METR/ENVS 113

Lecture 9: Particulate Matter & PM2.5

SJSU Fall Semester 2020

Module 3: Outdoor Air Pollution (Ozone and PM2.5)

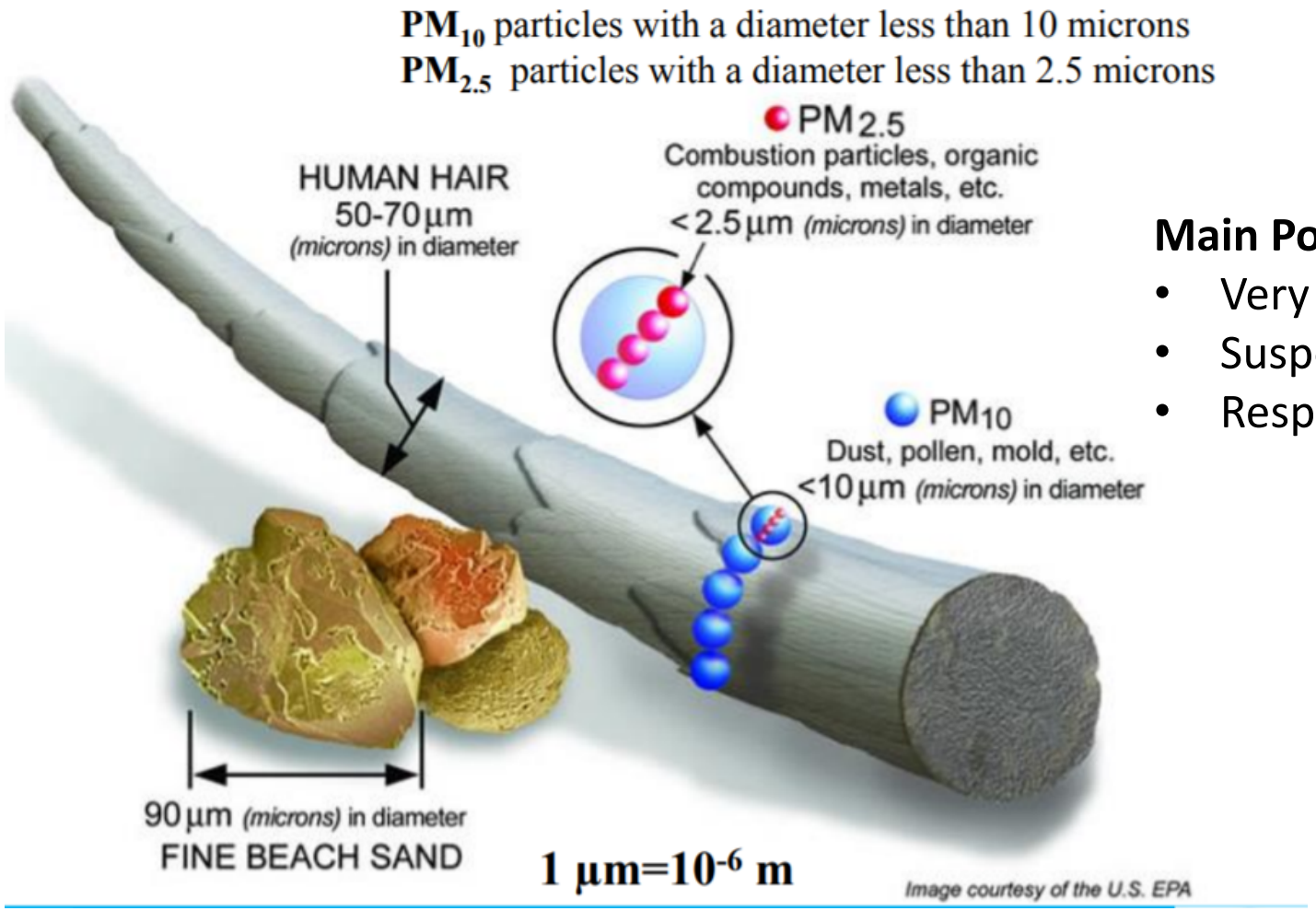
Frank R. Freedman (Course Instructor)

Outline

- **Overview**
  - Fine Particulate: Definition
  - Health Effects (brief)
  - Concentration Patterns & PM2.5 Regulatory Attainment Status
- **Composition**
  - Composition: PM10 vs. PM2.5 vs. Ultrafine
  - Primary vs. Secondary PM2.5
- **Emission Sources: Combustion PM**

Fine Particulate Air Pollution
(Overview)

What is Particulate Matter (PM)?

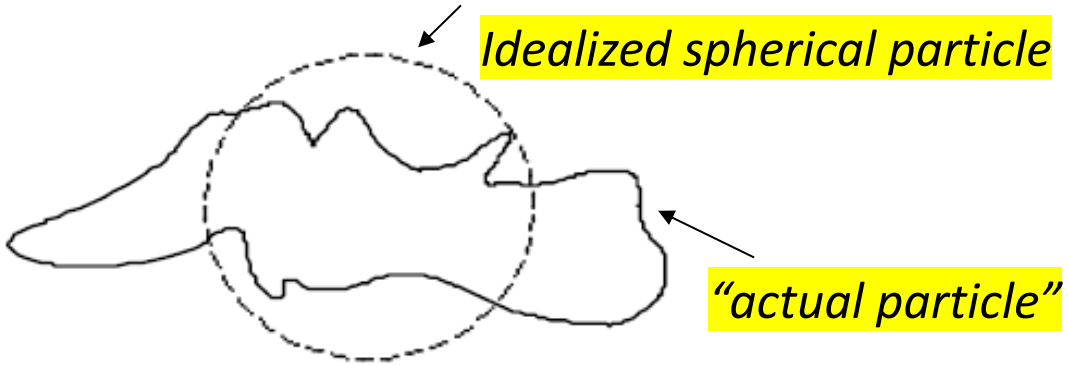


Main Points

- Very tiny particles
- Suspended in air – can travel in air much like a gas
- Respirable – can penetrate deeply into lungs

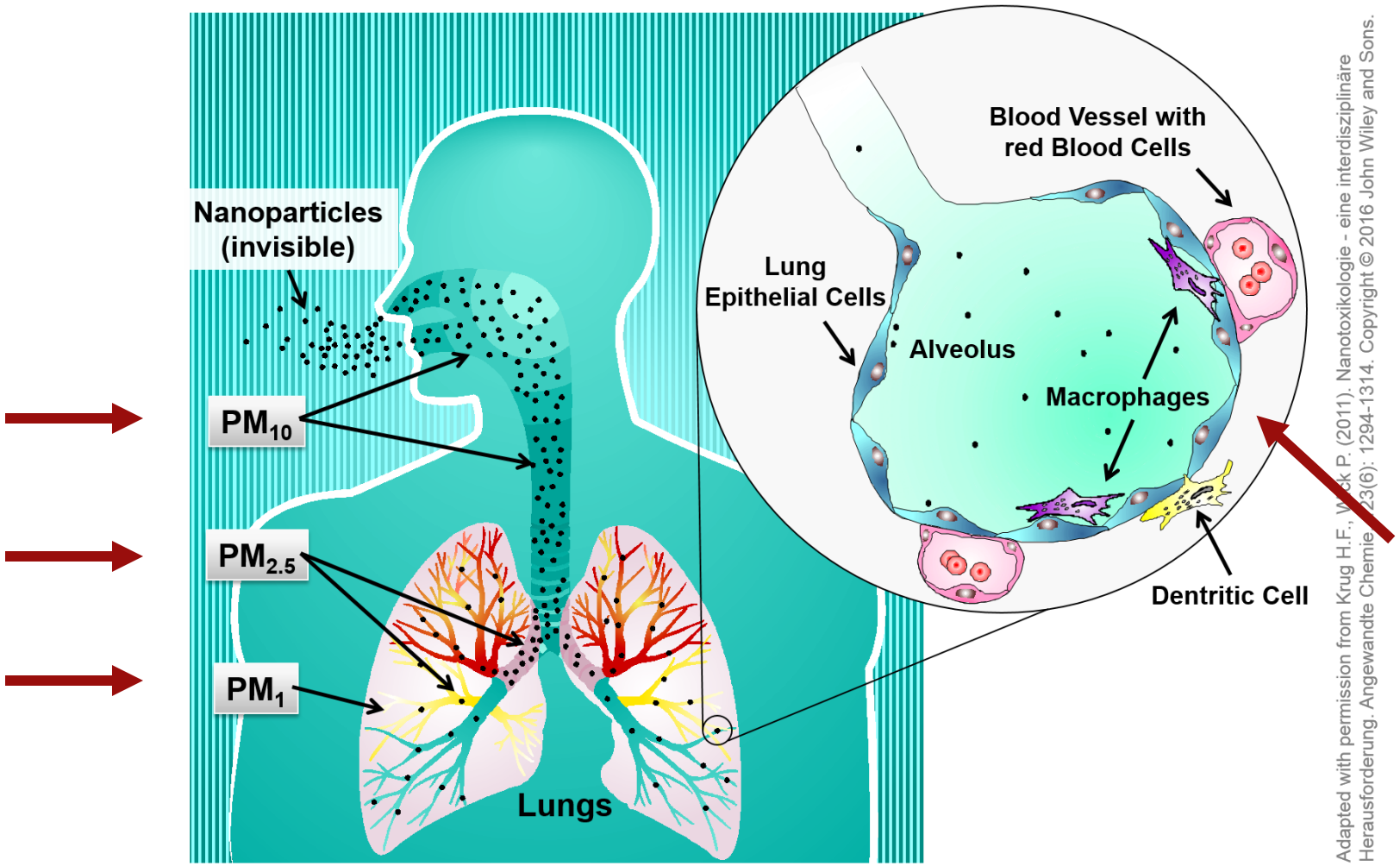
Aerosol & “particle size”

- Aerosol: the ensemble or group of solid, liquid, or mixed phase particles suspended in air.
- Aerosol size is typically measured by its “diameter”. This is an approximate size assuming aerosol is a sphere.



- More precisely, it refers to something called the “aerodynamic” diameter
- Technical details (if interested … not on exam) https://en.wikipedia.org/wiki/Aerosol#Aerodynamic_diameter

Health Effects, Particle Size & Lung Penetration



Particle sizes < 1 µm are called “ultrafine” – most dangerous since penetrate deeply into lungs

Further Reading: PM Health Effects

- https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health
- https://en.wikipedia.org/wiki/Particulates#Health_effects
- https://oehha.ca.gov/air/press-release/press-release-air/study-finds-long-term-exposure-ultrafine-particle-air-pollution
- More details also in Module 4.

