two wheelers
- Conventional CVS system + dilution tunnel

Particulate Emissions Characterisation:

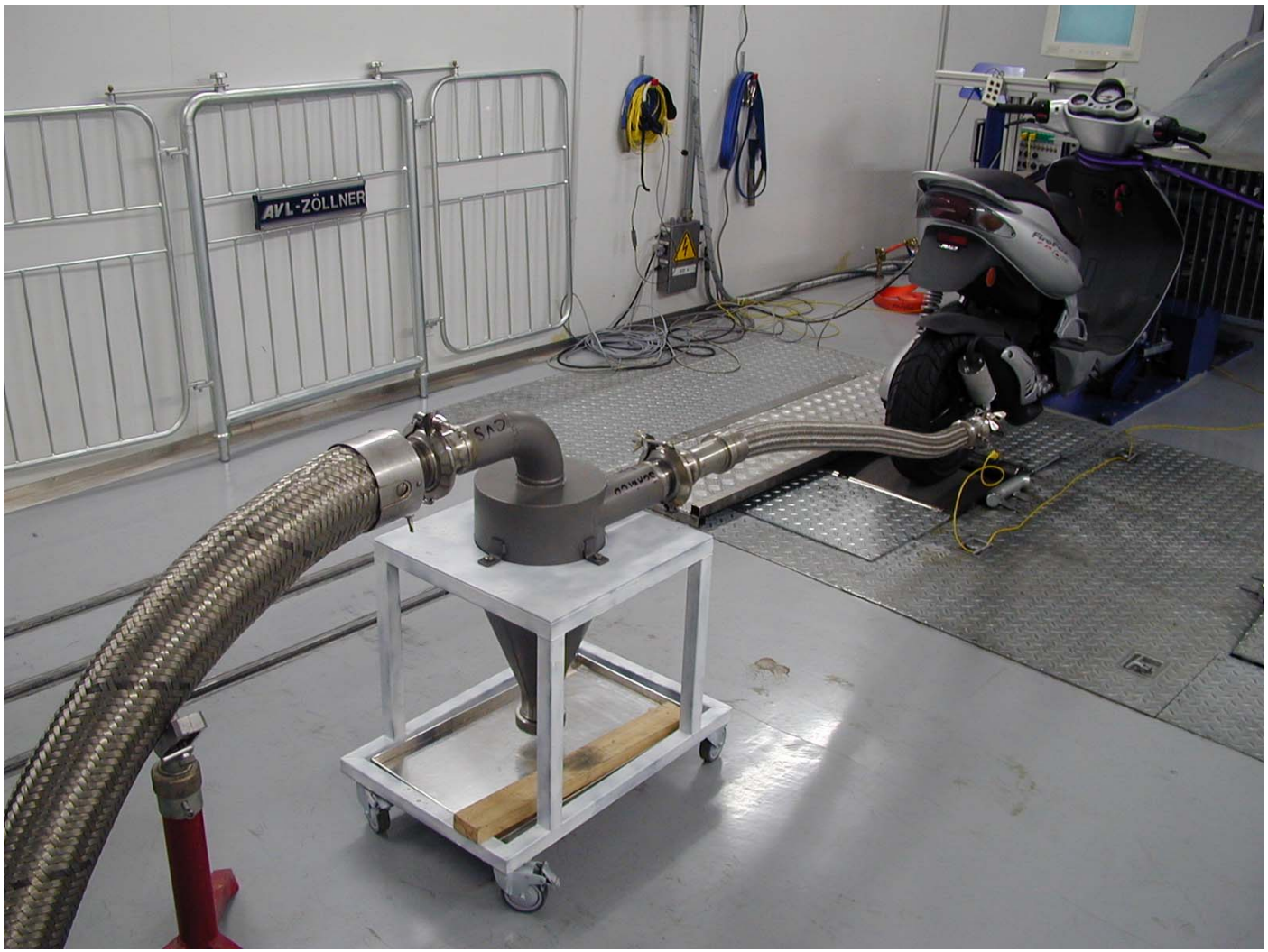
- **Measurement of particulate total mass**
  - The legislative procedure prescribed for Diesel was used to measure particulate total mass
  - In addition, a cyclone was used to avoid contaminating the sampling system and the analysers with very large droplets of lubricant

- **Particulate physical properties:**
  - Number/size distribution (TSI – SMPS)
  - Mass/size distribution (LPI)

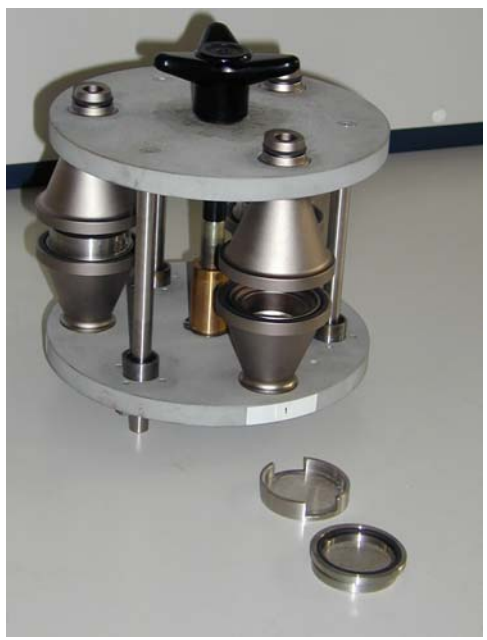
Particulate physical properties:

- **Number/size distribution (TSI – SMPS)**
  - *Constant speed (40 km/h)*
  - *Sampling: from dilution tunnel*

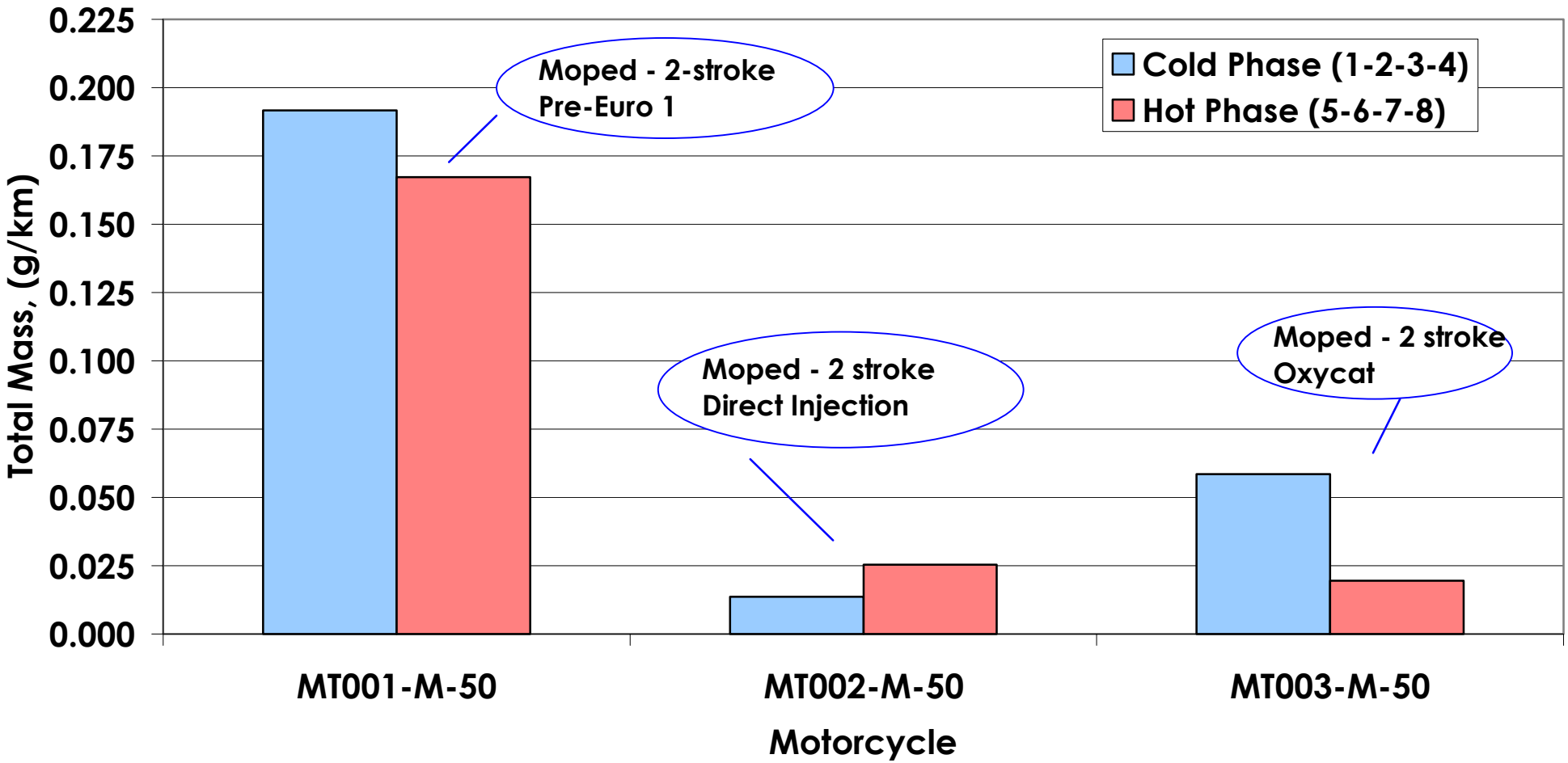
- **Mass/size distribution (Low Pressure Impactor)**
  - *11+1 stages*
  - *Volume flow rate: 25 l/min*
  - *Measuring range: 0.0085 μm-16 μm*
  - *Constant speed (40 km/h) and ECE 47 cycle*
  - *Sampling: from dilution tunnel*


