Measurement and simulation of volatile particle emissions from military aircraft

WP 1625, WP-1626, WP-1627

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14. ABSTRACT

Many military airfields are located in nonattainment areas for fine particulate matter (PM2.5) but the contribution of aircraft emissions to local and regional PM2.5 concentrations is not well understood. Aircraft directly emit particles, but the vast majority of the emissions are gases and vapors, some of which undergo gas-to-particle conversion in the atmosphere. Primary particulate matter is defined as directly emitted particles plus any material that condenses into the particle phase without undergoing chemical reactions. This latter component is often referred to as volatile particulate matter. Secondary particulate matter is formed from oxidation of gas-phase species such as sulfur dioxide and organics. To develop effective control strategies one must understand the overall contribution of military aircraft emissions to ambient particulate matter? both direct particle emissions and particulate matter formed in the atmosphere. To assist the Department of Defense in meeting the current and future regulations related to PM2.5 concentrations, SERDP initiated a research program in 2007 to investigate volatile particulate matter emissions. Three projects were funded within this program; the lead organizations of these programs were Aerodyne Research Inc., Carnegie Mellon University, and Oak Ridge National Laboratories. The projects included experiments to measure the formation and atmospheric evolution of volatile particulate matter, the development volatile emission models, and the evaluation of new instrumentation and experimental techniques. This presentation will summarize the major findings of the SERDP volatile particulate matter program, including the contribution of lubricating oil and atmospheric oxidation to volatile particulate matter emissions.

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MEASUREMENT AND SIMULATION OF VOLATILE PARTICLE EMISSIONS FROM MILITARY AIRCRAFT

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Many military airfields are located in nonattainment areas for fine particulate matter ($PM_{2.5}$), but the contribution of aircraft emissions to local and regional $PM_{2.5}$ concentrations is not well understood. Aircraft directly emit particles, but the vast majority of the emissions are gases and vapors, some of which undergo gas-to-particle conversion in the atmosphere. Primary particulate matter is defined as directly emitted particles plus any material that condenses into the particle phase without undergoing chemical reactions. This latter component is often referred to as volatile particulate matter. Secondary particulate matter is formed from oxidation of gas-phase species such as sulfur dioxide and organics. To develop effective control strategies one must understand the overall contribution of military aircraft emissions to ambient particulate matter—both direct particle emissions and particulate matter formed in the atmosphere.

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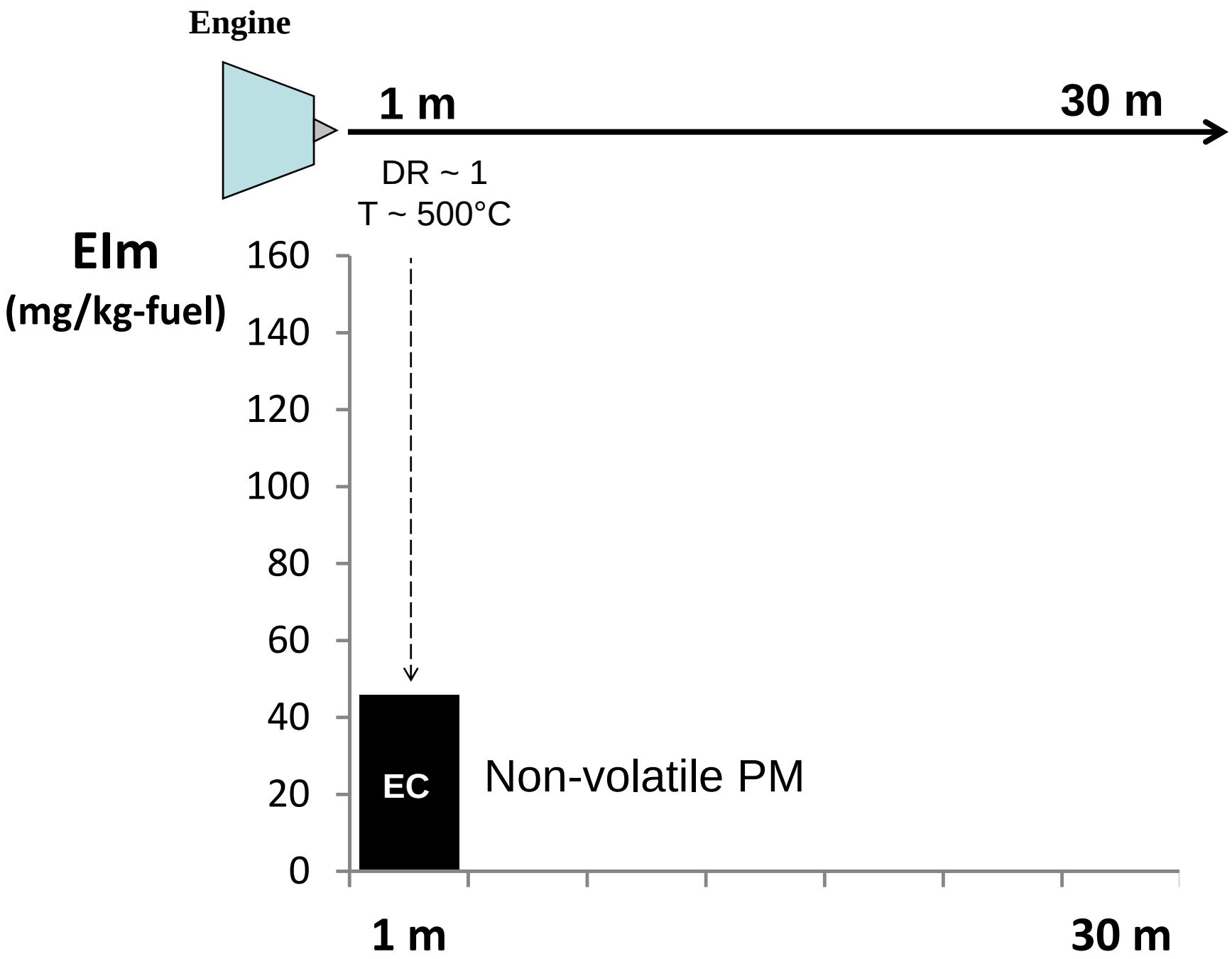
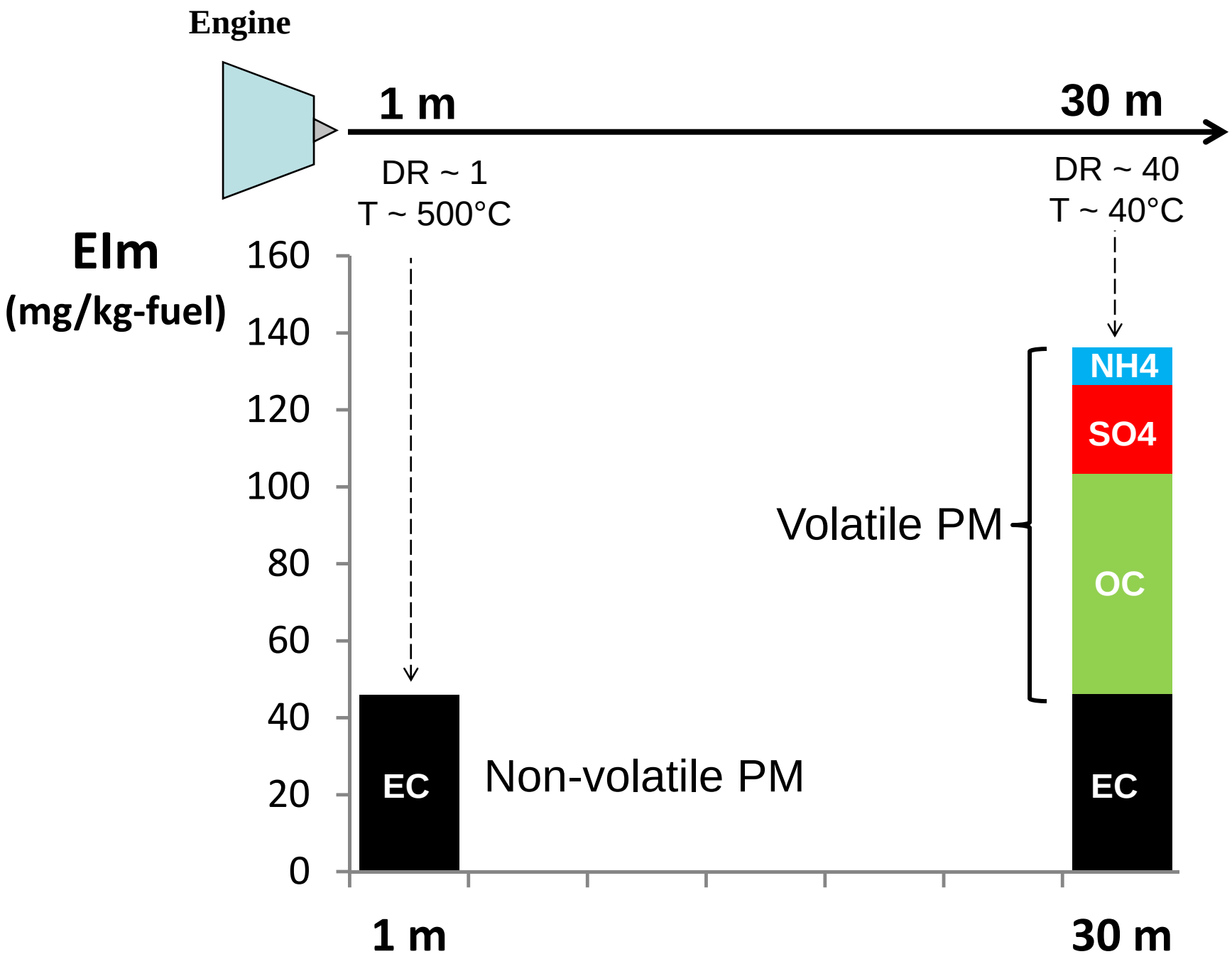
What is volatile PM?