Ambient Air Quality Standards: PM10 and PM2.5

$PM_{2.5}$: (particles smaller than 2.5 μm)

Federal (annual): 12 μg/m³
Federal (24-hour): 35 μg/m³

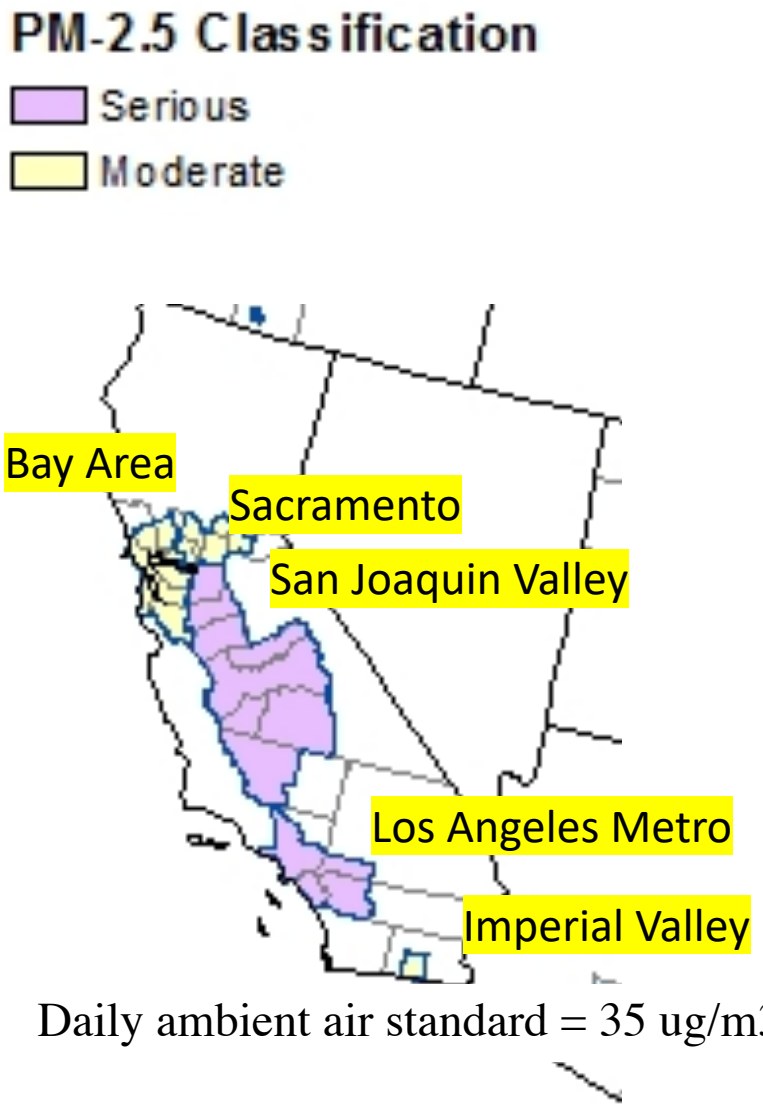
PM_{10}: (particles smaller than 10 μm)

California (annual): 20 μg/m³
California (24-hour): 50 μg/m³
Federal (24-hour): 150 μg/m³

Both 24-hour and annual standards to protect against both acute and chronic health impacts

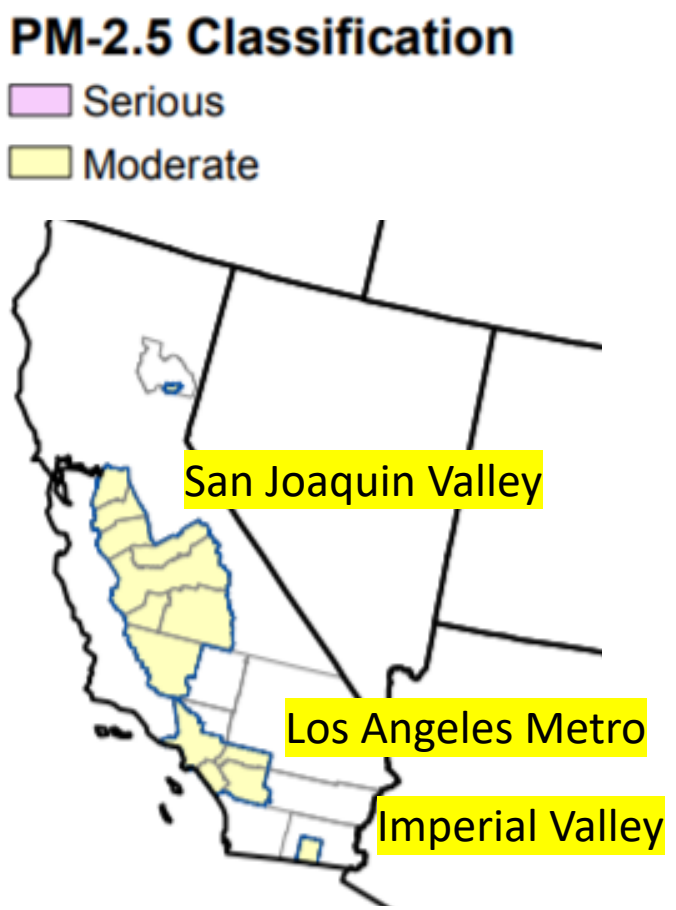
Current PM2.5 non-attainment areas (California)

