



# Physical and Chemical Characterization of the Particles Emitted by A Hydrogen Fueled DI SI Engine: the Role of Lube Oil

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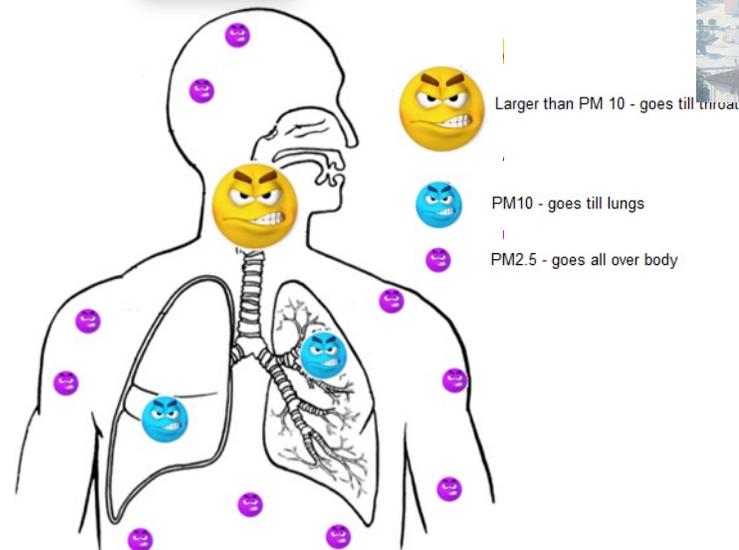
## Climate Change



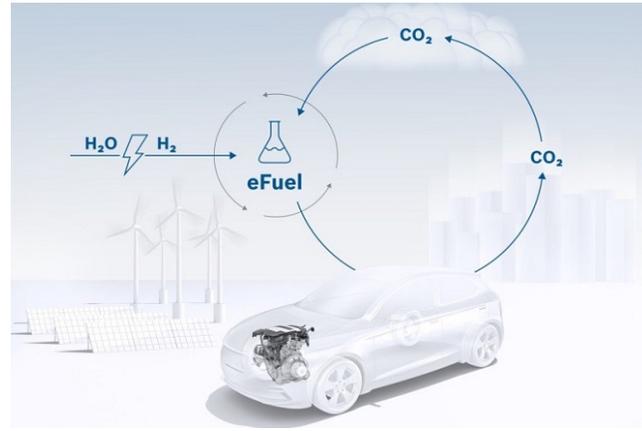
## Deterioration of Air Quality



**PM**



# Environmentally Friendly



*eFuels*



*H2*

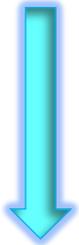


*EV*

# H2 Engines: Emissions



No «C»

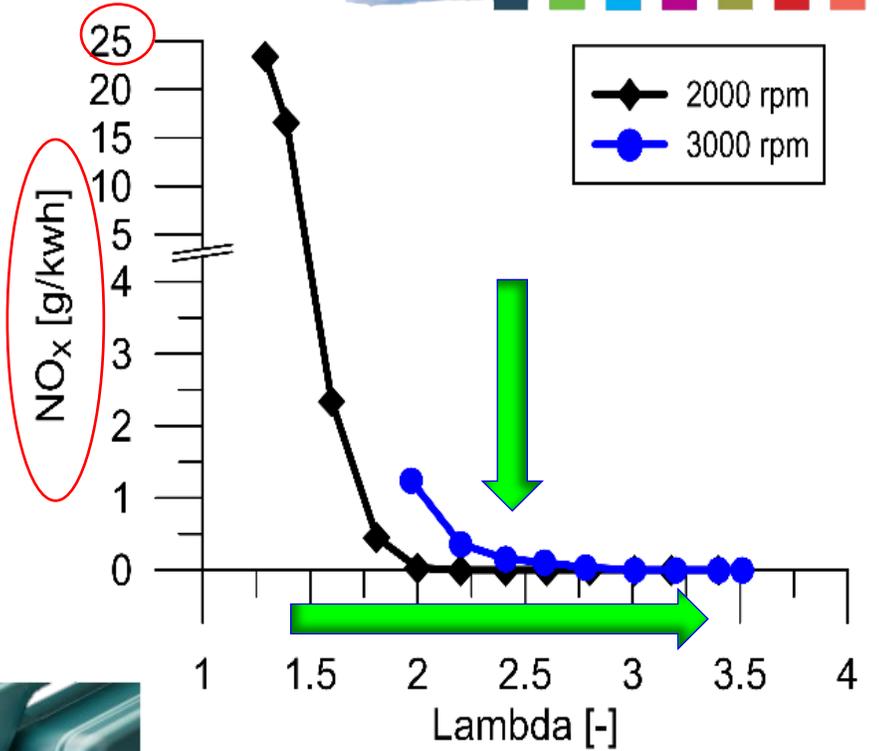
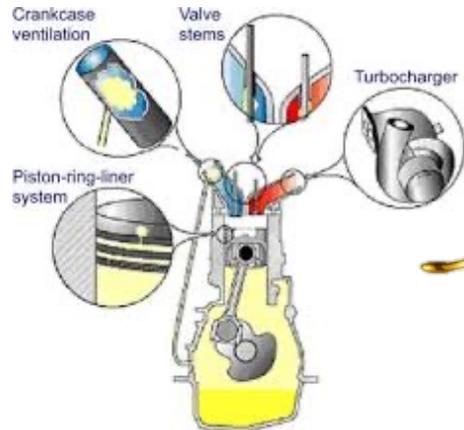


CO    CO<sub>2</sub>    HC

PM



*PM & Lube Oil*





Comprehensive investigation on the contribution of the lubricating oil on particle emissions from a DI hydrogen fueled engine

Physical analysis



Size/Number

Chemical analysis

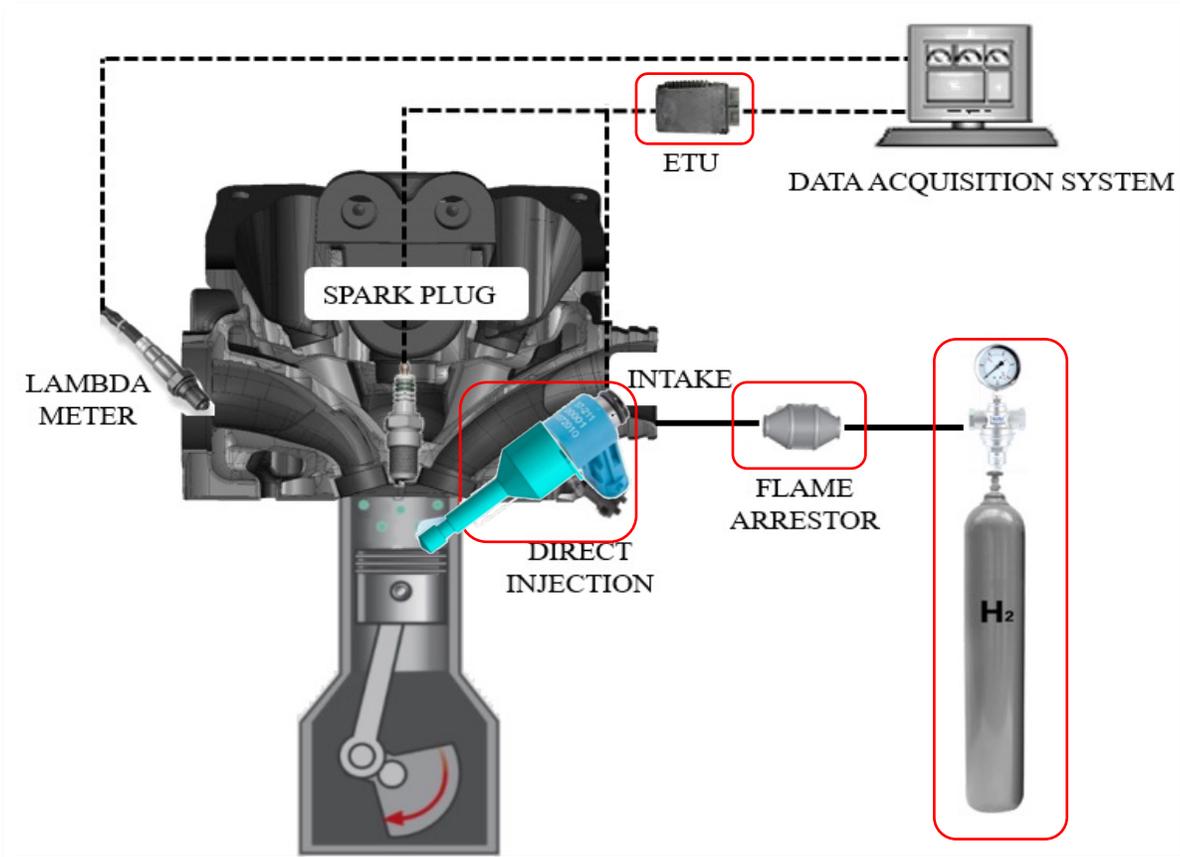


SOF/Soot

Speed/Load



Environmental  
Conditions



DI SI Engine	
Cylinder volume [cm <sup>3</sup> ]	250
Bore [mm]	72
Stroke [mm]	60
Compression ratio	9:1
Max power [kW]	7.9 @ 5000 rpm
Max torque [Nm]	14.7 @ 5000 rpm

Oil Properties	
Viscosity	10W-40
Density @ 20 °C	0.870 kg/l
Viscosity @ 40 °C	101.7 mm <sup>2</sup> /s
Viscosity @ 100 °C	14.5 mm <sup>2</sup> /s
Viscosity index	151
Pour point	-35.0 °C
TBN	10.1 mg KOH/g
Flash point	228 °C