(Wey et al. NASA/TM—2006-2143822006)

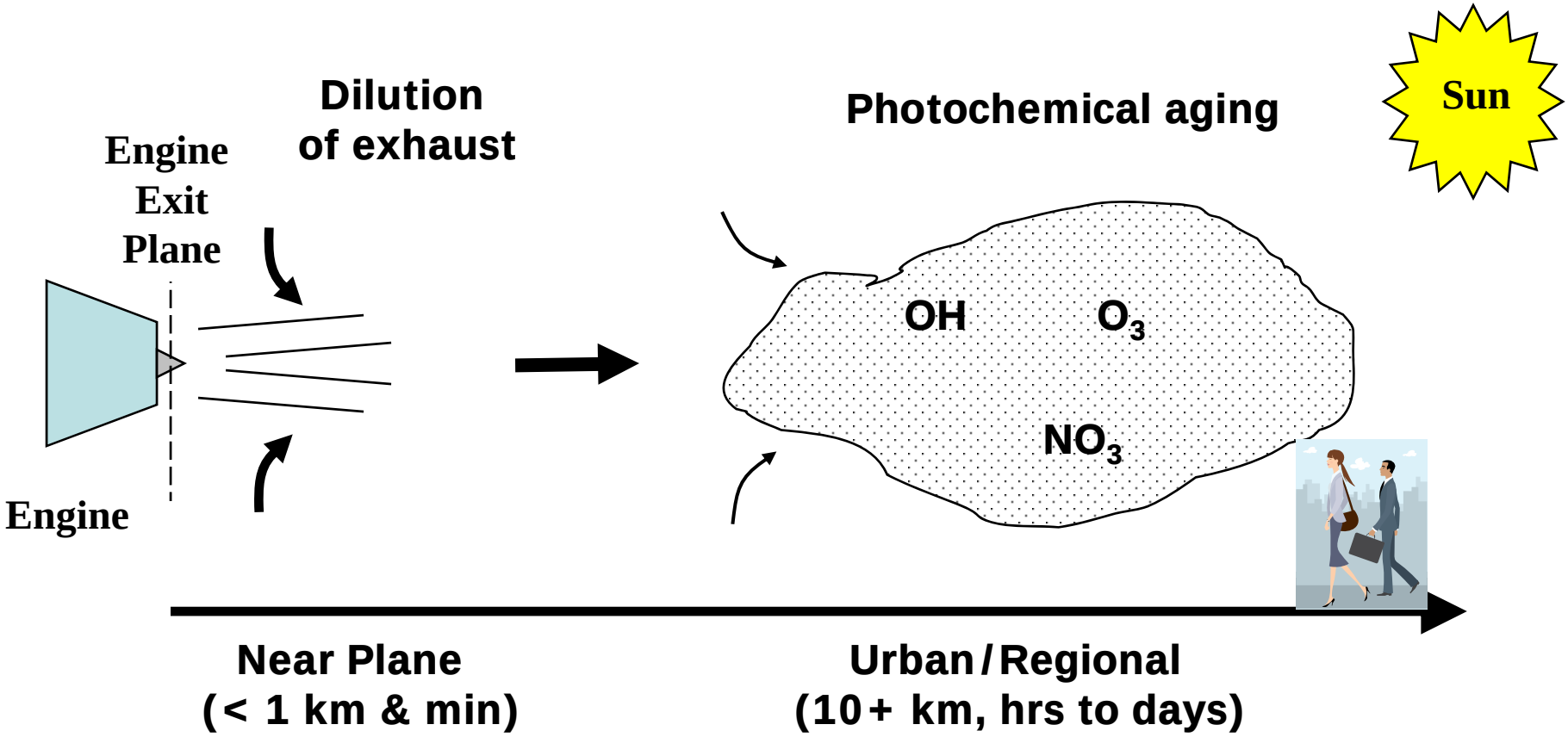


(Kinsey et al. EST 2011)



(Kinsey et al. EST 2011)

How does volatile PM evolve in the atmosphere?



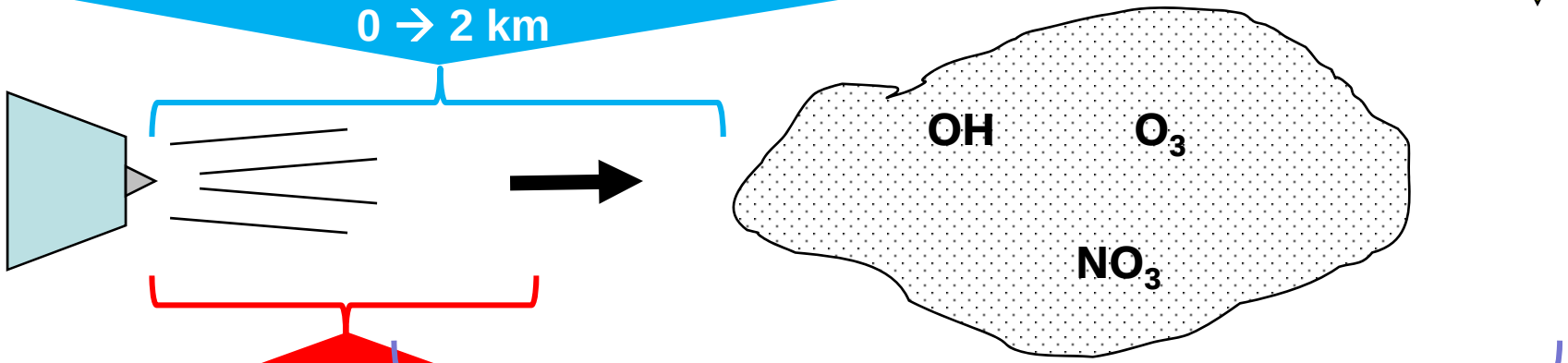
Spatial / Temporal Scales

SERDP Volatile PM Projects

Oak Ridge National Lab Team (WP-1627)

- Measurement Systems
  - Thermodenuder
  - Dilution sampler & aging chamber
- Measurements of gas turbine engine emissions

0 → 2 km



0 → 1 km

Aerodyne Team (WP-1625)

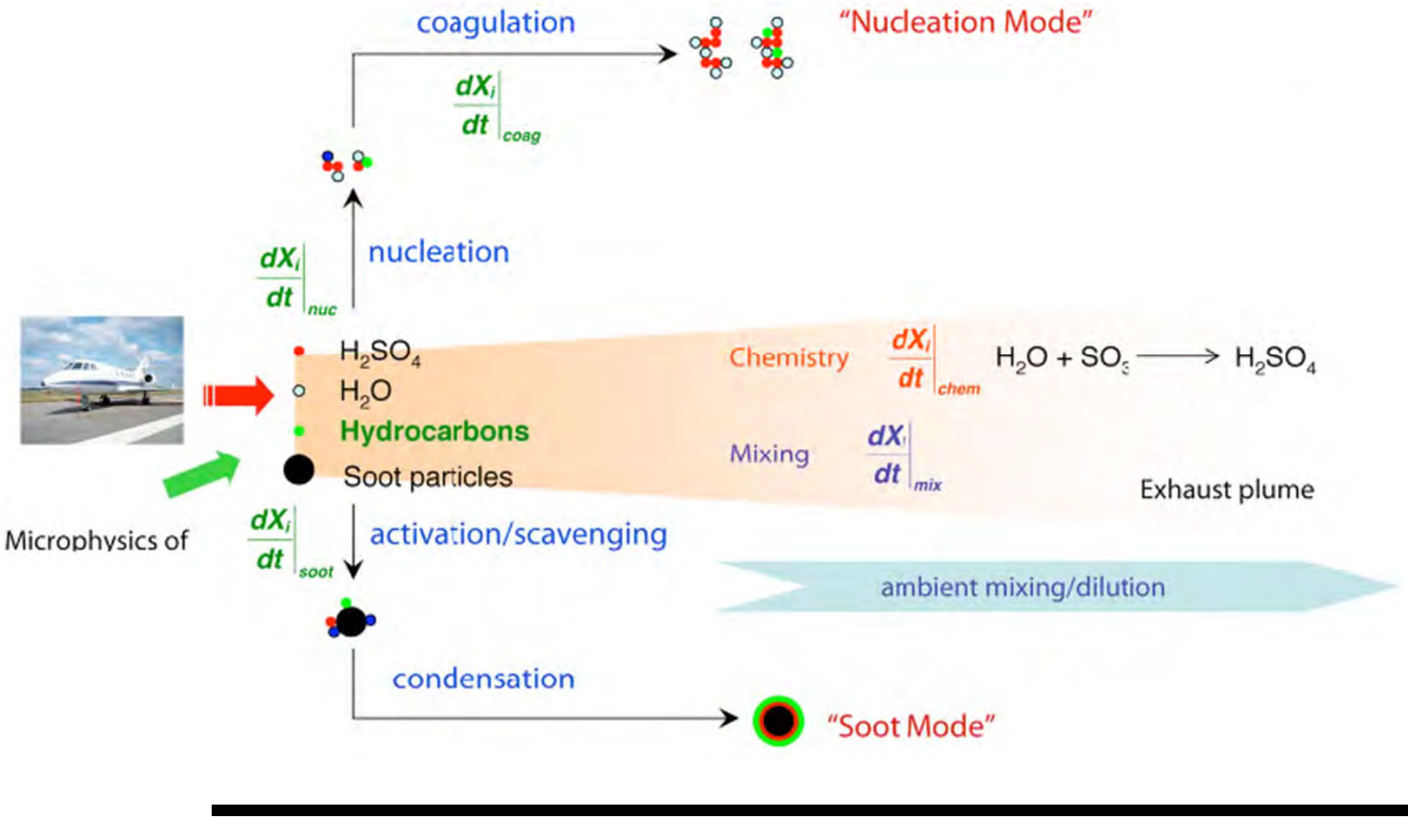
- Microphysical Kinetic Model for Plume
- Contributions of lube oil
- Laboratory studies of specific HCs and Sulfate
- Combustor system studies

0.1 → 50 km

Carnegie Mellon University Team (WP-1626)

- Measurement of PM in engine exhaust
- Aging in "smog" chamber
- Modeling of gas-particle partitioning and SOA production