Daily



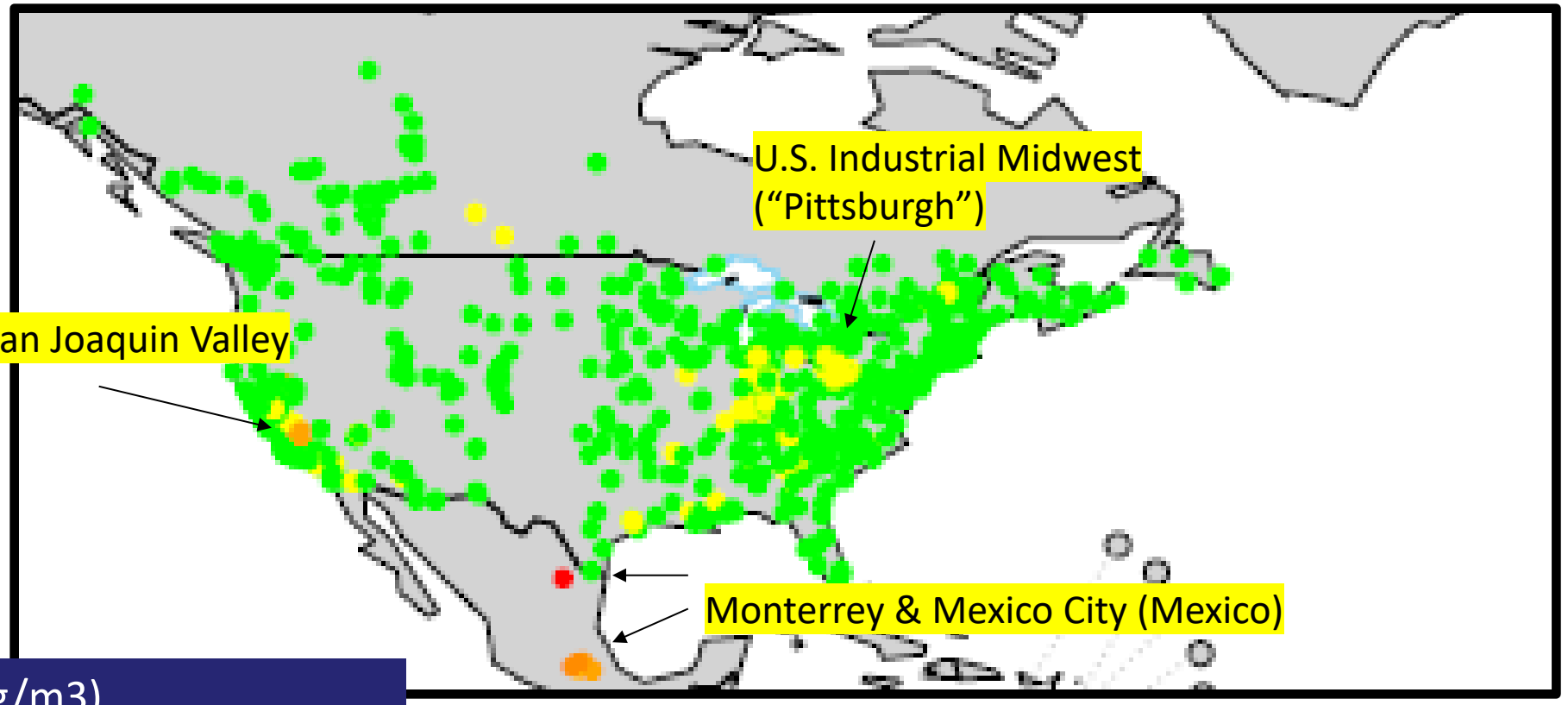
Daily ambient air standard = 35 ug/m3

Annual



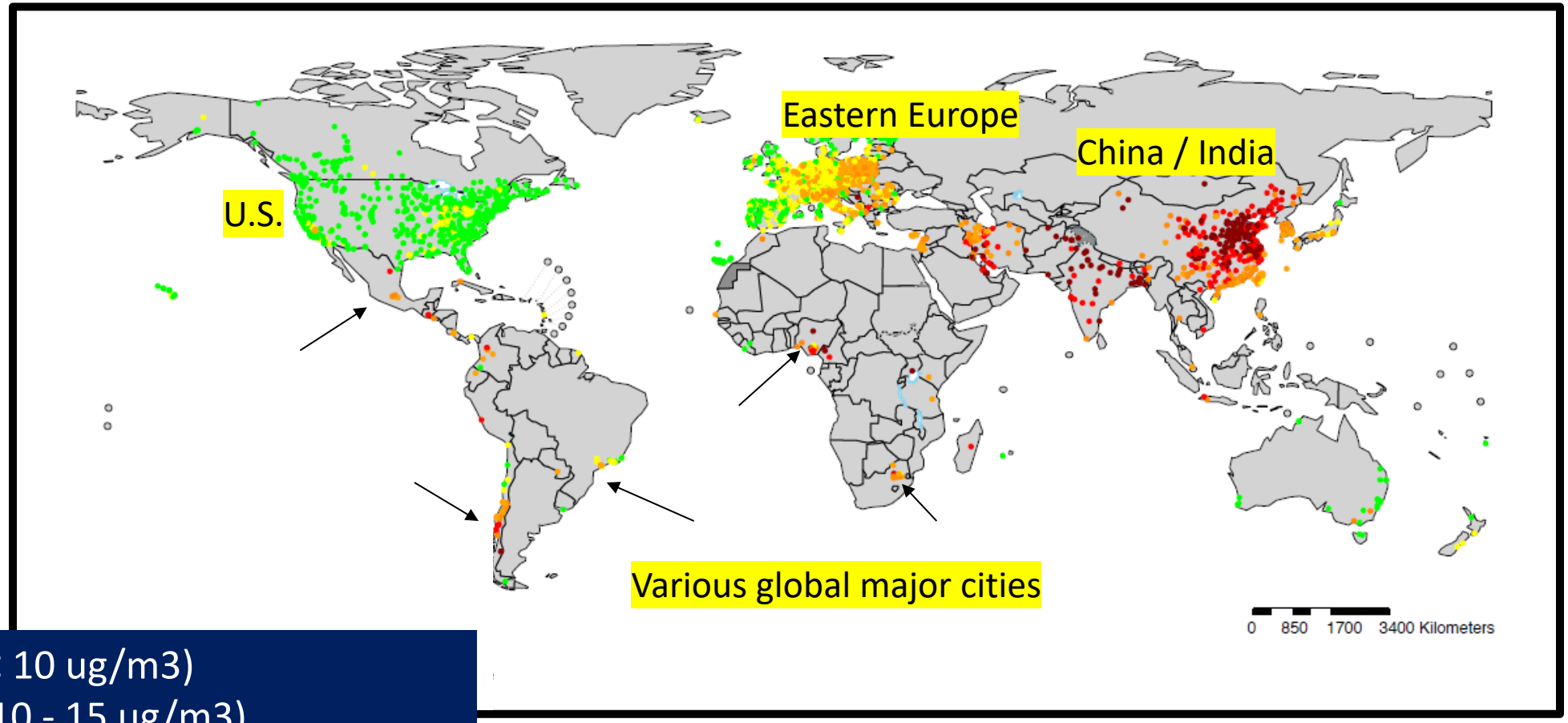
Annual ambient air standard = 12 ug/m3

Annual PM2.5 Concentration Map (U.S.)



Green (< 10 ug/m3)
Yellow (10 - 15 ug/m3)
Orange (15 - 35 ug/m3)
Red (> 35 ug/m3)

Annual PM2.5 Concentration Map (global)



Green (< 10 ug/m3)
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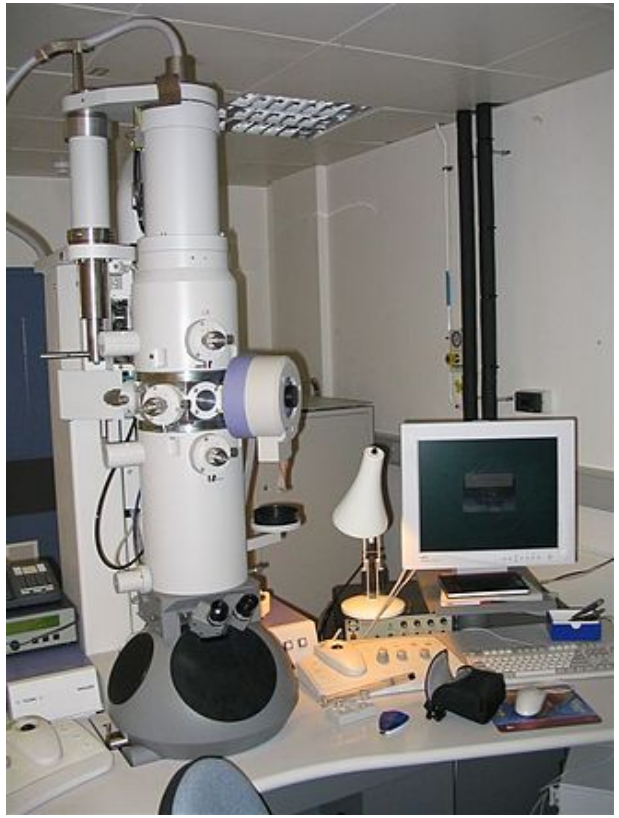
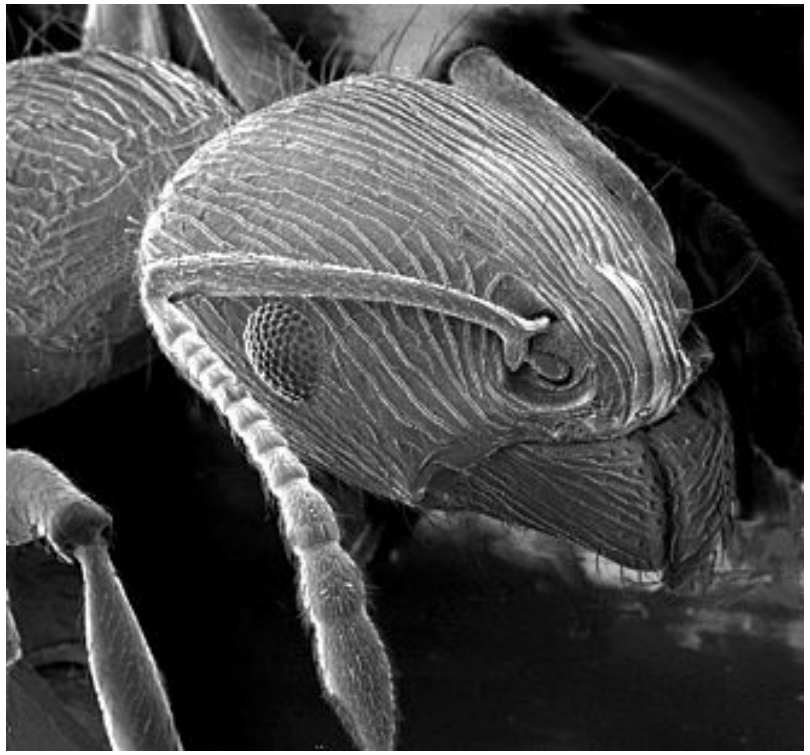
Fine Particulate Air Pollution (Composition)

Electron Microscopy (EM)





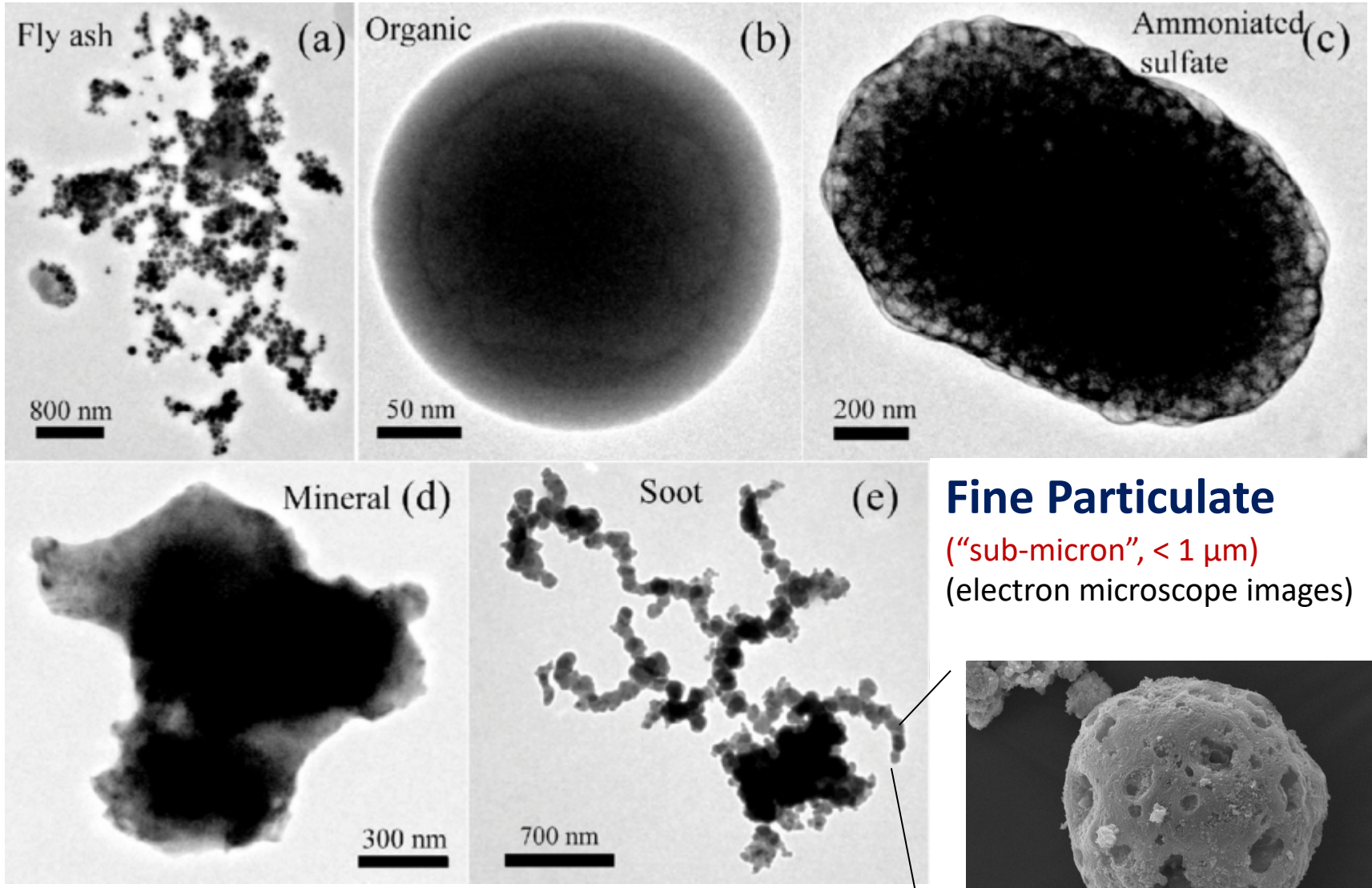
an ant viewed from electron microscope
(example illustrating magnification power of EM)

https://en.wikipedia.org/wiki/Electron_microscope

Ash

Organic Carbon

Ammonium Sulfate ("secondary PM")



