Ultrafine Particles – SCAQMD/CARB Los Angeles April 30 – May 2, 2006

Why use Size, Substance and Number of Solid Particles instead of PM-Mass

to characterize and limit

Particle Emissions of IC-Engines

A. Mayer

History of Evidence

- 1775 P.Pott „cancer and soot correlated“
- 1868 Tyndall „ultrafines measured“
- 1916 number count correlates with silicosis (english mines)
- 1936 Staub: ultrafines more dangerous but not measureable
- 1954 VDI regulation against opacity of Diesel smoke
- 1959 Johannesburg convention on size
- 1982 PM-Limit for Diesel cars in California
- 2000 Filter efficiency by number and size in CH

Claim 1

Particle Size matters

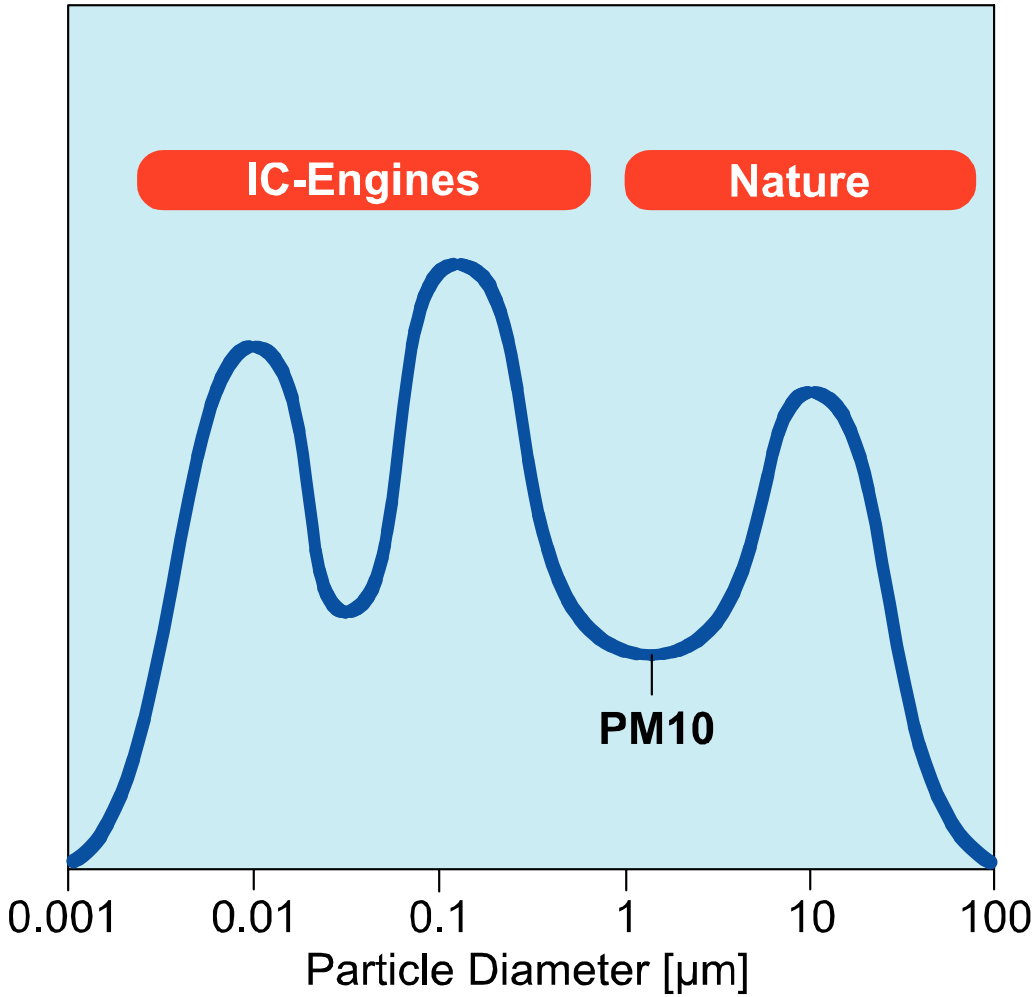
simply because we are dealing with an aerosol in size range 10 – 10‘000 Nanometer

and

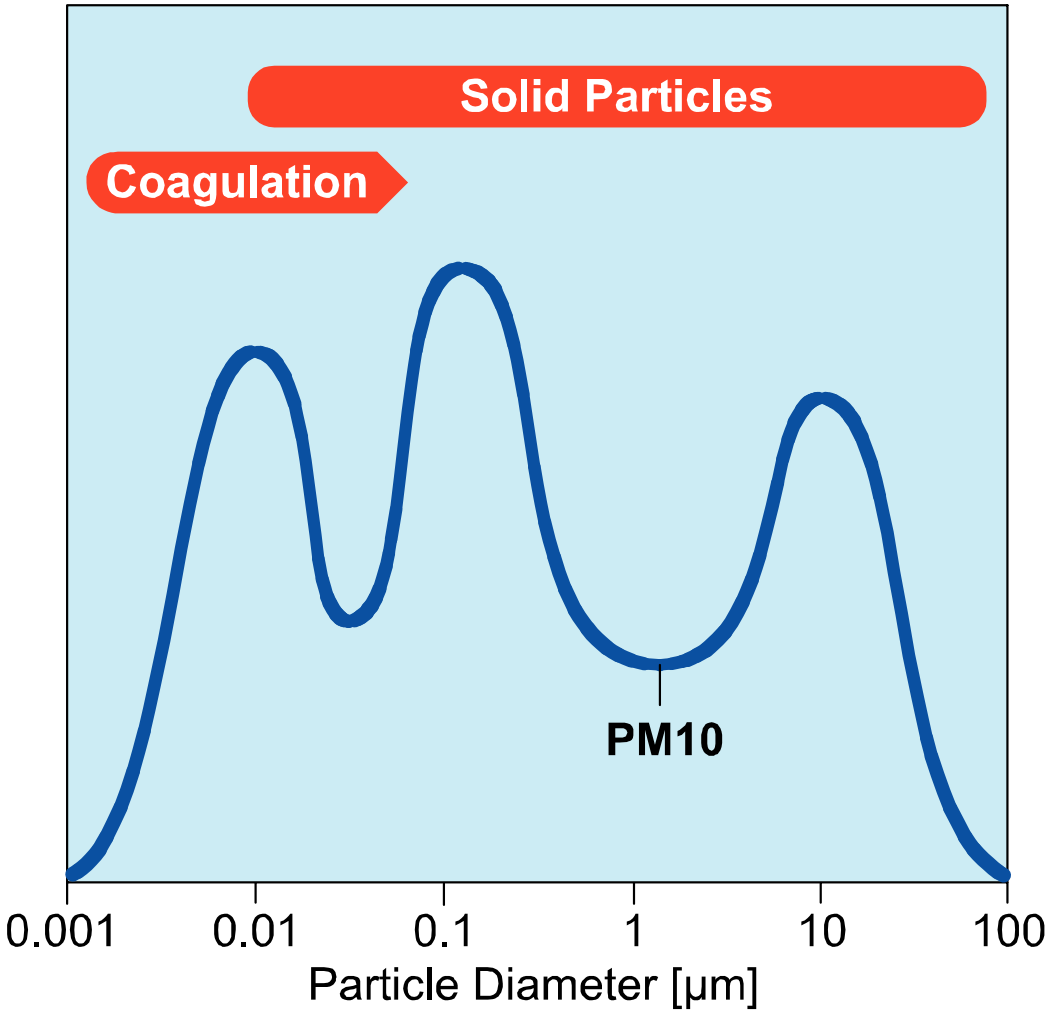
because aerosols = f (size and number) have very different properties

Size Distribution of Ambient Particles

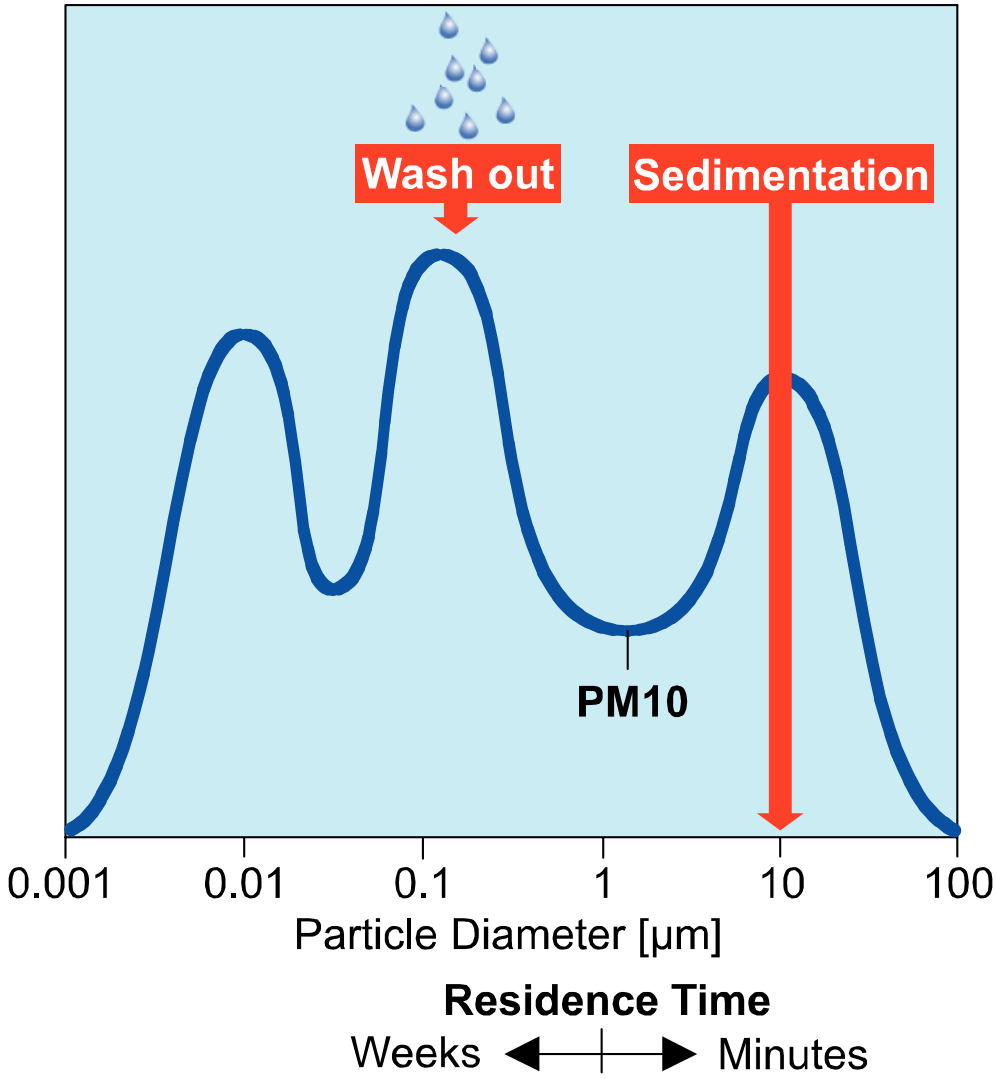
2 entirely different Formation Mechanismes



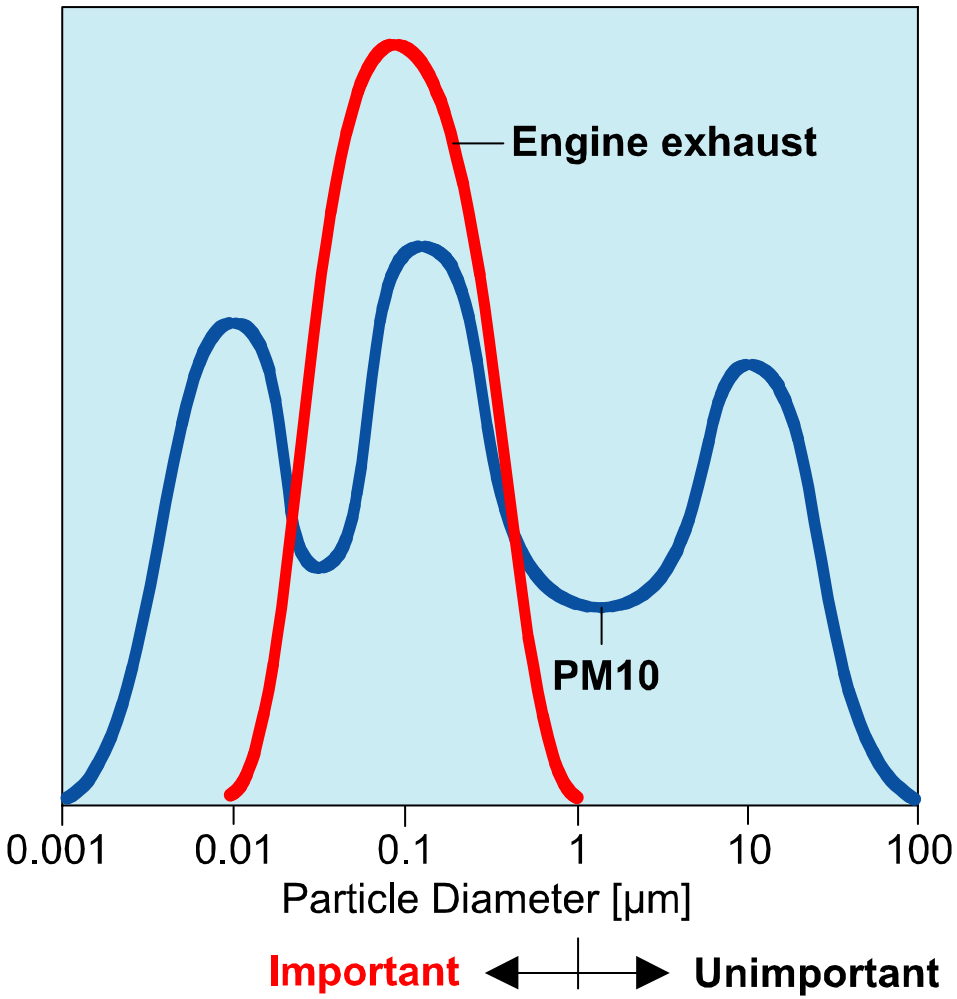
Mix of Solid Particles and Condensates



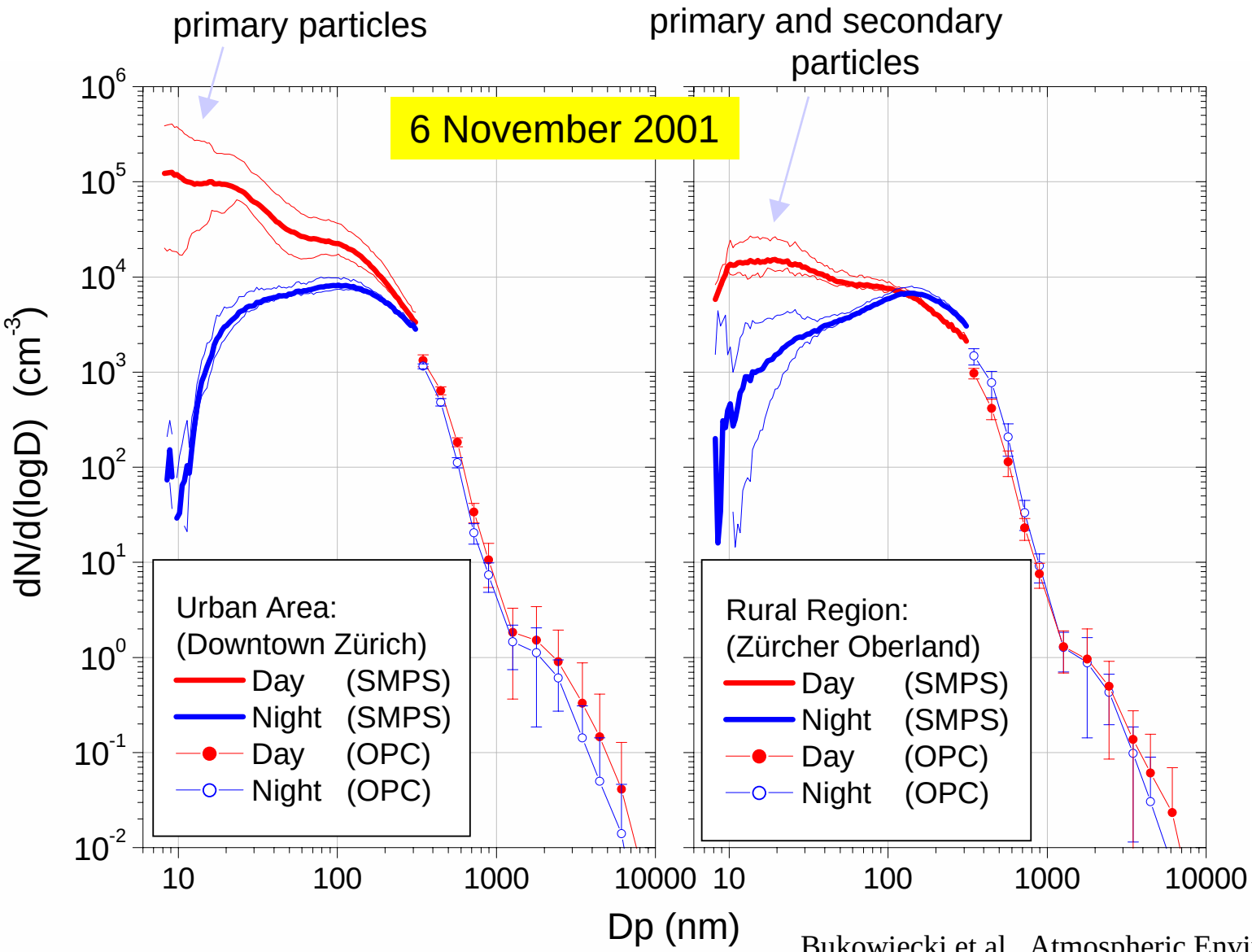
Ultrafines can have very long Life until cleaned out