Microphysical Modeling of Near-Field Evolution of Volatile PM



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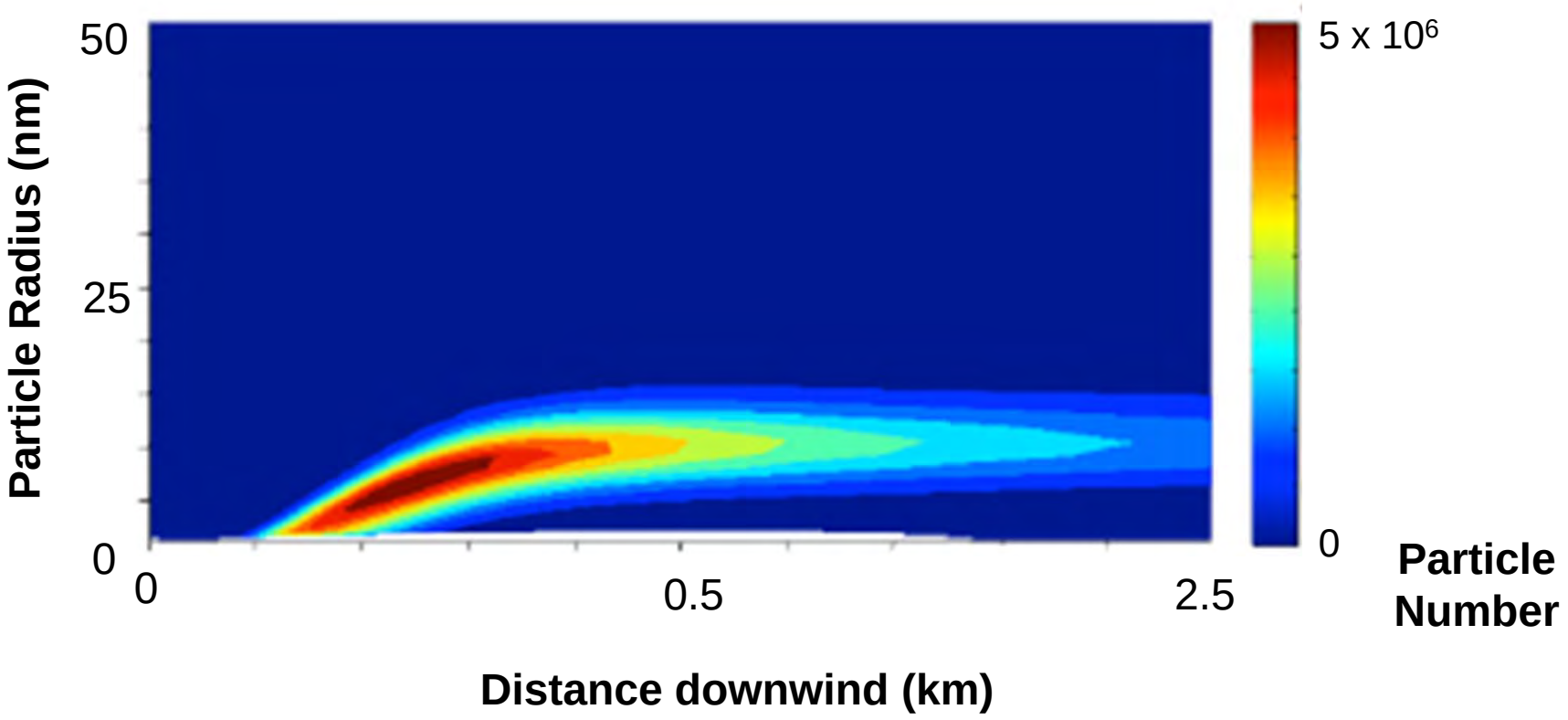
Predicted evolution of nucleation mode



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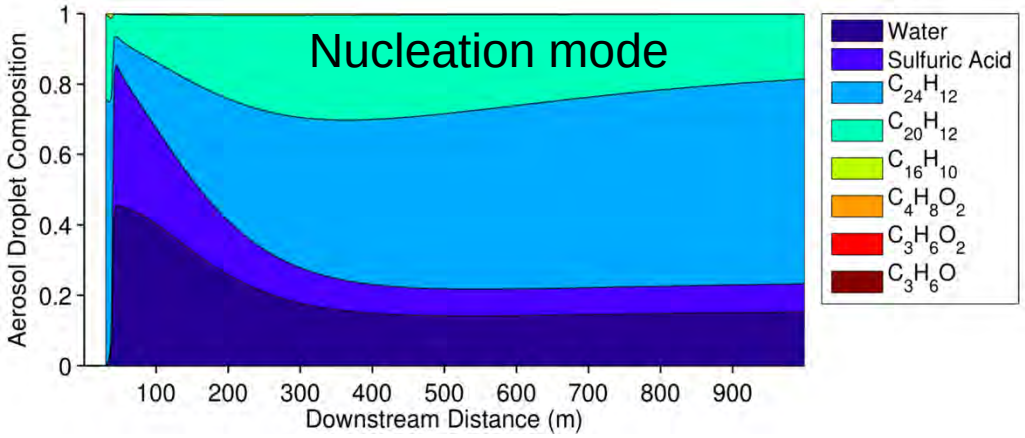
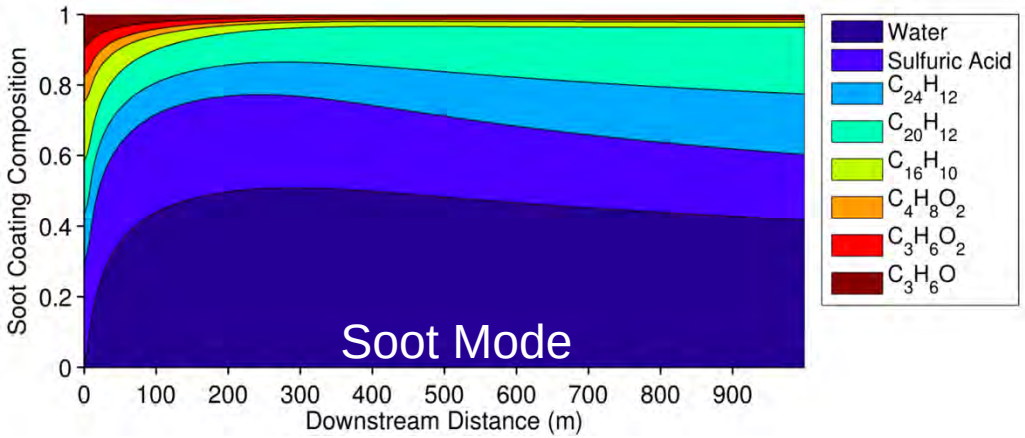
Predicted Particle Composition in Aircraft Plume





Findings:

- **Highly Dynamic Systems**
- **Nucleation driven by sulfuric acid and water**
- **Hydrocarbons critical for growth**