AVL-ZÖLLNER

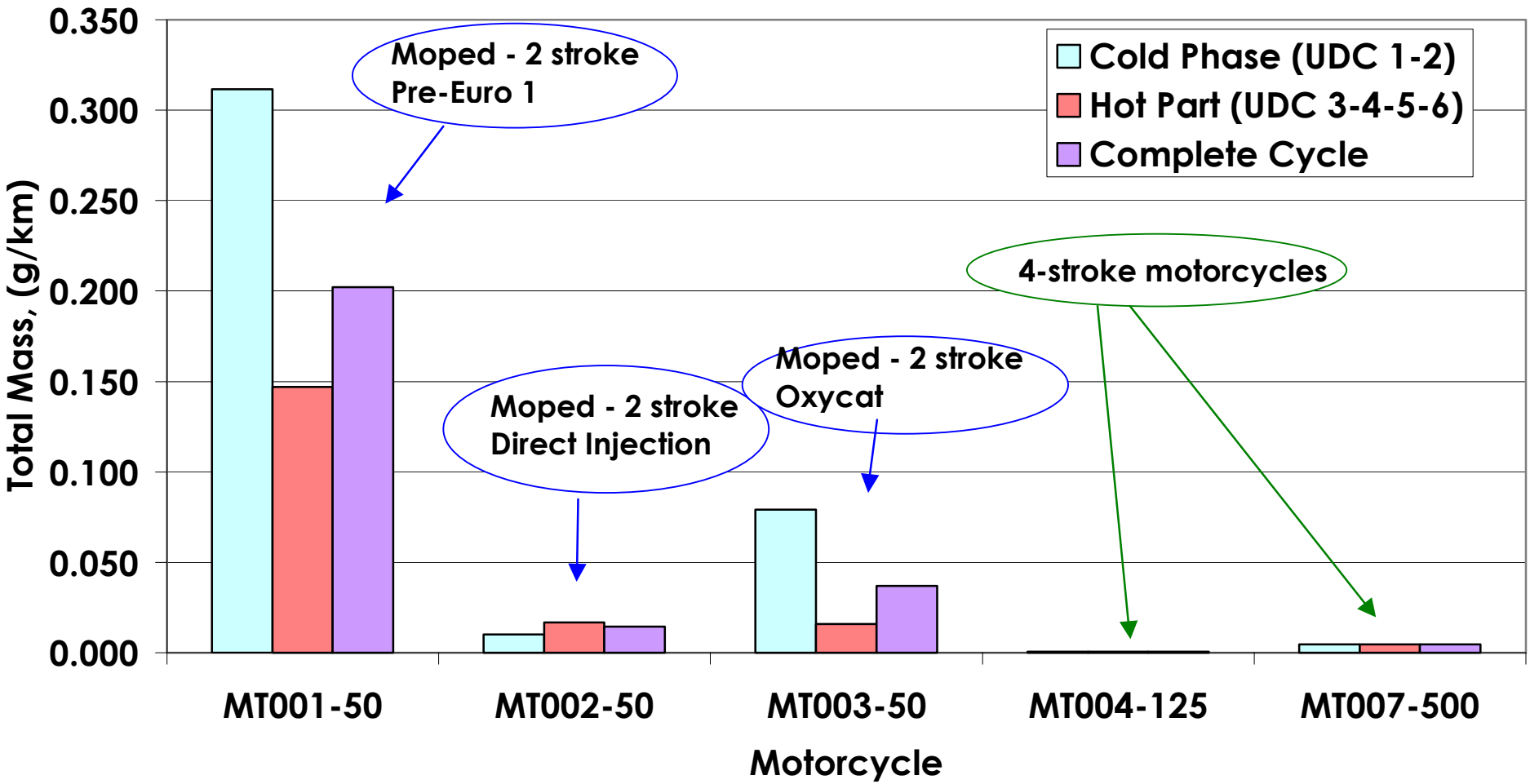
Total Mass



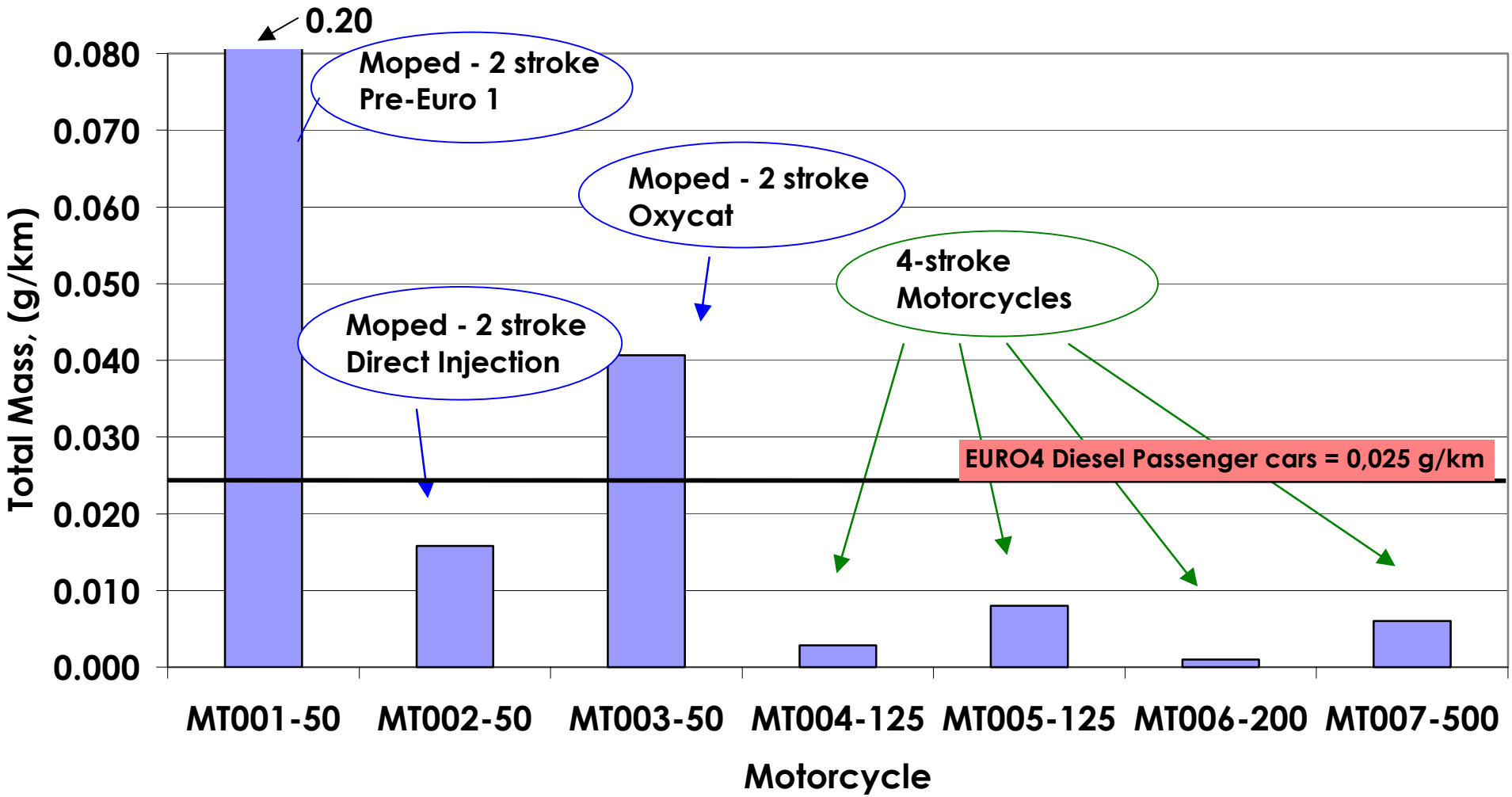
Particulate Emissions from Mopeds - Total Mass
ECE 47 Cycle



Particulate Emissions from Mopeds and Motorcycles - Total Mass
Euro 2 Cycle (ECE 40)