Fine Particulate

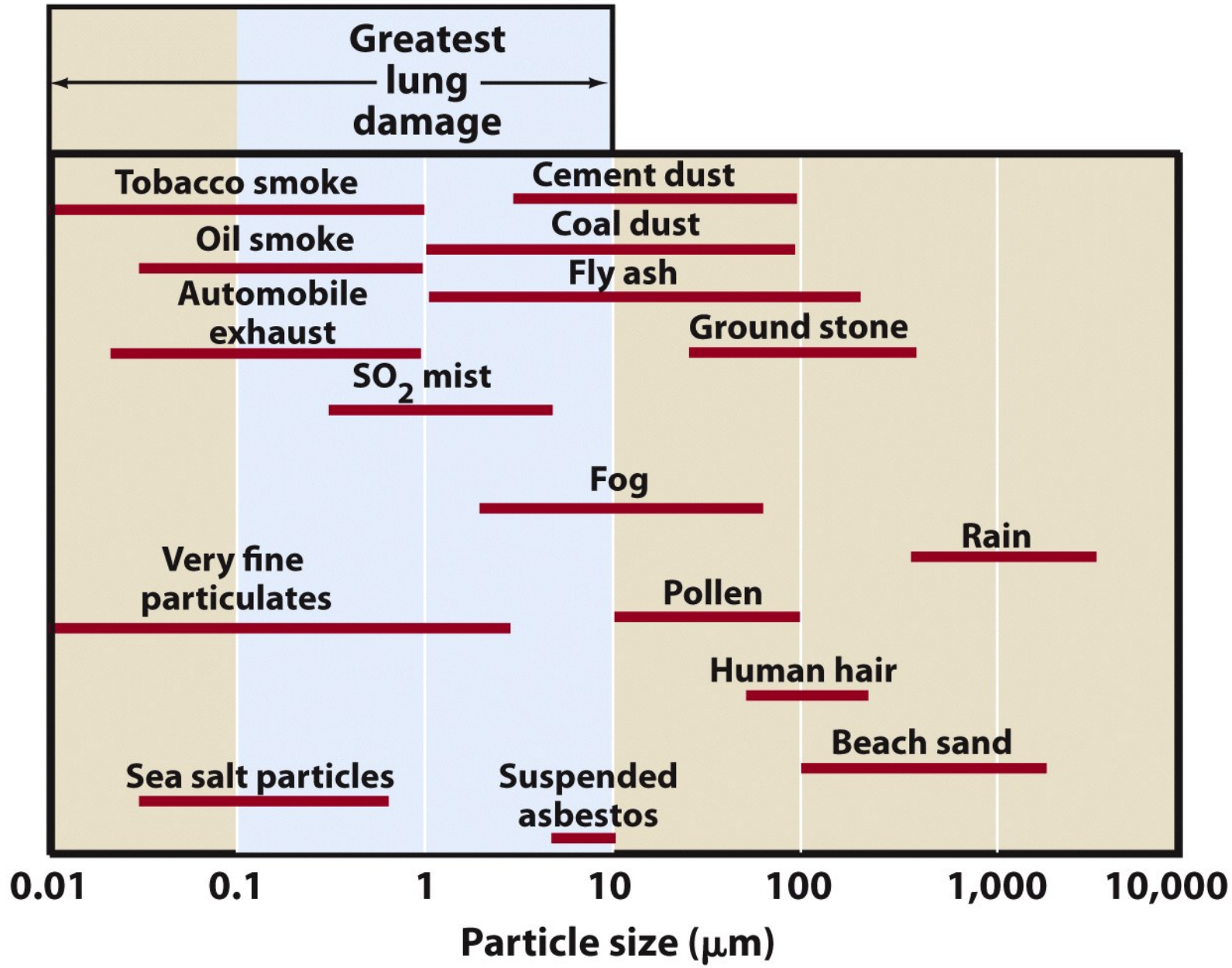
("sub-micron", < 1 µm)

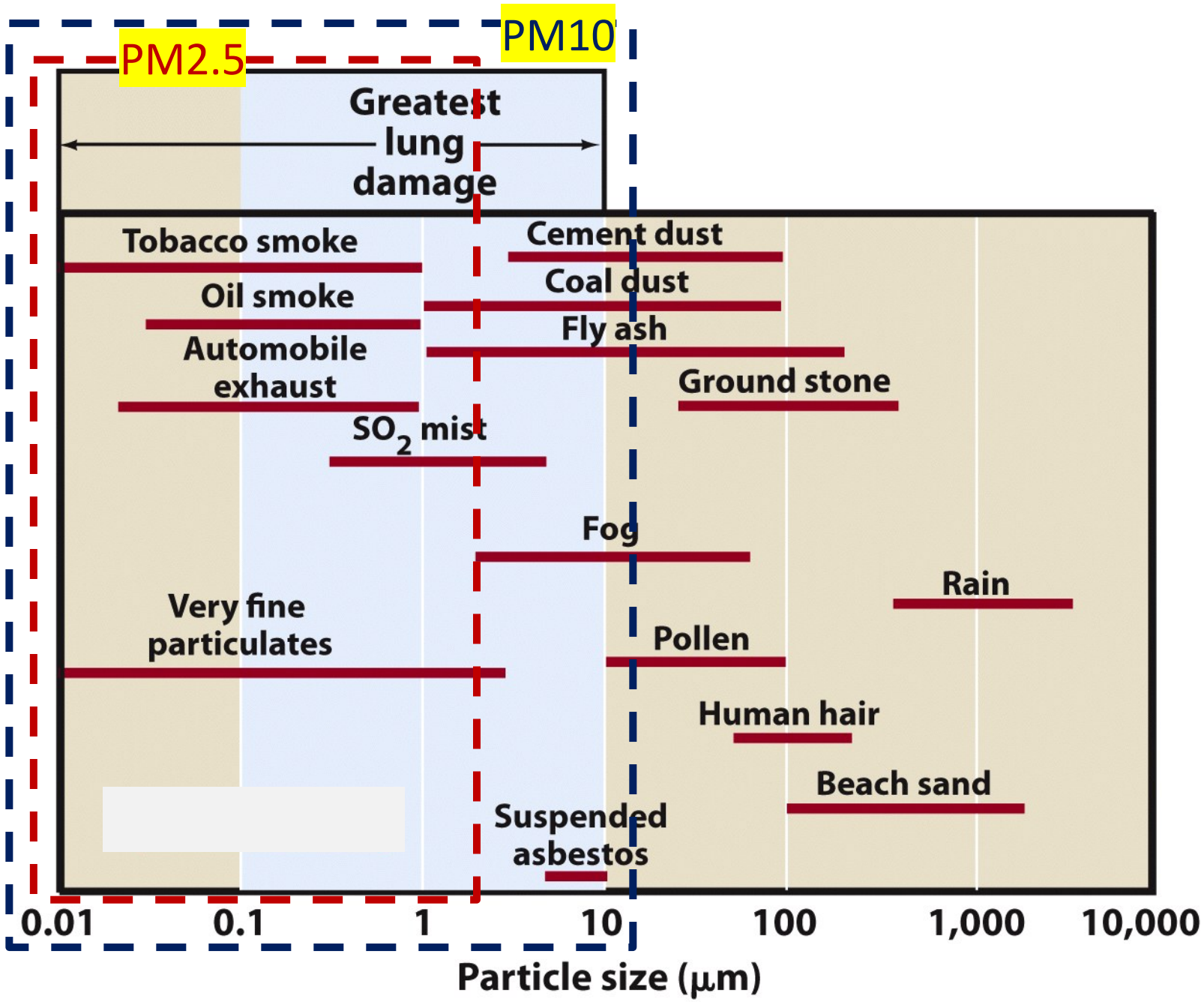
(electron microscope images)

Individual soot particulate (3000 x blow-up)

Mineral Dust

Black Carbon ("Soot")


Greatest lung damage
Tobacco smoke
Oil smoke
Automobile exhaust
SO_2 mist
Cement dust
Coal dust
Fly ash
Ground stone
Fog
Rain
Very fine particulates
Pollen
Human hair
Beach sand
Sea salt particles
Suspended asbestos
0.01
0.1
1
10
100
1,000
10,000
Particle size (μm)