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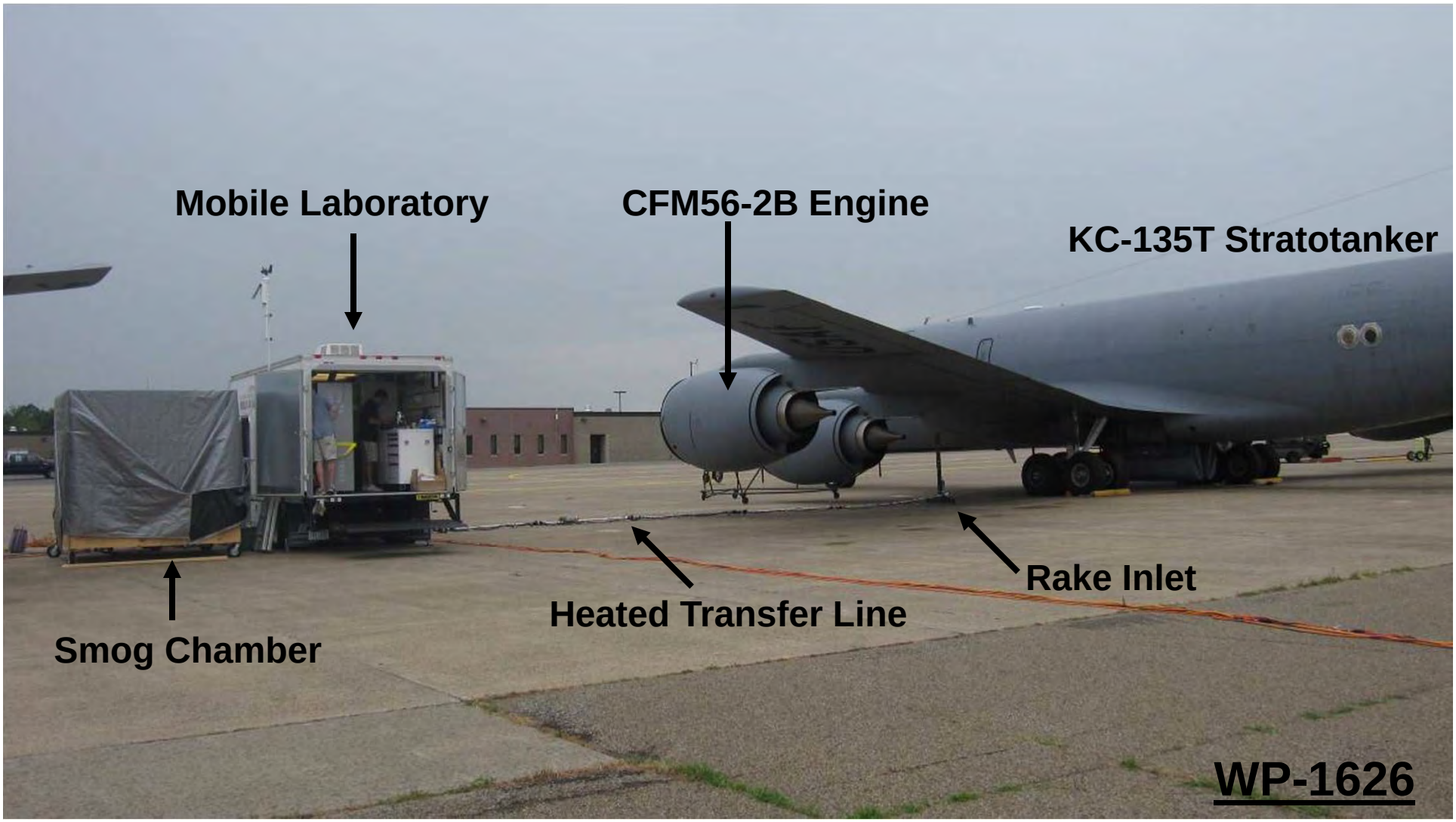
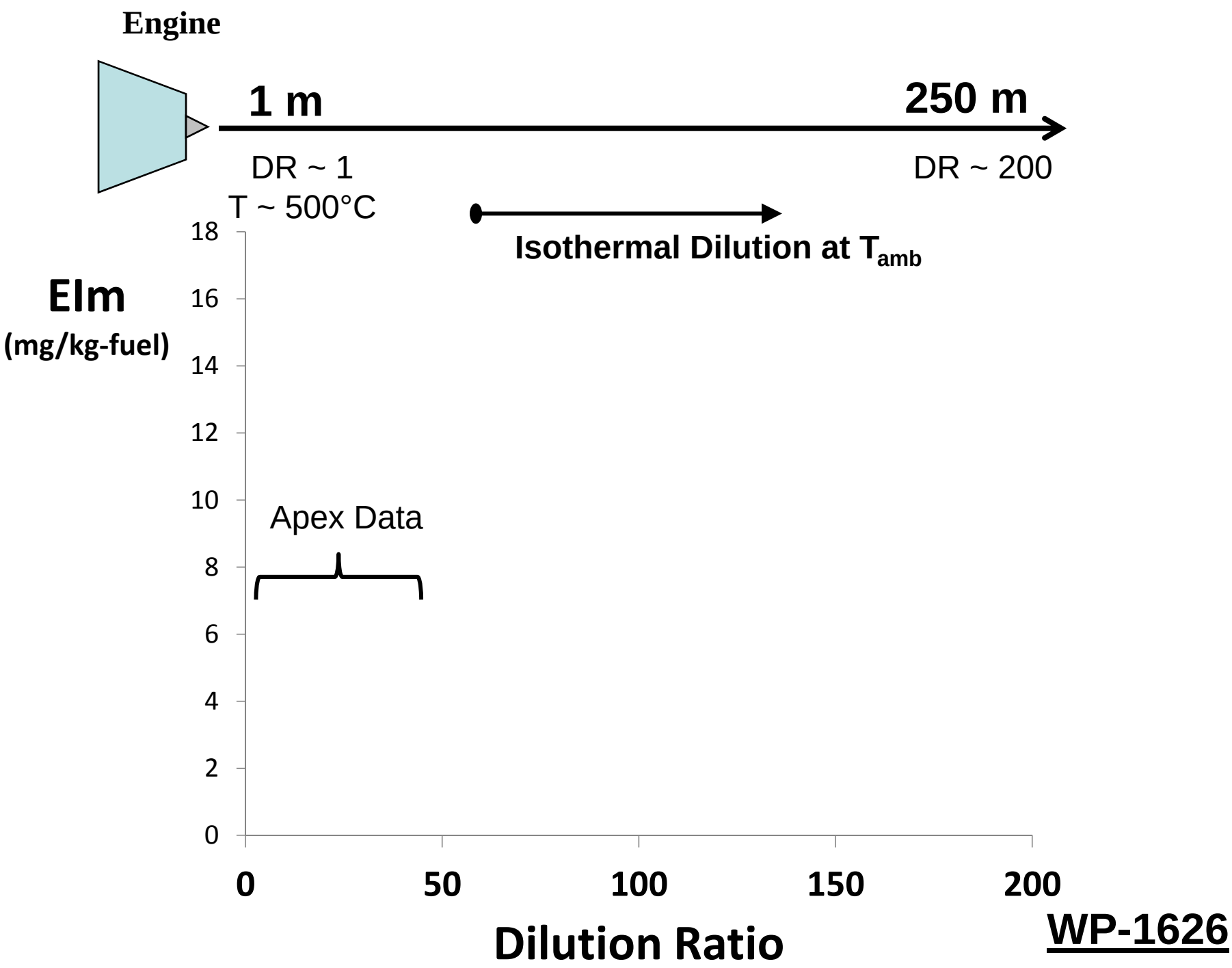
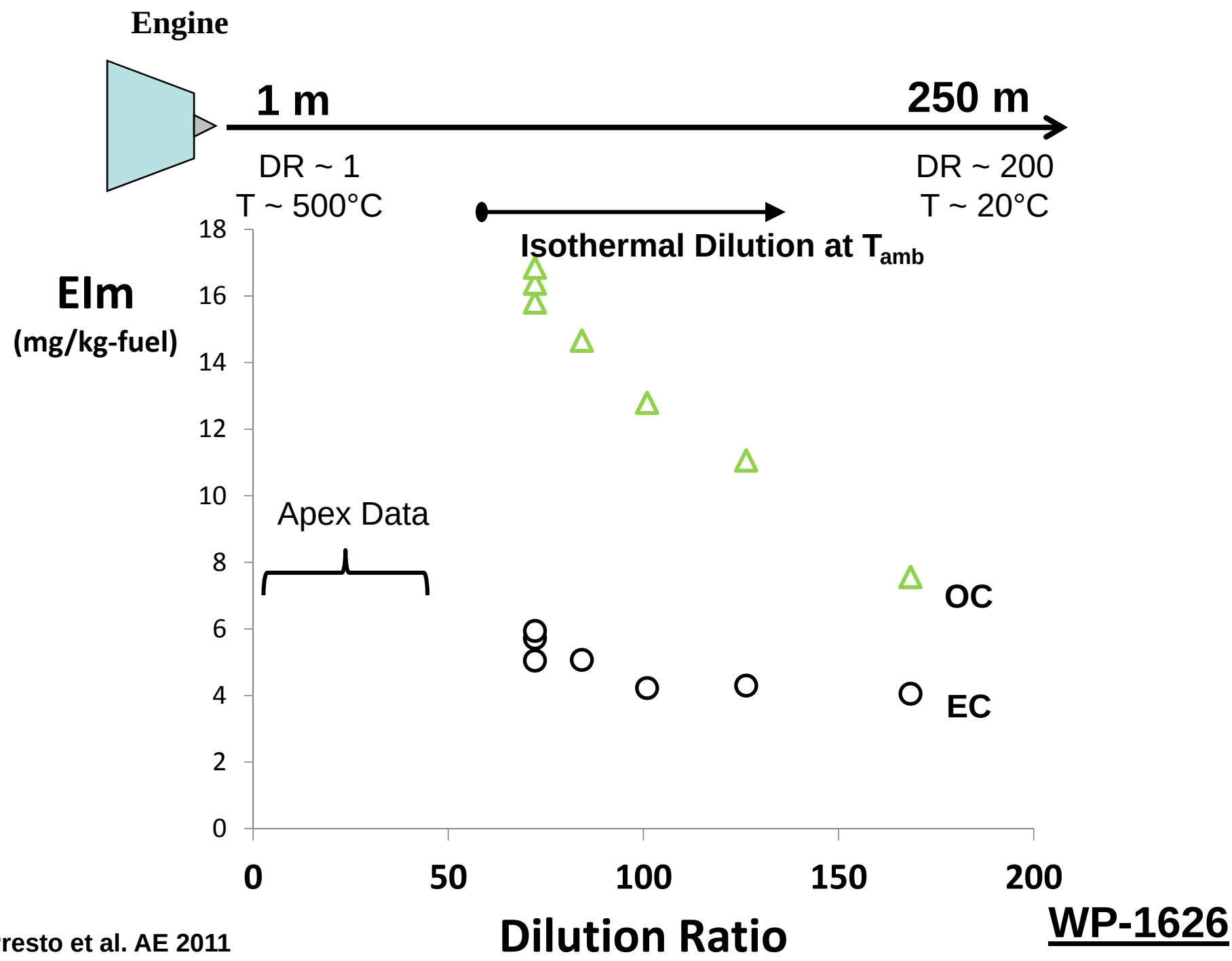
Staged Testing




Engine
1 m
250 m
DR ~ 1
T ~ 500°C
DR ~ 200
Isothermal Dilution at T_{amb}
EIm
(mg/kg-fuel)
18
16
14
12
10
8
6
4
2
0
Apex Data
0
50
100
150
200
Dilution Ratio
WP-1626