IC-Engine-emitted solid Nanoparticles a Part of PM10 but the most critical Fraction

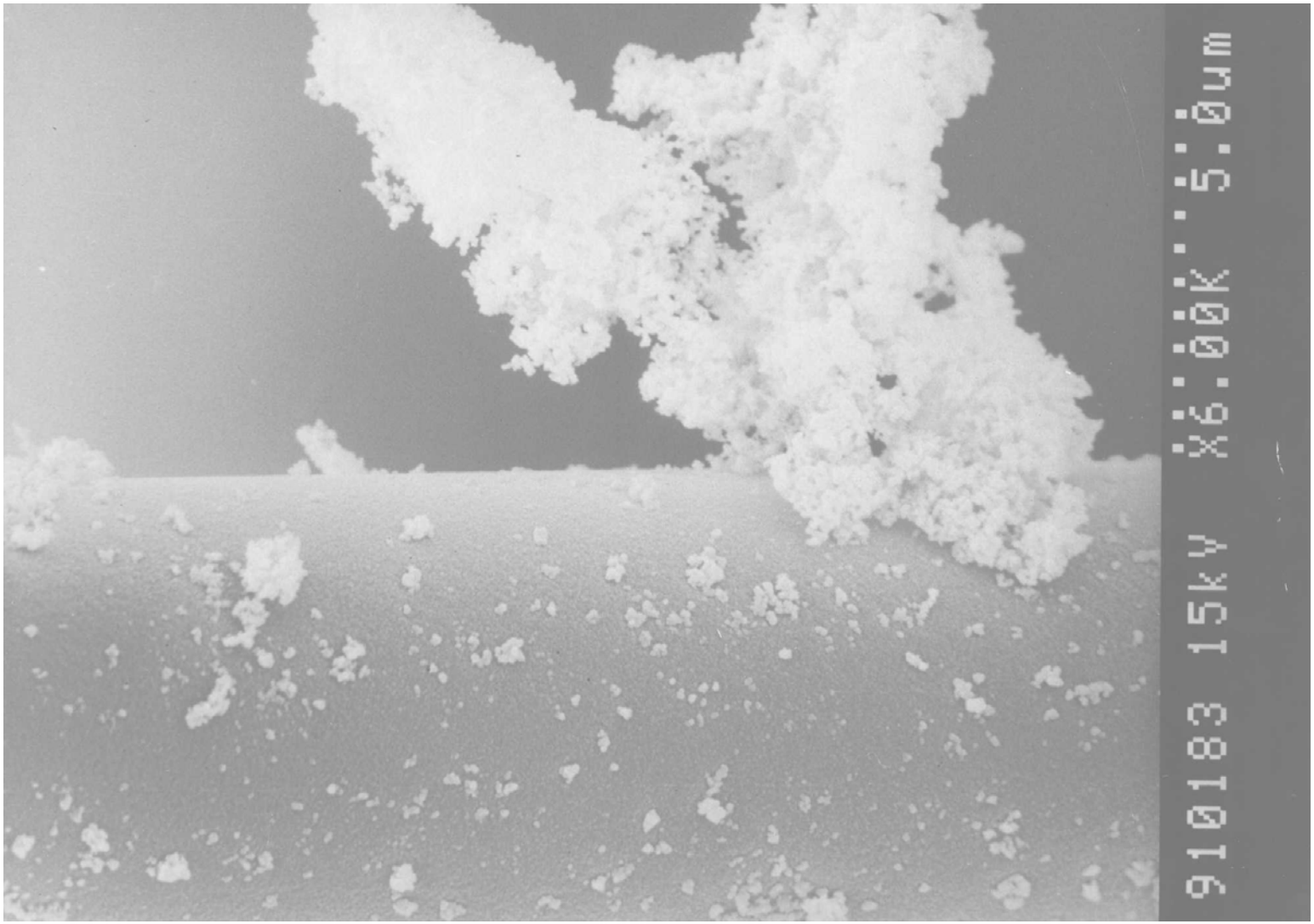


Aerosol Number-Size distributions in the Zürich area



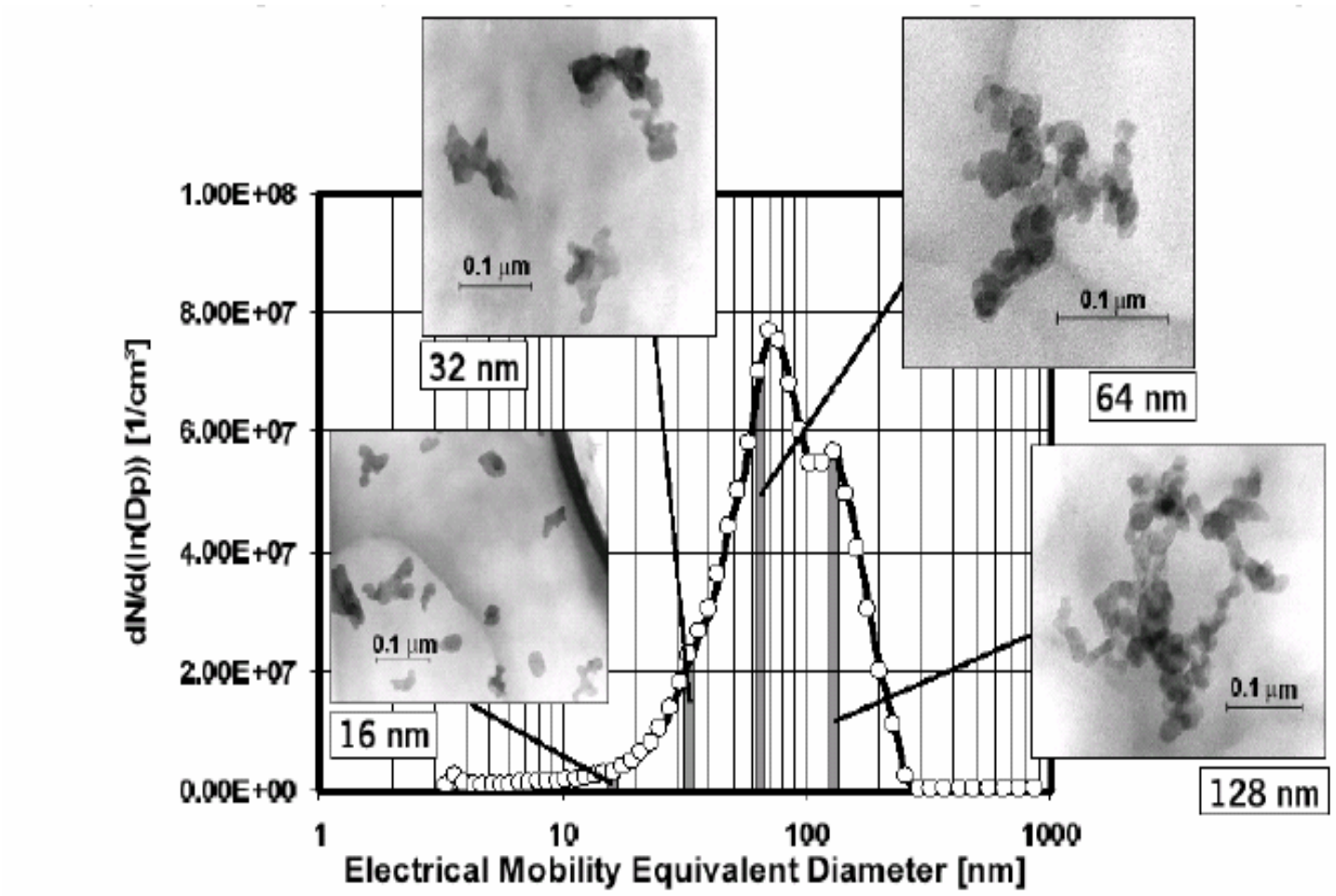
Bukowiecki et al., Atmospheric Environment, 2002