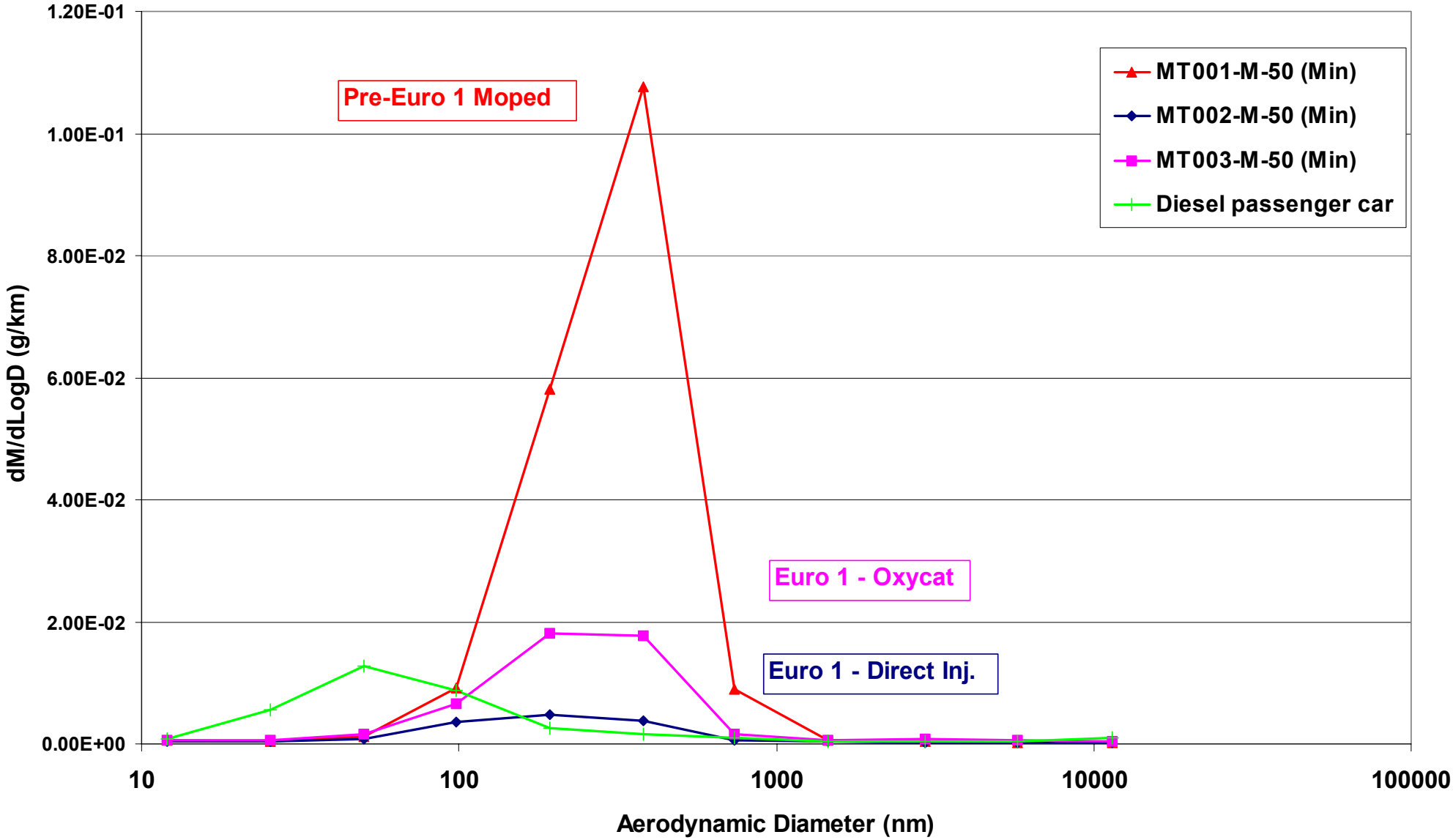


Particulate Emissions from Mopeds and Motorcycles - Total Mass (Filter)
Complete Euro 3 Cycle (6 Urban Driving Cycles)

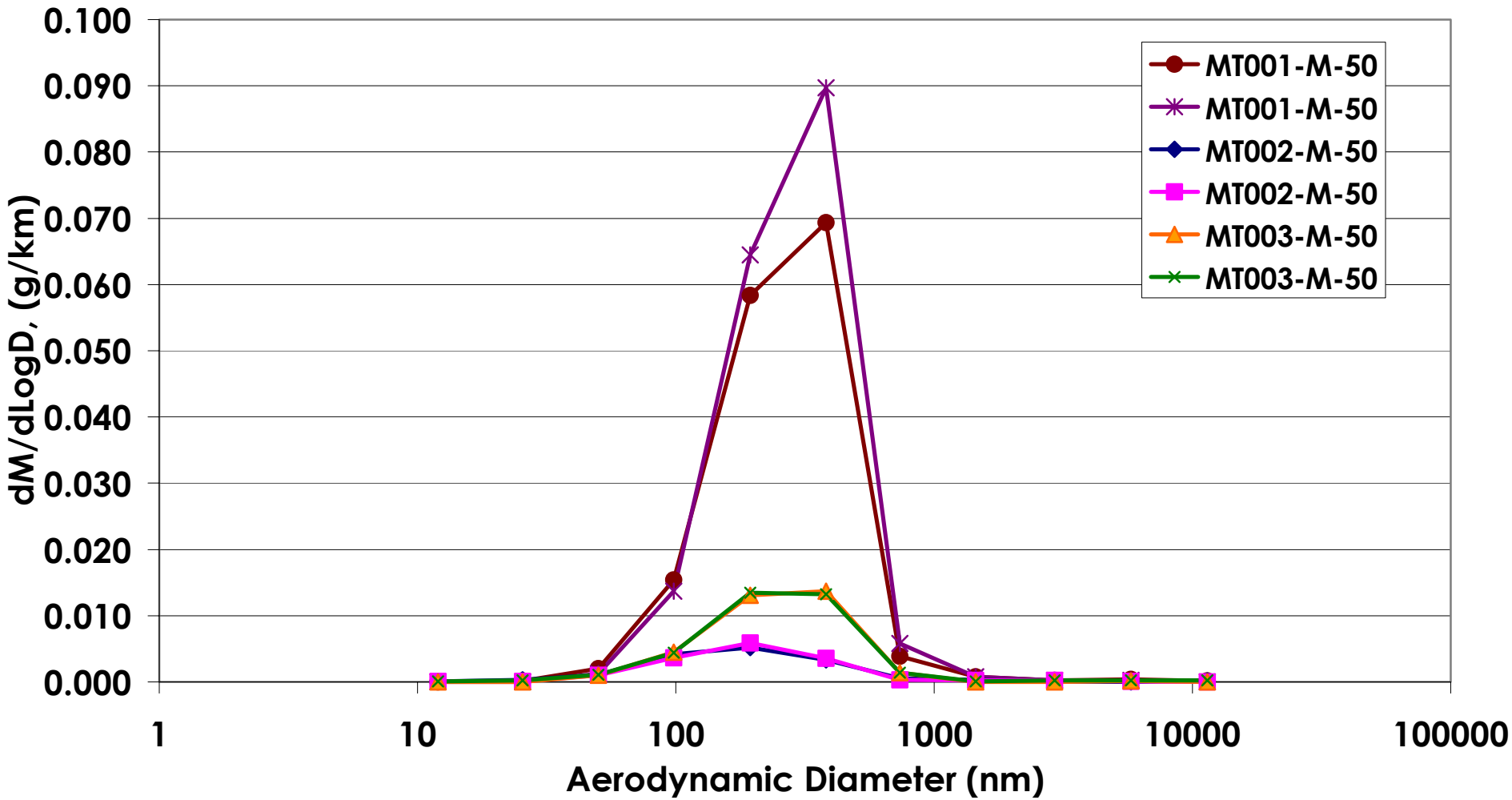


Mass/Size Distribution

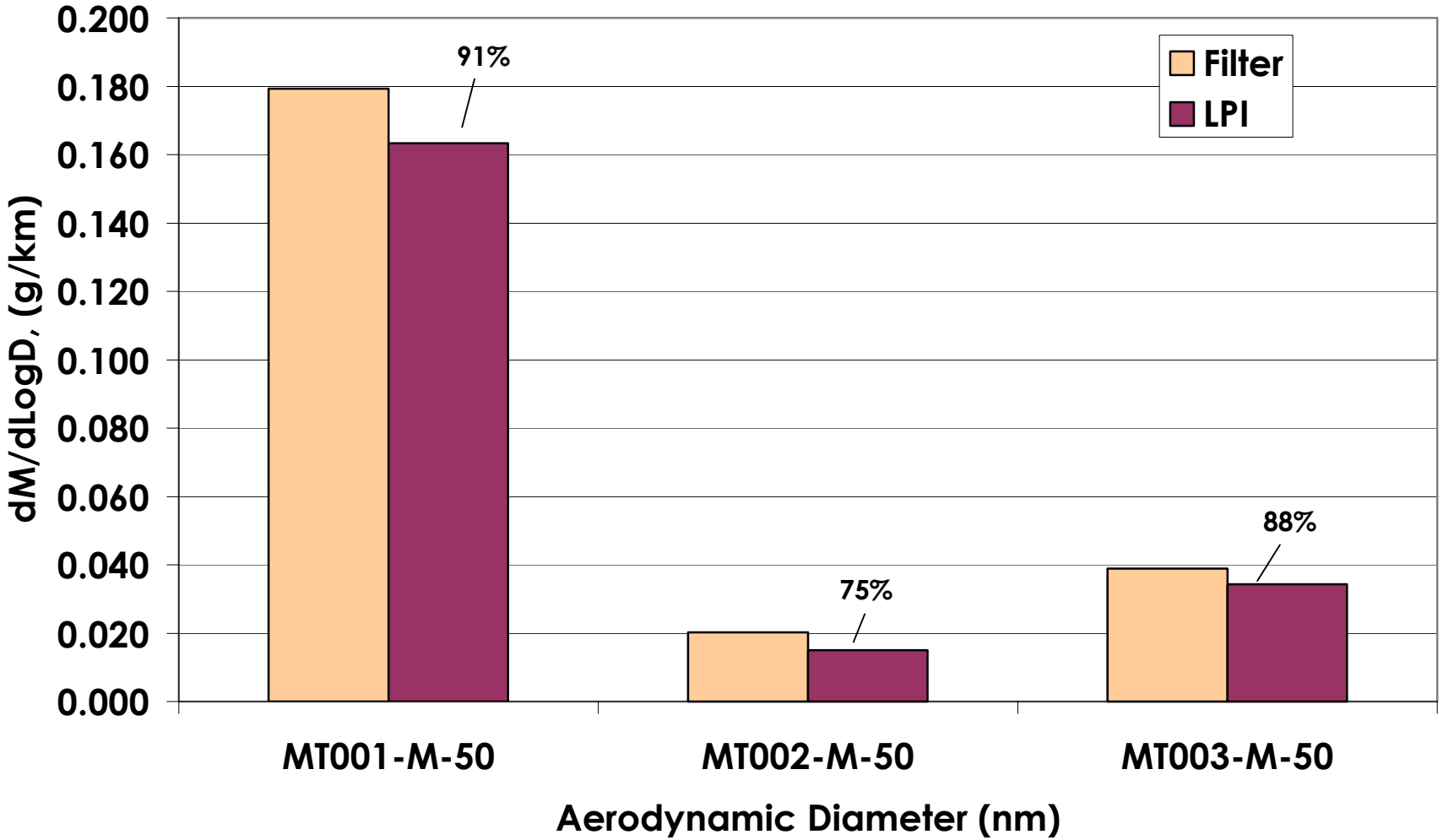
Particulate Emissions from Mopeds
ECE 47 Cycle - Mass/Size Distribution (LPI 11 stages)