Presto et al. AE 2011

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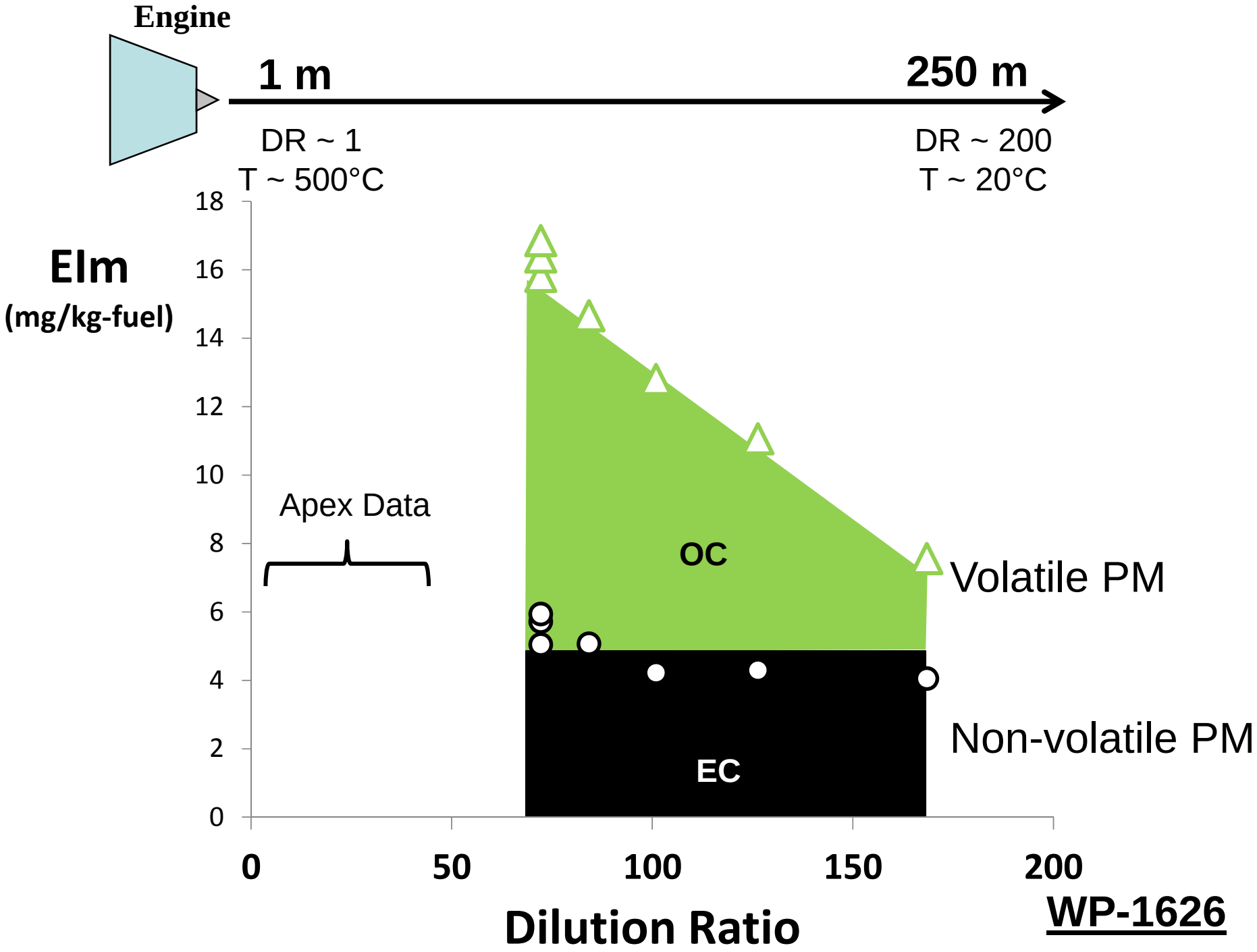
Engine
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250 m
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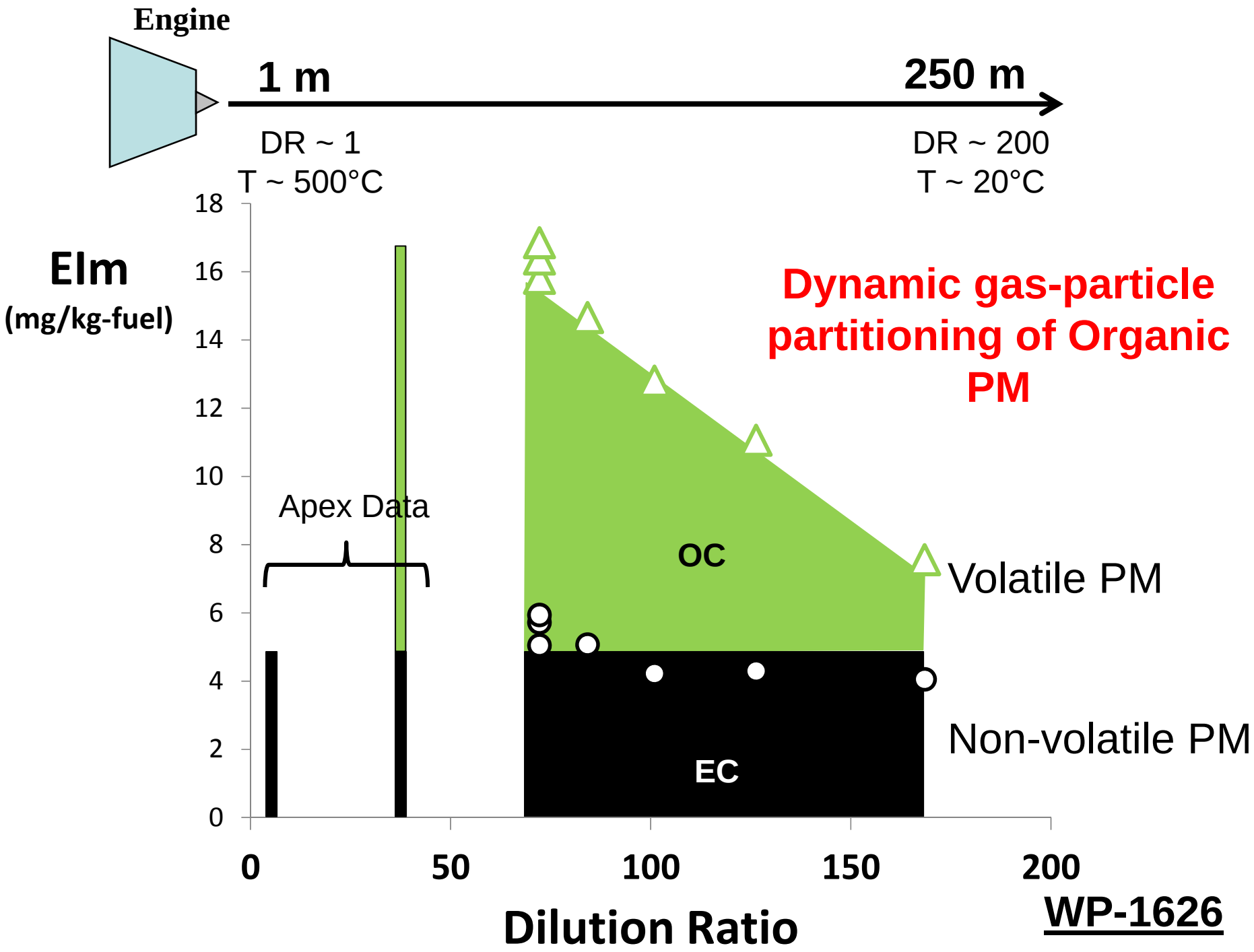
T ~ 500°C
DR ~ 200
T ~ 20°C
Elm
(mg/kg-fuel)
18
16
14
12
10
8
6
4
2
0
Apex Data
OC
EC
Volatile PM
Non-volatile PM
0
50
100
150
200
Dilution Ratio
WP-1626


Engine
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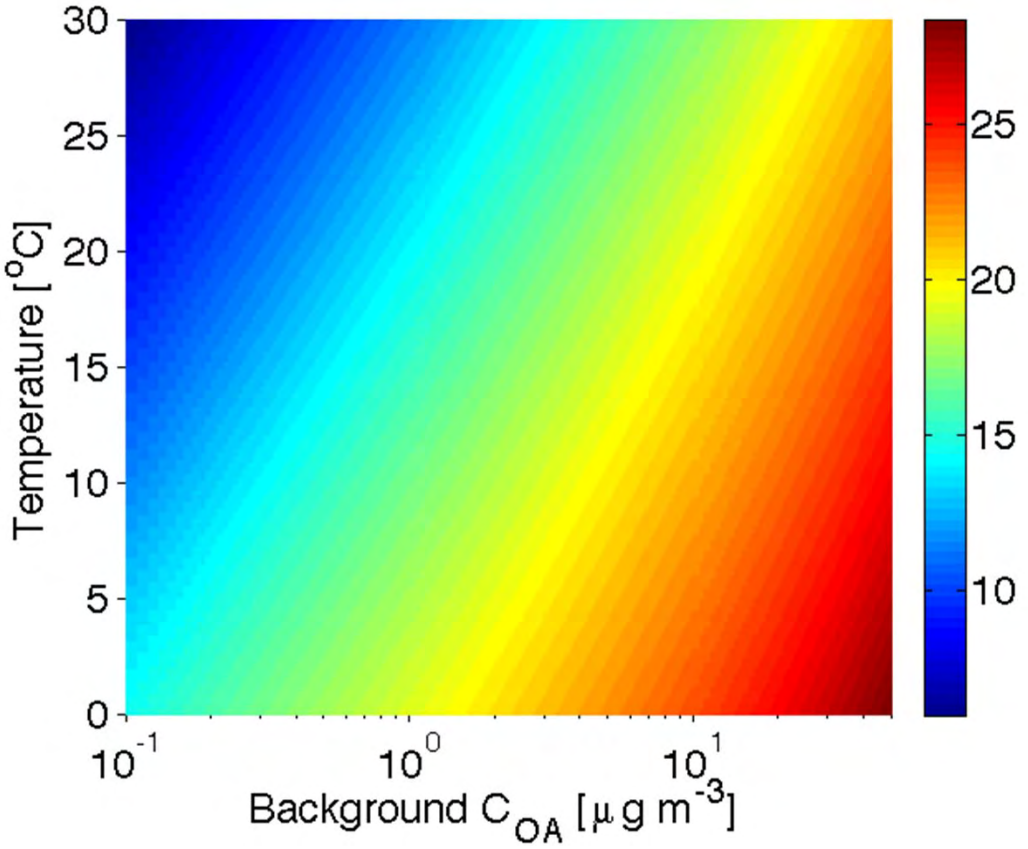
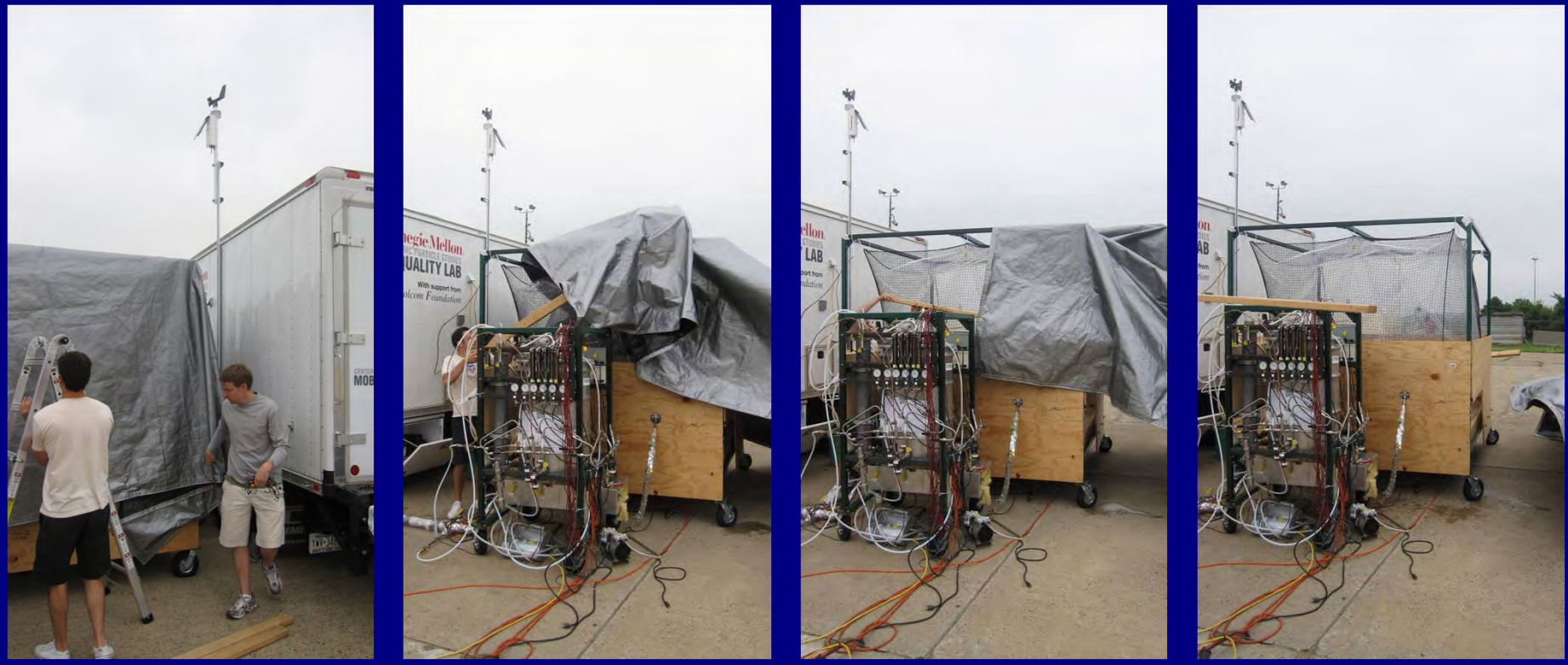
Elm
(mg/kg-fuel)
18
16
14
12
10
8
6
4
2
0
Apex Data
OC
EC
Volatile PM
Non-volatile PM
0
50
100
150
200
Dilution Ratio
Dynamic gas-particle partitioning of Organic PM
WP-1626

