http://time.com/4448813/worst-smog-in-years-southern-california/

1 Feb 2019

Common Air Pollutants

What they are and where they come from

Adam Dean for *NYTimes*

No data reported by government monitors

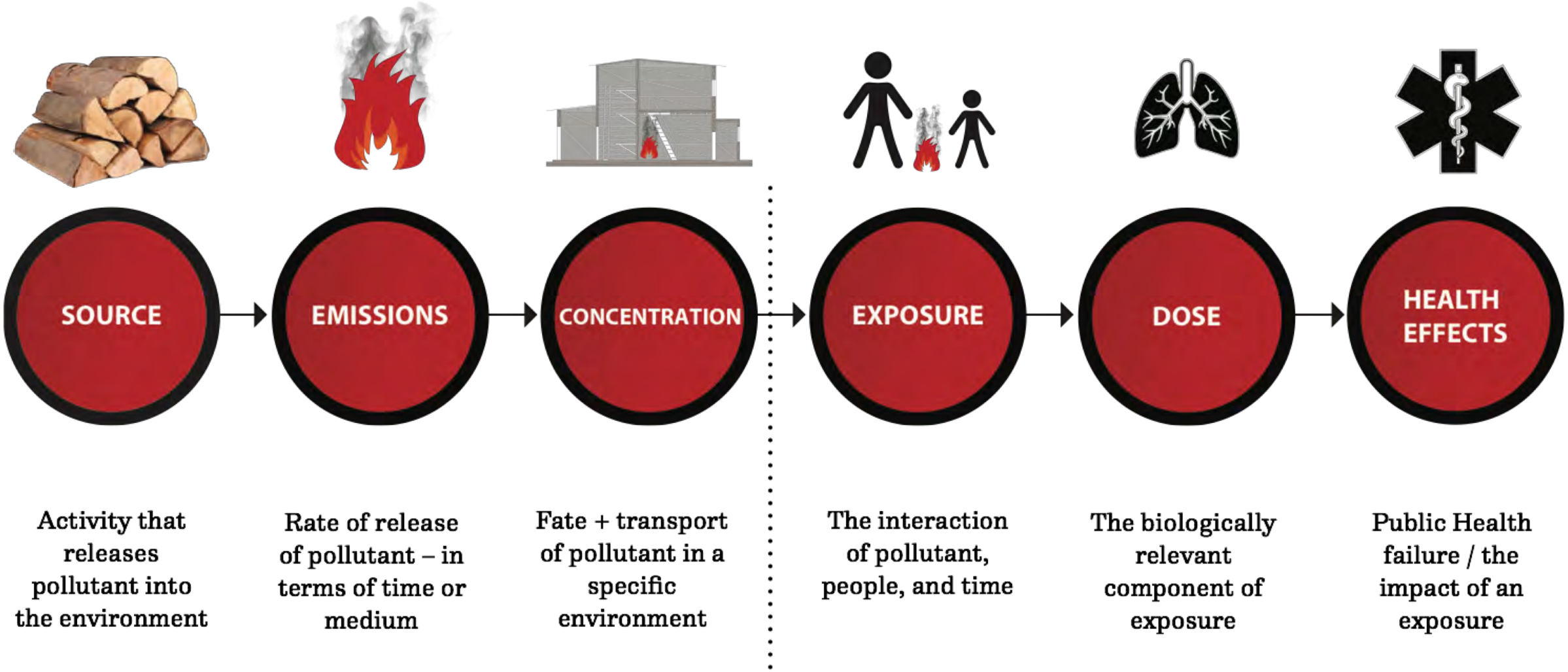
AFP – Getty – 31 Jan

No data reported by government monitors

Thai EPA

A little review

Environmental Health Pathway



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Any questions?

Air Pollution + Health

Present in class on March 1, 2019

The objective of this project is to review the existing scientific literature on the relationship between air pollution exposure and health effects. In groups of 2-3, select a health endpoint of interest (chronic obstructive pulmonary disease, stroke, ischemic heart disease, pneumonia, cognitive effects, low birthweight, neurologic effects) and describe what is known about the relationship between that health outcome and exposure to air pollution (or a component of air pollution).