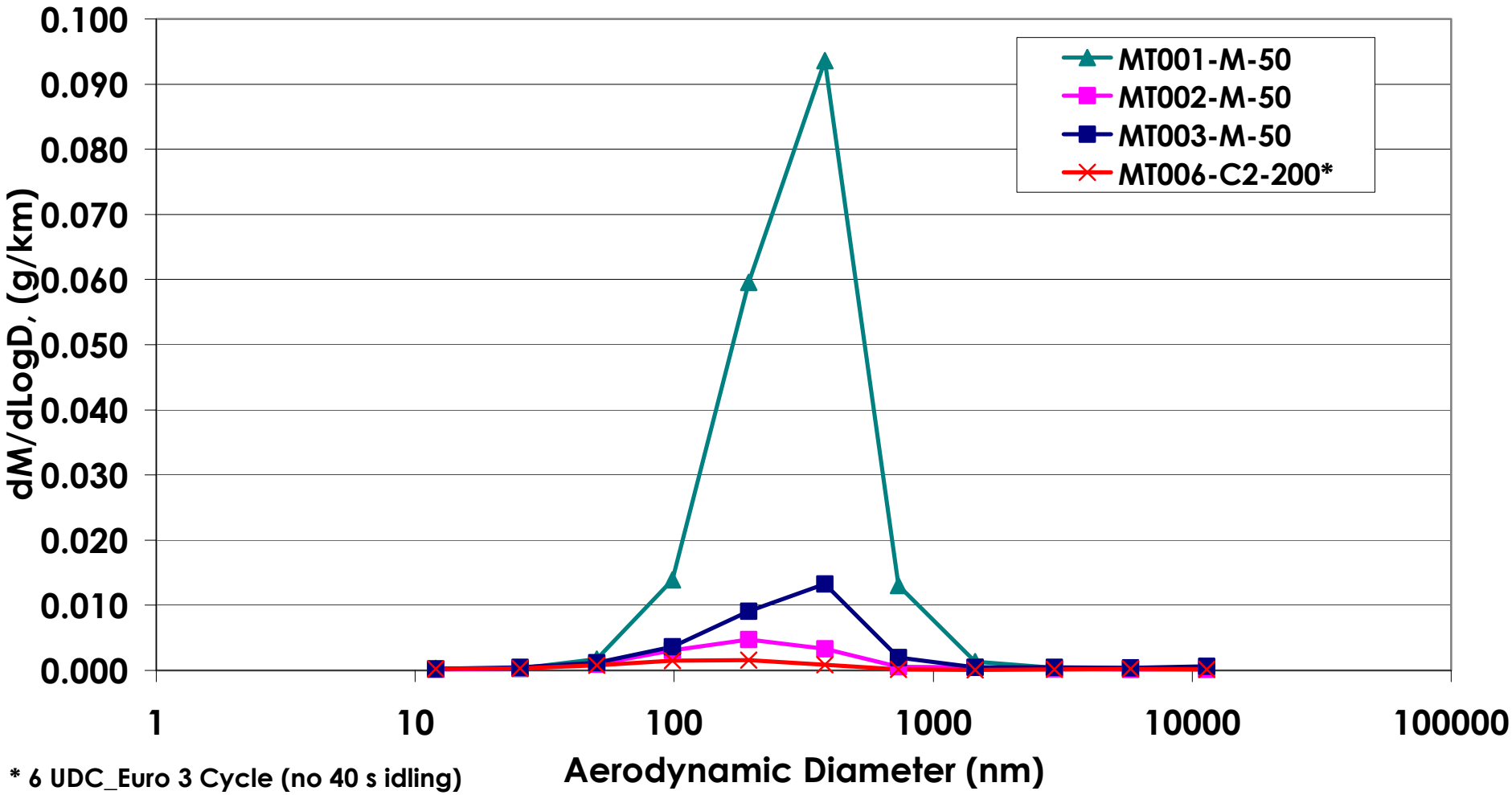
Mass/Size Distribution (LPI 11 stages) - Measurement Repeatibility
ECE 47 (Cold Phase + Hot Phase)



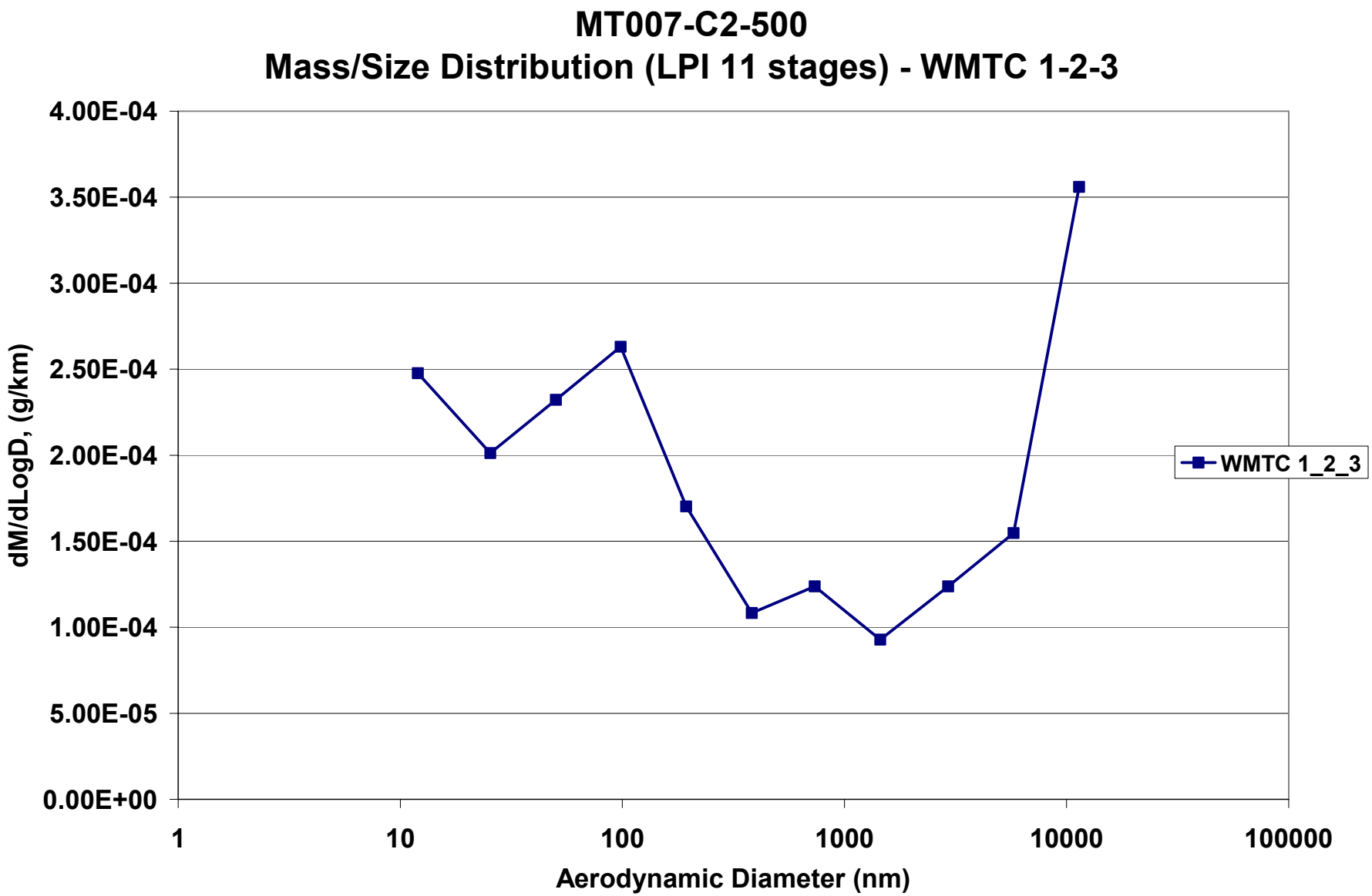
Particulate Emissions from Mopeds - Total Mass - LPI vs Filter
ECE 47 Cycle (Cold Phase + Hot Phase)