Soot Particles deposited on a 5 micron Filter Fibre



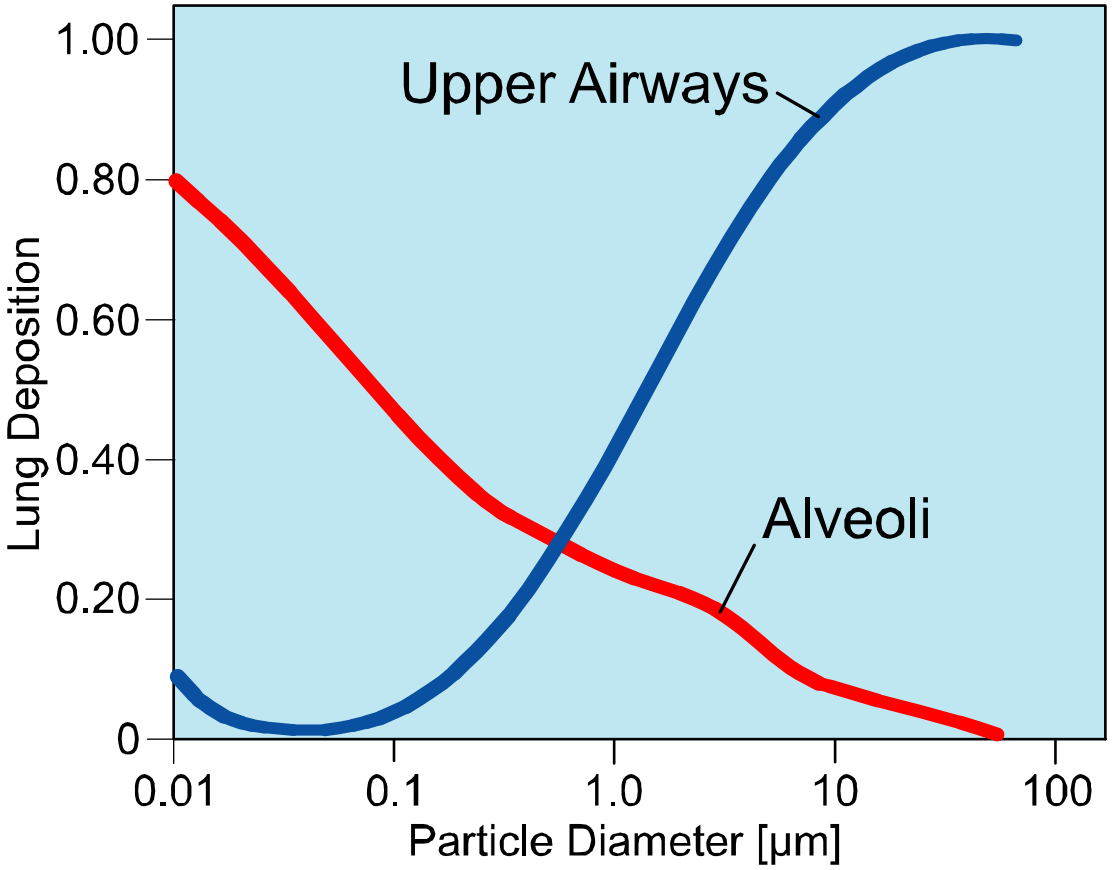
Diesel Soot

invisible
no taste
no smell
inert

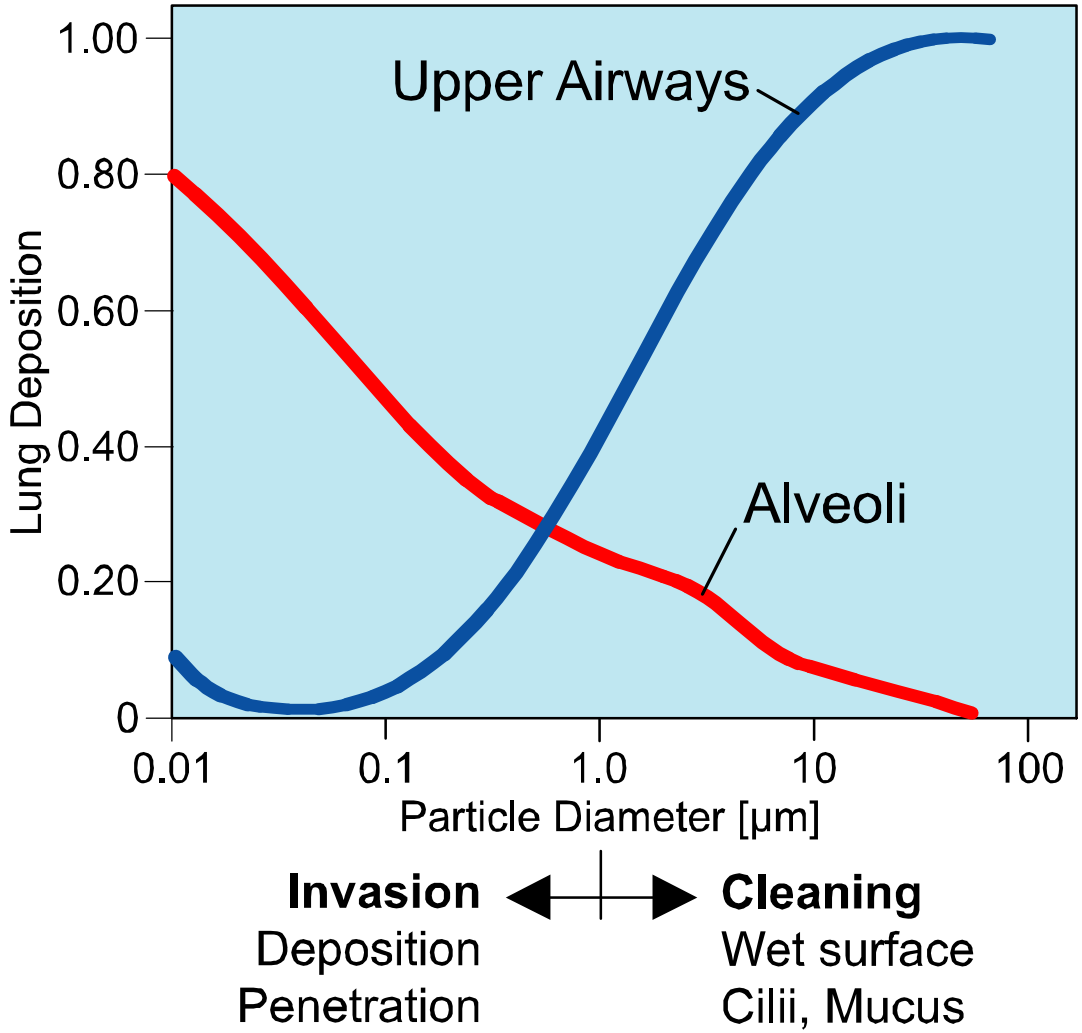


Source: METZ, BMW

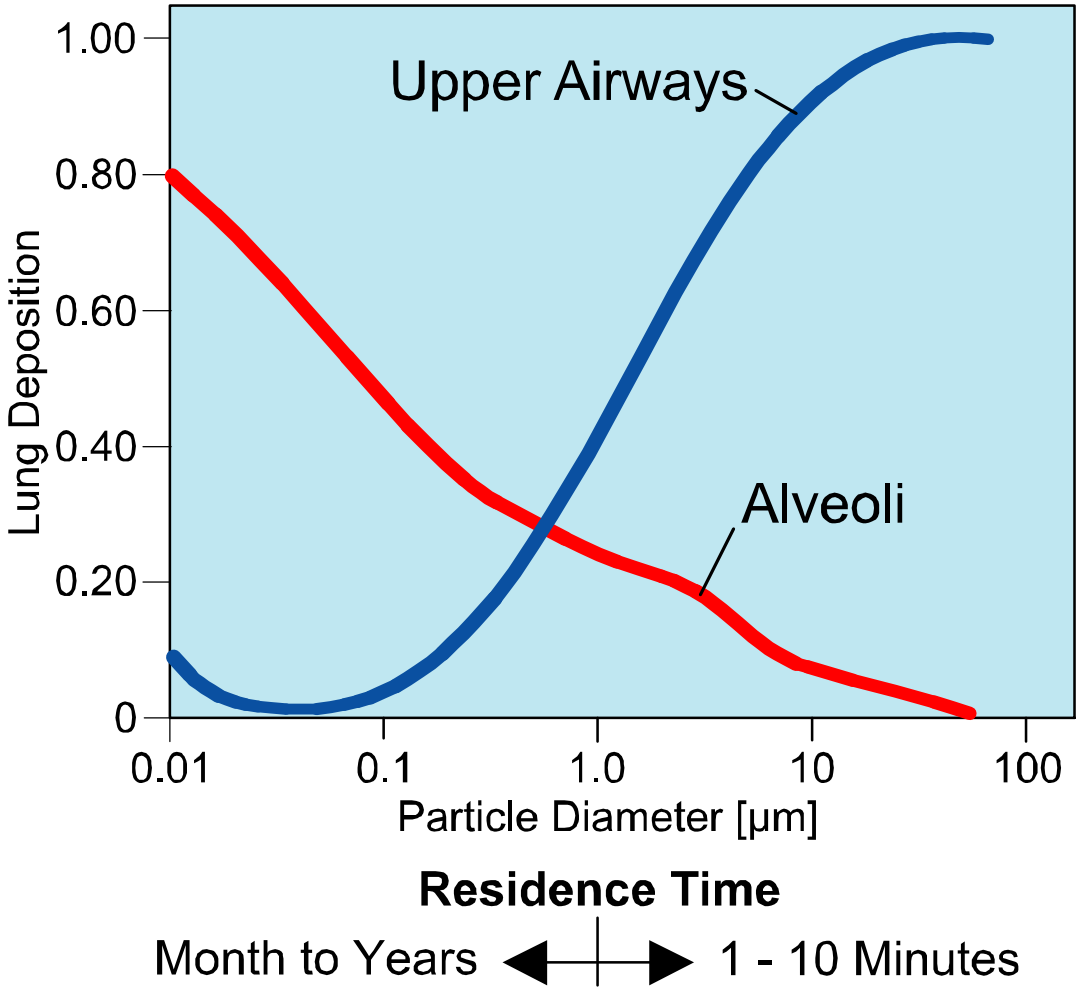
Particles of different Size are deposited in different Parts of the Lungs



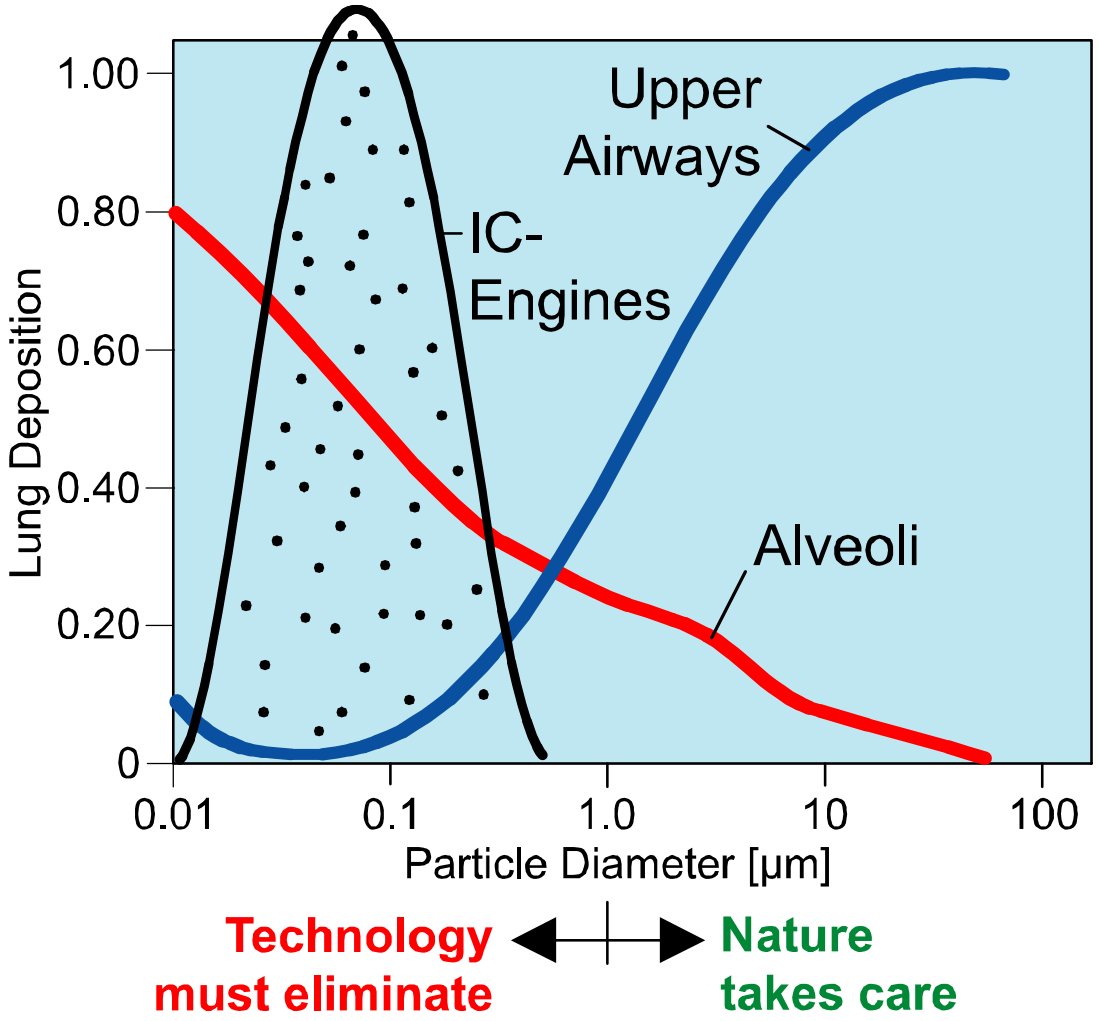
Perfect Clearing Mechanismes for large Particles – hardly any for Nanoparticles



Residence time is short for large (natural) Particles – extremely lang for Nanoparticles



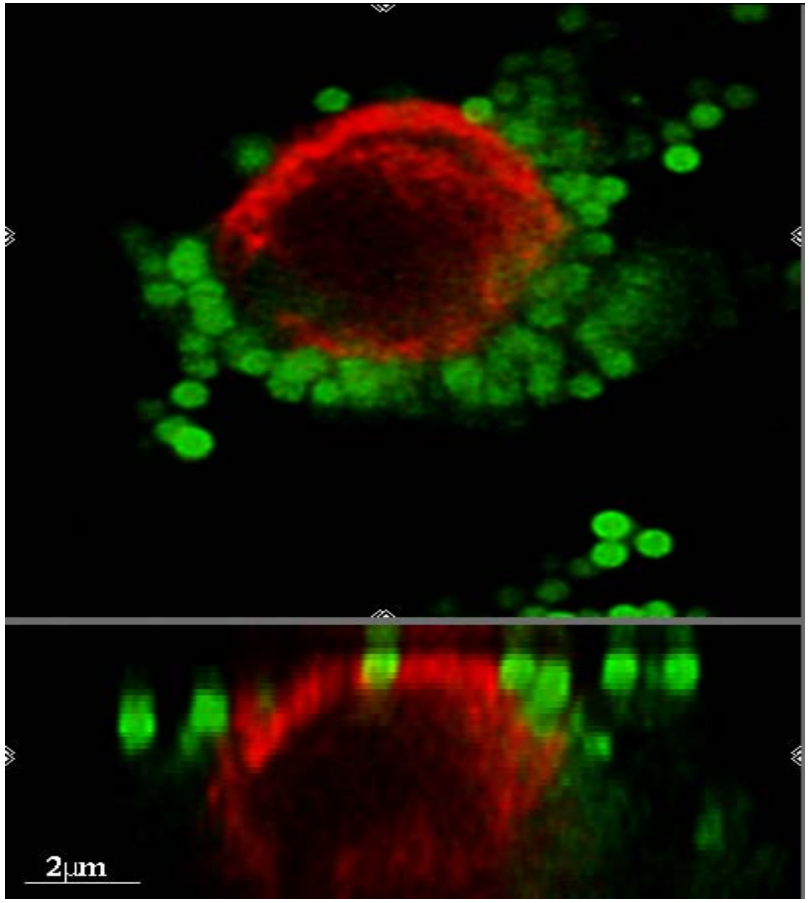
Combustion generated Particles fall into a very critical Size Range



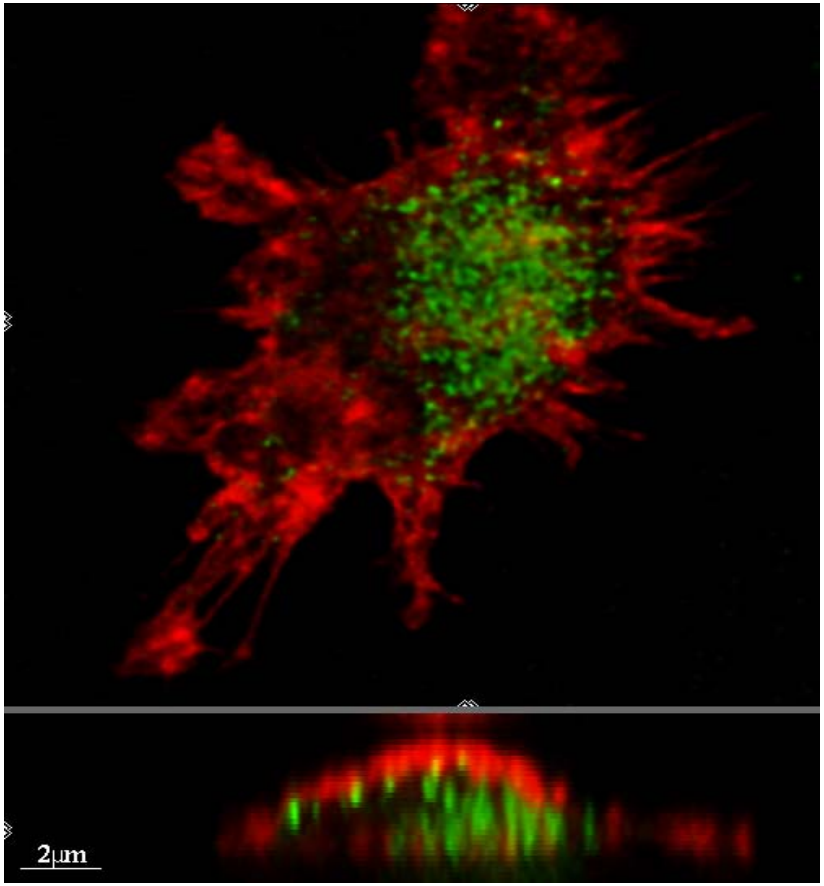
Alveoli and Blood Veins – 1µ Membrane

Macrophages *in vitro*: Laser Scanning Microscopy

- **1000 nm Polystyrene Particles**



- **78 nm Polystyrene Particles**



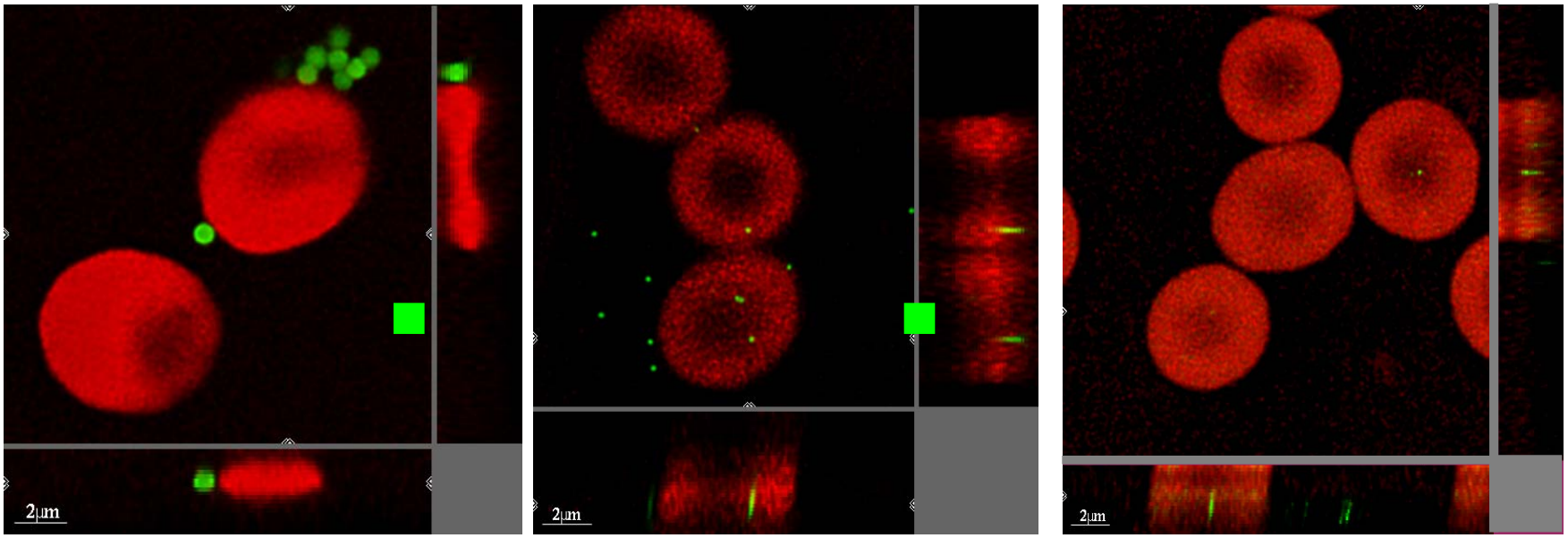
B. Rothen-Rutishauser

Red Blood Cells *in vitro*: Laser Scanning Microscopy

1000 nm = 1mm
polystyrene particles

0.2 mm
polystyrene particles

78 nm
polystyrene particles



B. Rothen-Rutishauser / University

Particle Size matters

because but our organisme has no barrier for Nanoparticles !