Groups should each choose a separate health endpoint – there are plenty – and prepare a 15-20 minute PowerPoint or Keynote presentation describing the health endpoint, its relationship to air pollution (relying on the epidemiological literature, systematic reviews, and meta-analyses), and conclude with a set of emergent issues related to the state of scientific knowledge about the endpoint.

Please provide a short reference list and your Powerpoint / Keynote file via email to ajaypillarisetti@gmail.com after presenting. We will post the presentations and references on bCourses.

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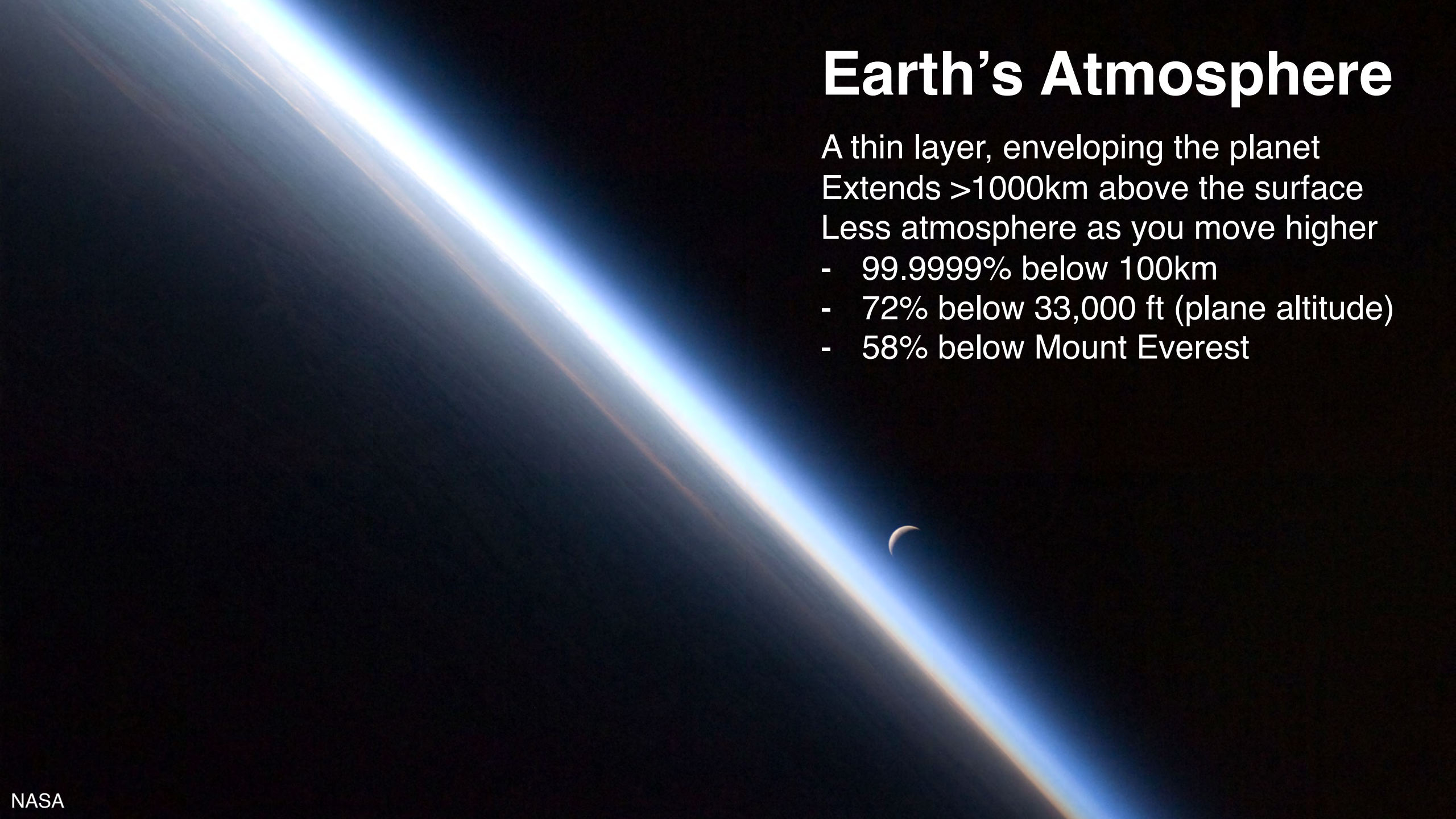
Any questions?