PM2.5
PM10
Greatest lung damage
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Oil smoke
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SO_2 mist
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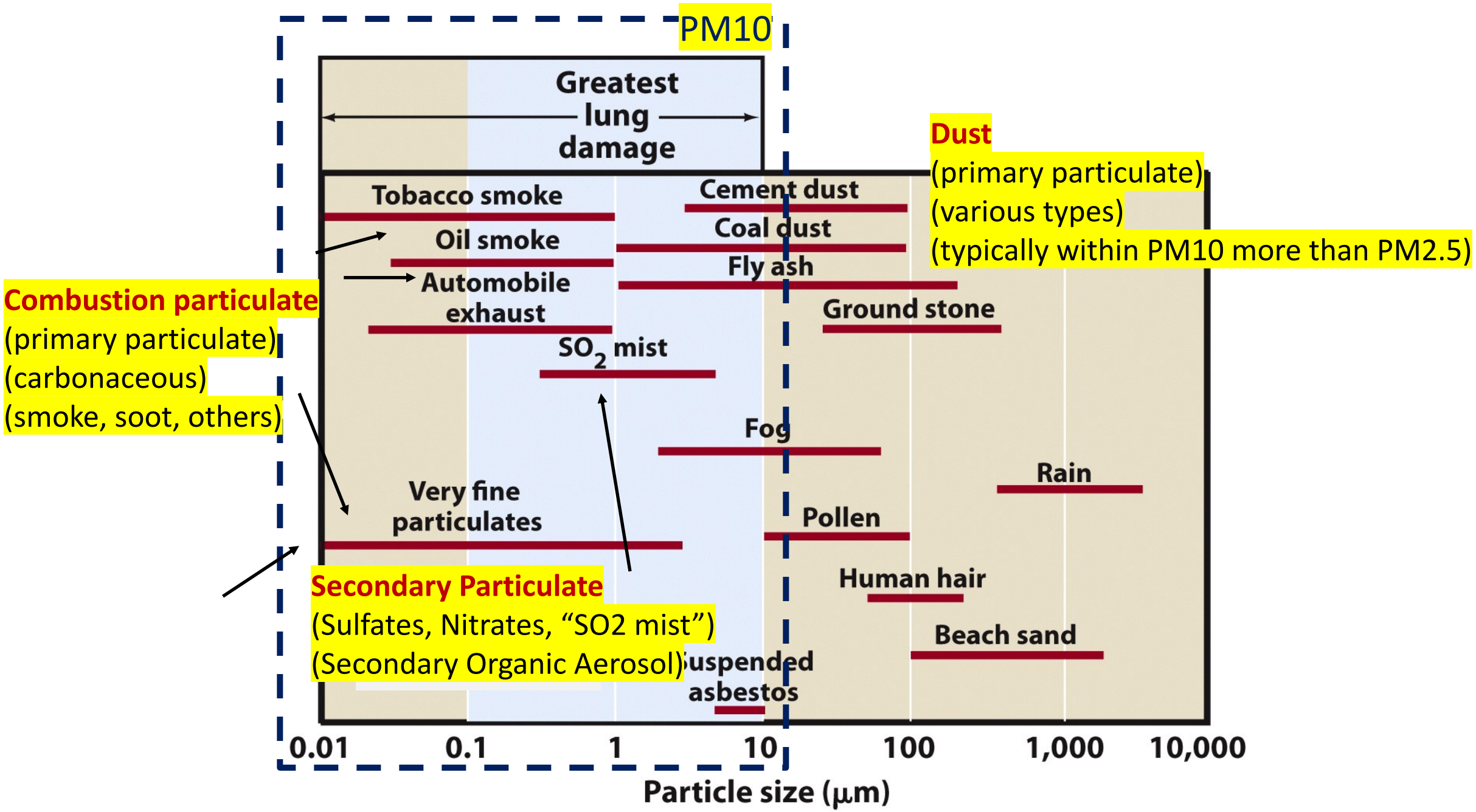
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Fog
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Pollen
Human hair
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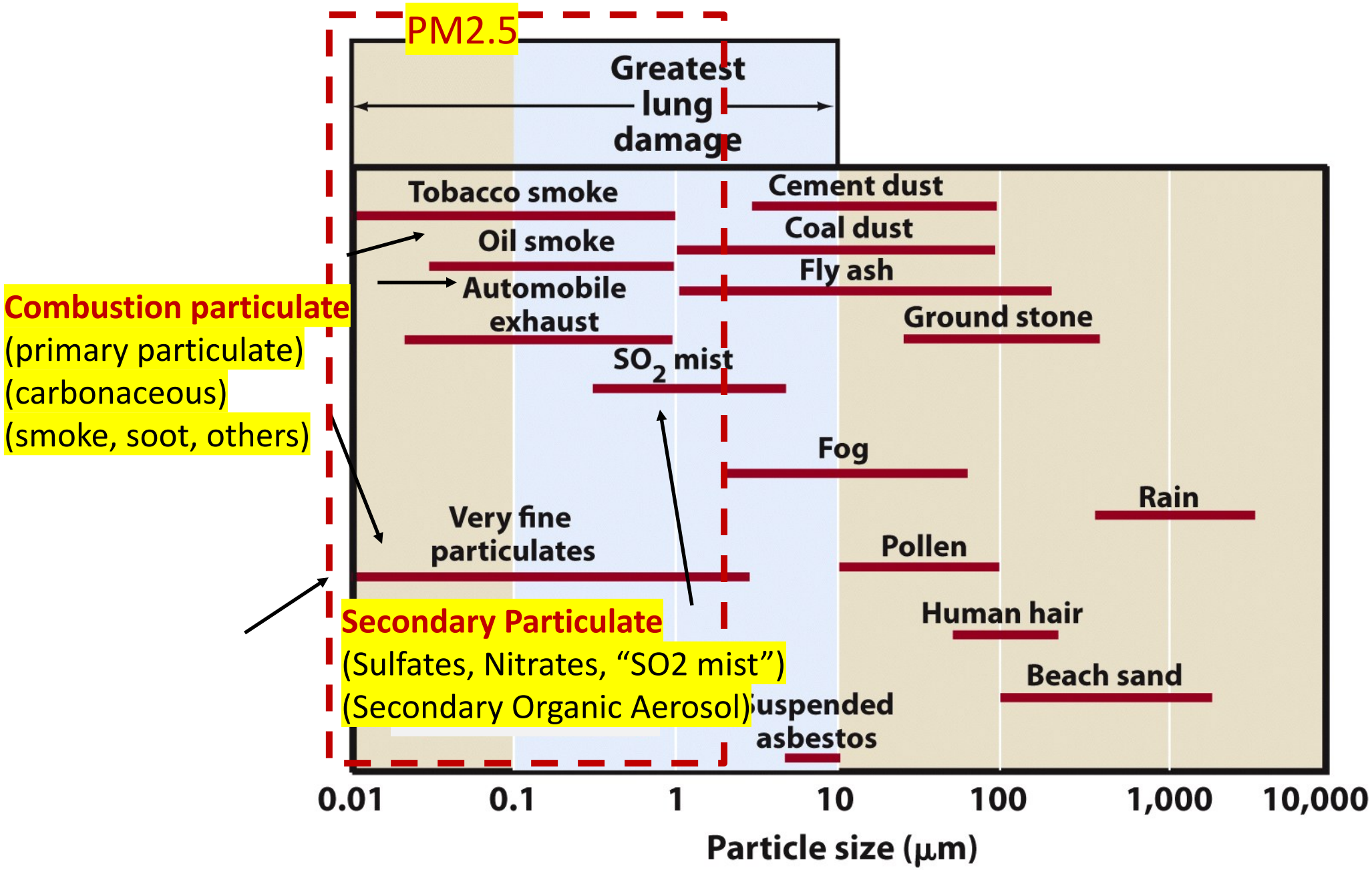
Suspended asbestos
0.01
0.1
1
10
100
1,000
10,000
Particle size (μm)
Dust
(primary particulate)
(various types)
(typically within PM10 more than PM2.5)
Combustion particulate
(primary particulate)
(carbonaceous)
(smoke, soot, others)
Secondary Particulate
(Sulfates, Nitrates, "SO2 mist")
(Secondary Organic Aerosol)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Greatest lung damage
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Automobile exhaust
SO_2 mist
Very fine particulates
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Particle size (μm)
Combustion particulate
(primary particulate)
(carbonaceous)
(smoke, soot, others)
Secondary Particulate
(Sulfates, Nitrates, "SO2 mist")
(Secondary Organic Aerosol)

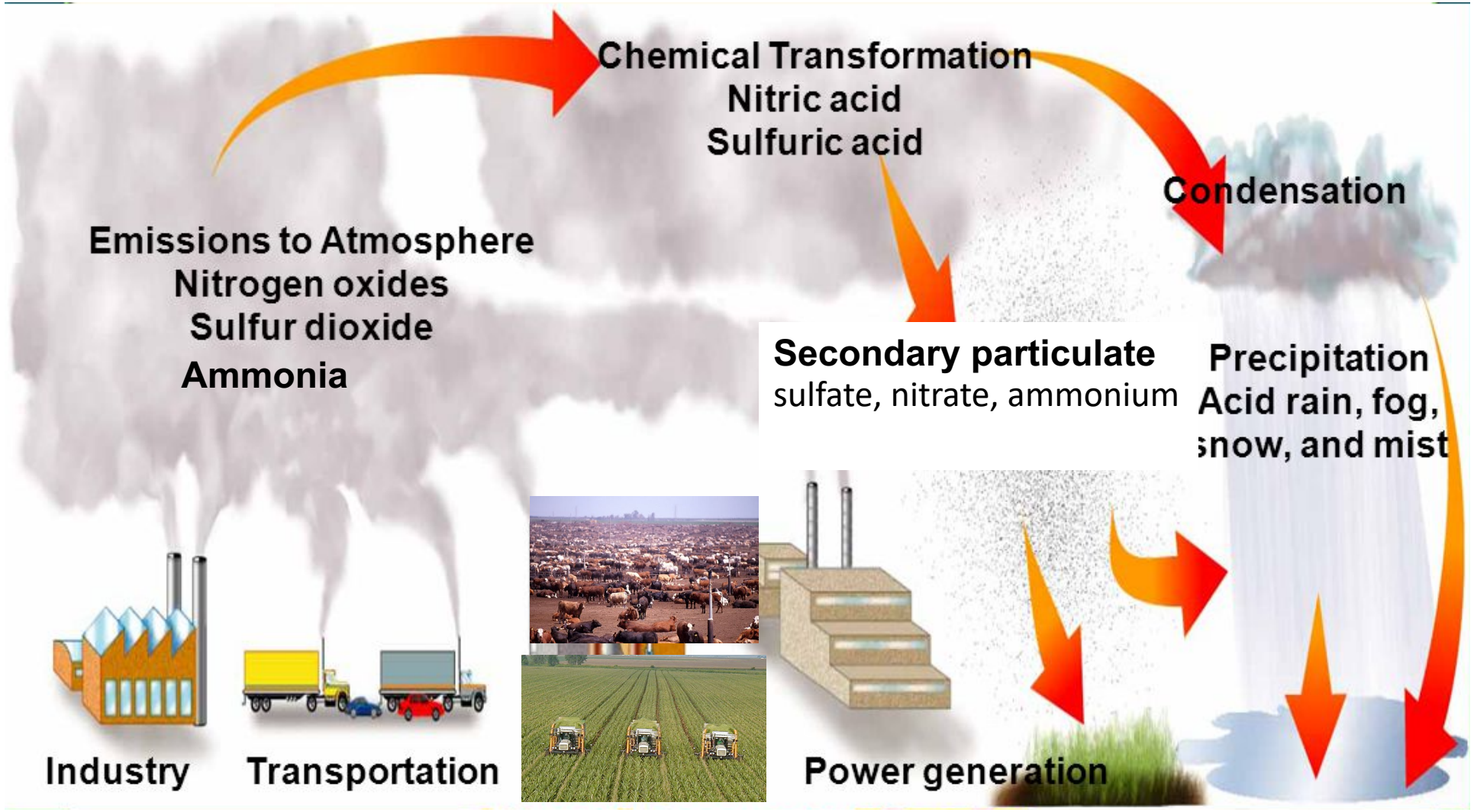
PM2.5 Composition: Combustion vs. Secondary

- **Combustion PM2.5 (Carbonaceous)**
  - Fine particulate emitted during combustion.
  - Very small particle size (< 1 µm … “sub-micron”)
  - Various sub-types, terms: Smoke, Soot, Black Carbon, Elemental Carbon, Organic Carbon, tar, etc ...
  - Directly emitted from source (“primary particulate”)
- **Secondary PM2.5**
  - Fine particulate formed from chemical reactions
  - Very small particle size (< 1 µm … “sub-micron”)
  - Various sub-types: Sulfates, Nitrates, Ammonium Nitrate, Secondary Organic Aerosol
  - **Not** directly emitted from source. Forms from chemical reactions from gaseous precursor emissions
  - See next slide: gaseous pre-cursors for main secondary PM2.5 species