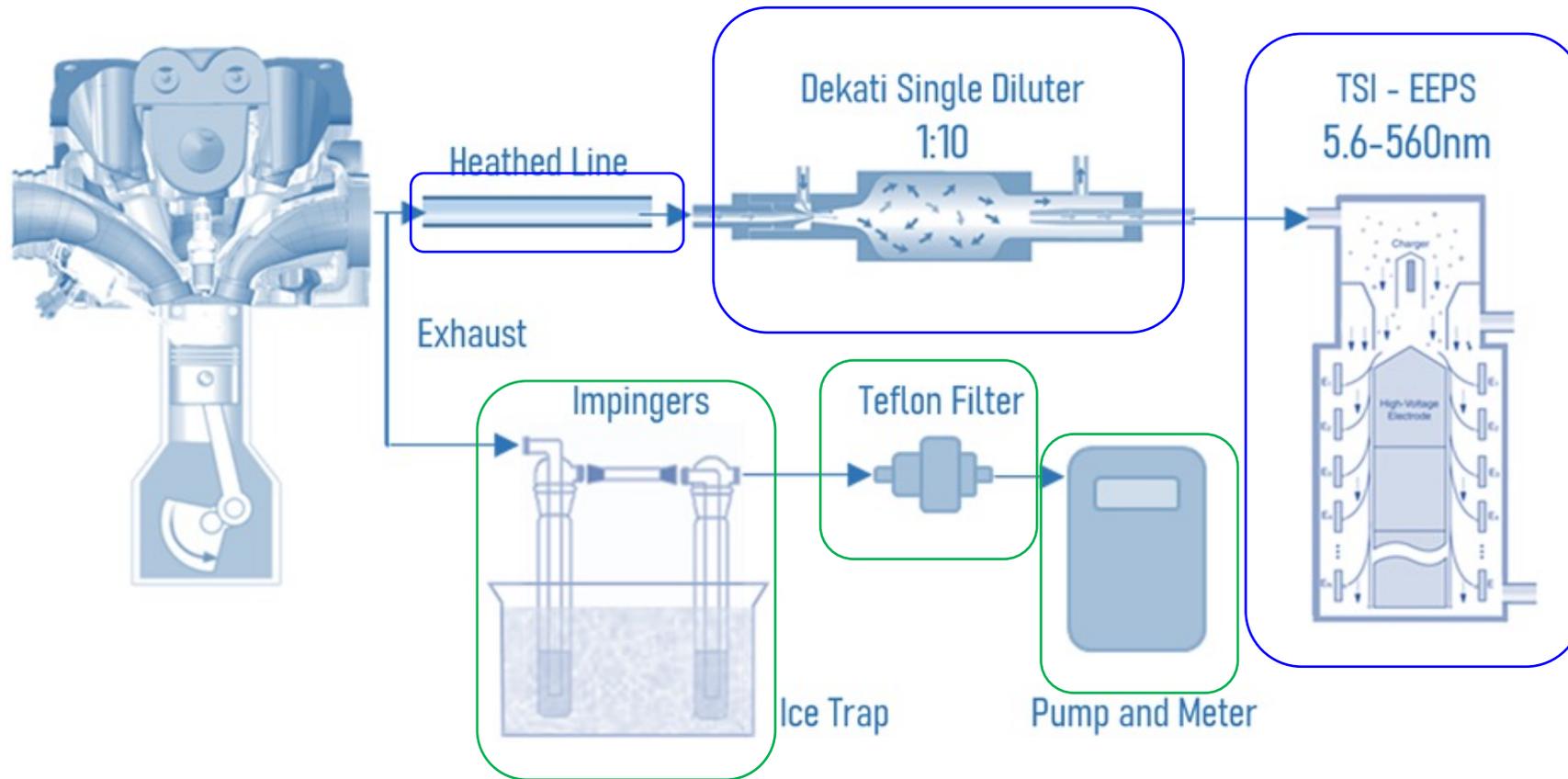


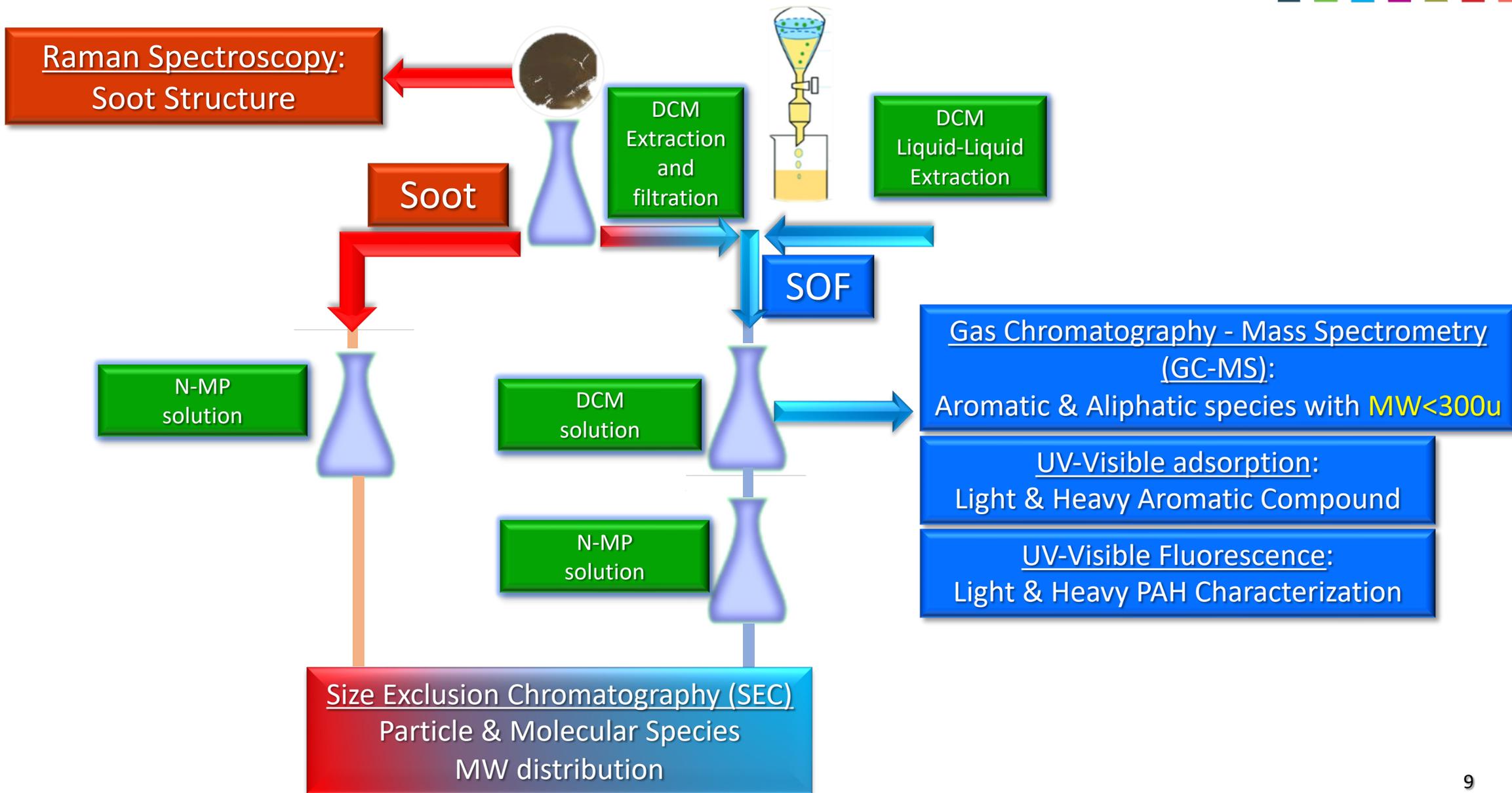


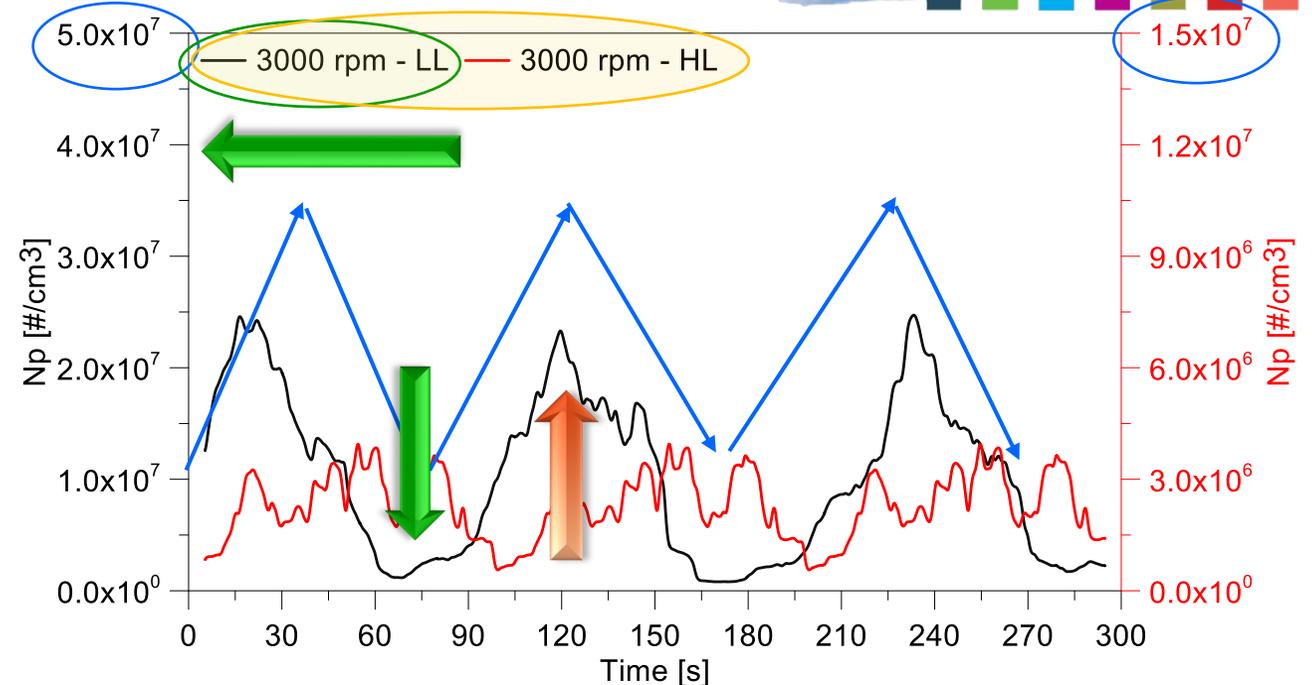
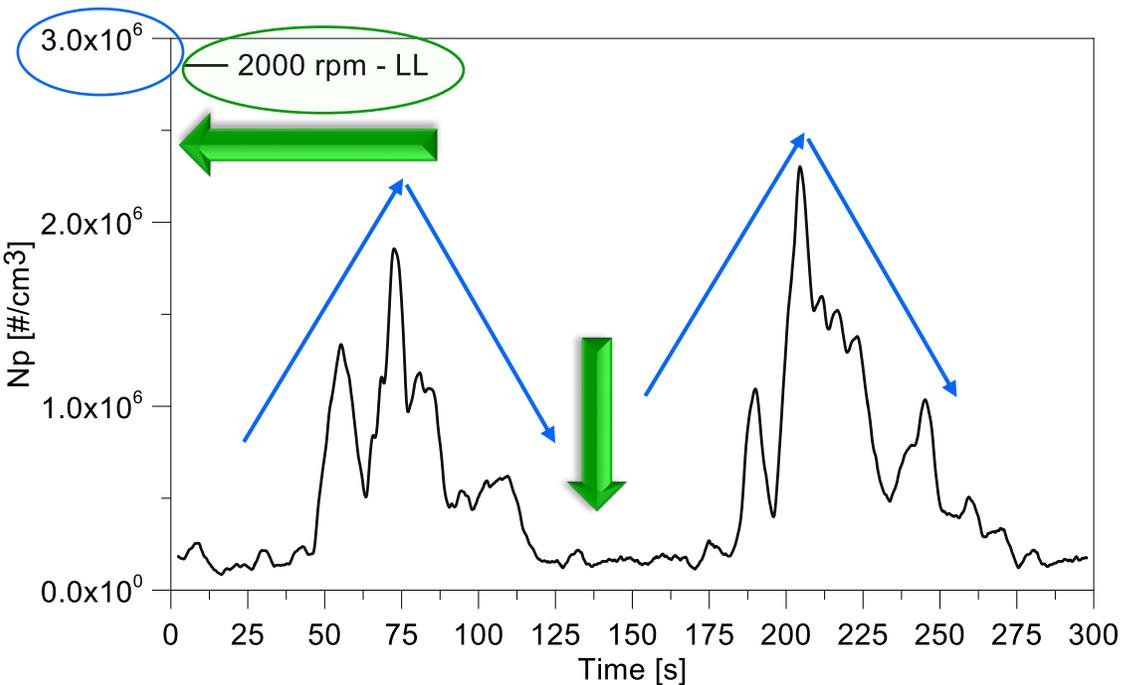
	Engine speed [rpm]	Throttle opening [%]	SOI [cad BTDC]	DOI [cad]	SOS [cad]	$\lambda$ [-]	imep [bar]	COV imep [%]
2000 rpm -LL	2000	15	-270	170	7.0	1.6	4.0	1.0