→ ***Technology must take care for man-made particles < 1 micron***

This does not mean that larger particles are healthy but nature takes much better care of them and engine technology is not responsible

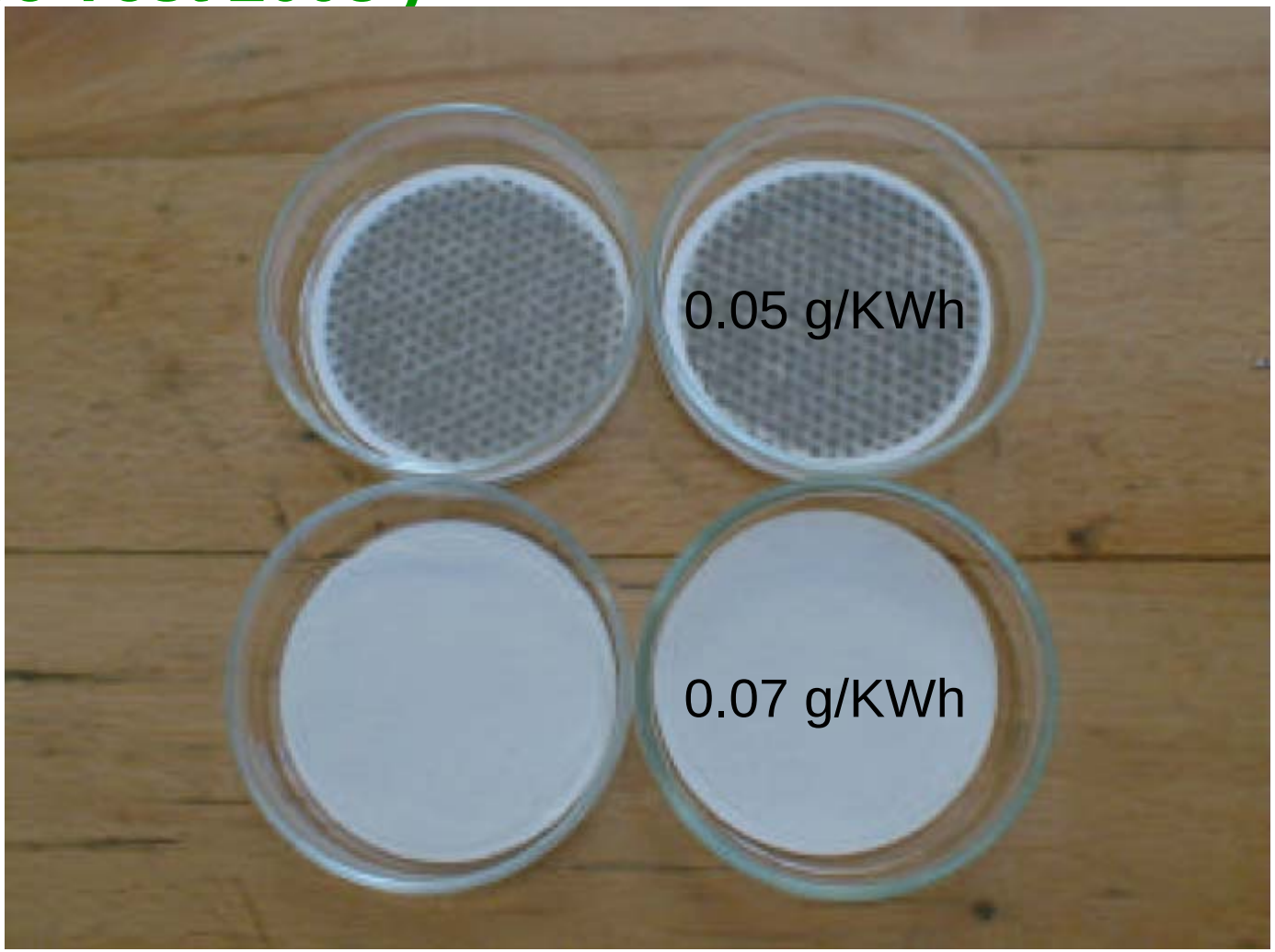
Claim 2

Particle Composition matters

because of

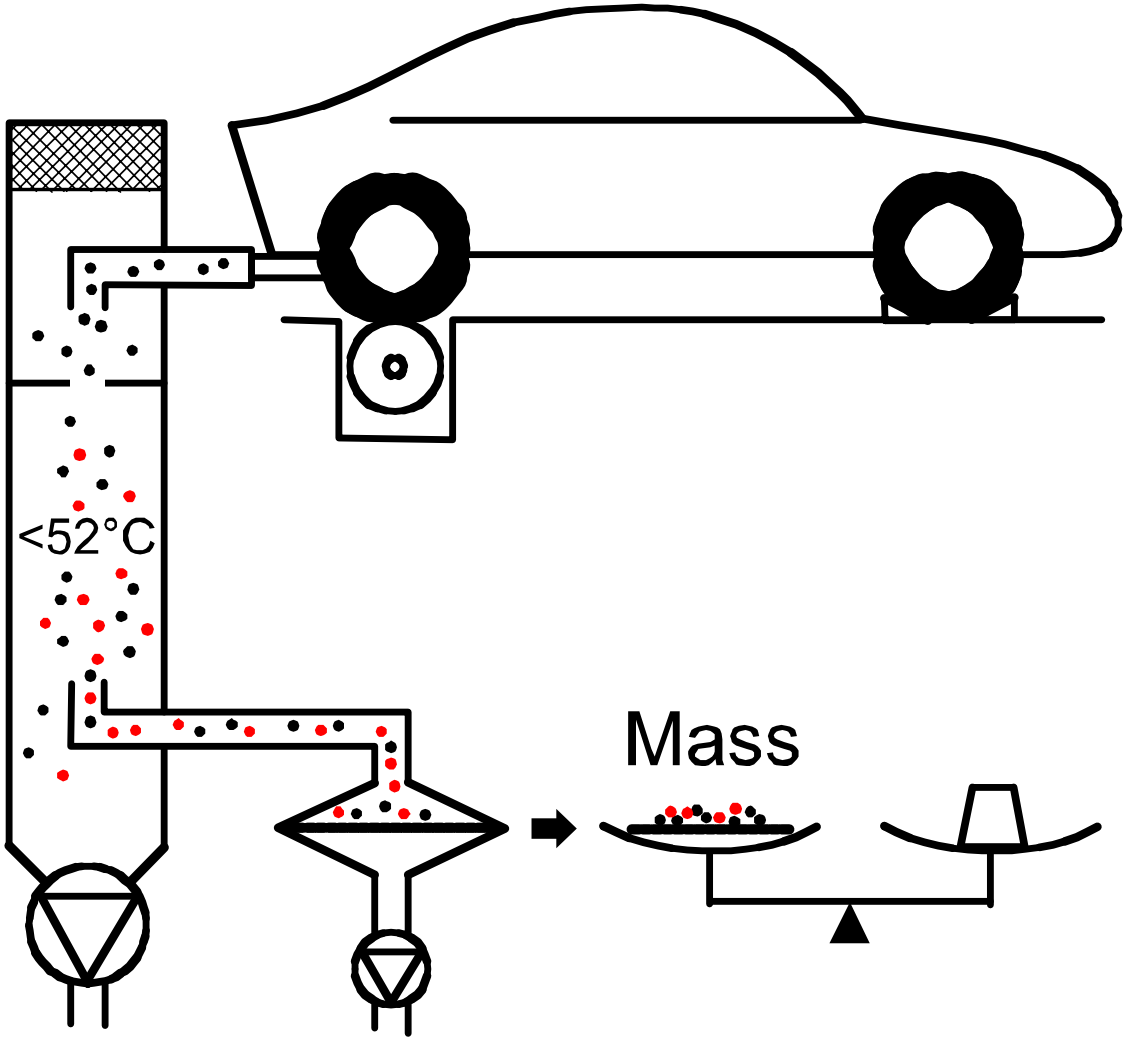
- ***toxicity***
- ***solubility***
- ***residence time***

Particulate Mass Samples upstream and downstream of a Particle Filter in a Bus (Odense Test 2003)



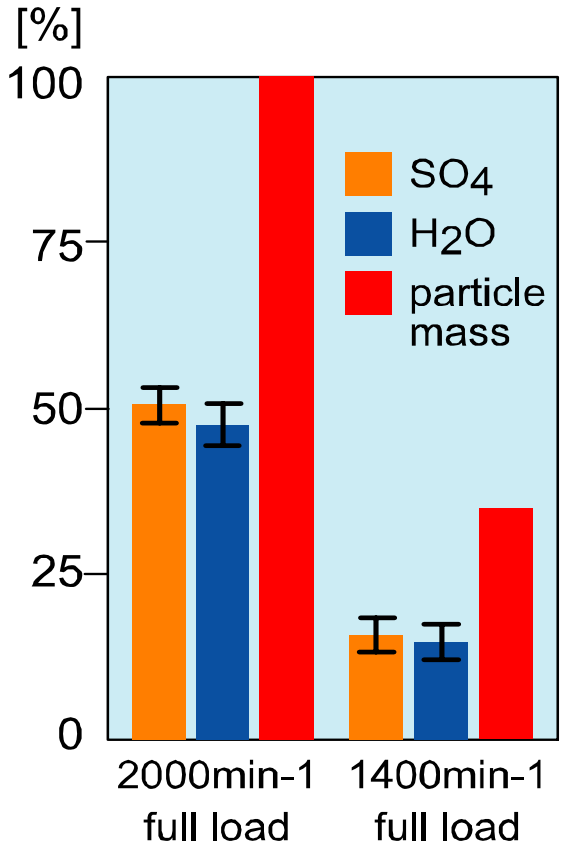
Hansen, Jensen, Ezerman (2001) Report 270-1-0019, Engine Technique Aarhus

How do we measure Particle Mass PM according to the legal procedure

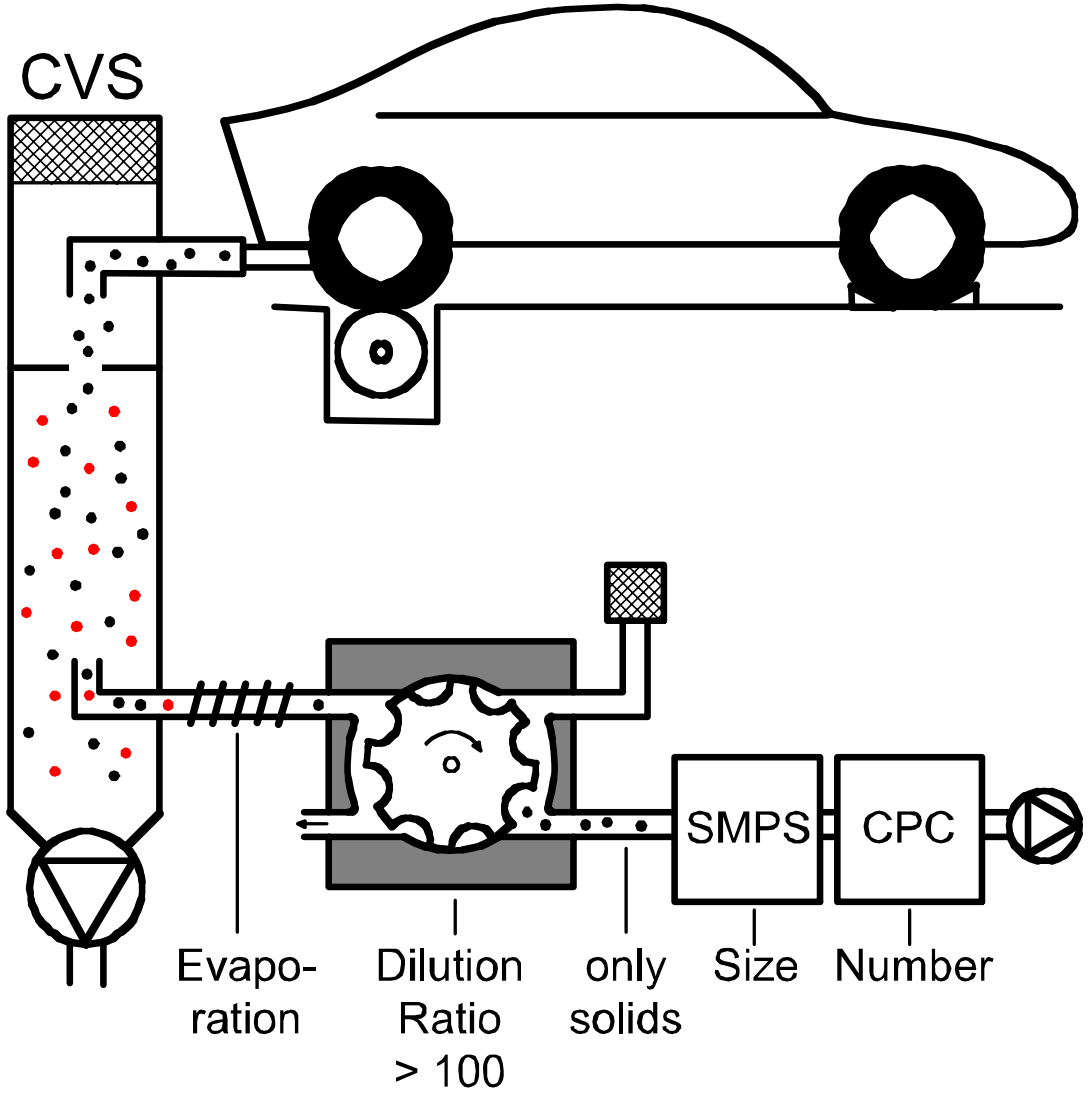


What is the result?

Filtration Efficiency by mass: - 40 %



How do we measure solid Particle Number and Size acc. to EU-PMP



What is the result ?

Filtration Efficieny
by number
of solid particles

99.9 %

PM = particle mass is an excellent metric only if composition and properties of the samples are identical

If composition and properties are different – mass becomes a secondary criterion for comparison, difficult to handle and can be very misleading

Why do we claim
Solid Particles more important than Liquid Droplets

Solid Particles: EC and Metal Oxides are

- invasive (Size)
- persistant (Substance: inert by nature)
- carcinogenic (each single particle can trigger cancer !)
- carriers of toxics like PAH and Nitro-PAH

they can be measured accurately and eliminated by filters

Liquid Droplets : Water, Sulfate, HC

- not persistant: dilution and emulgation by surfactants
- thresholds well known → dose far below critical
- not invasive
- not carcinogenic

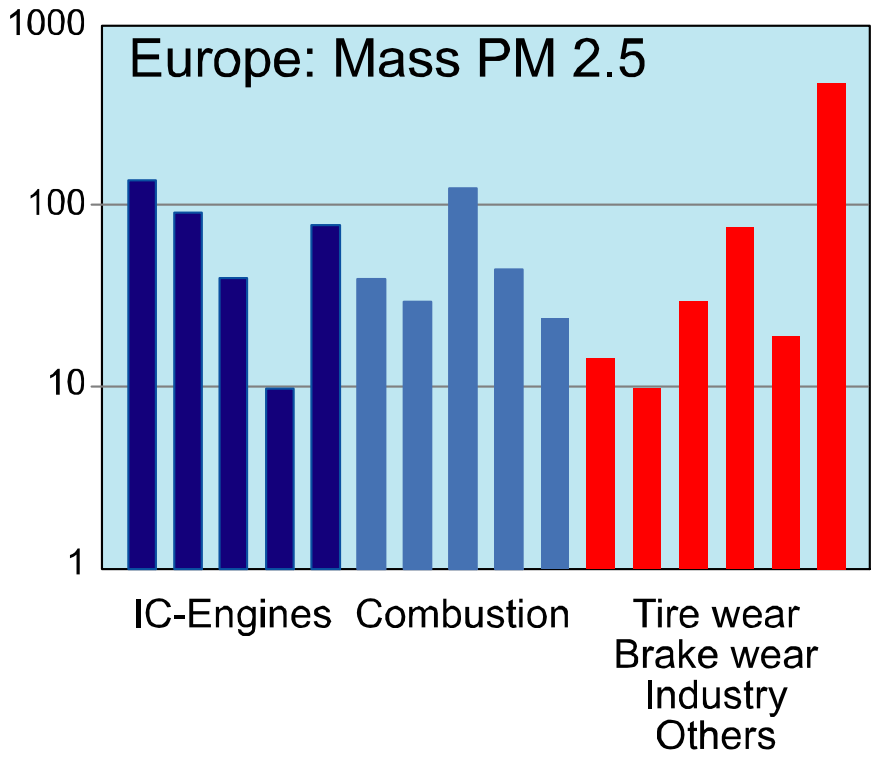
Fuel Quality (ULSF) and DOC take perfectly care