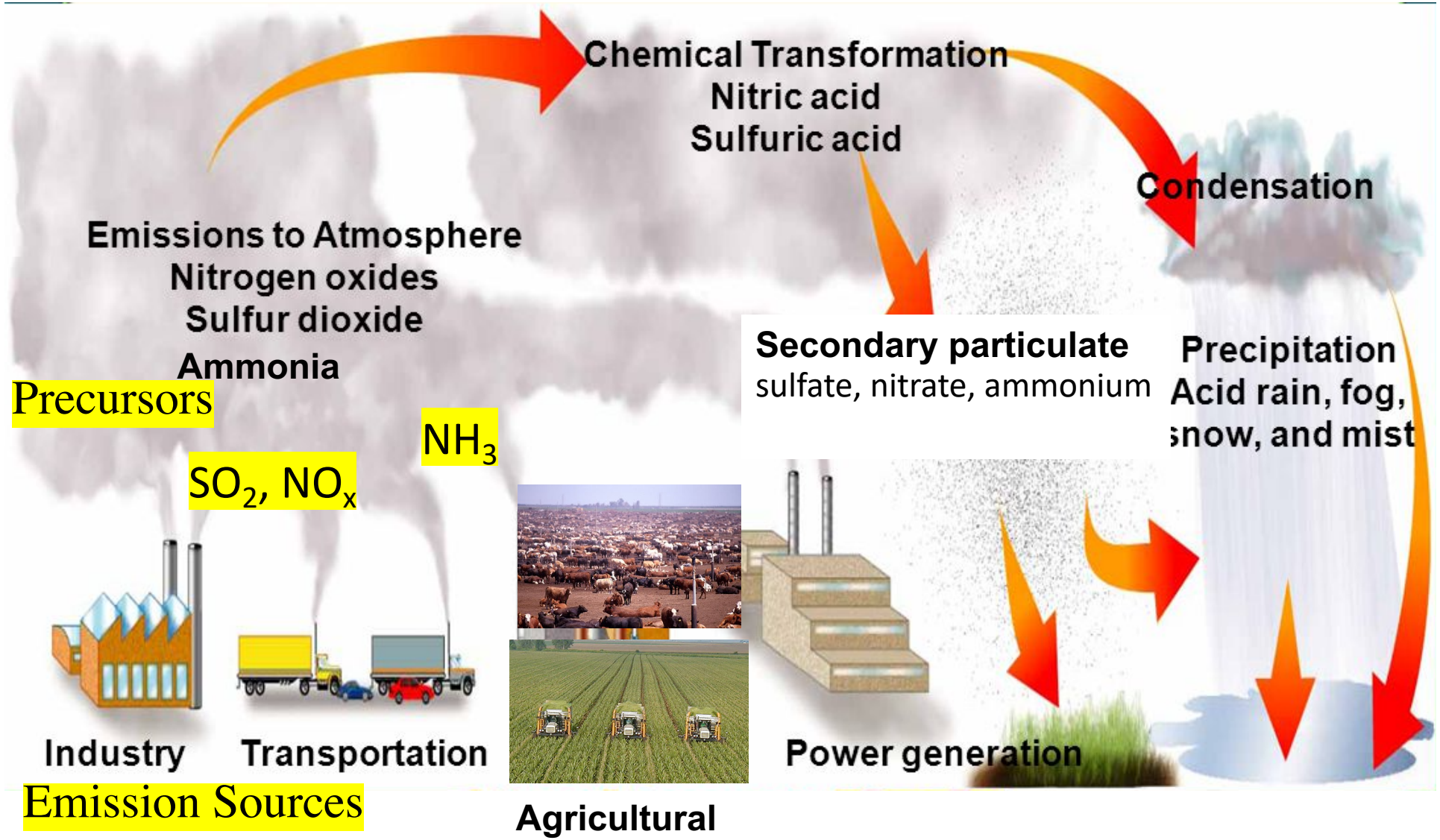
Secondary PM2.5: Precursors & Formation Conditions

- **Nitrates**
  - Precursors: Nitrogen Oxides (NOx), Ammonia (NH3)
  - Formation: Aqueous chemistry. Favors high humidity environment.
- **Sulfates**
  - Precursors: Sulfur Dioxide (SO2), Ammonia (NH3)
  - Formation: Favors high humidity environment (aqueous chemistry)
- **Secondary Organic Aerosol (SOA)**
  - Precursors: Volatile Organic Compounds (VOCs)
  - Formation: Favors hot, sunny weather (photochemical … similar to ground-level ozone)
  - Relatively little known … active area of research

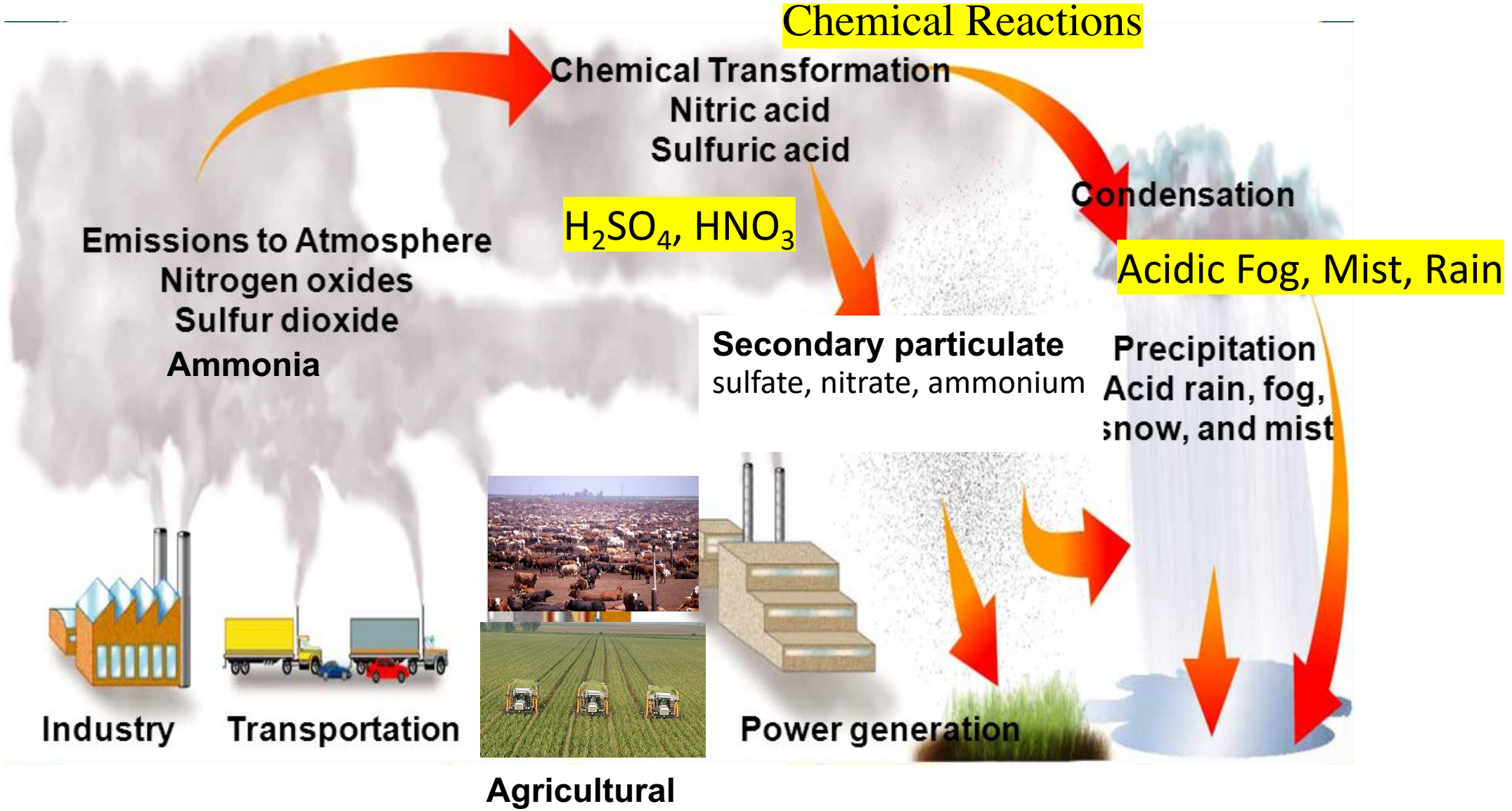
Nitrates & Sulfates: Summary of Formation Process



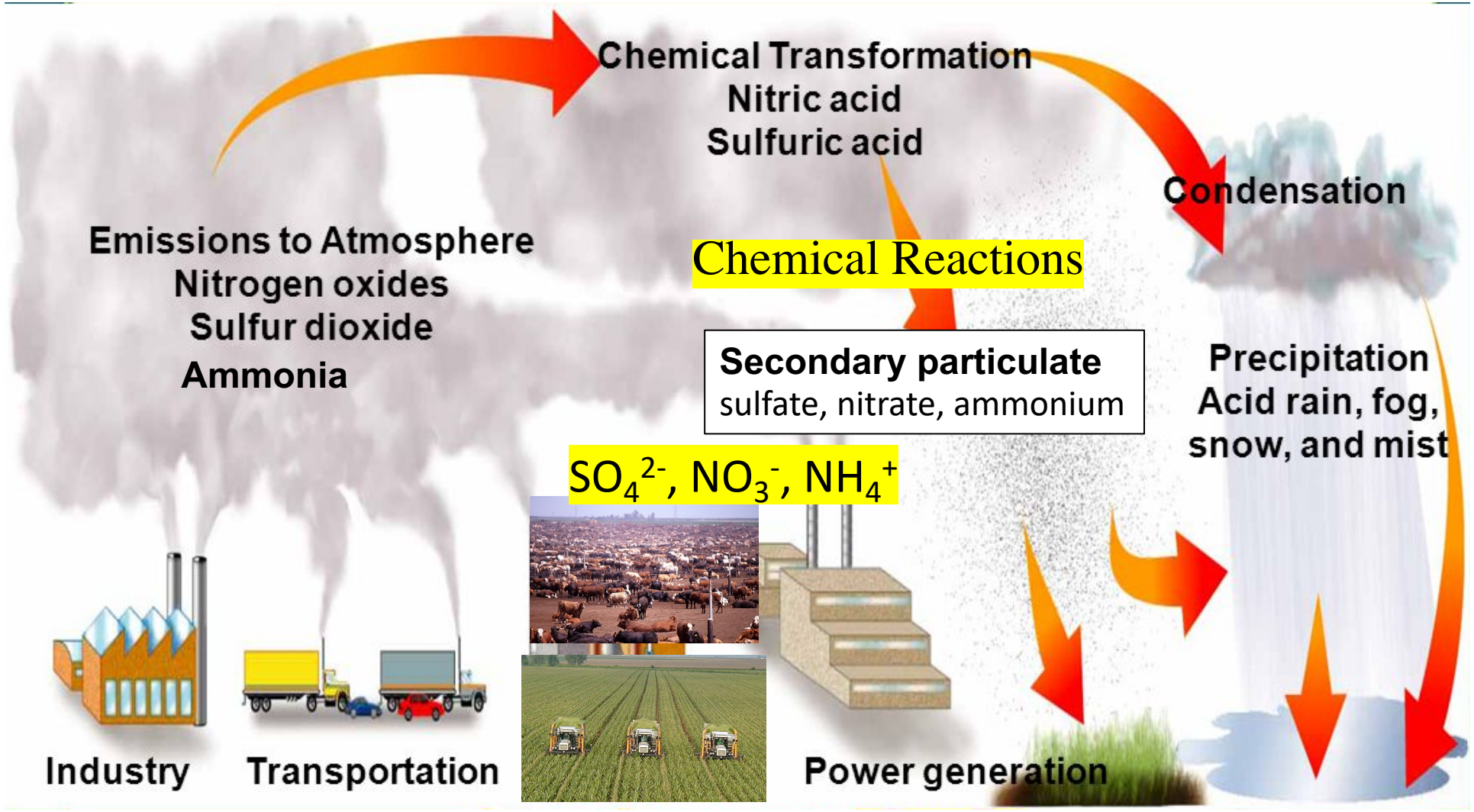
NOx and SO2 Emissions (Precursors)