2000 rpm -HL	2000	95	-260	225	11.6	1.5	5.5	1.2
3000 rpm -LL	3000	15	-270	260	13.7	1.5	4.3	1.5
3000 rpm -HL	3000	95	-352	240	10	1.6	5.7	1.6

Urban & Extra Urban driving conditions

Environmental Conditions







PN Intensity and Frequency changes with speed & load

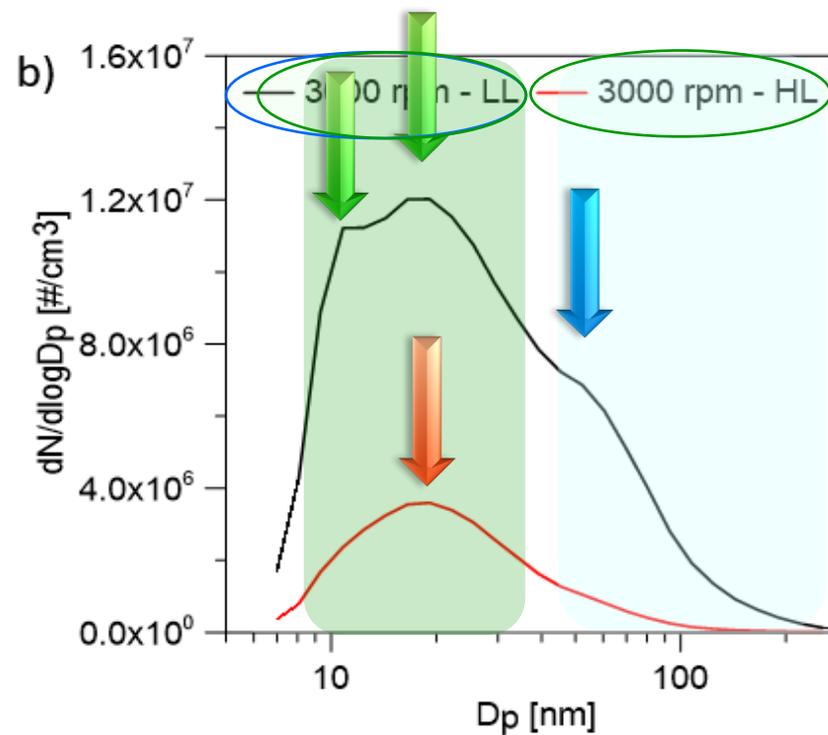
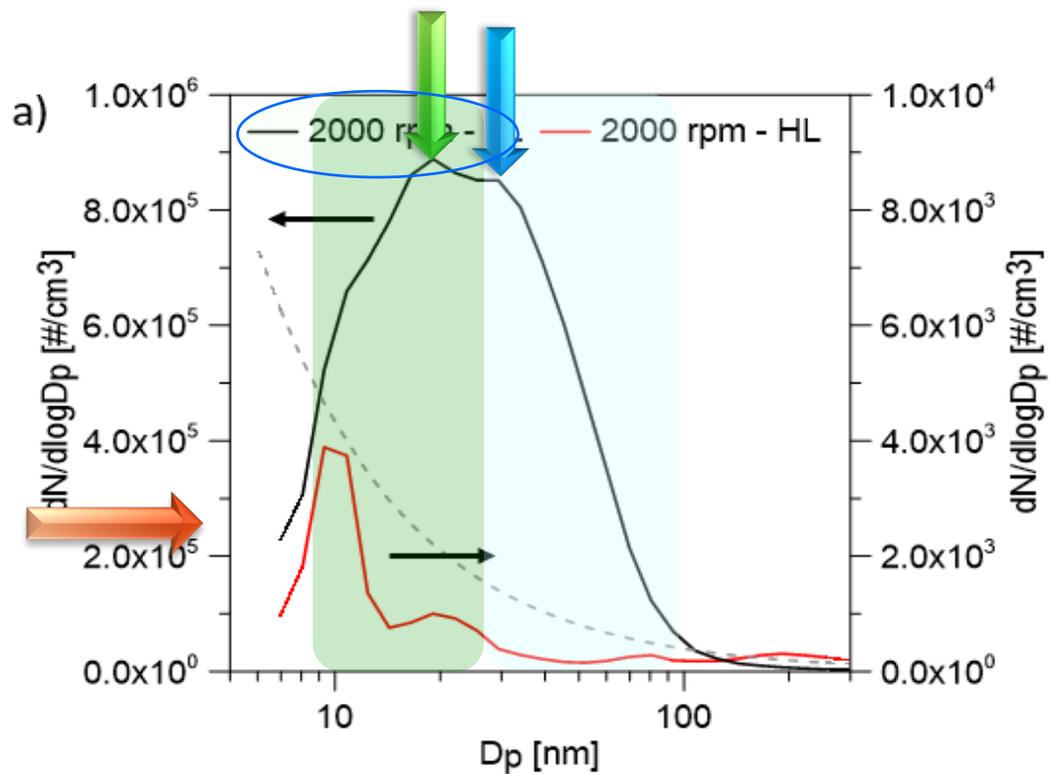
Higher speed:  
Larger PN