Amount of volatile PM emissions vary with atmospheric conditions



POA
mg/kg-fuel

What are effects of photo-chemical aging?



Taking off the chamber cover

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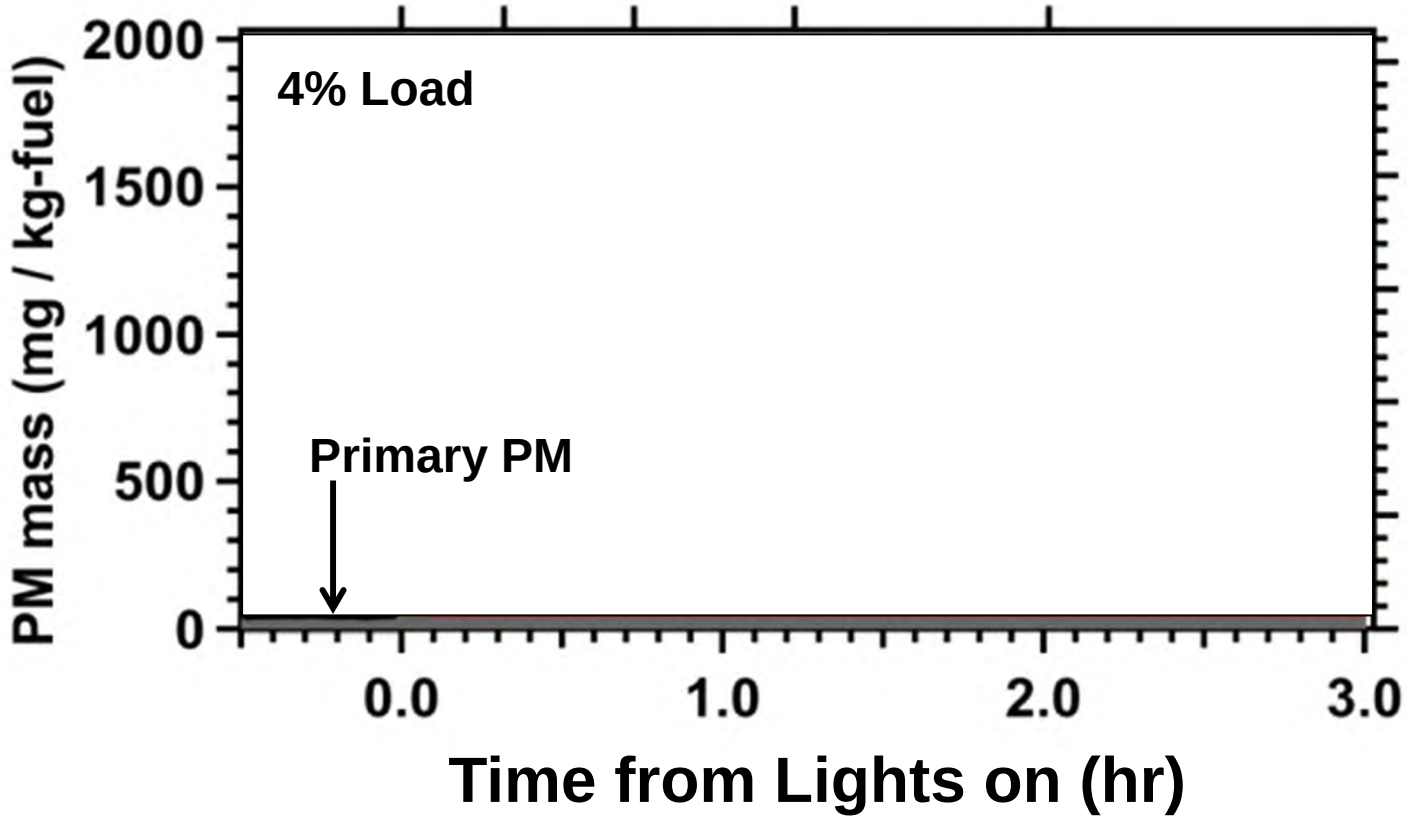
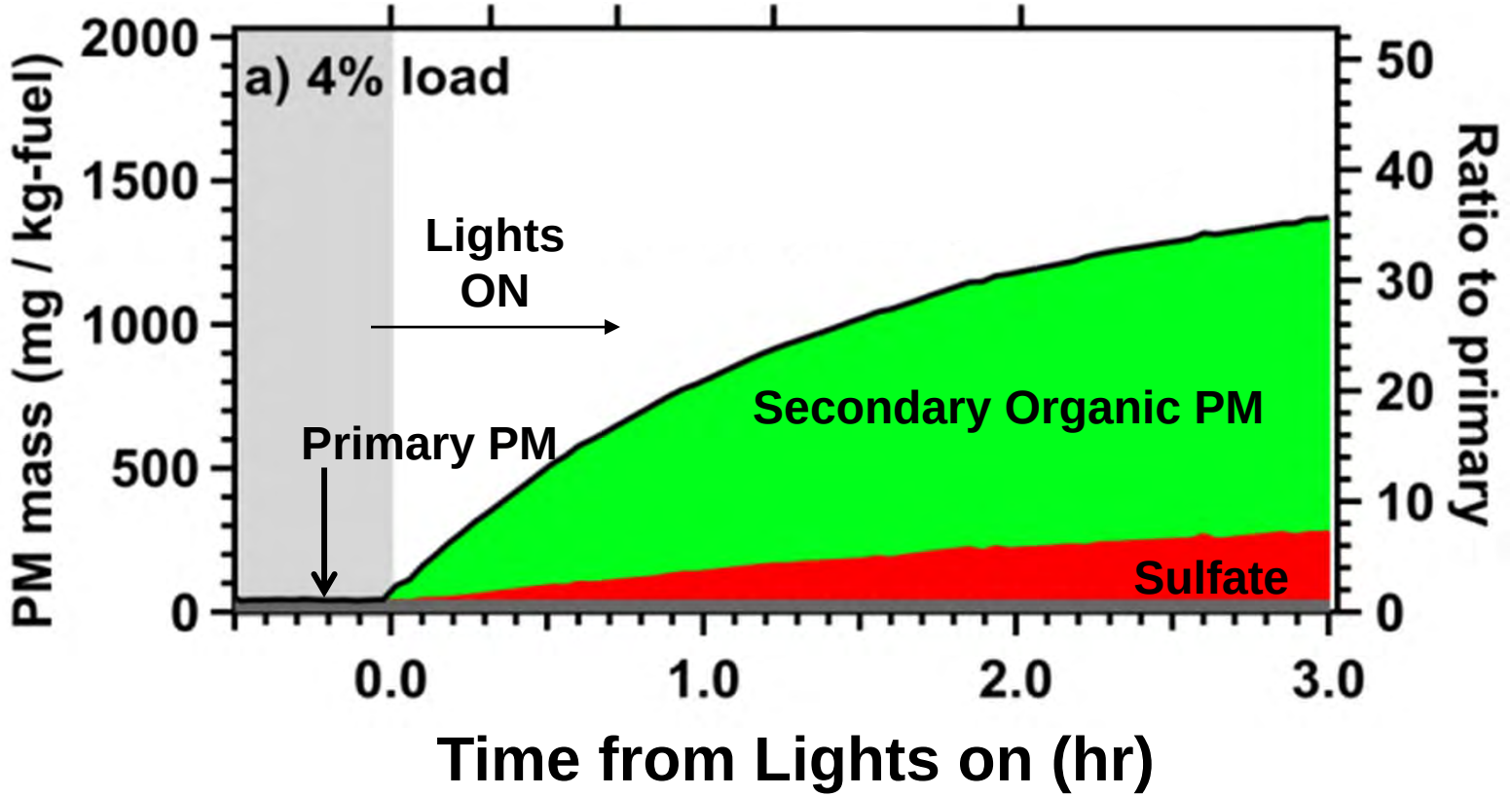
Primary PM in Chamber