Claim 3

Particle Number matters

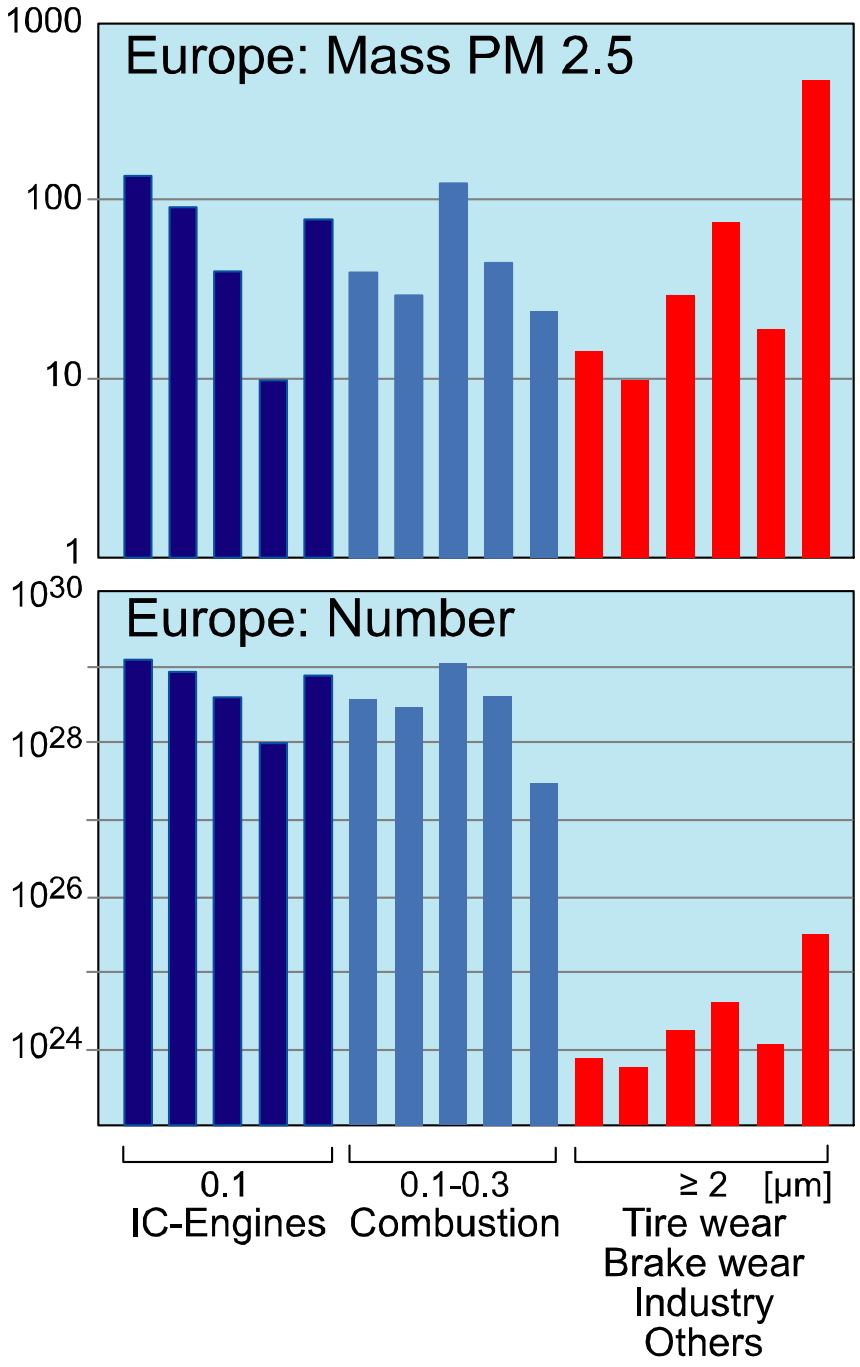
because Nanoparticles are well represented by number and hardly by overall mass
size range is 1:100 - mass range 1: 1000‘000