Particulate Emissions from Mopeds and Motorcycles
Mass/Size Distribution (LPI 11 stages) - EURO2 (Cold+ Hot Phase) Cycle

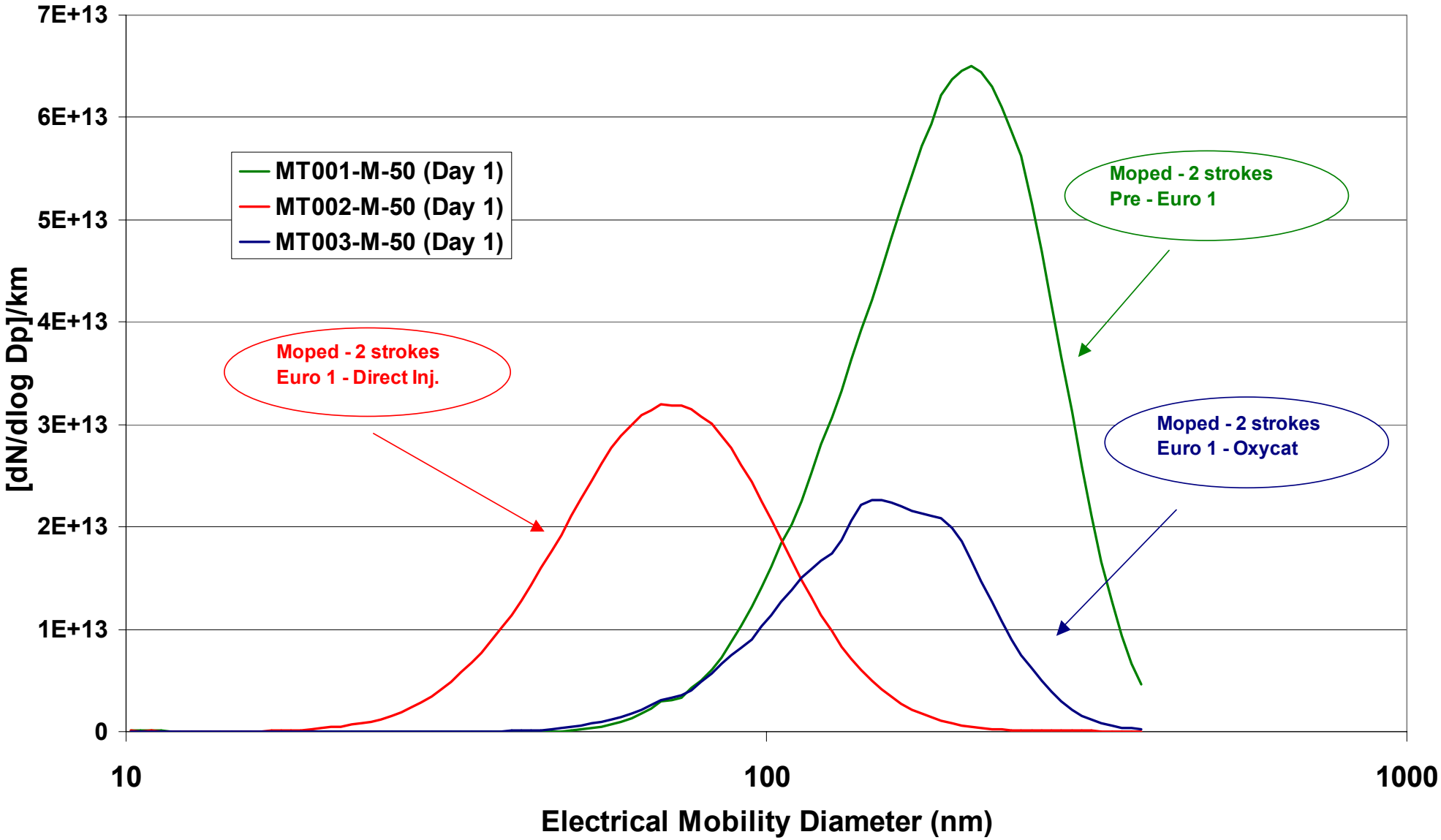


* 6 UDC_Euro 3 Cycle (no 40 s idling)

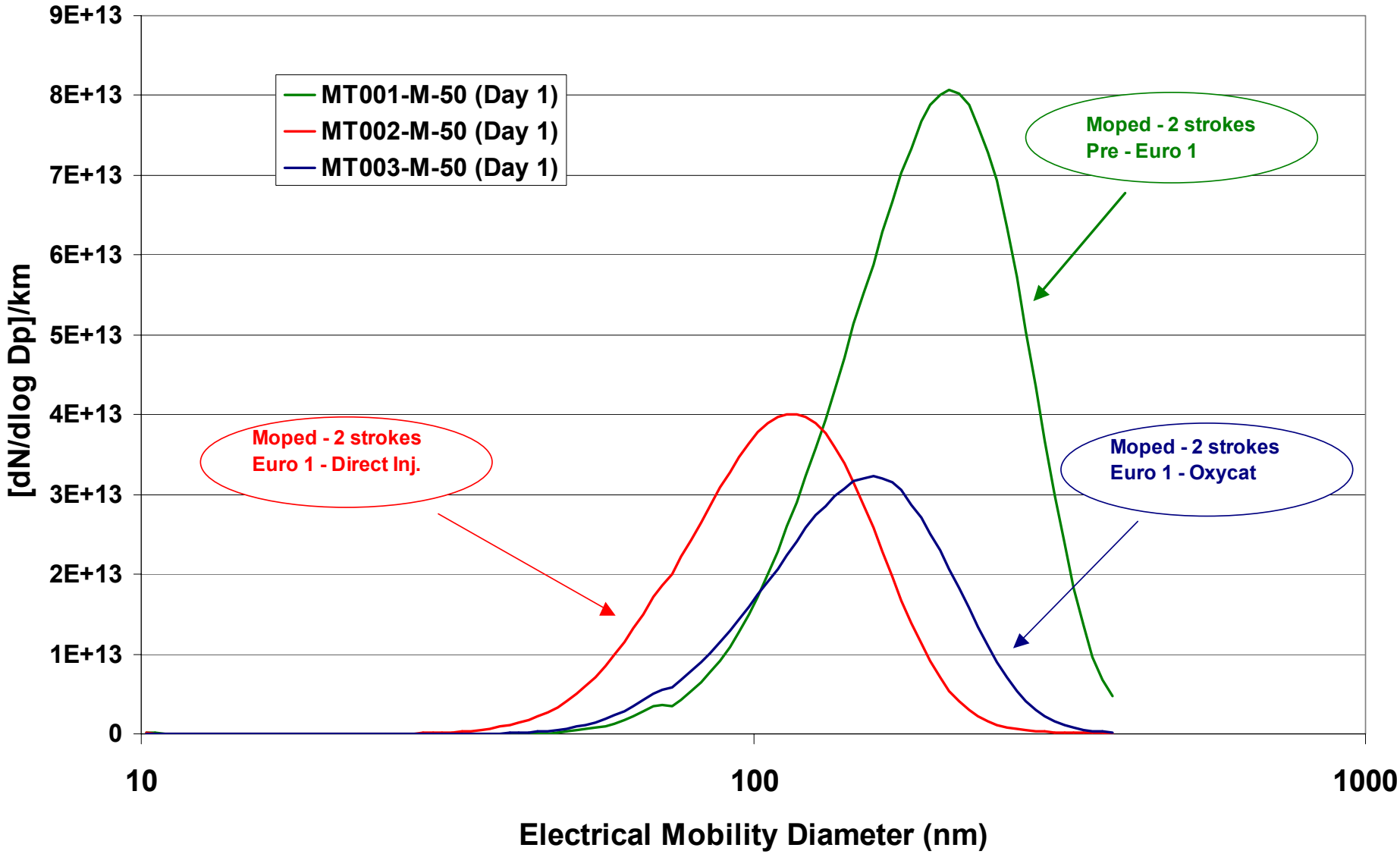

MT007-C2-500
Mass/Size Distribution (LPI 11 stages) - WMTC 1-2-3
dM/dLogD, (g/km)
4.00E-04
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
1
10
100
1000
10000
100000
Aerodynamic Diameter (nm)
WMTC 1_2_3