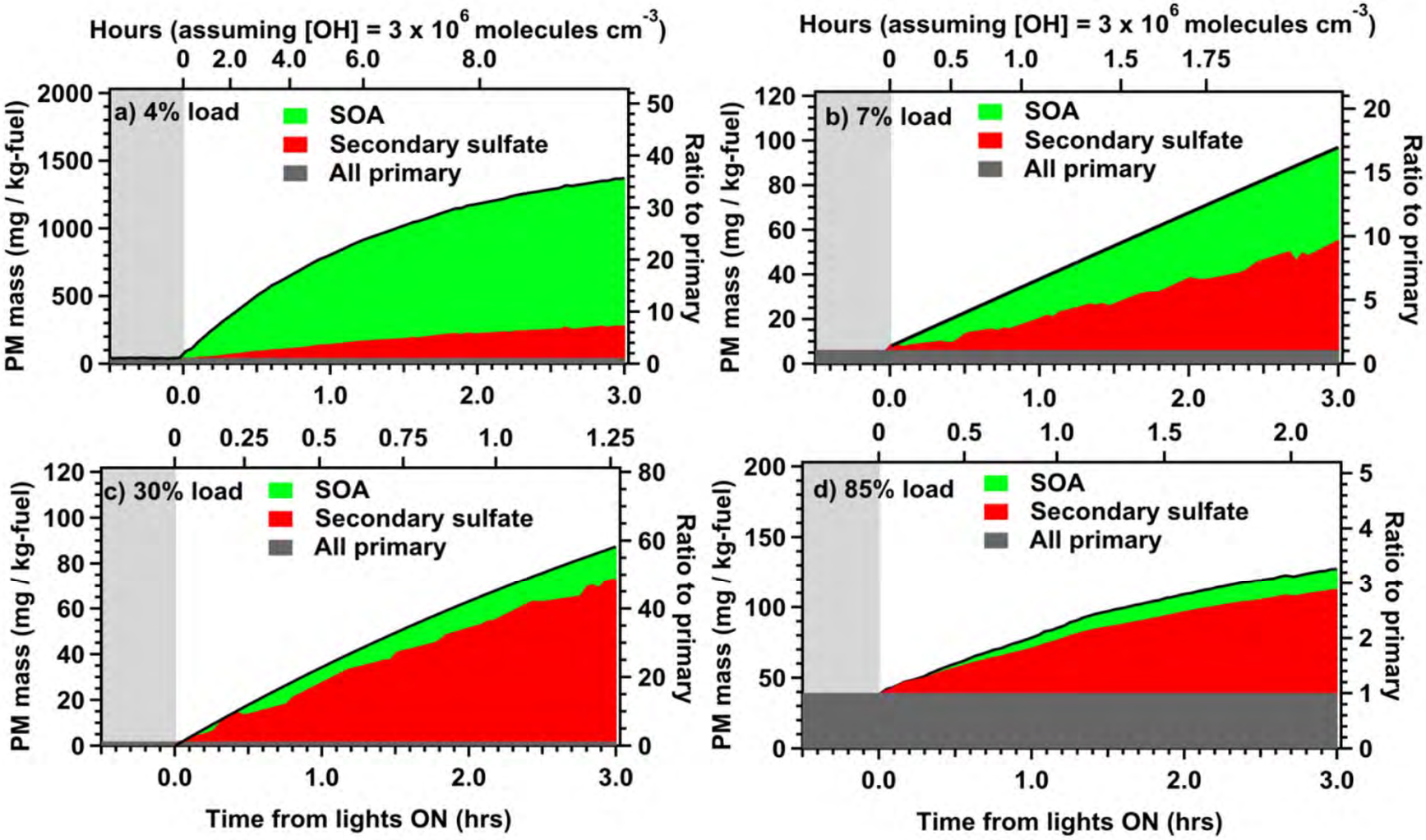
Miracolo et al. ACP 2011

Secondary aerosol production overwhelms primary emissions



Ave [OH] ~ 6 x 10^6 molec/cm^3

At every engine load



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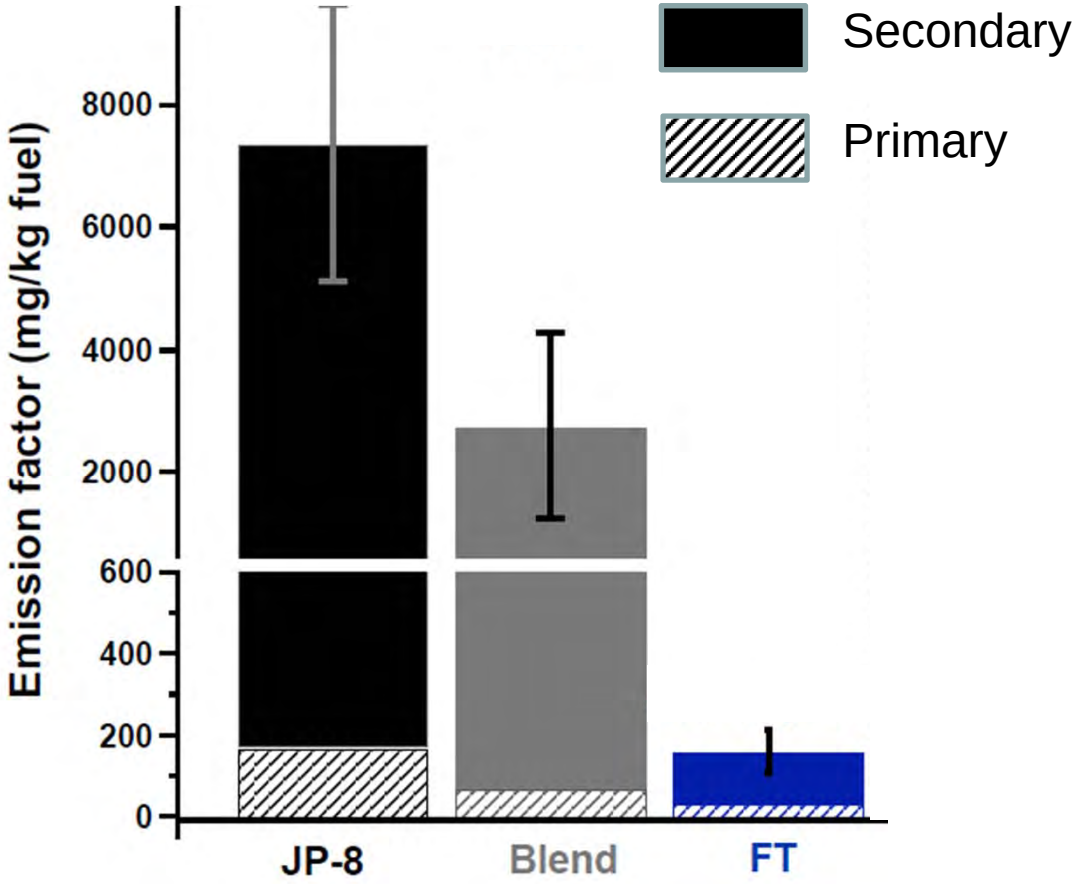
Effect of Fuel Composition on Secondary Aerosol



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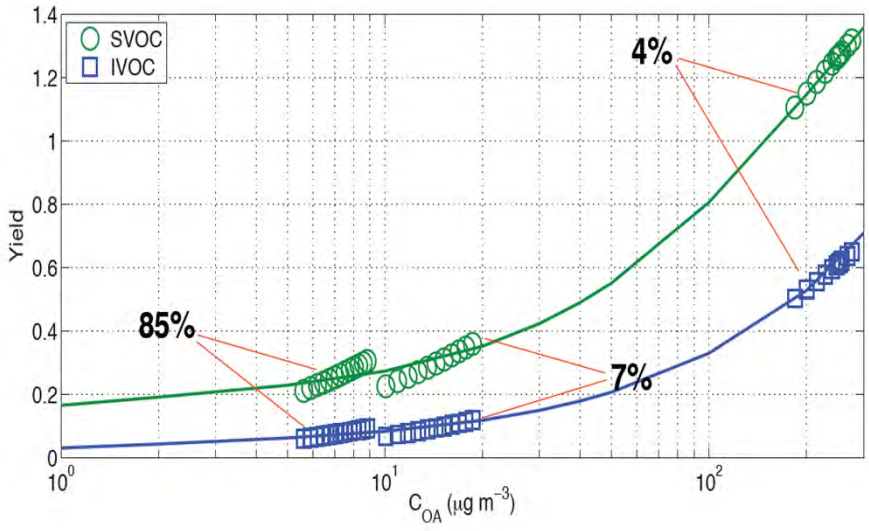
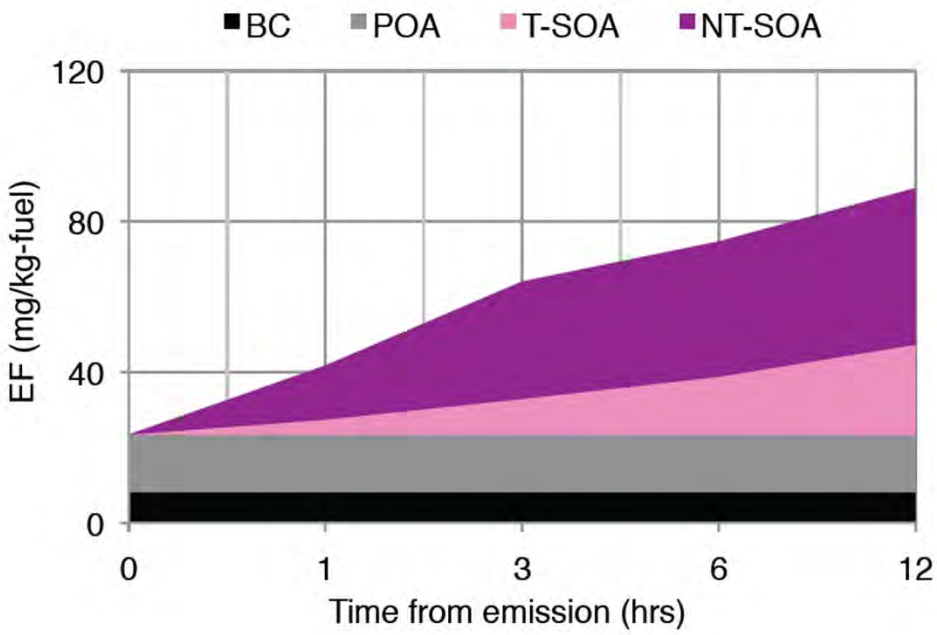
Modeling Secondary Aerosol Formation