Sources of PM 2.5 Particulate Mass in Europe

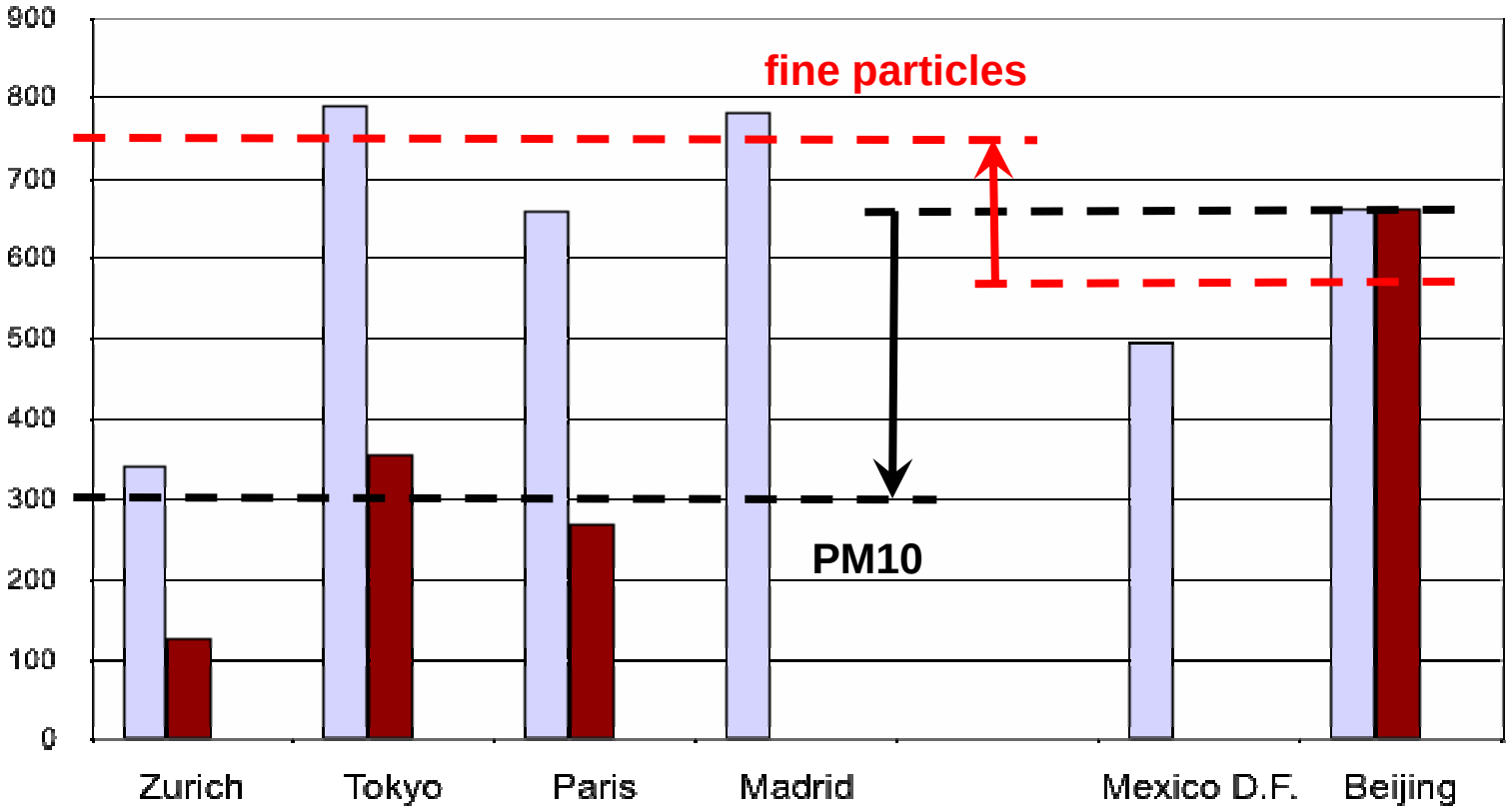


... And the same Inventory represented in Particle Number

→**Particles larger than 1μ can be neglected**



How was ambient PM10 and Particle Number Concentration influenced by Technlology



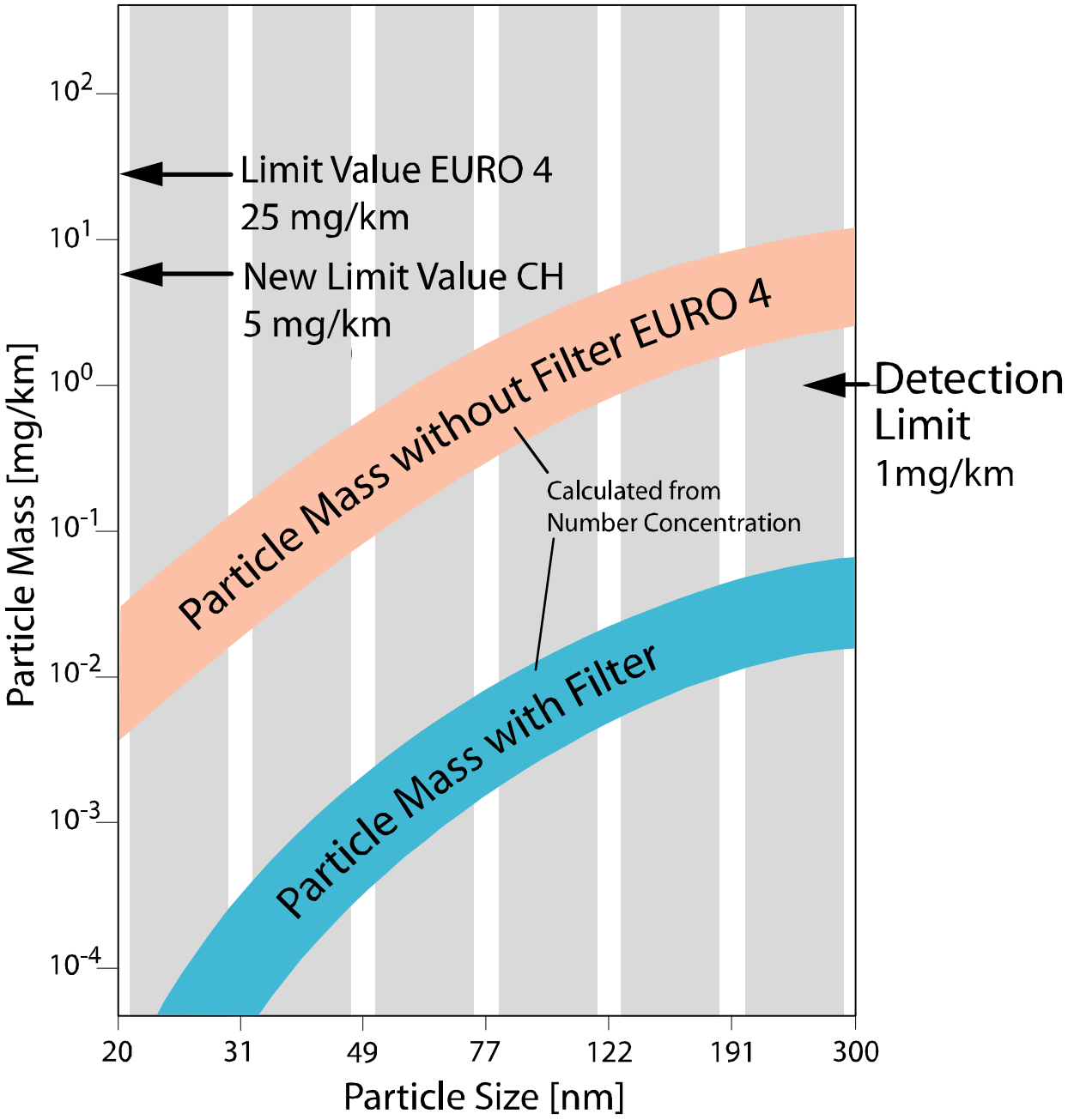
Source: Siegmann / ETH-Zürich

Mass-Limits

underestimate ultrafine contribution

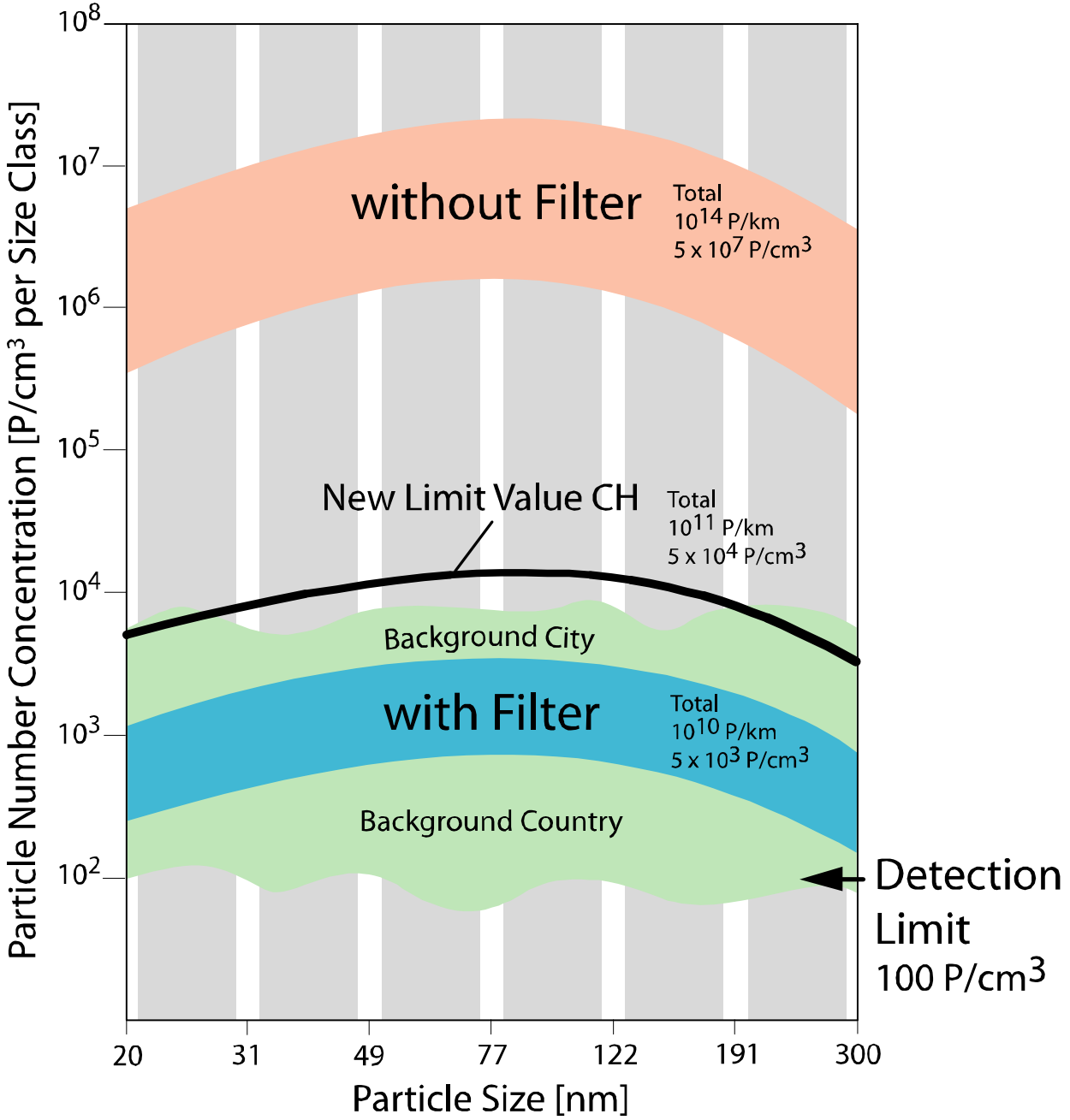
and can not exploit Filter

Technology

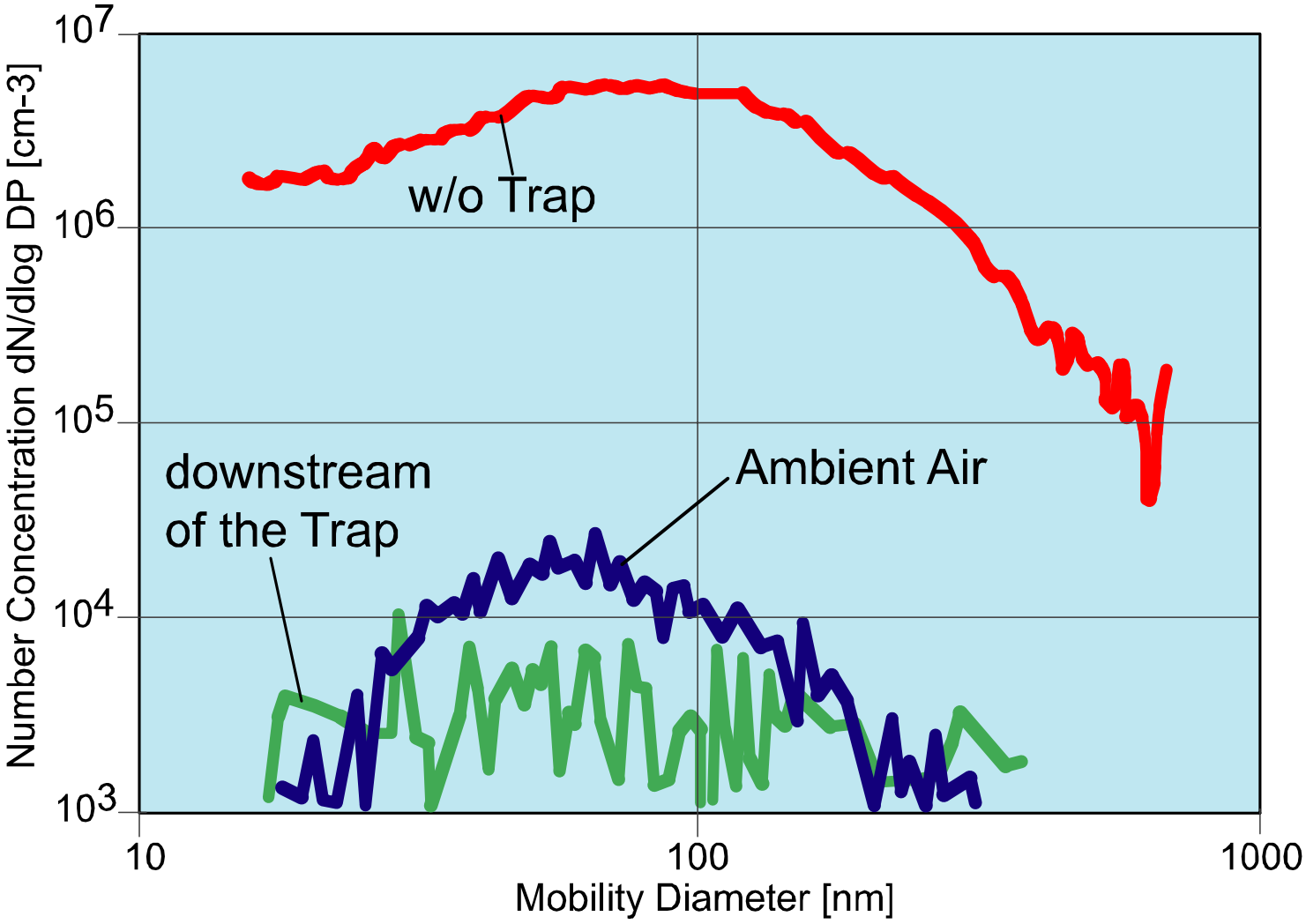


Number – Limits

address the HE-metric and force the introduction of best available Technology



Exhaust Gas downstream of the Filter is cleaner than Ambient Air !

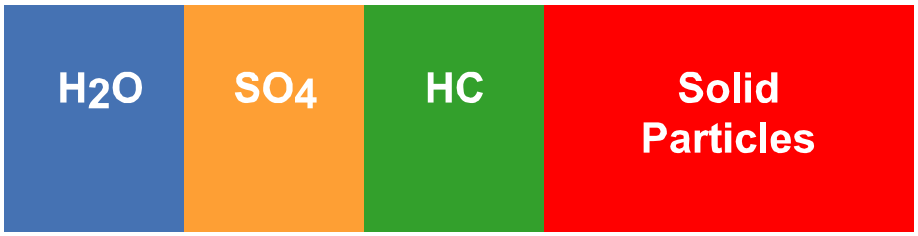


Counting particle numbers

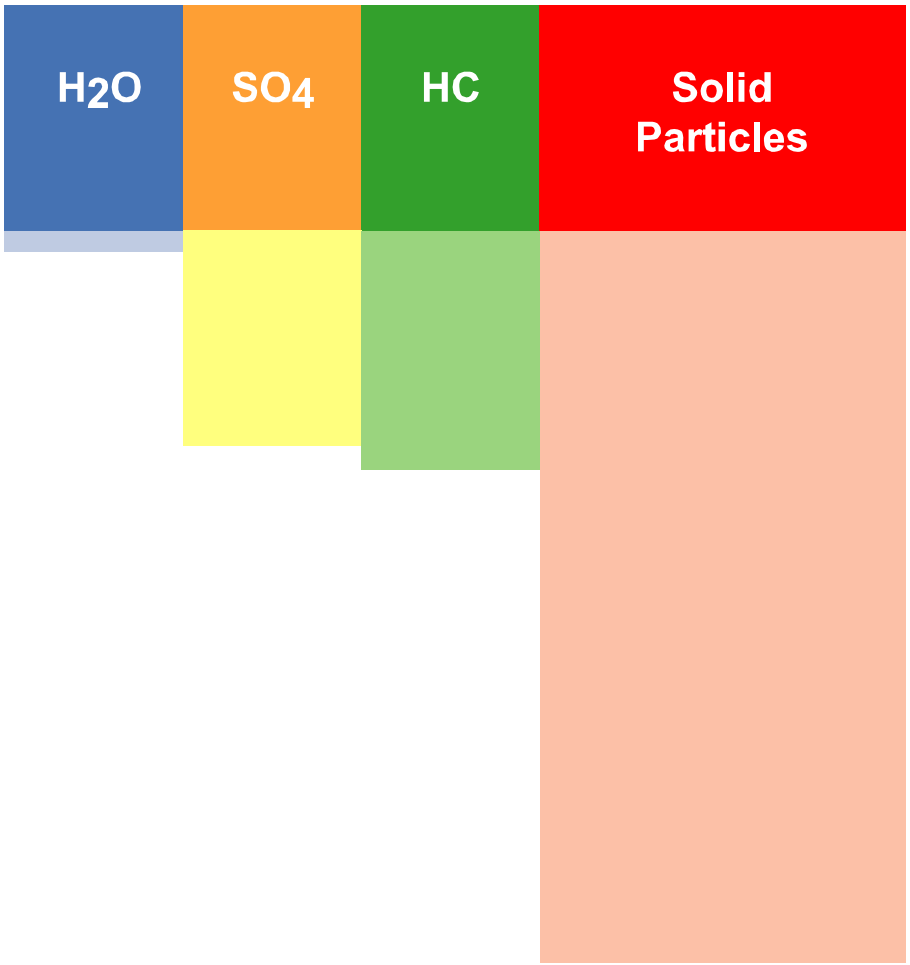
is the only way

- to introduce filters
- to ensure filter quality
- to drive filter technology
- to drive engine technology
- to perform in-compliance testing
- to guarantee high breathing air quality

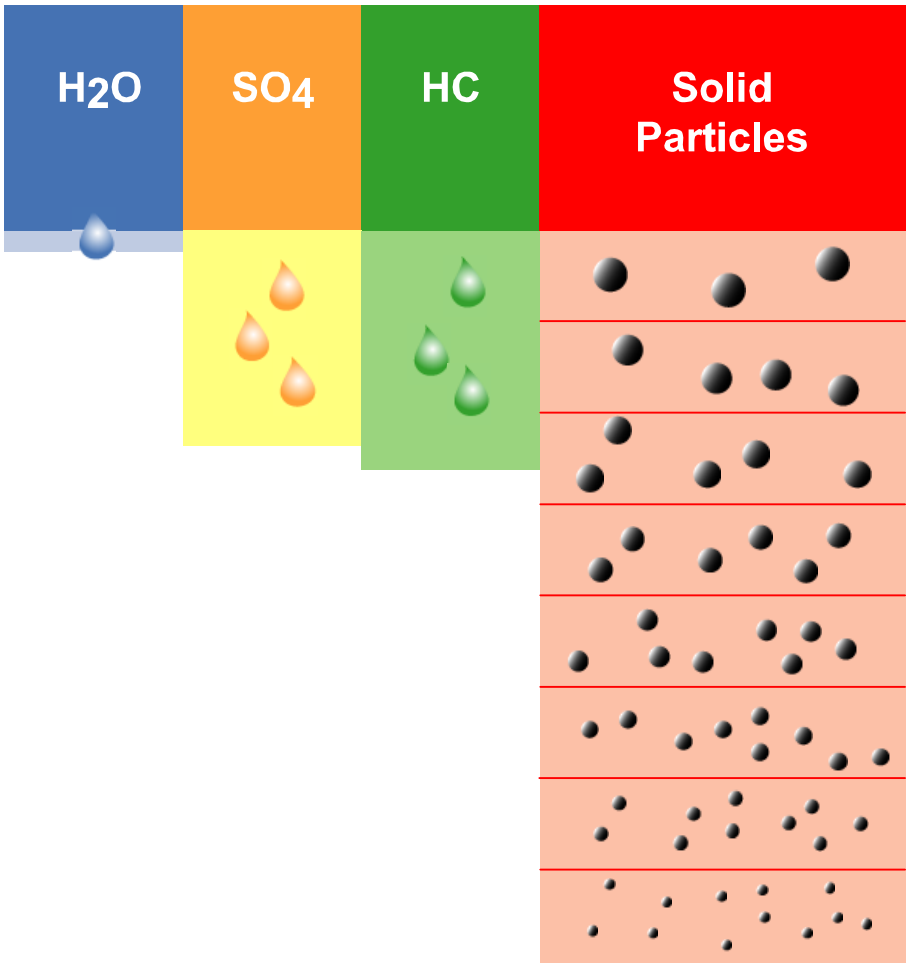
PM consists of different Substances ...



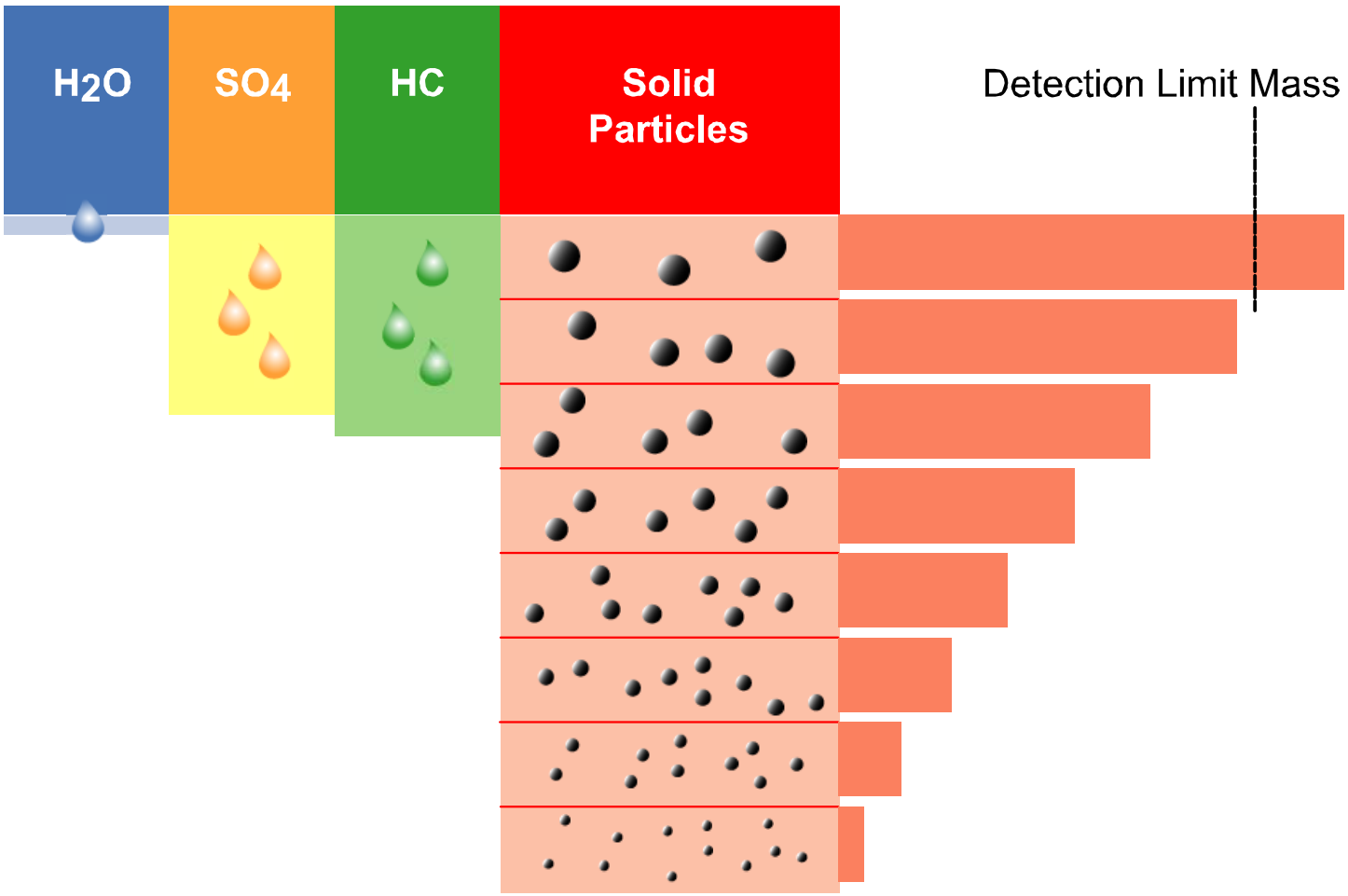
…. with very different Toxicity and different Tools must be applied