Less time between peaks

-Oil Pool  
-Expansion of  
the rings

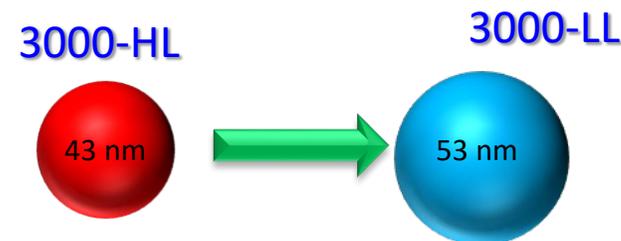
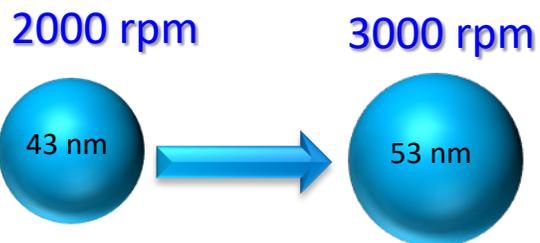
Lower load:  
Larger PN

Negligible effect on  
fluctuaton frequency



**Higher speed:  
Larger particles**

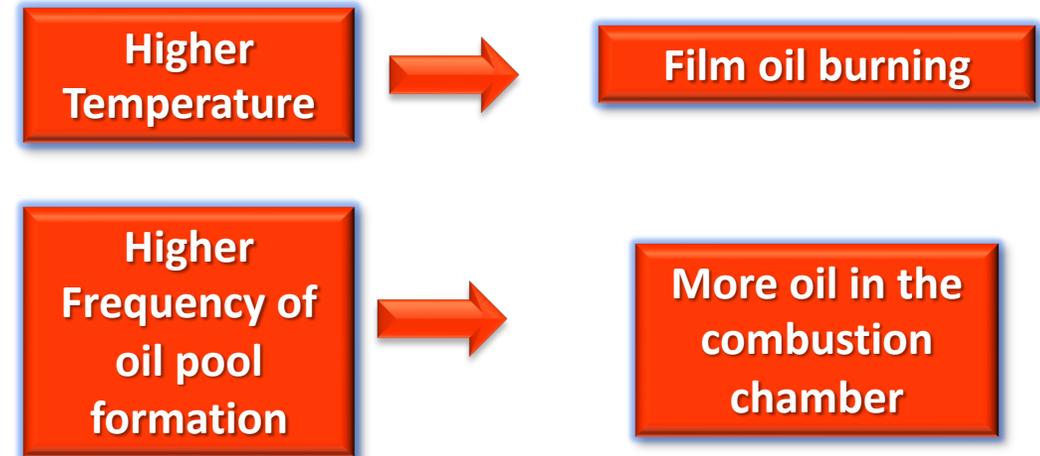
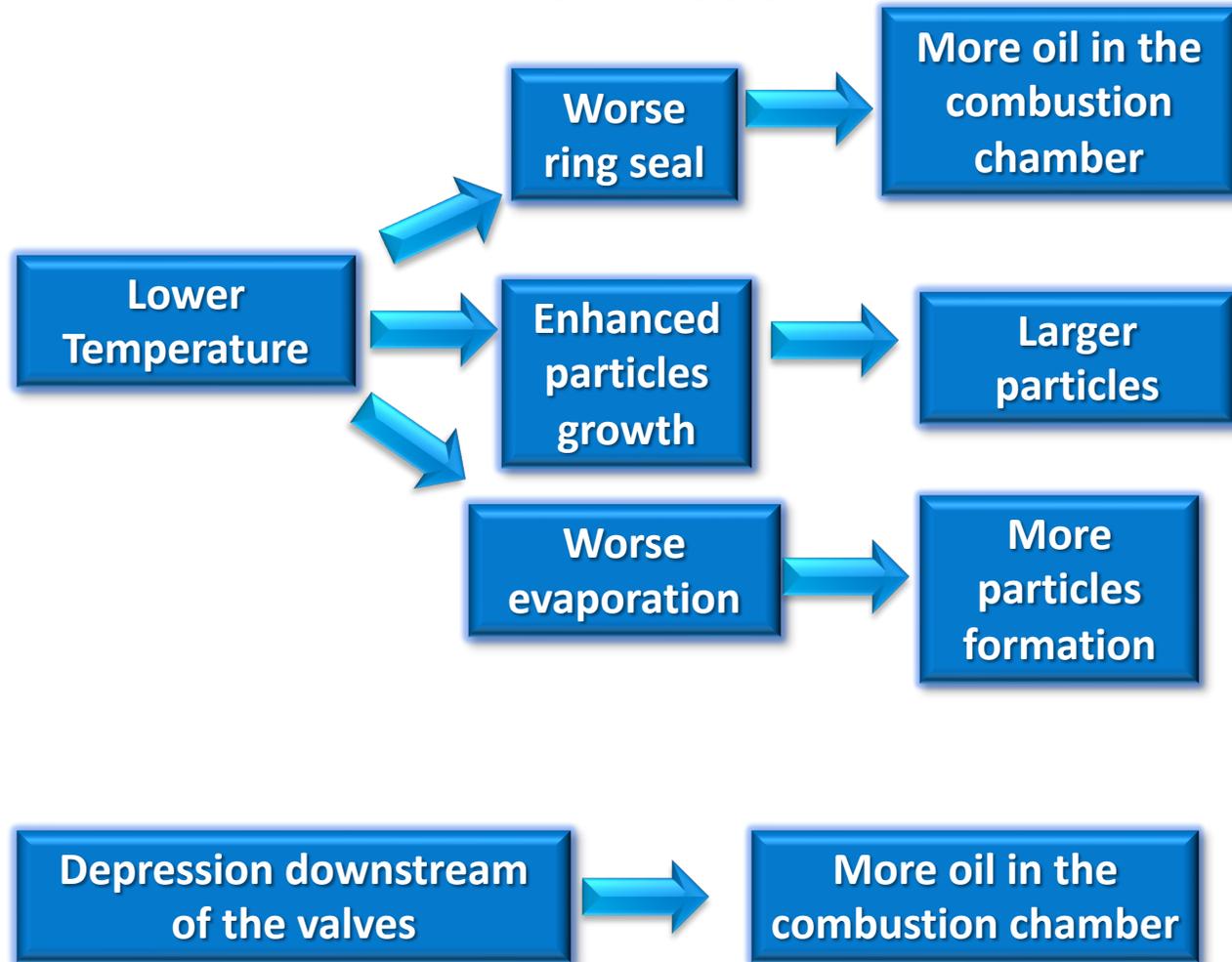
**Lower load:  
Larger particles**