Chemical Reactions in Air to Nitric Acid (HNO3) and Sulfuric Acid (H2SO4) and Absorption into liquid H2O

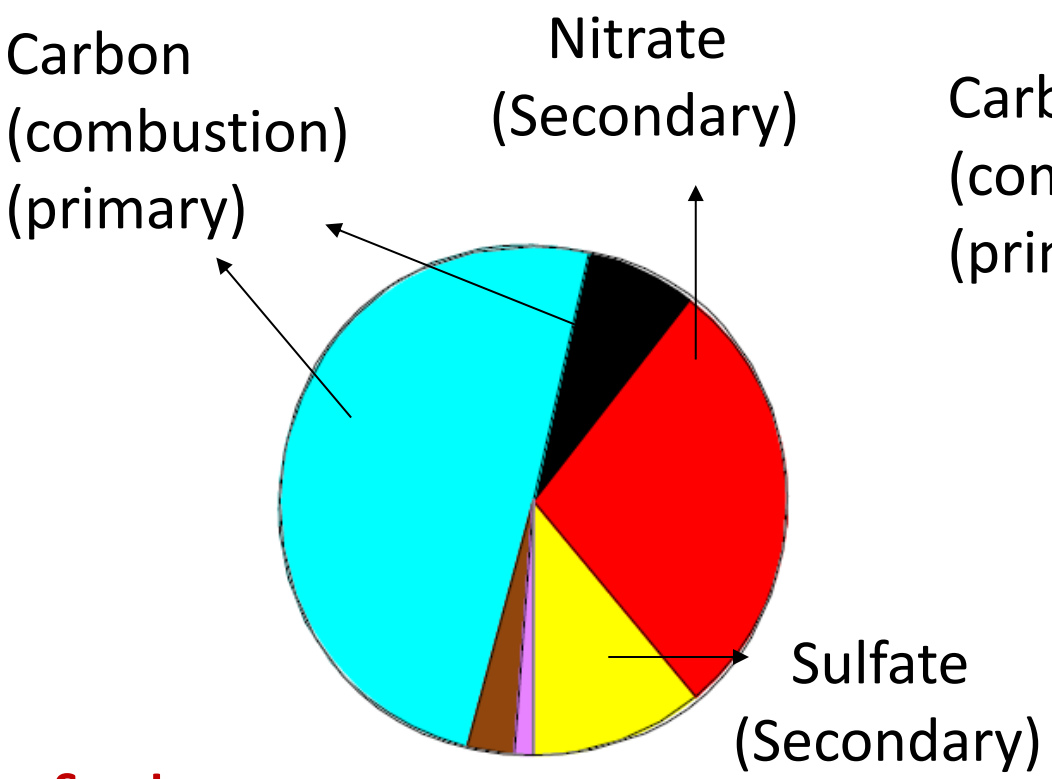


Further chemical reactions
(Nitric Acid to Nitrate PM2.5)
(Sulfuric Acid to Sulfate PM2.5)



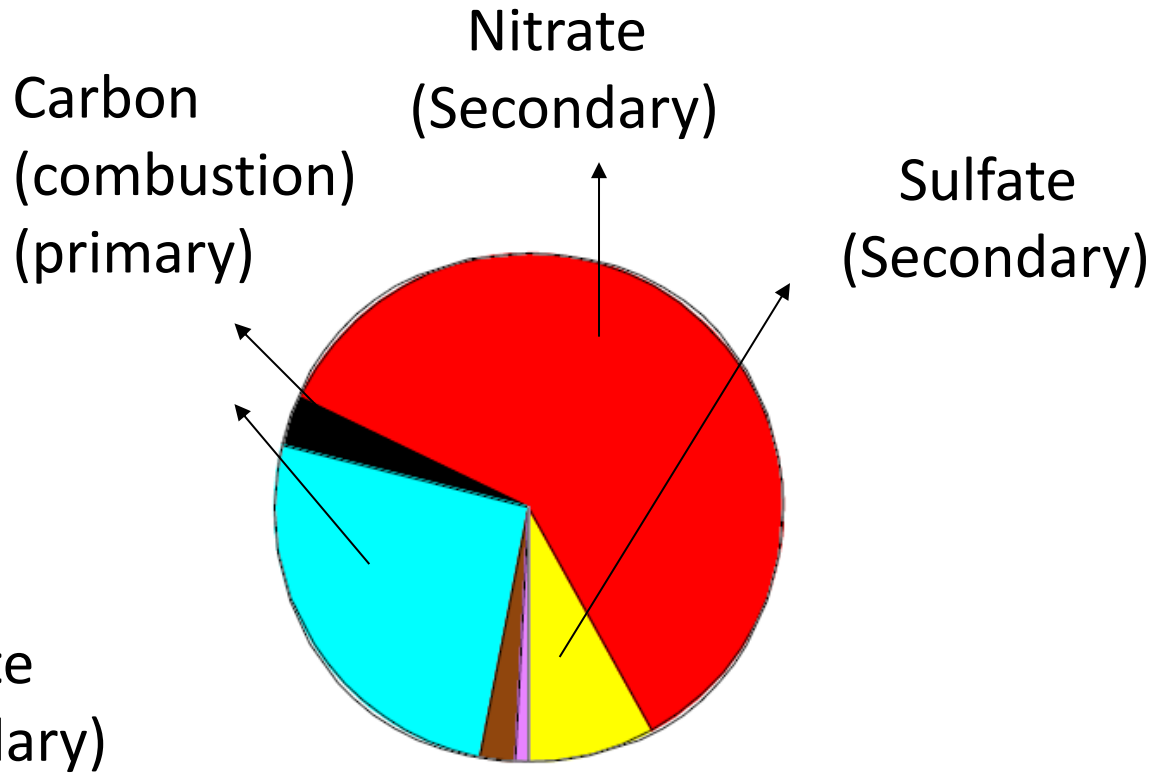
PM2.5 Composition in CA

(cold wintertime high pollution days)



San Jose
(4th and Jackson St.)

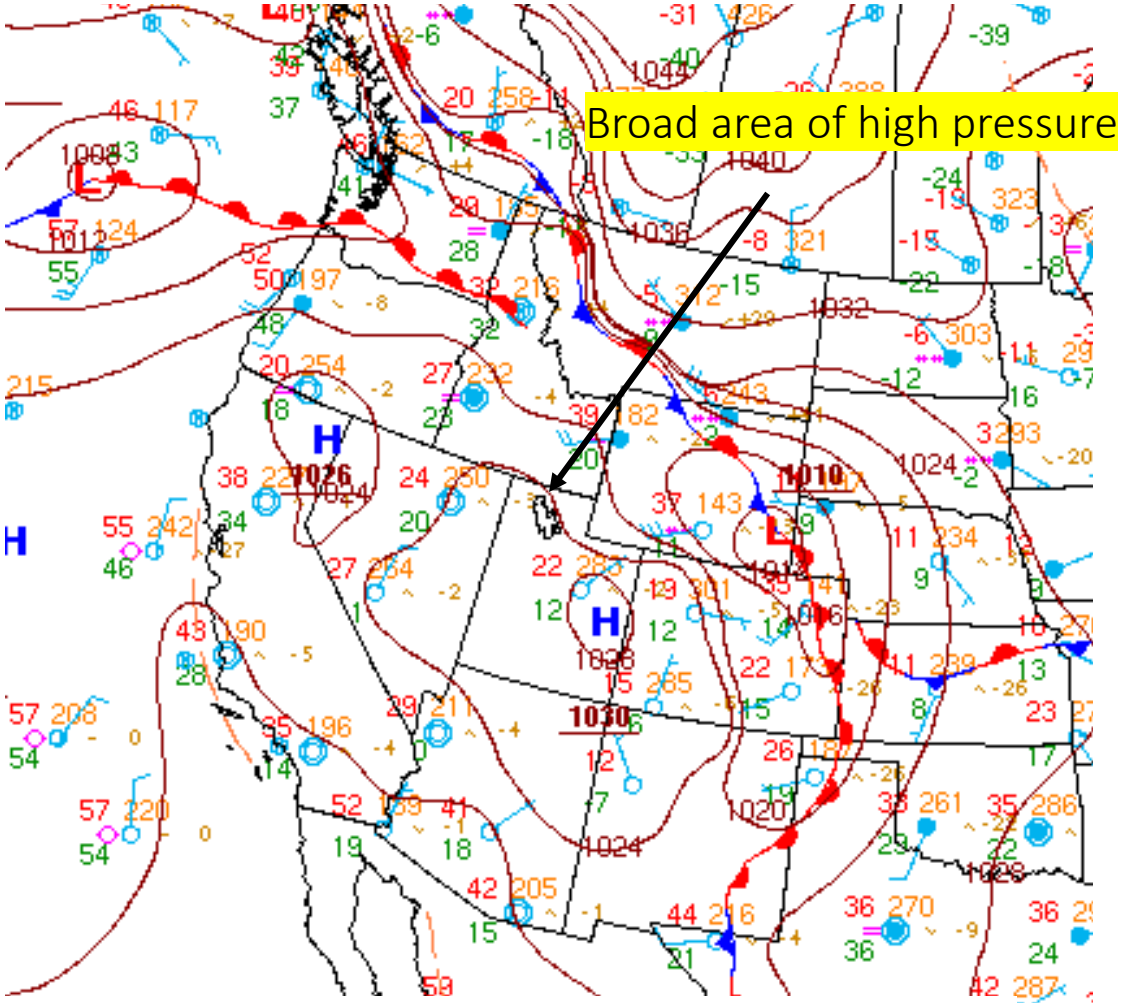
Mix of primary combustion based PM2.5 and secondary nitrate in Bay Area



Bakersfield
(California Ave.)