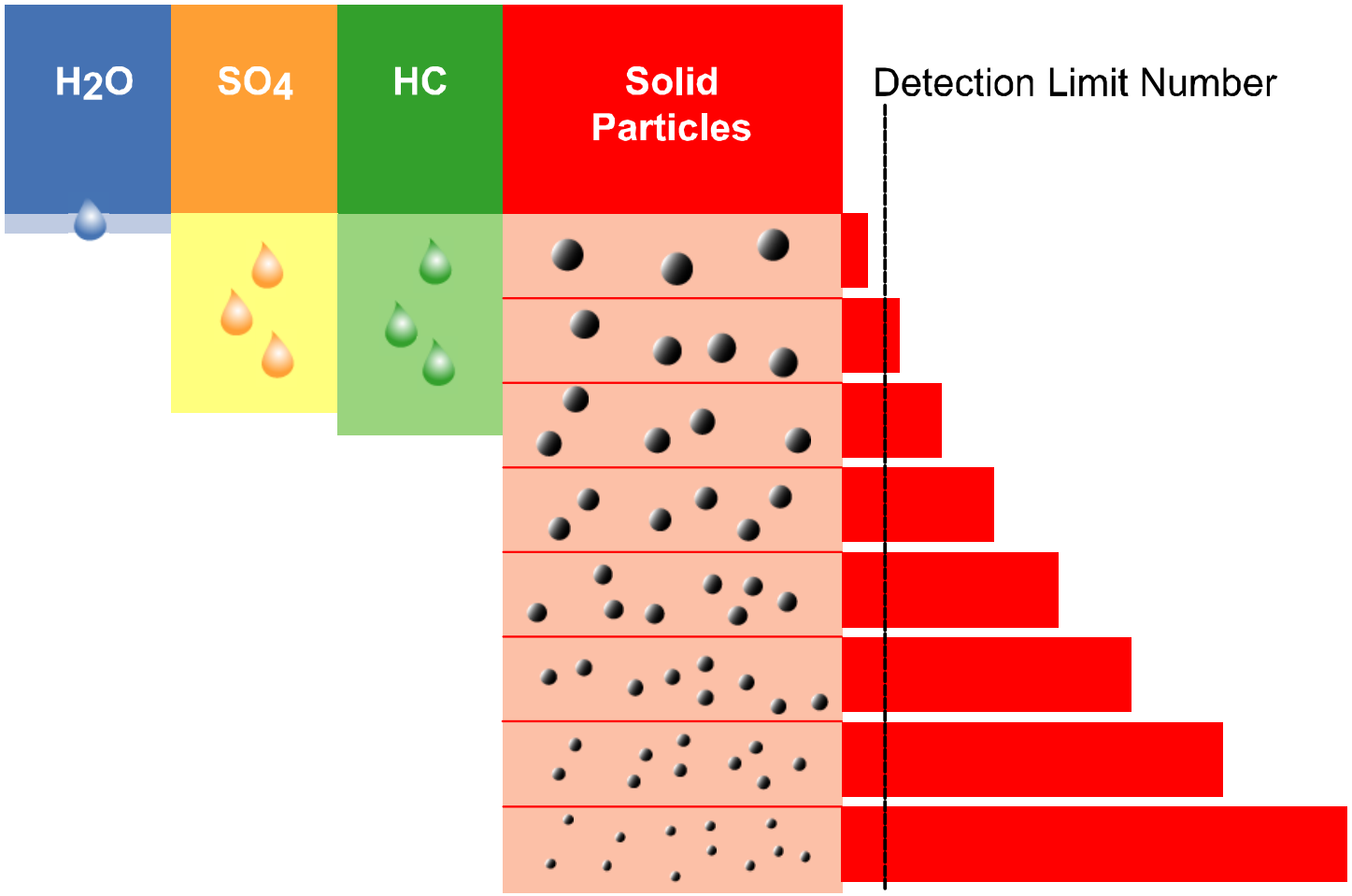
for solid Particles Size must be respected



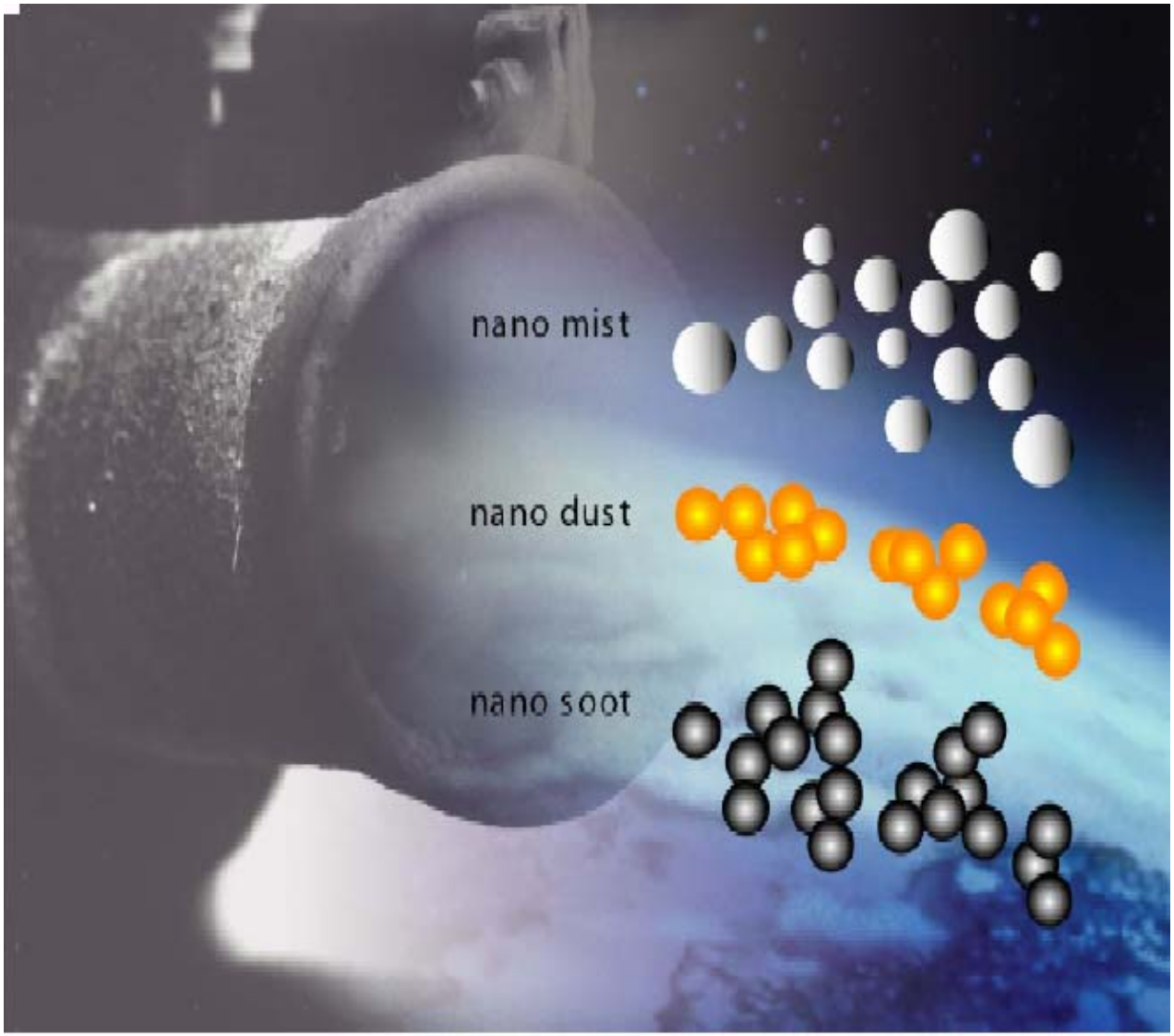
Mass does not represent the ultrafine Particles penetrating the Alveoli and DL is too high



Number Measurement addresses the right Metric and DL permits Technology Forcing



Exhaust - Aerosols



(Quelle:
M.Kasper/ ME)

Conclusion

- ***Particle Size matters***
- ***Particle Number matters***
- ***Particle Composition matters***

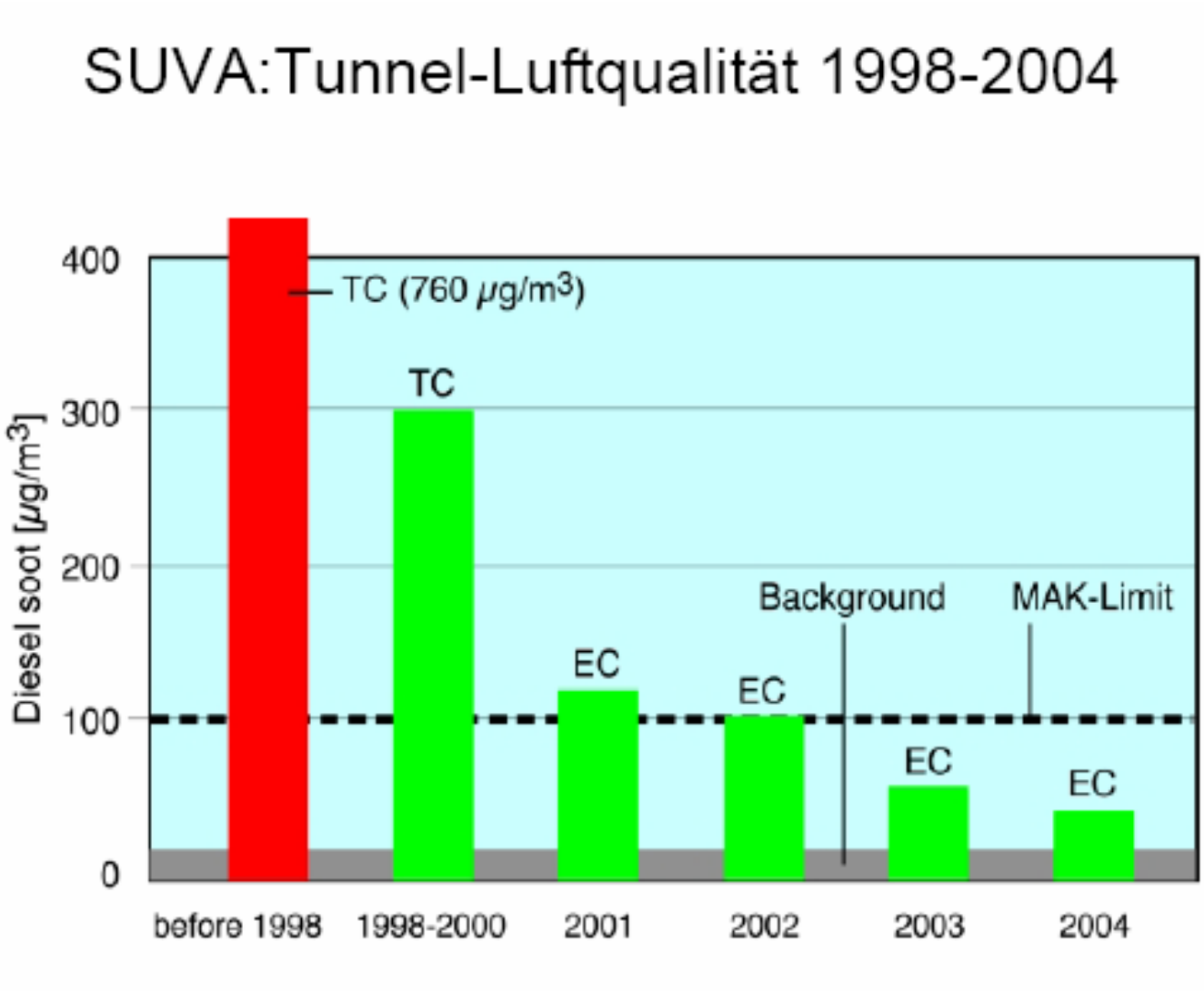
Swiss retrofit projects are based on particle size, substance and number and require the elimination of solid particles size range 20-300 nm acc. to BACT

Solid Particles 20-300 nm
Air Contaminant No.1

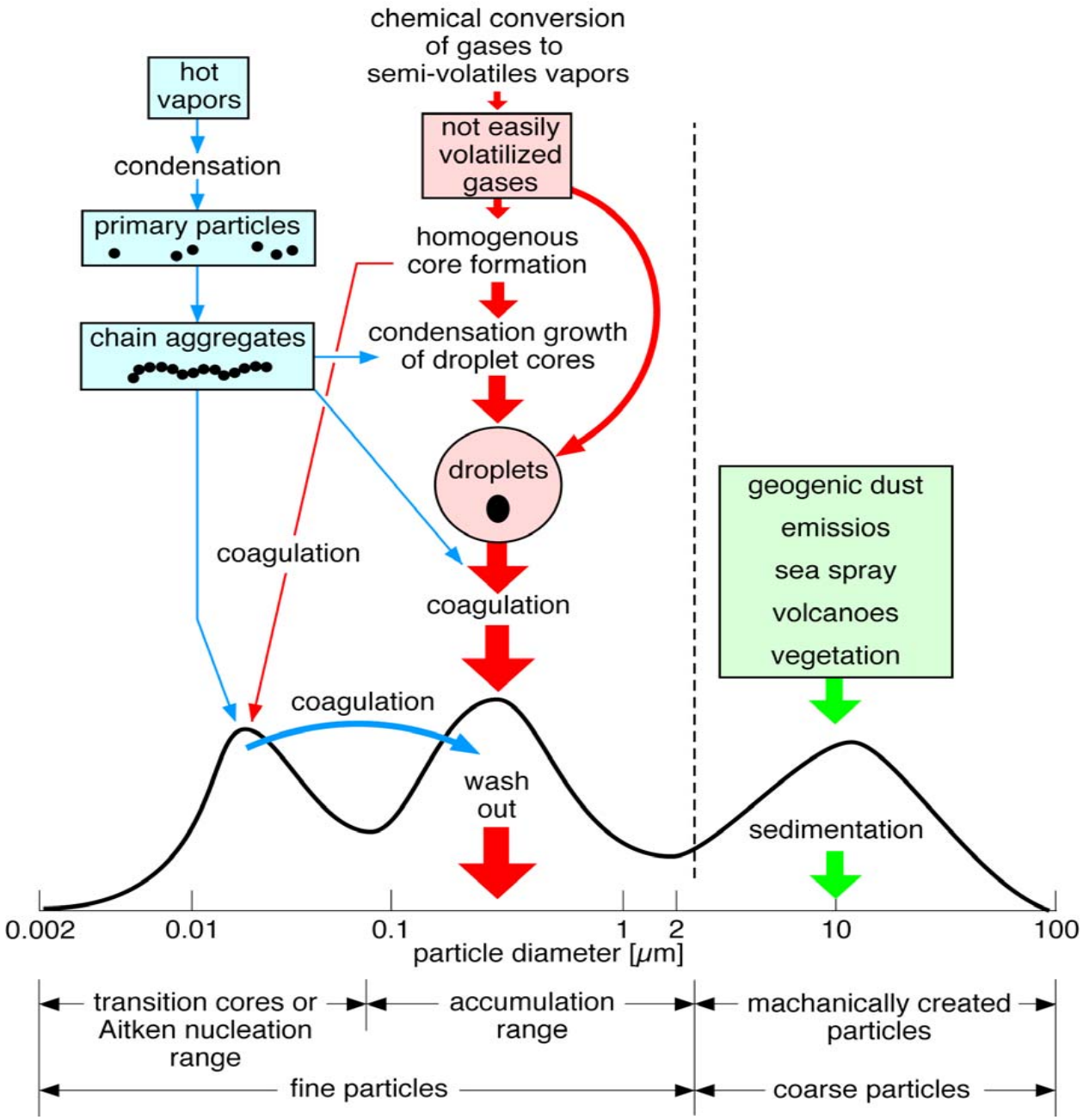
once this definition is accepted
Engineers can

- **measure**
- **design and develop**
- **manufacture and distribute**
- **implement and enforce**
- **and control**

q.e.d.