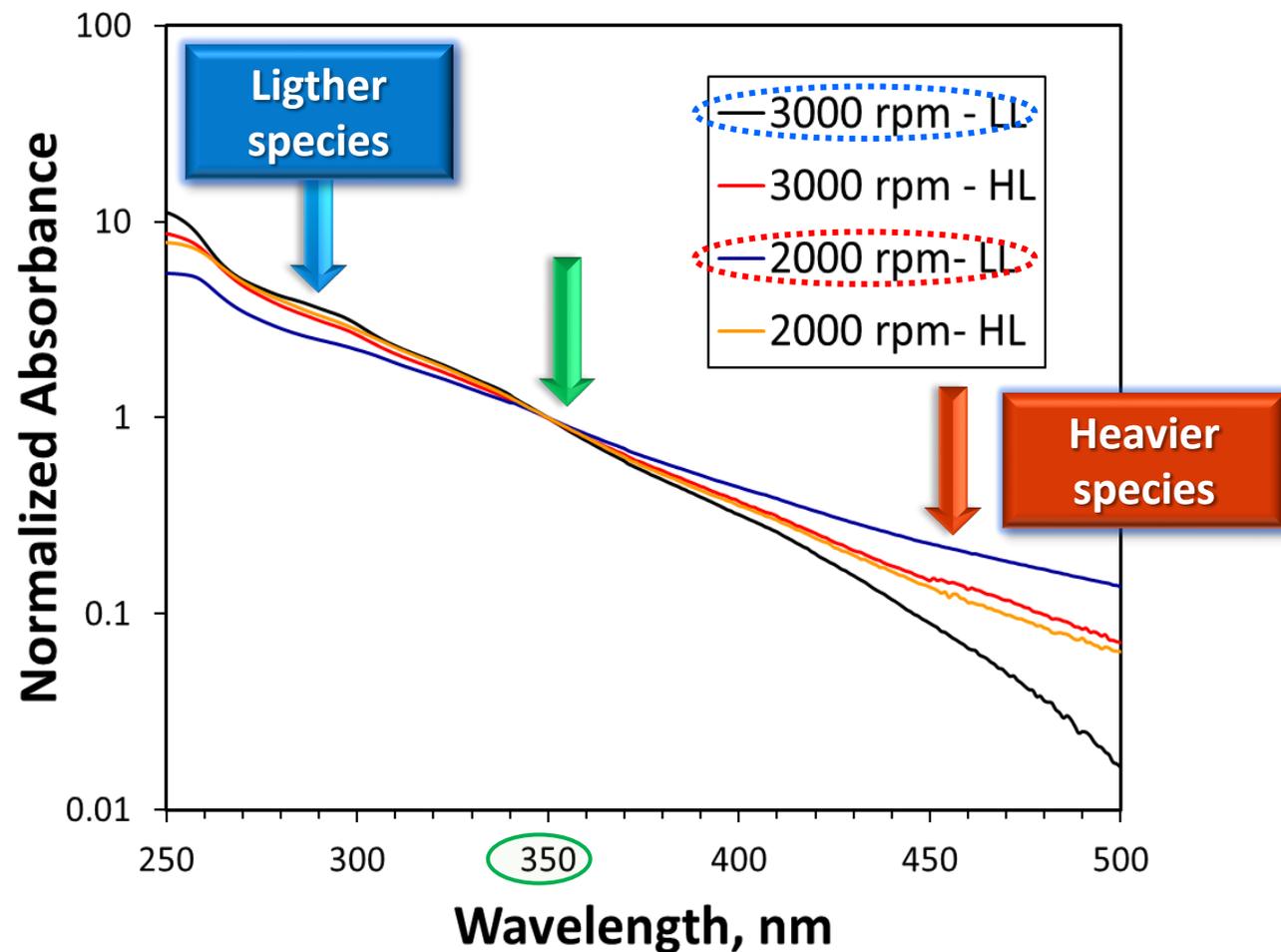
## Low Load

## High Speed



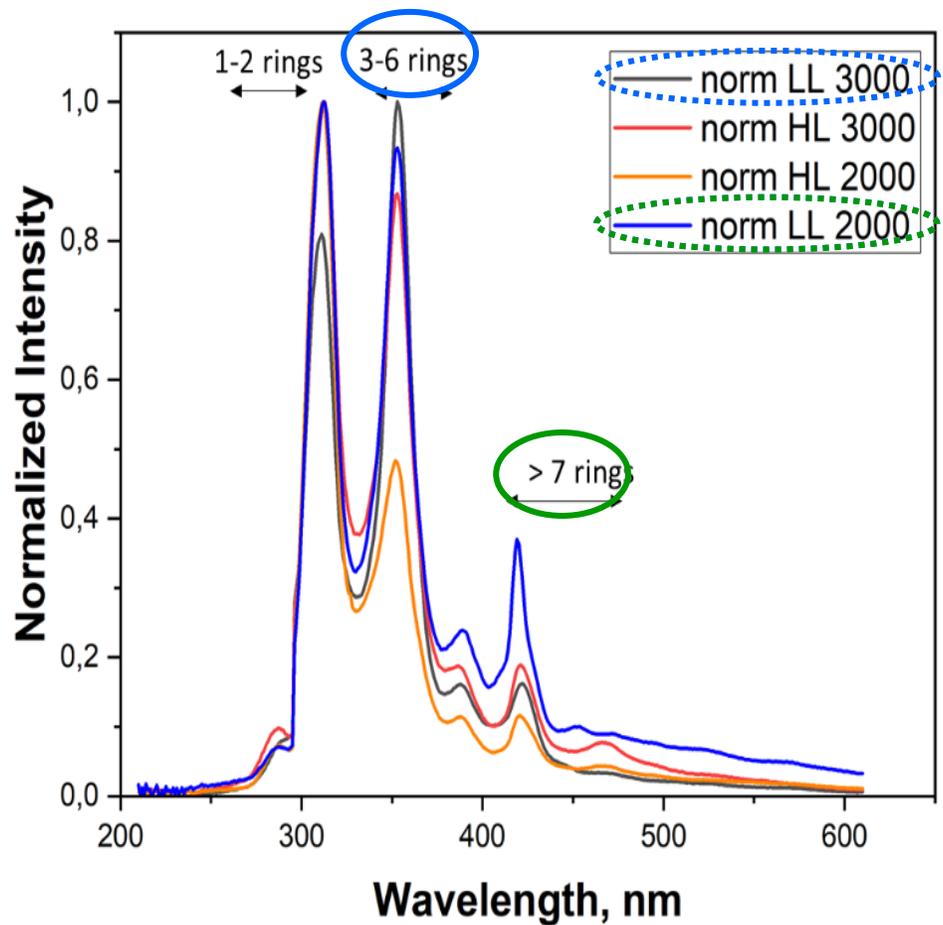


## Proportion between the Lighter and Heavier Aromatic Compounds

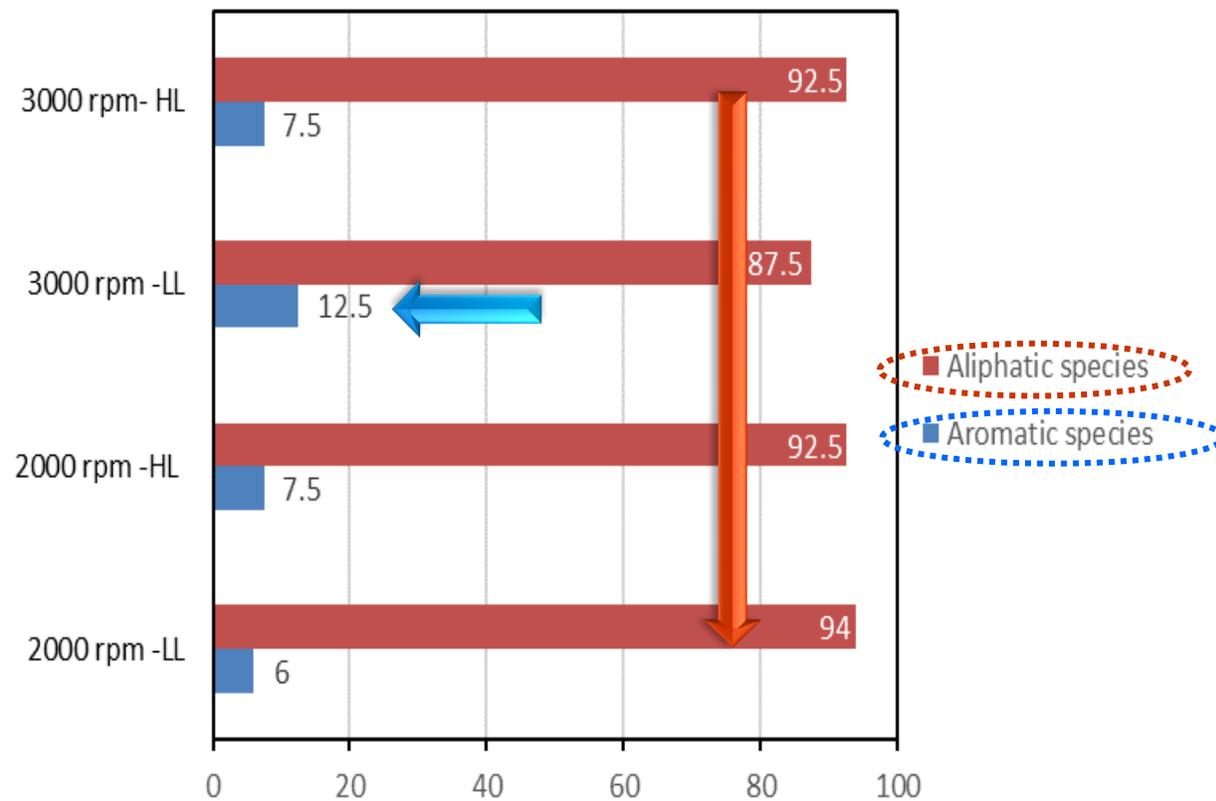




## PAH structure

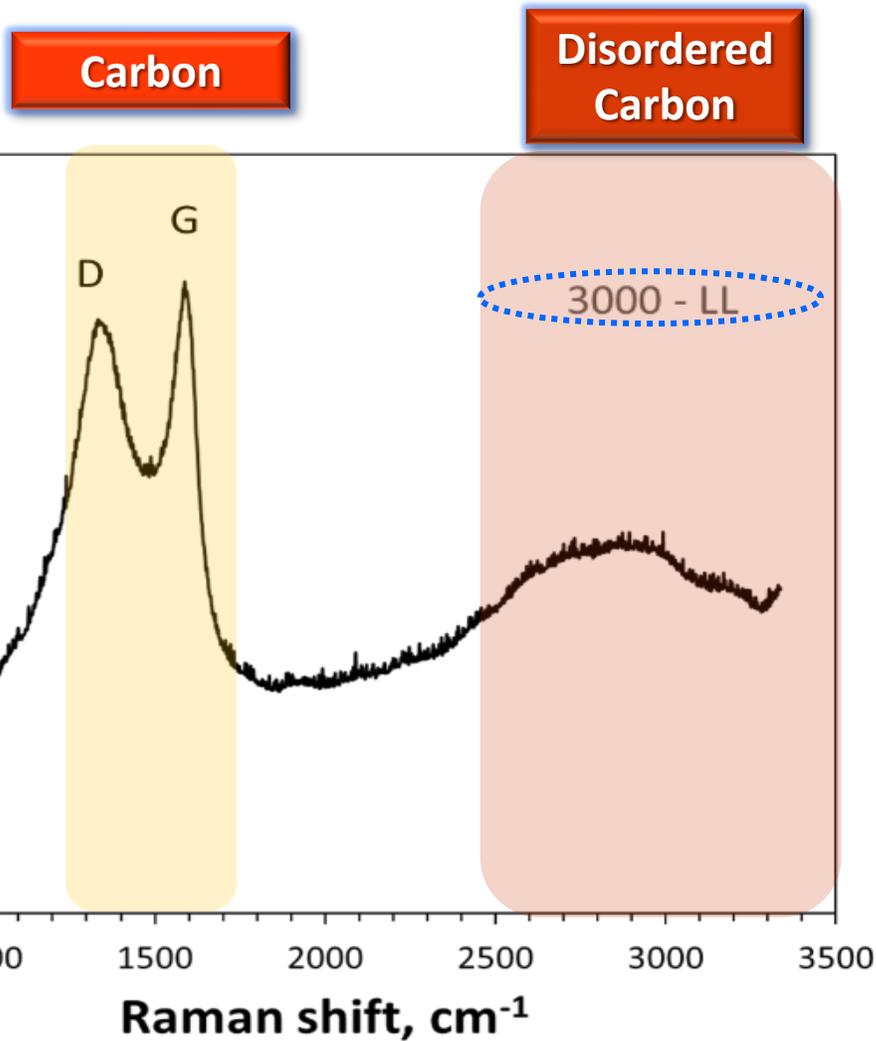


## PAH concentration

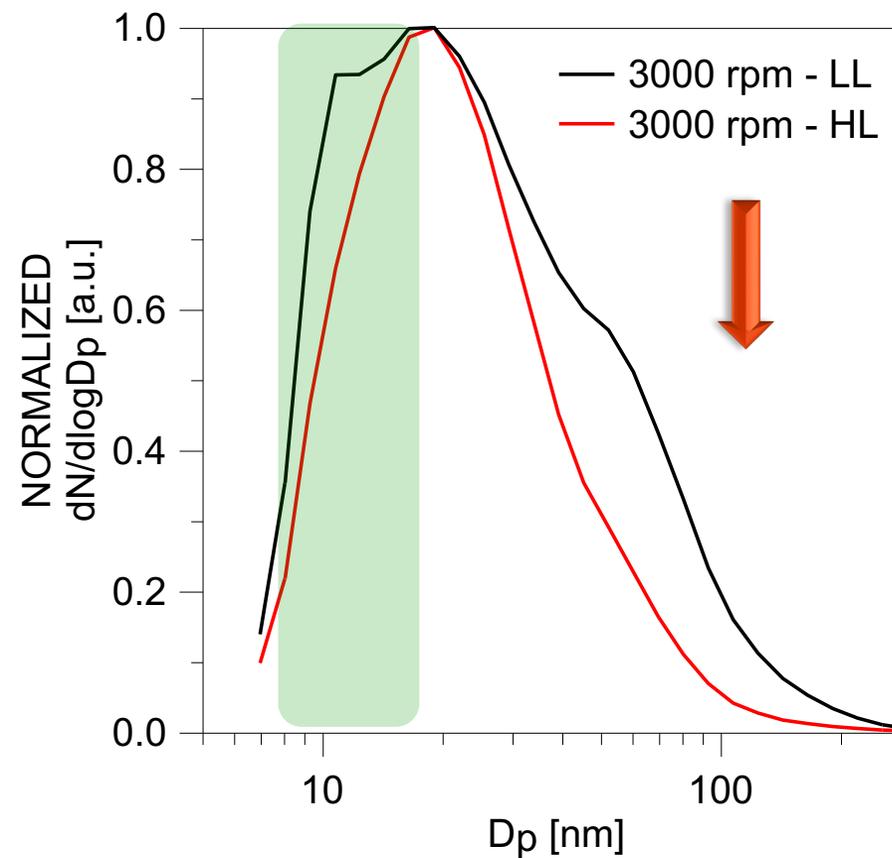
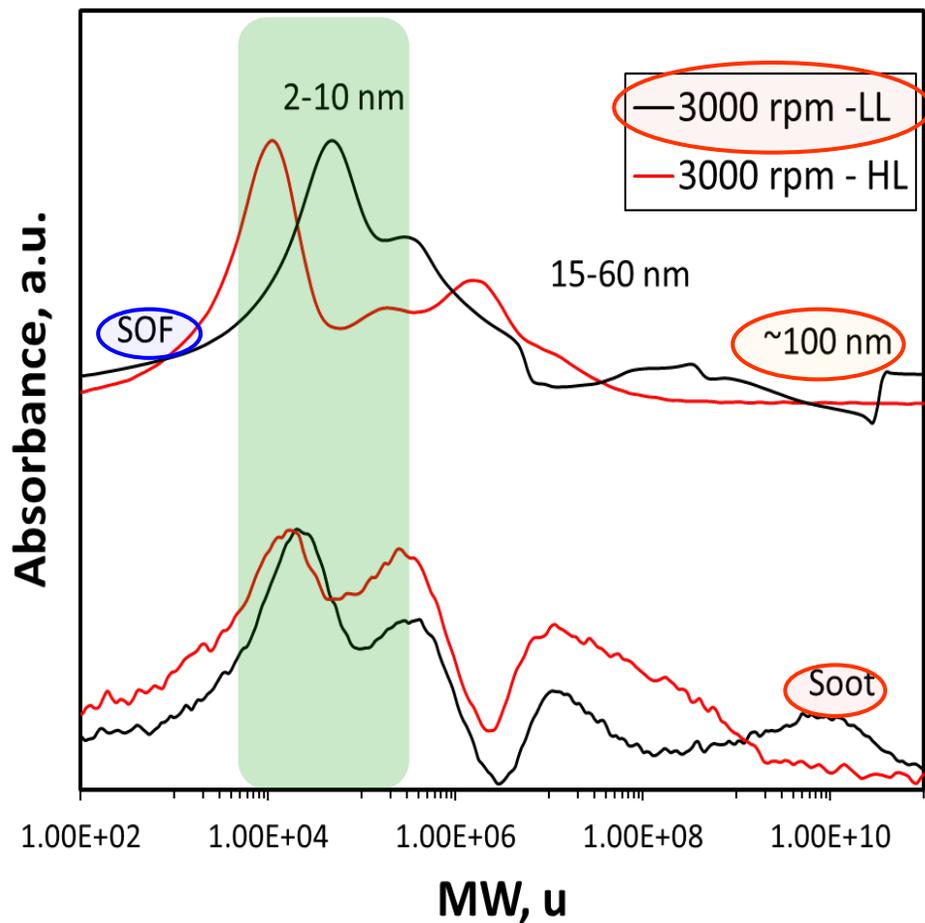


**Toxicity and Mutagenicity**

**Contamination of soil bacterial communities**



Soot is comparable in terms of nanostructures to a mature soot having low hydrogen content and a relatively high extension of the aromatic plane



Higher presence of PAH species in the SOF samples at 3000 rpm -LL