Larger nitrate contribution in Southern San Joaquin Valley

High PM2.5 Episodes in California: Stagnation Period



https://www.bakersfield.com/news/air-district-blames-atmospheric-stagnation-for-wintertime-pollution-spikes/article_acb6f950-1da5-11e8-a175-77fd45139ccc.html

Meteorology

- *Weak Winds*
- *Cold Temperatures*
- *Ground-based inversion Layers*
- *High Relative Humidity / Fog*

PM2.5 Effect

- *High episodic PM2.5 (combustion and nitrates)*
- *Emission Sources:*
  - *Primary PM: Smoke & carbon aerosol from residential heating and other combustion sources (woodsmoke, cars, trucks, factories)*
  - Secondary PM: *combustion (NOx) & agricultural (NH3) precursors for nitrate*

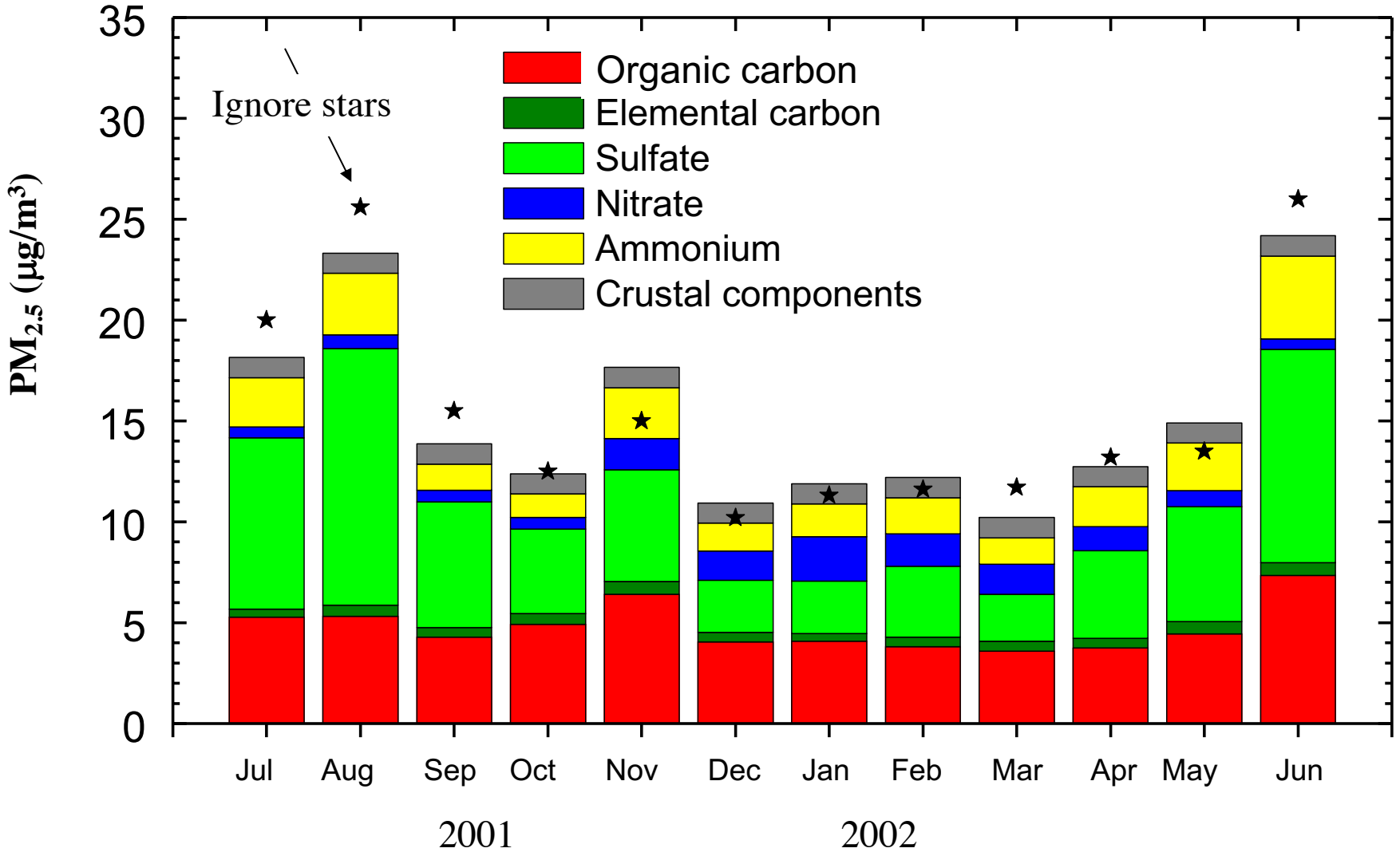
California Central Valley wintertime PM2.5

Ground-Level Fog (“Tule Fog”)
Ground-Level Temperature Inversion
(High humidity, low winds, little dilution)
(agricultural emissions of ammonia NH3)

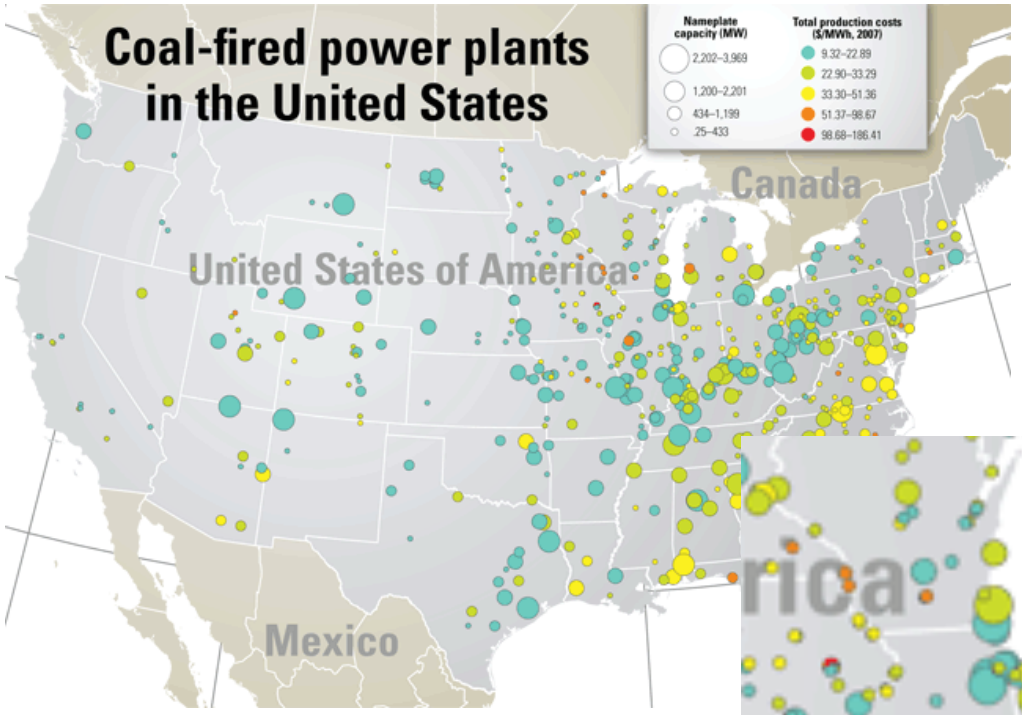
Mobile Source Emissions
(Trucks, Diesel PM Emissions)
(Trucks, NOx Emissions)

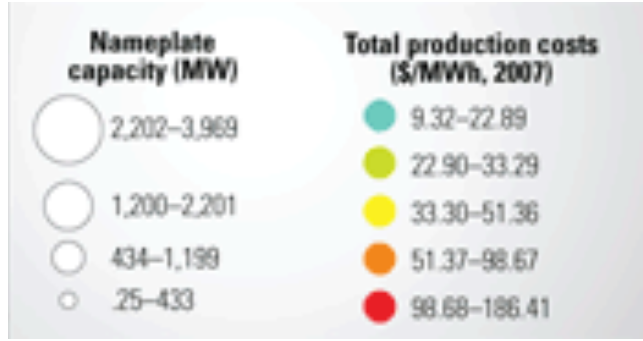
PM2.5 Composition in U.S. Industrial Midwest

(Measurements from Pittsburgh, PA)



Courtesy Spyros Pandas "*Atmospheric Aerosol From the Source to the Receptor Insights from the Pittsburgh Supersite*





Pittsburgh

Coal Fired Power Plants

- Precursor source of SO2 gas
- Forms sulfate PM2.5

http://www.powermag.com/map-of-coal-fired-power-plants-in-the-united-states/

Visual of high PM2.5

(Pittsburgh, PA)

$PM_{2.5}$=4 μg m^{-3}

"low PM2.5 day"

$PM_{2.5}$=45 μg m^{-3}

"high PM2.5 day"

Courtesy Spyros Pandas "*Atmospheric Aerosol From the Source to the Receptor Insights from the Pittsburgh Supersite*

Fine Particulate Air Pollution
(Emission Sources; Combustion PM)

Combustion Particulate: Sources

("smoke", "soot", black carbon, elemental carbon, organic carbon)

Srecko/Kenneth Sponsler/Efired/Dreamstime.com.

Diesel-Fired Trucks: Especially harmful source of combustion PM

Diesel Particulate Matter (DPM) is a strong carcinogen …

Biomass Combustion: Another large source especially globally

Wildfires

Tubbs Fire (Napa Valley Fires), October 2017

Agricultural Burning

http://www.theguardian.com/world/2015/oct/26/indonesias-fires-crime-against-humanity-hundreds-of-thousands-suffer#img-1