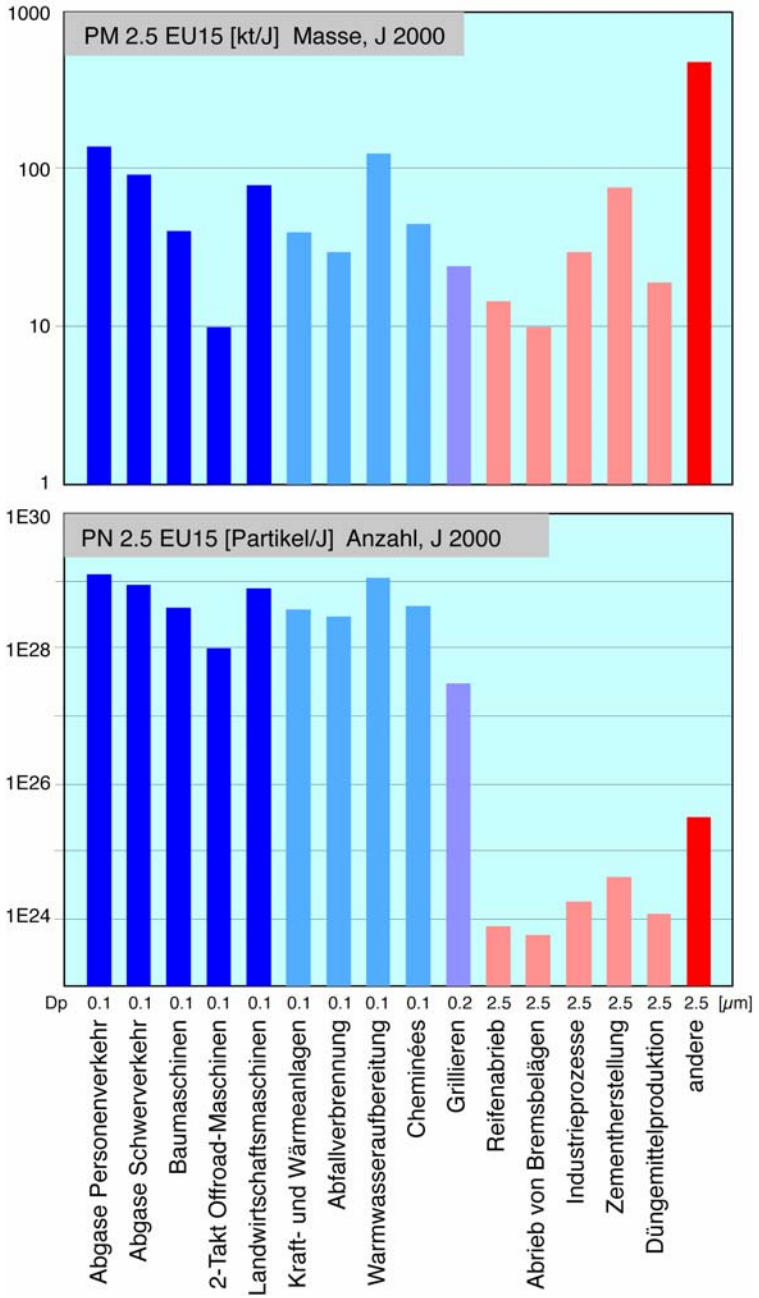


and Air will become as clean as in Swiss Tunneling Sites by Filter Technology



Formation of fine and ultrafine Particles:

2 different Mechanismes

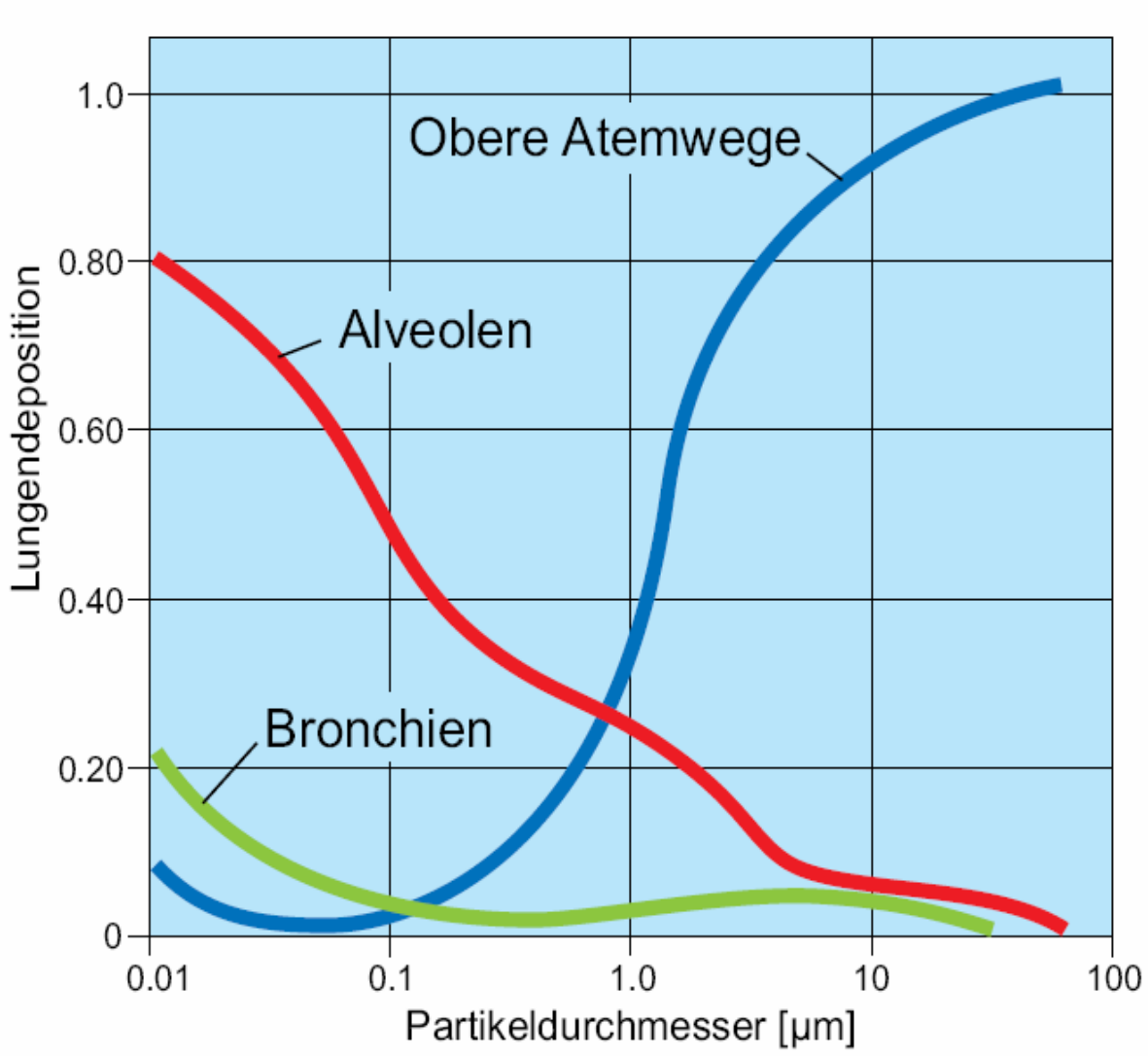

PM 2.5 EU15 [kt/J] Masse, J 2000
1000
100
10
1
PN 2.5 EU15 [Partikel/J] Anzahl, J 2000
1E30
1E28
1E26
1E24
Dp 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.2 2.5 2.5 2.5 2.5 2.5 2.5 [µm]
Abgase Personenverkehr
Abgase Schwerverkehr
Baumaschinen
2-Takt Offroad-Maschinen
Landwirtschaftsmaschinen
Kraft- und Wärmeanlagen
Abfallverbrennung
Warmwasseraufbereitung
Cheminées
Grillieren
Reifenabrieb
Abrieb von Bremsbelägen
Industrieprozesse
Zementherstellung
Düngemittelproduktion
andere

HDT-3, Bild 5

Deposition

of particles in the airways depends mainly on particle size not mass

(Source: Hinds, 1982 Aerosoltechnology)



Bronchien raus

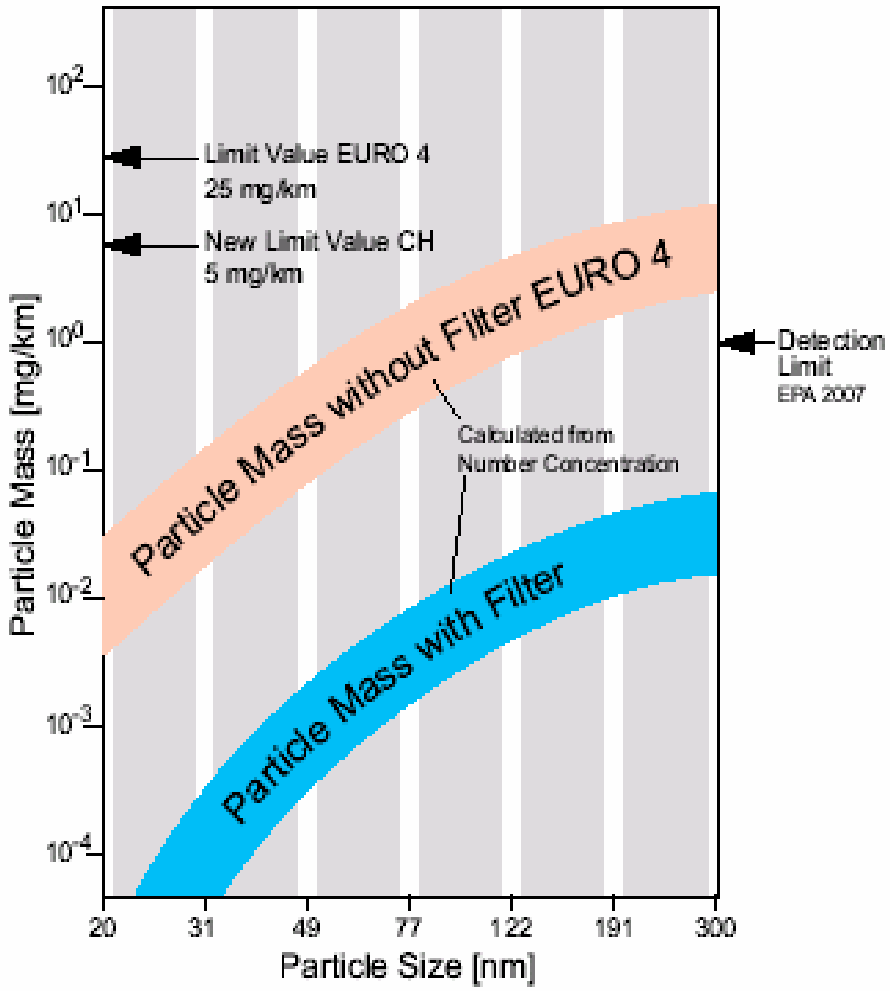
3-modale Verteilung einzeichnen

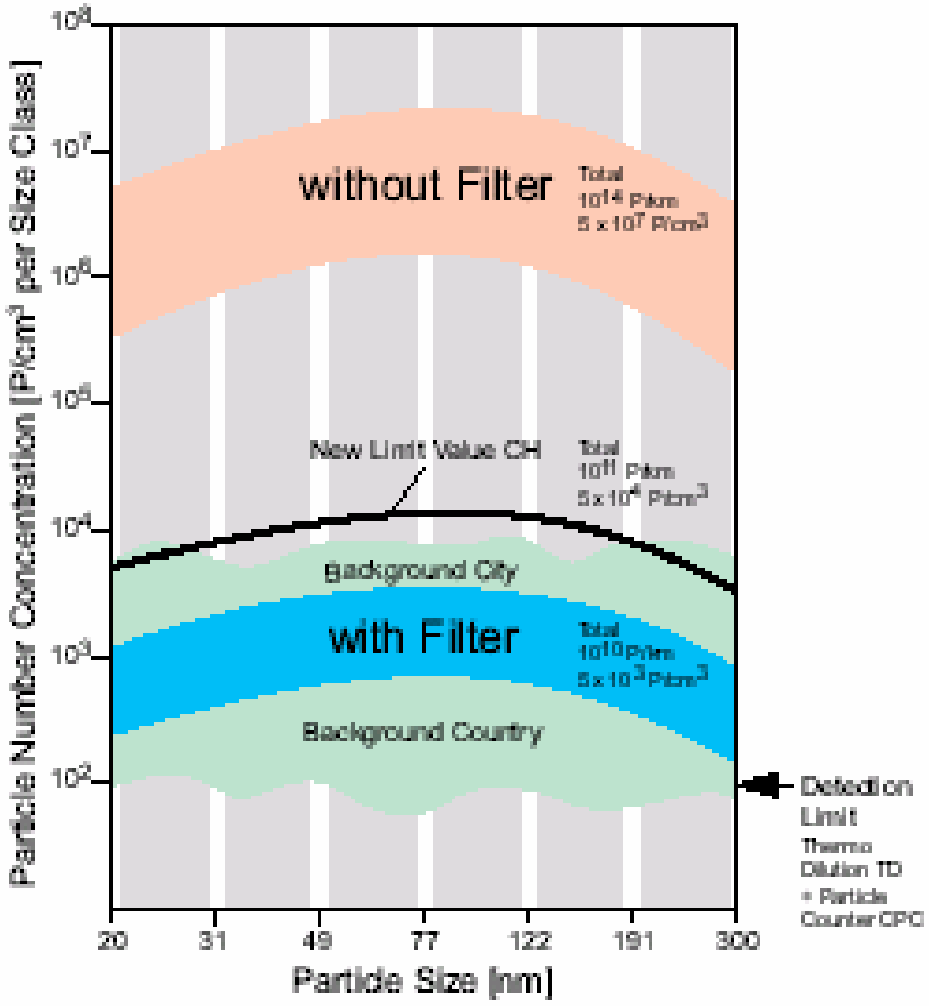
Bereiche Clearing und Absorptior

Einzeichnen

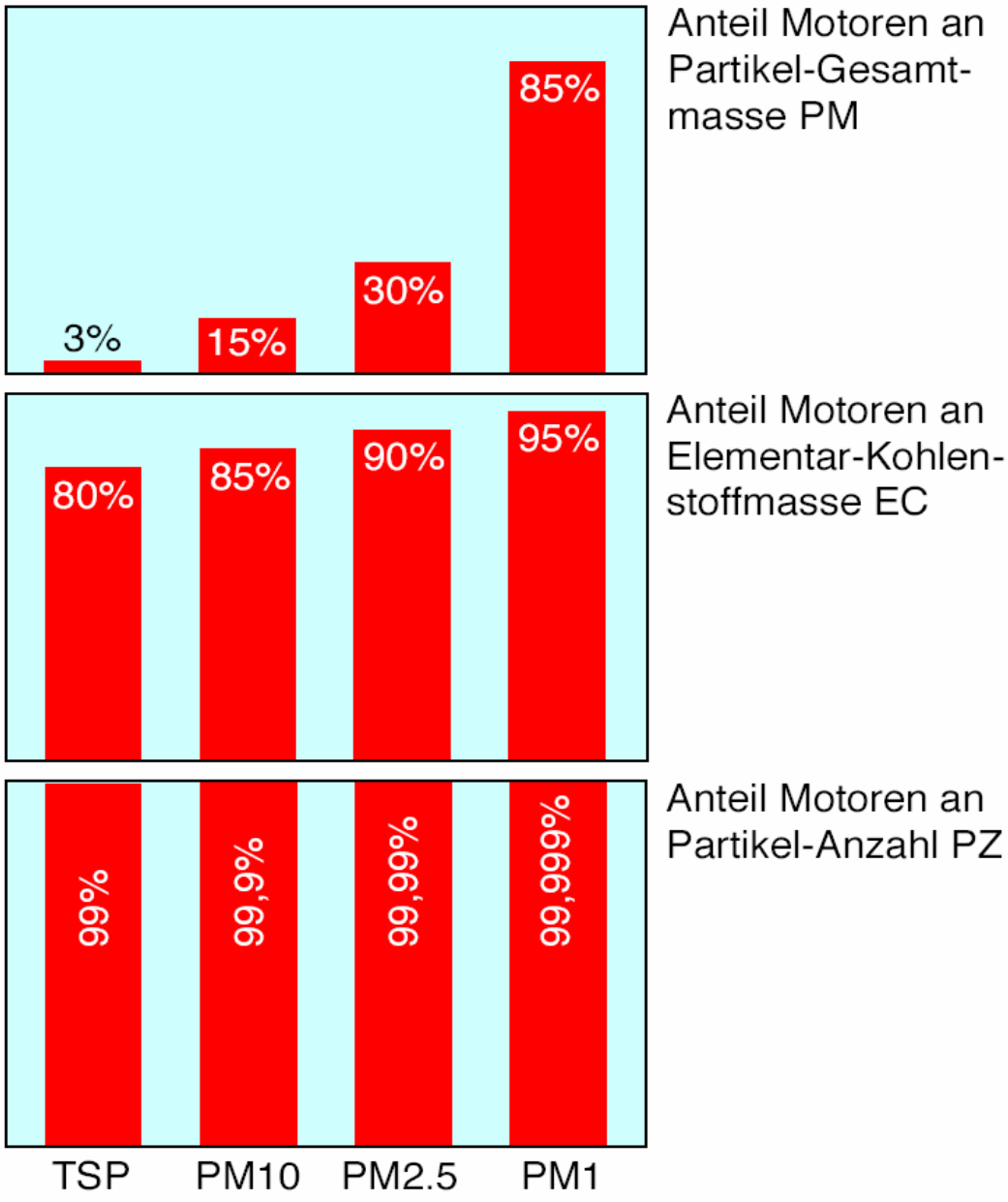
Innerhalb und ausserhalb des Körpers - Trennlinie

Number Measurement → lower Emission Limits and better Control Technology





Anteil der Partikelemission der Motoren an der Gesamt-Partikel“menge“



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