increases the formation of nucleated particles that rapidly grow and coagulate to form larger aggregates



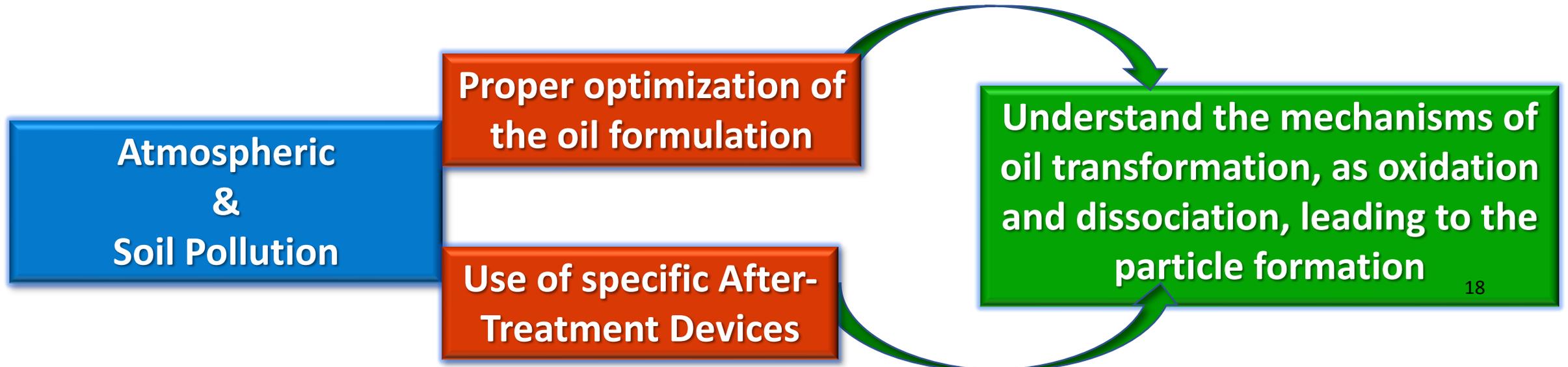
- Physical and chemical analysis of PM emitted from a DISI Hydrogen fueled engine was performed.
- Not negligible particle emissions were found at the exhaust.
- PN fluctuation can be ascribed at the presence of oil pool that burns periodically.
- Particle number and size varies with speed and load: increase with speed and decrease with load.
- PAH were found at all engine conditions: lighter species were more abundant at 3000-LL and heavier species were more abundant at 2000-LL.
- Soot was collected on the filter only at high engine speed.



Particles can be due to:

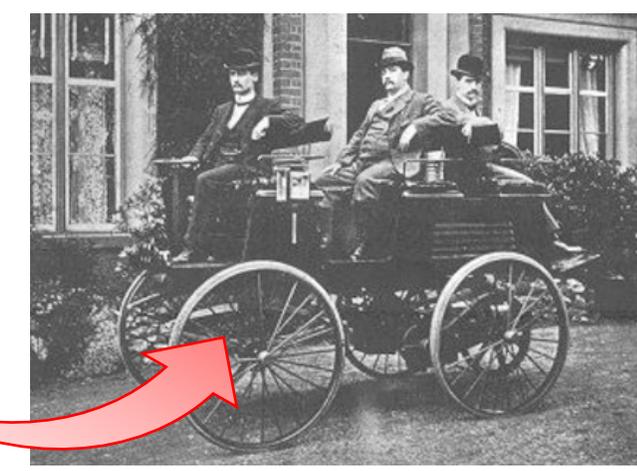
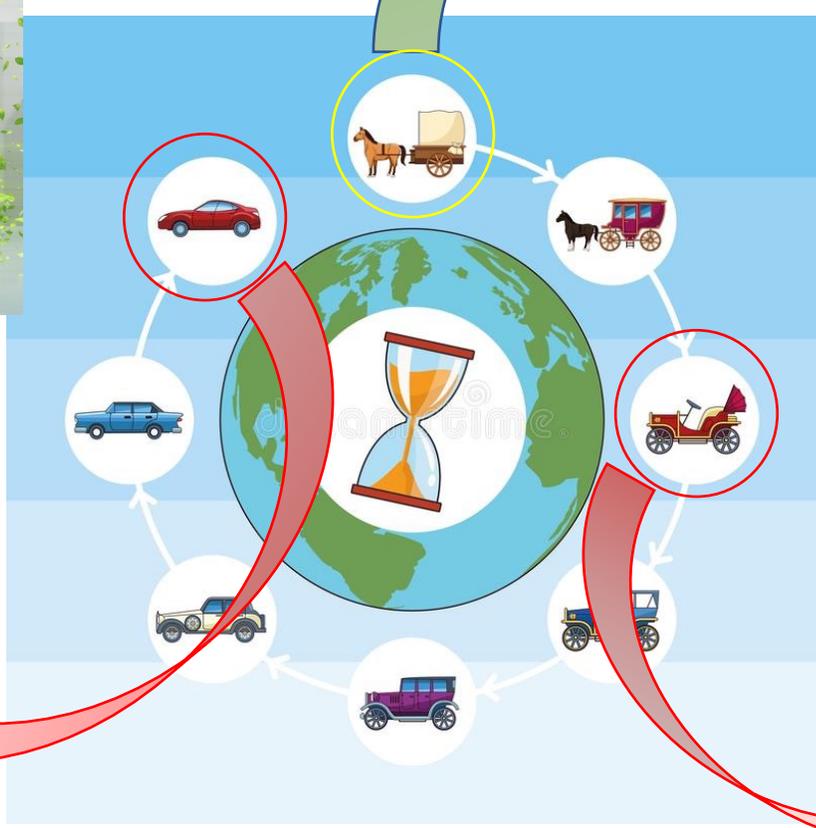
- the incomplete combustion of the organic components in the lubricating oil;
- the breakdown of the carbon.

The different behavior (N, Dp, SOF, Soot) with speed and load can be ascribed to the different environmental conditions encountered by the oil in the combustion chamber.





# Thank You for the Attention





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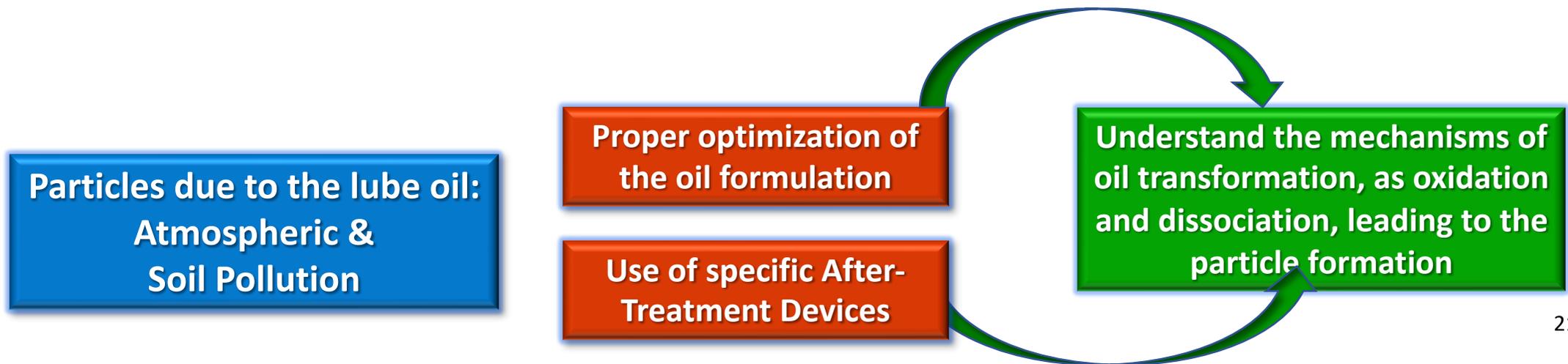
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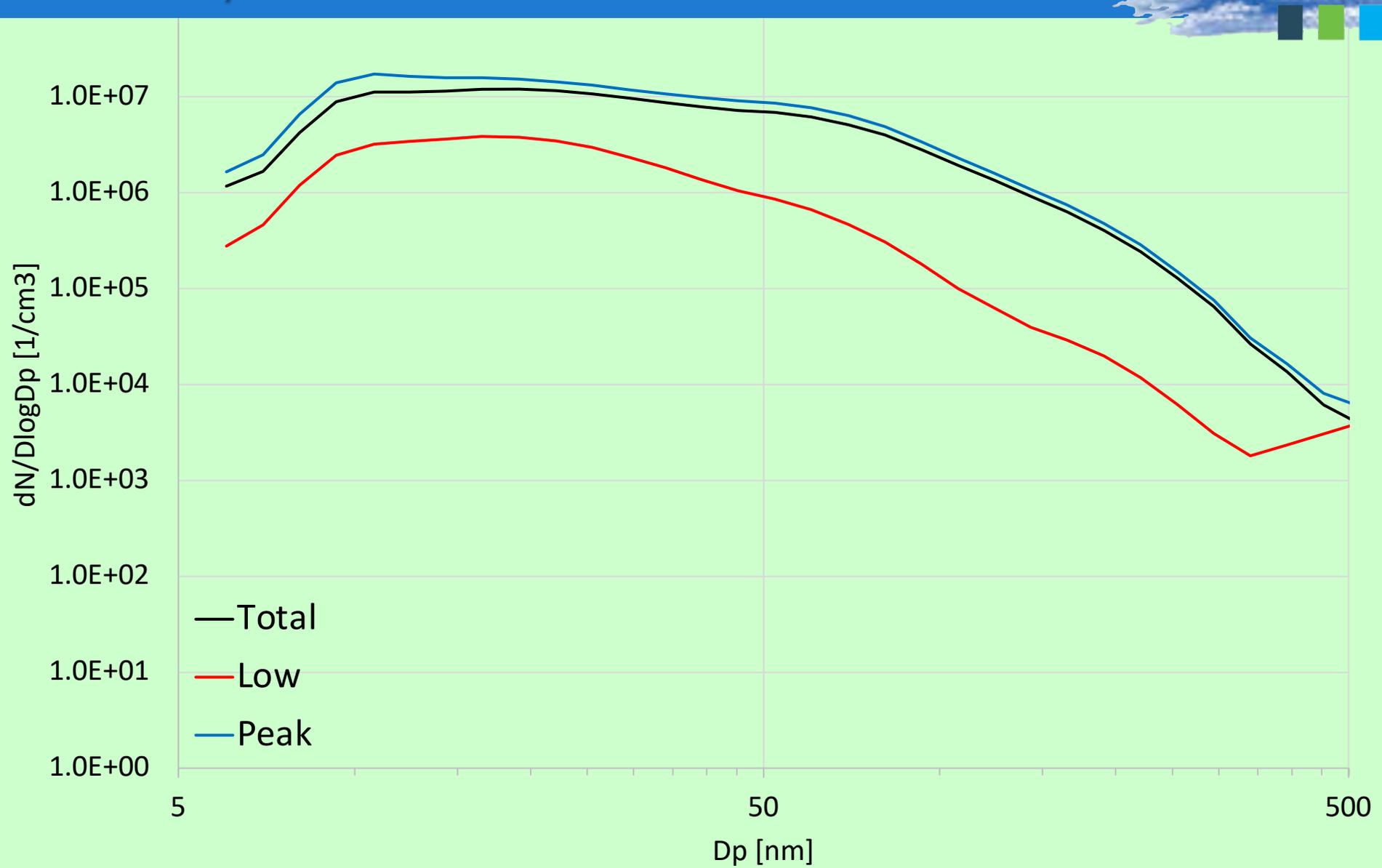
Incomplete combustion of the organic components in the lubricating oil and the breakdown of the carbon can be responsible for PM.