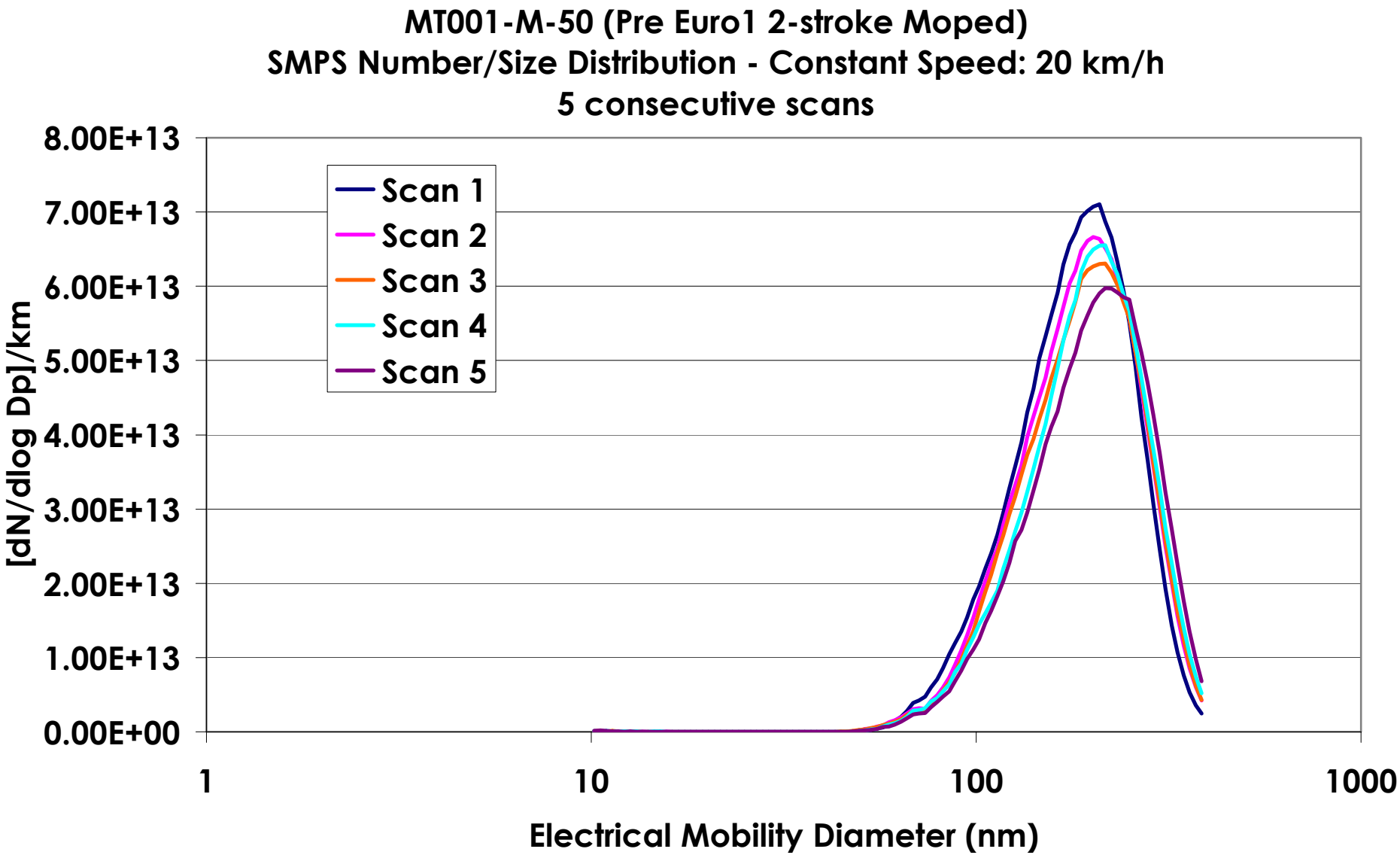
Number/Size Distribution

Number/Size Distribution - Constant Speed 20 km/h
Engine Technology Effect

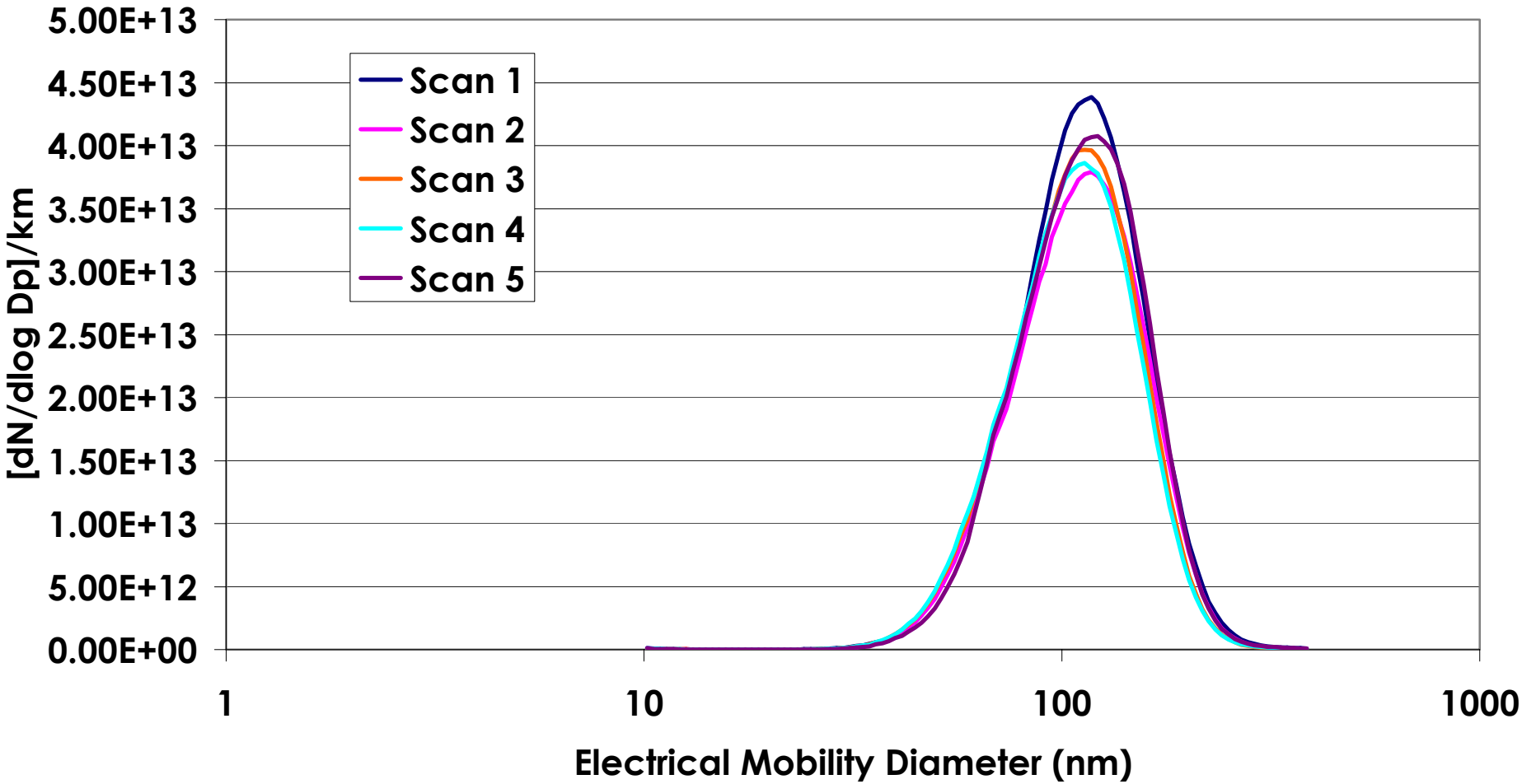


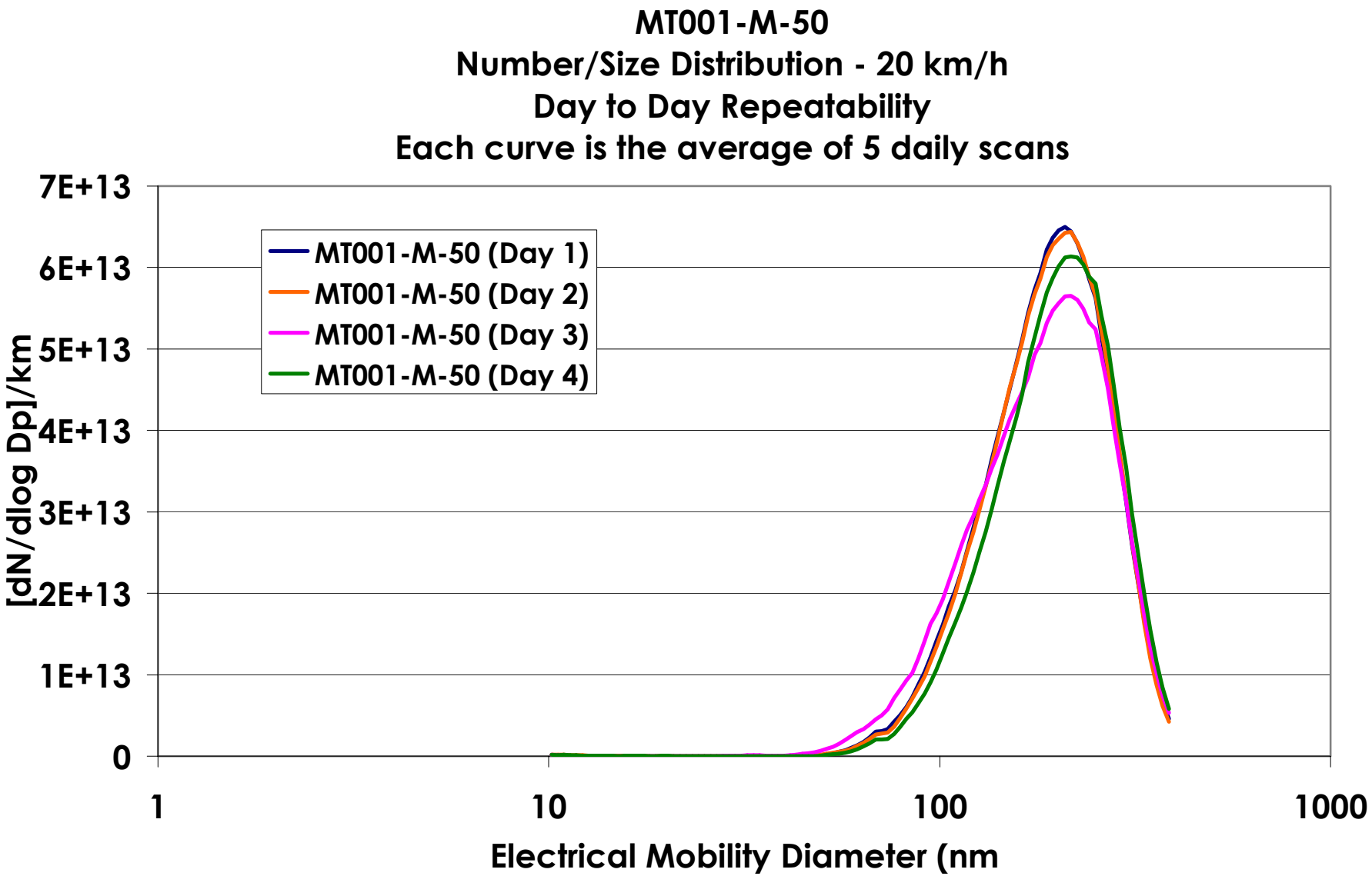
Number/Size Distribution - Constant Speed: 40 km/h
Engine Technology Effect