Parameterizing Yields



Predicted Evolution Yields

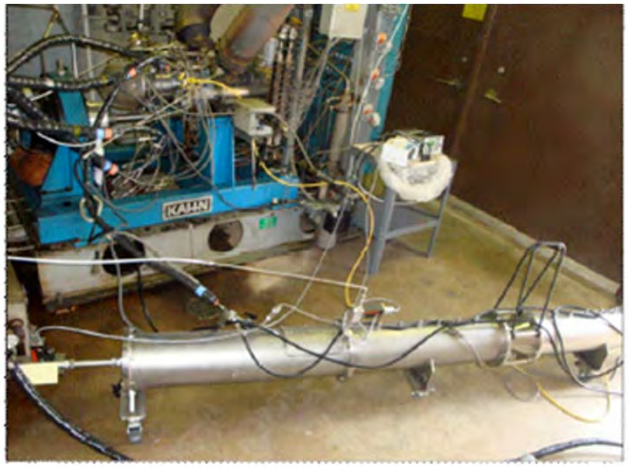


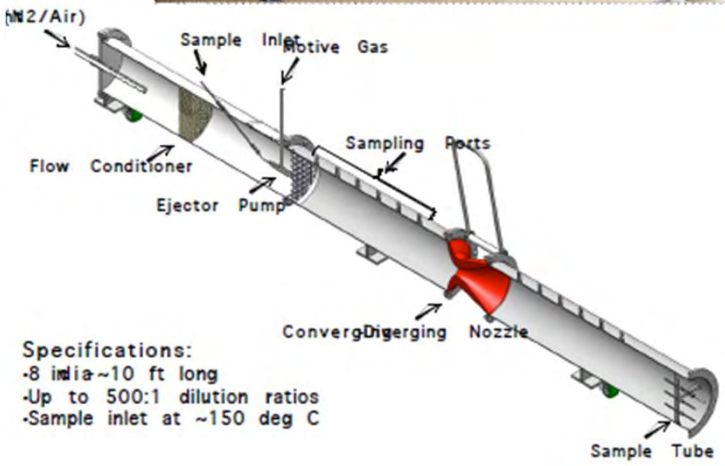
Secondary PM dominant at urban and regional scales

WP-1626

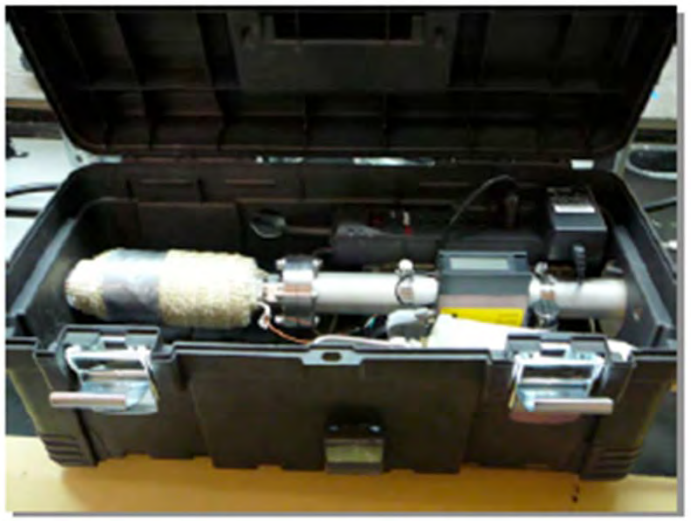
Instrumentation development

Dilution sampler





New Thermodenuder



- Low particle losses
- Portability
- Turnkey

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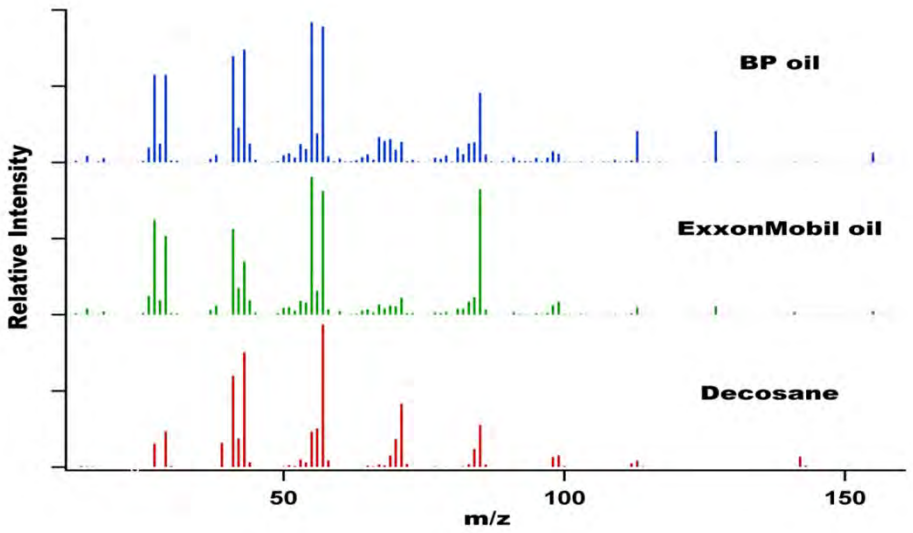
Lubrication Oil and Volatile PM

Mass spectra of lube oil



Findings:

The emission of lubrication oil varies significantly among the aircraft engines with different designs

Contribution from oil can be dominant in organic PM emission in some cases.

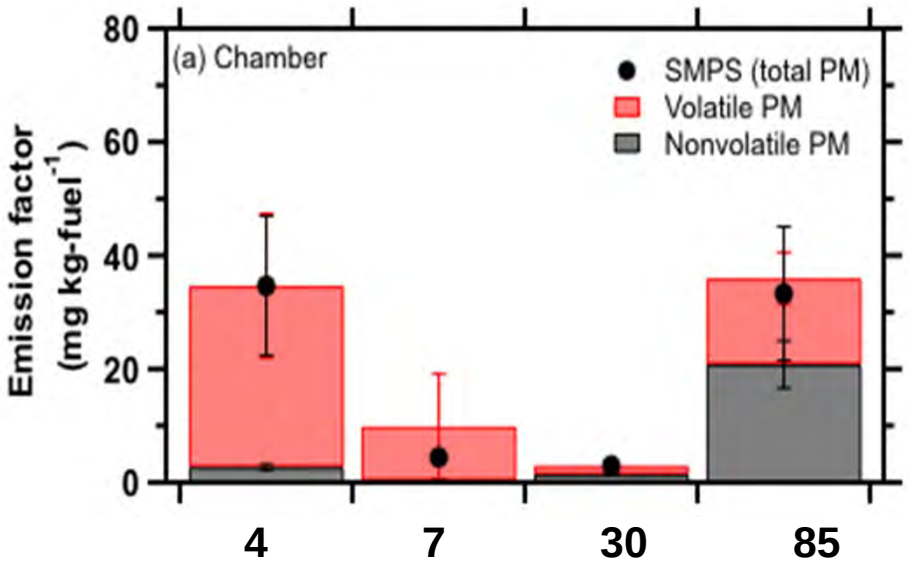
WP-1625

Key findings SERDP Volatile PM

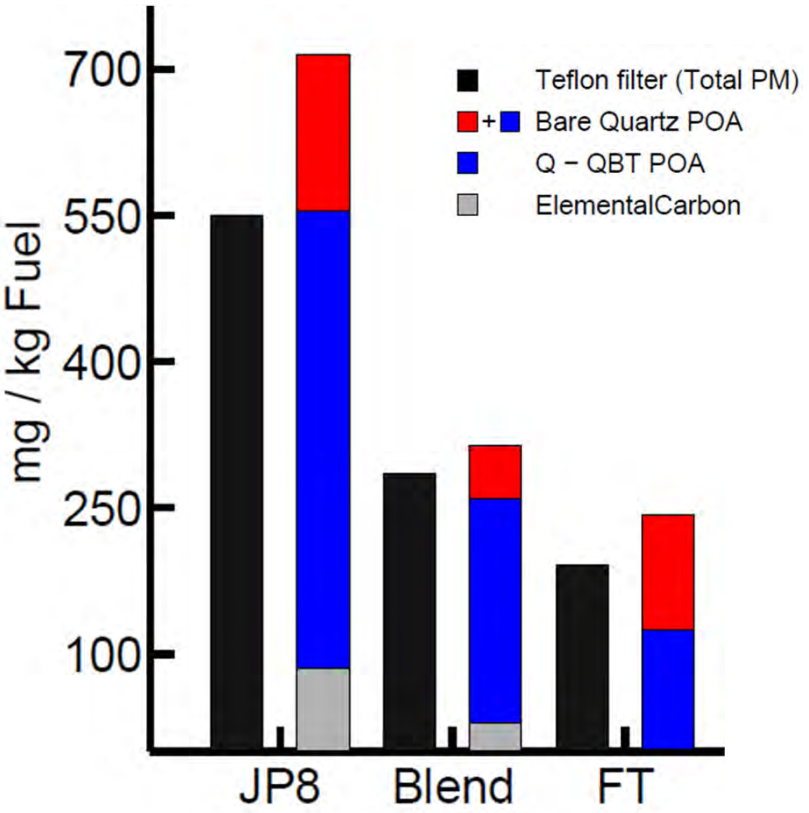
- Volatile PM highly dynamic system in atmosphere
- Secondary volatile PM production very significant
- Lube oil important constituent of volatile PM
- New tools:
  - Detailed microphysical kinetic model for plume soot, sulfate, and organic
  - Volatility basis set model for gas-particle partitioning of primary organic aerosol and production of secondary organic aerosol (SOA) in atmosphere
  - Dilution sampler, thermodenuder, and smog chamber techniques
- Archival Papers: 7 published, 4 near submission, others in process

Primary PM Emissions

CFM56 with Engine Load



T63 with Fuel Composition



Presto et al. AE 2011

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