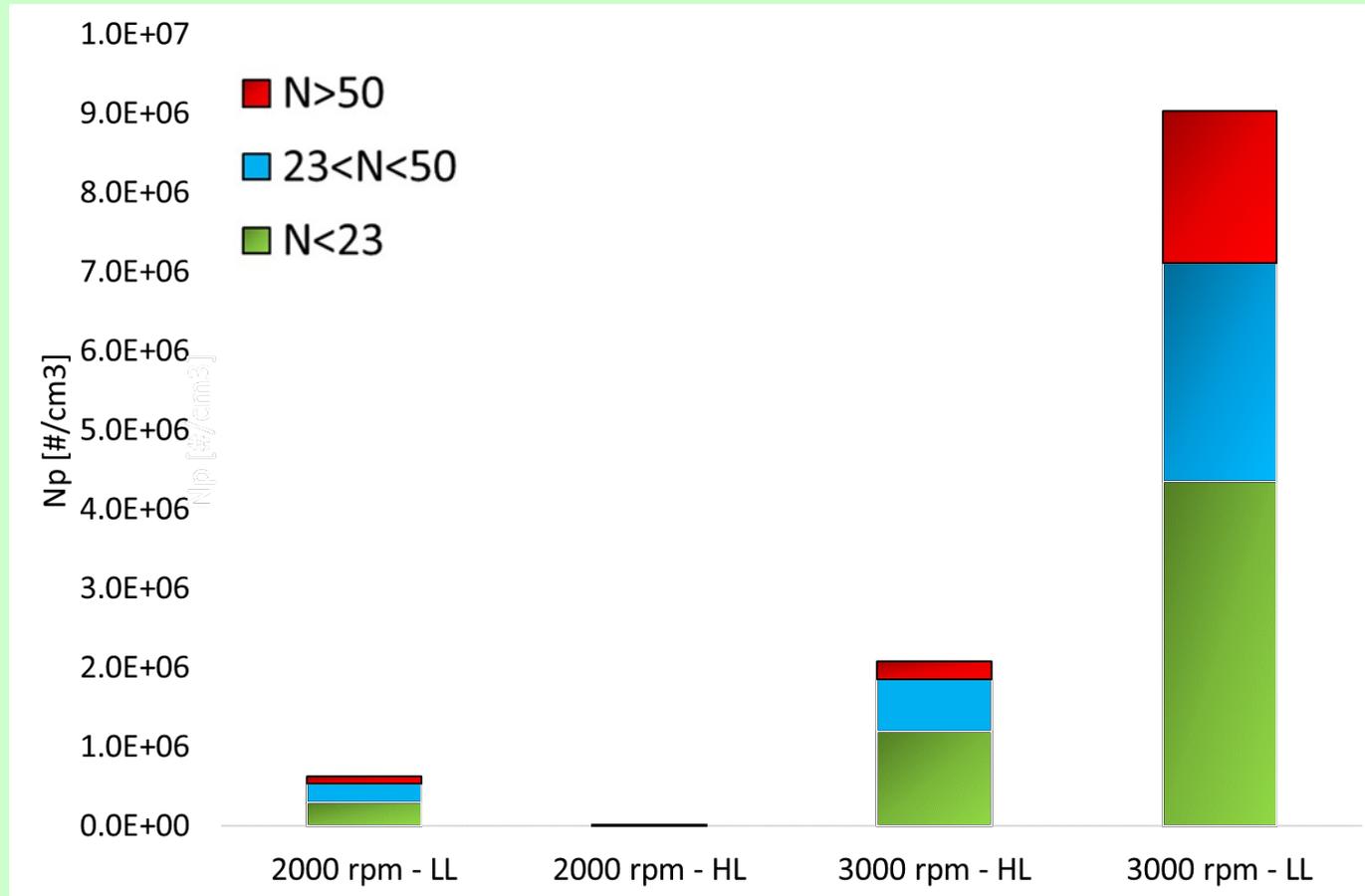
At 2000 rpm-LL aromatic species with more than 7 rings are present but their concentration and the experienced temperature are not enough to convert them in soot.

The different behavior with load at 2000 and 3000 rpm can be ascribed to the different environmental conditions encountered by the oil in the combustion chamber



# Experimental Results: Number & Size

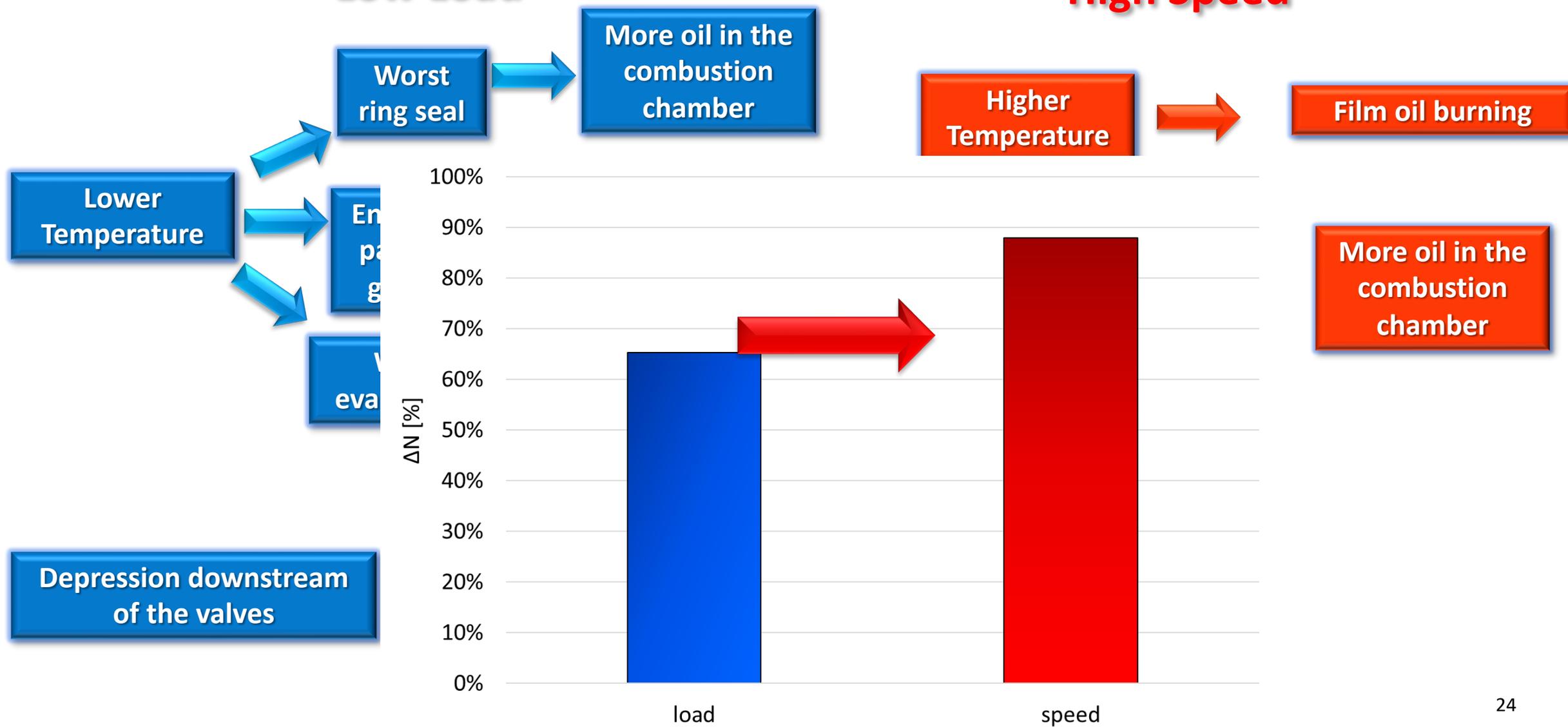






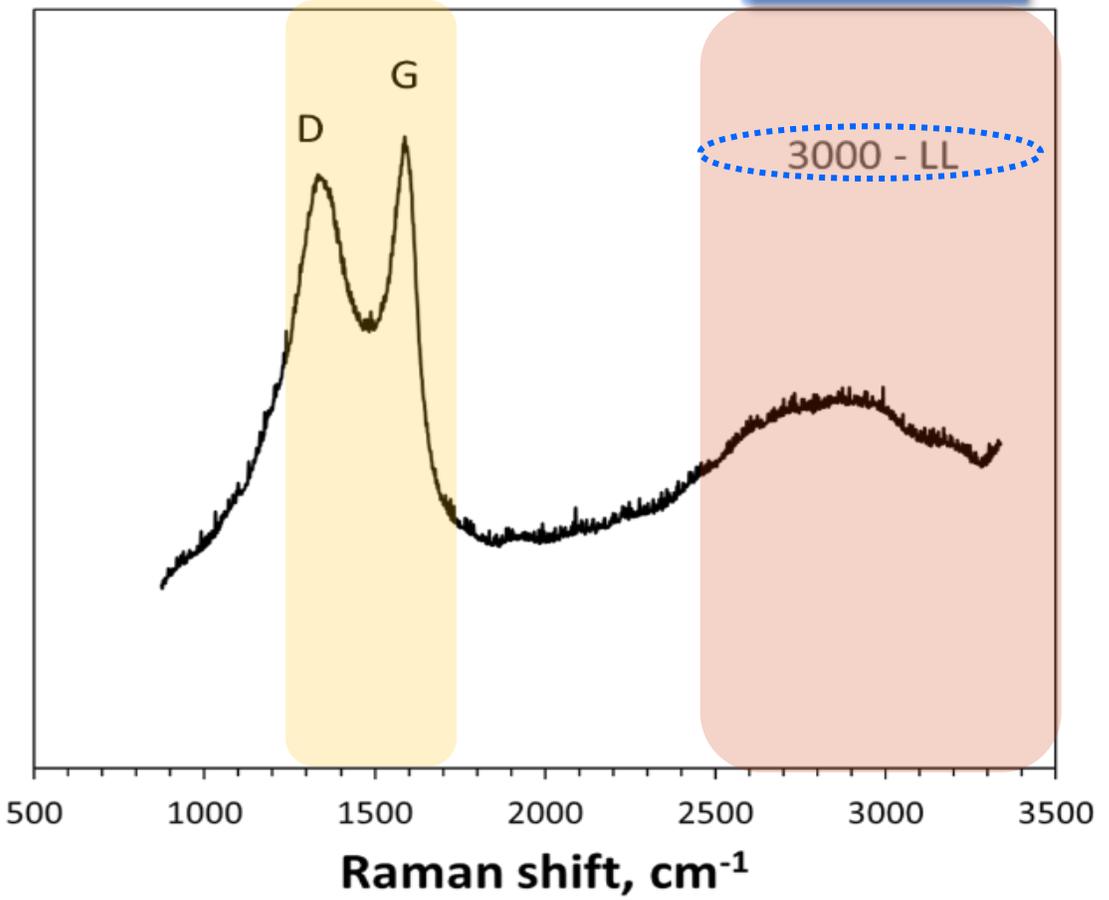
## Low Load

## High Speed





**Carbon**                      **Disordered Carbon**



Soot is comparable in terms of nanostructures to a mature soot having low hydrogen content and a relatively high extension of the aromatic plane

Size of the Aromatic Layer Length  
I(D)/I(G) 0.95  
corresponding to an aromatic length of 1.23 nm