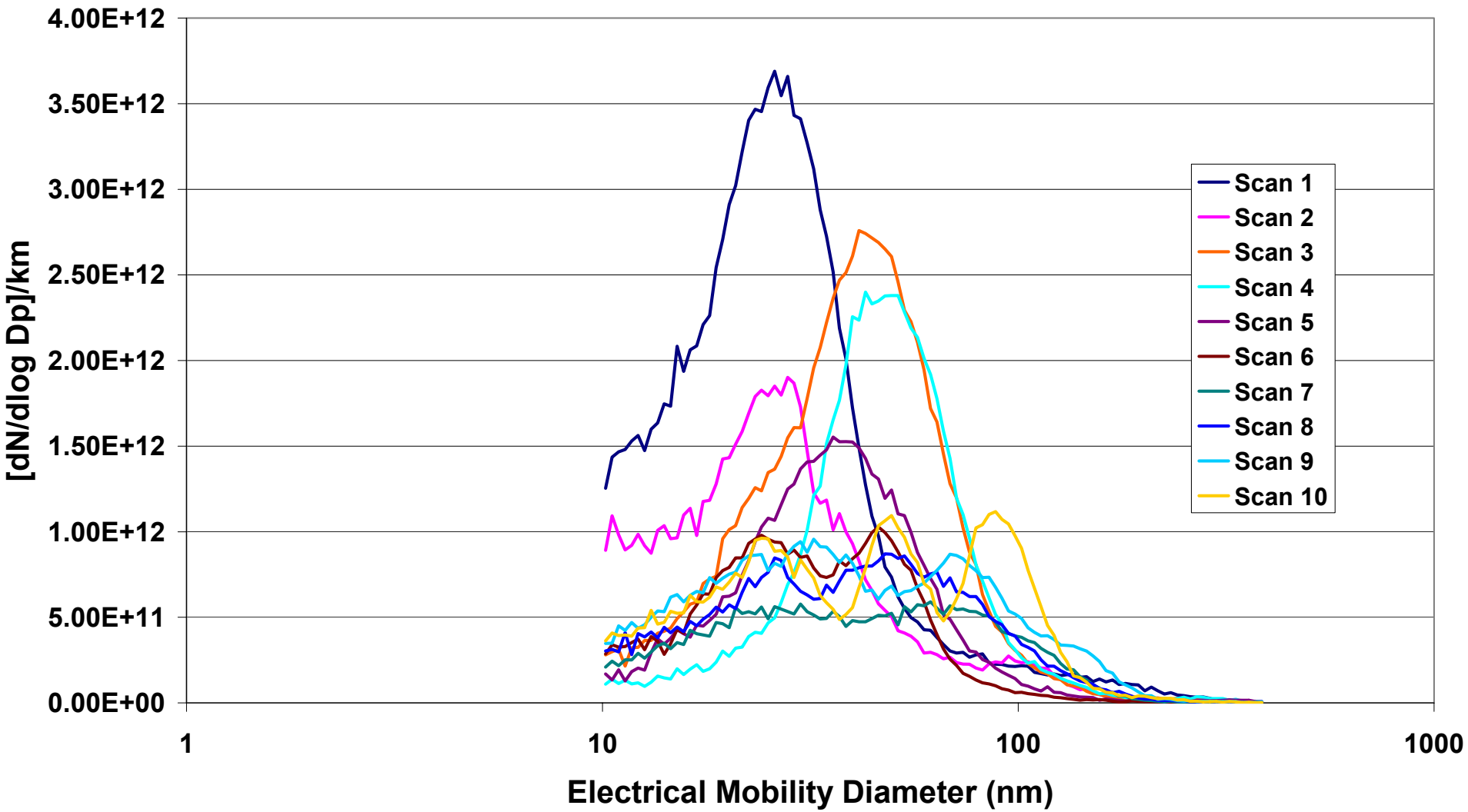

MT001-M-50 (Pre Euro1 2-stroke Moped)
SMPS Number/Size Distribution - Constant Speed: 20 km/h
5 consecutive scans
8.00E+13
7.00E+13
6.00E+13
5.00E+13
4.00E+13
3.00E+13
2.00E+13
1.00E+13
0.00E+00
[dN/dlog Dp]/km
Scan 1
Scan 2
Scan 3
Scan 4
Scan 5
1
10
100
1000
Electrical Mobility Diameter (nm)

MT002-M-50 (2-stroke Moped - 50 cc Direct Injection)
Number/Size Distribution - Constant Speed: 40 km/h
5 consecutive scans

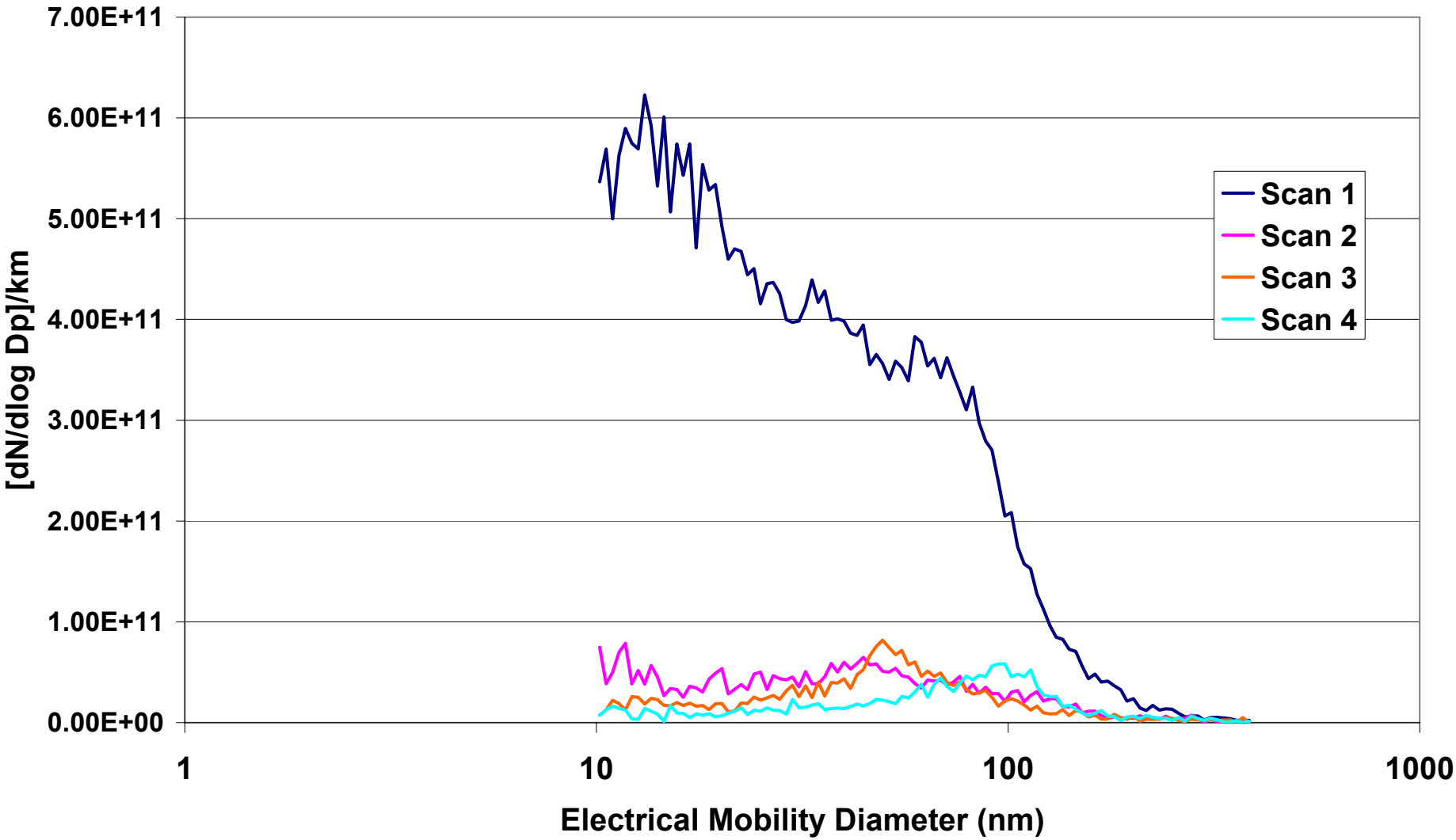



MT001-M-50
Number/Size Distribution - 20 km/h
Day to Day Repeatability
Each curve is the average of 5 daily scans
MT001-M-50 (Day 1)
MT001-M-50 (Day 2)
MT001-M-50 (Day 3)
MT001-M-50 (Day 4)
[dN/dlog Dp]/km
7E+13
6E+13
5E+13
4E+13
3E+13
2E+13
1E+13
0
1
10
100
1000
Electrical Mobility Diameter (nm

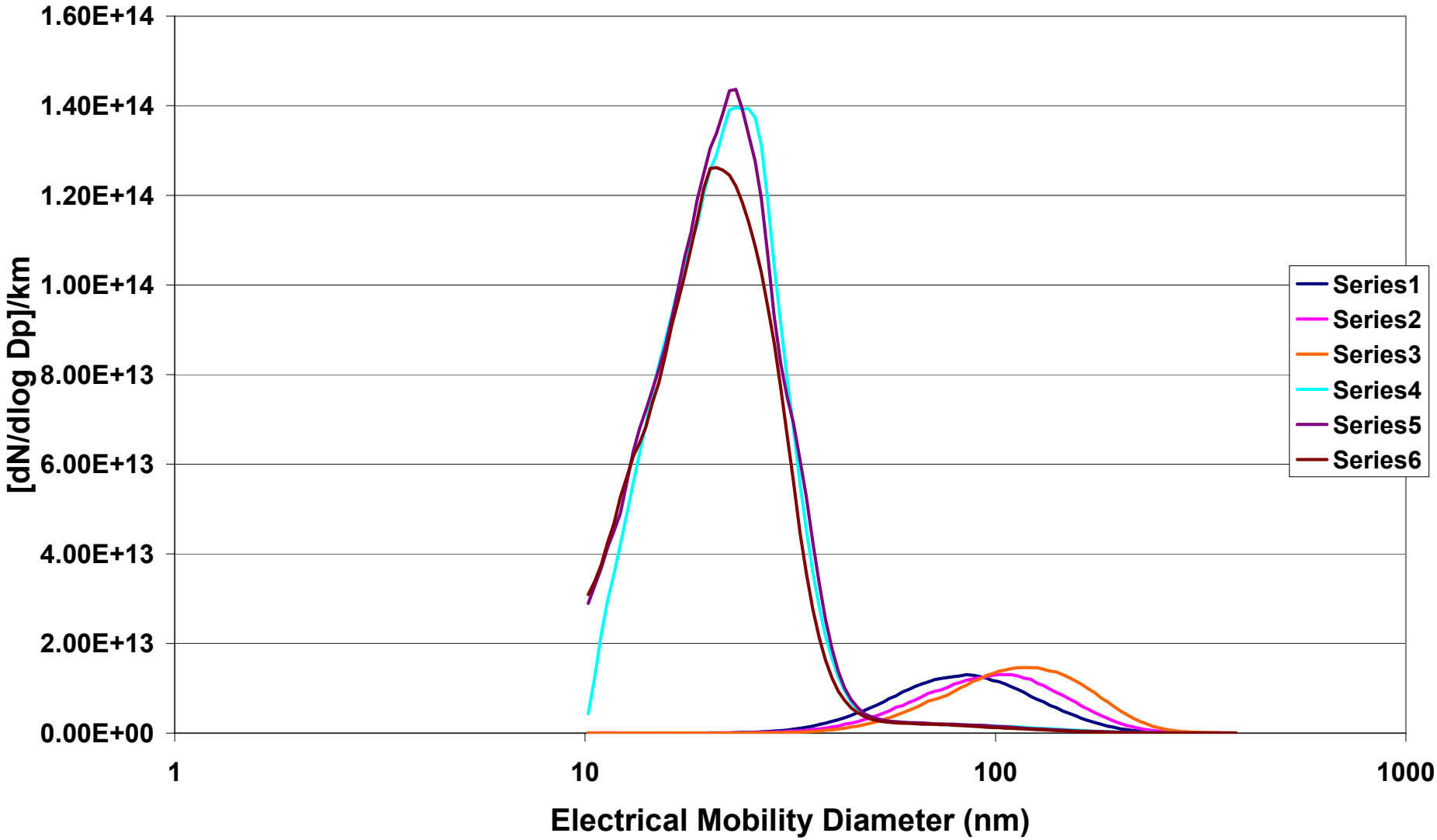
MT006-C2-200 (4 strokes)
SMPS Number/Size Distribution - Constant Speed: 20 km/h
10 consecutive scans



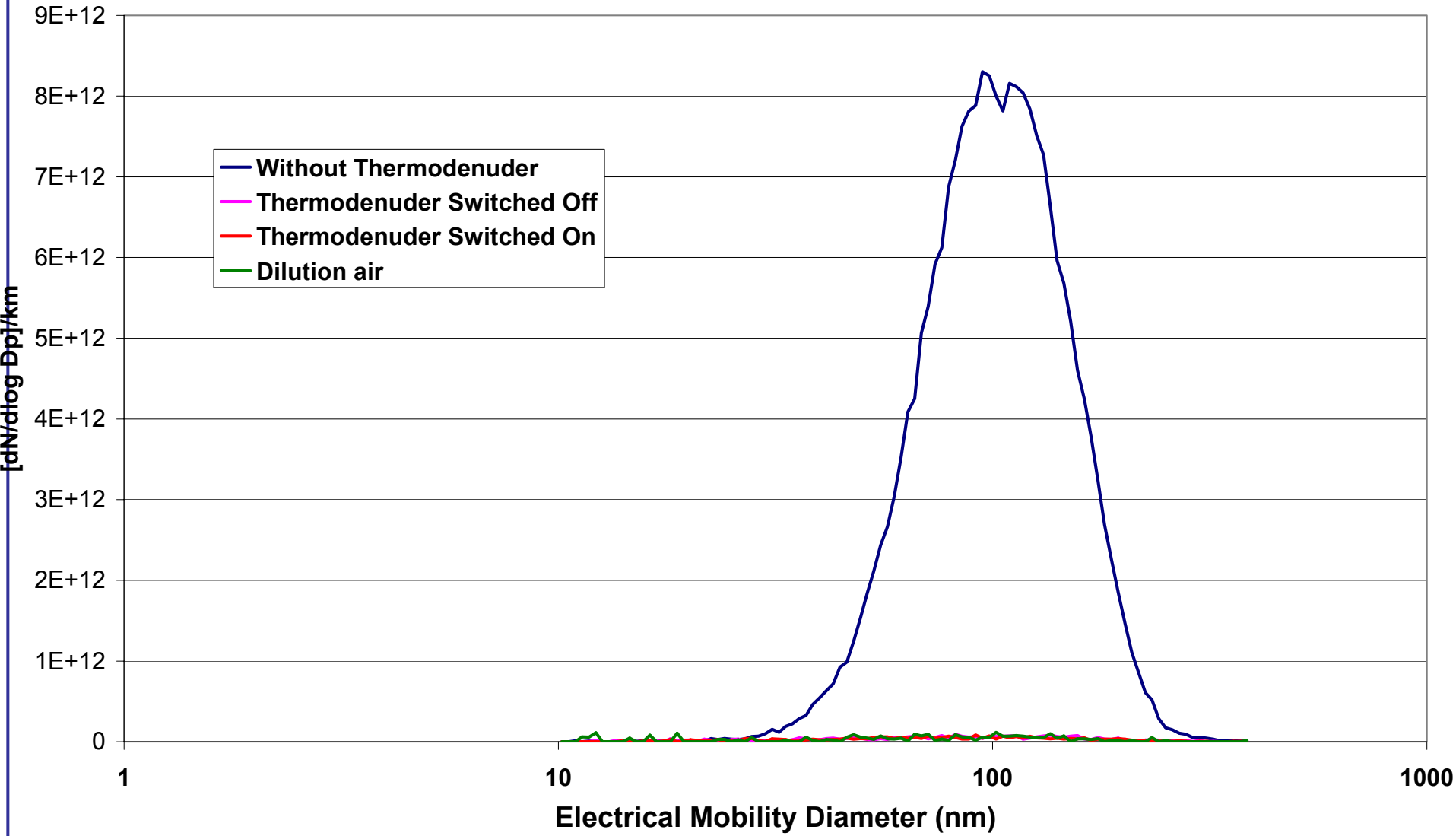
MT006-C2-200 (4 strokes)
SMPS Number/Size Distribution - Constant Speed: 40 km/h
4 consecutive scans



MT002-M-50 (2 strokes- Dir. inj)
SMPS Number/Size Distribution - Constant Speed: 40 km/h
Effect of Thermodenuder - 6 consecutive scans



Effect of Thermodenuder - MT002-M-50 (2 strokes - Injection)
Number/Size Distribution - Constant Speed: 40 km/h



Conclusions:

- The engine technology has a huge effect on particulate emissions from mopeds
- Pre-Euro1 conventional 2-stroke engines emit high masses and numbers of particulate matter.
- There is some potential to reduce these levels using 2-stroke engines with direct injection and/or catalytic converters technologies.
- All 4 stroke engines, even the less modern ones, emit masses of particulate matter comparable to those observed for gasoline passenger cars

- On going works now focusing on:
  - 1. Toxicity of PM (also for passenger cars), performing chemical analysis of the PM emissions
  - 2. Limits of the instruments (Repeatability from test bench to test bench, Detection limits)