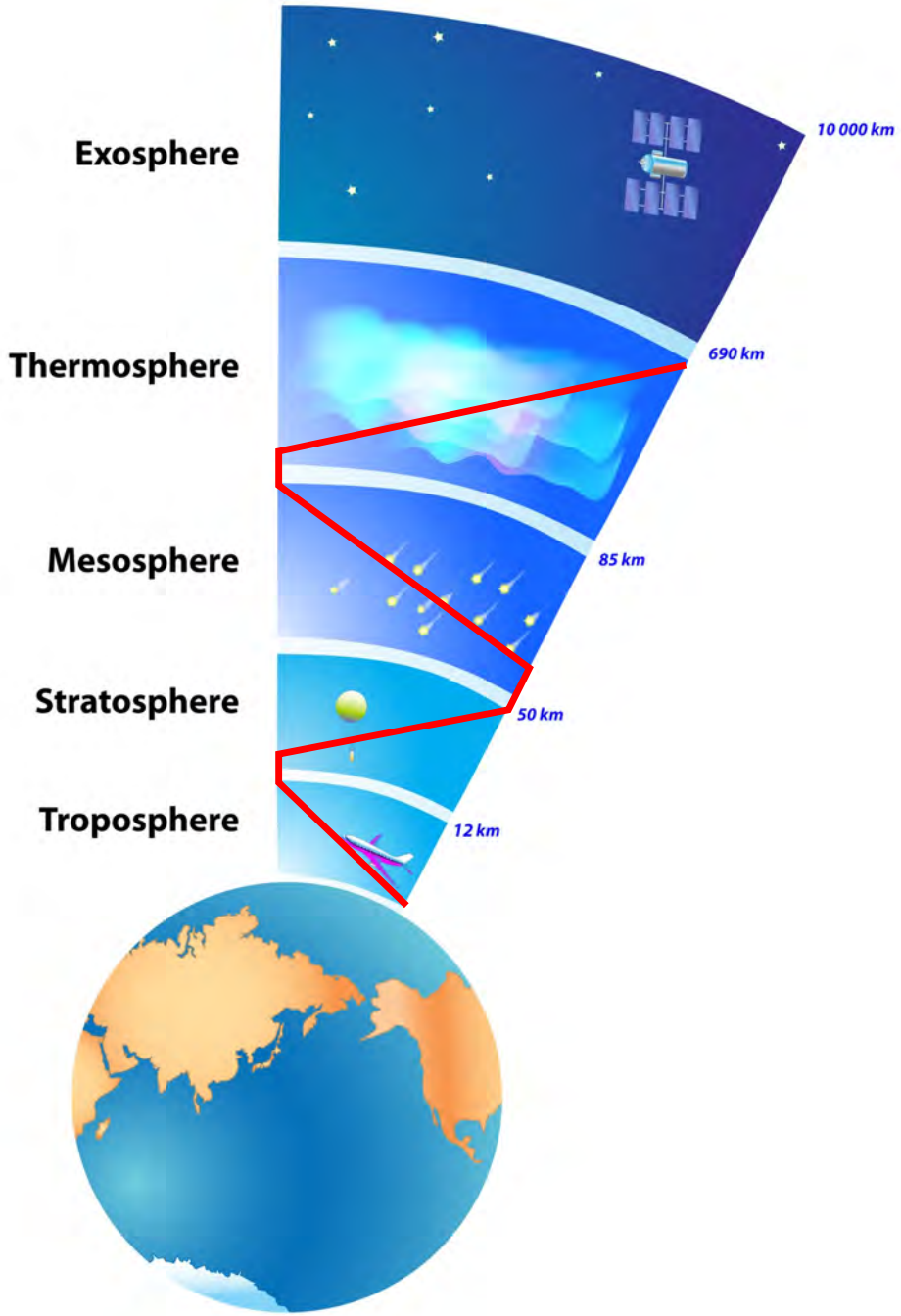


Earth’s Atmosphere

A thin layer, enveloping the planet
Extends >1000km above the surface
Less atmosphere as you move higher

- 99.9999% below 100km
- 72% below 33,000 ft (plane altitude)
- 58% below Mount Everest

NASA



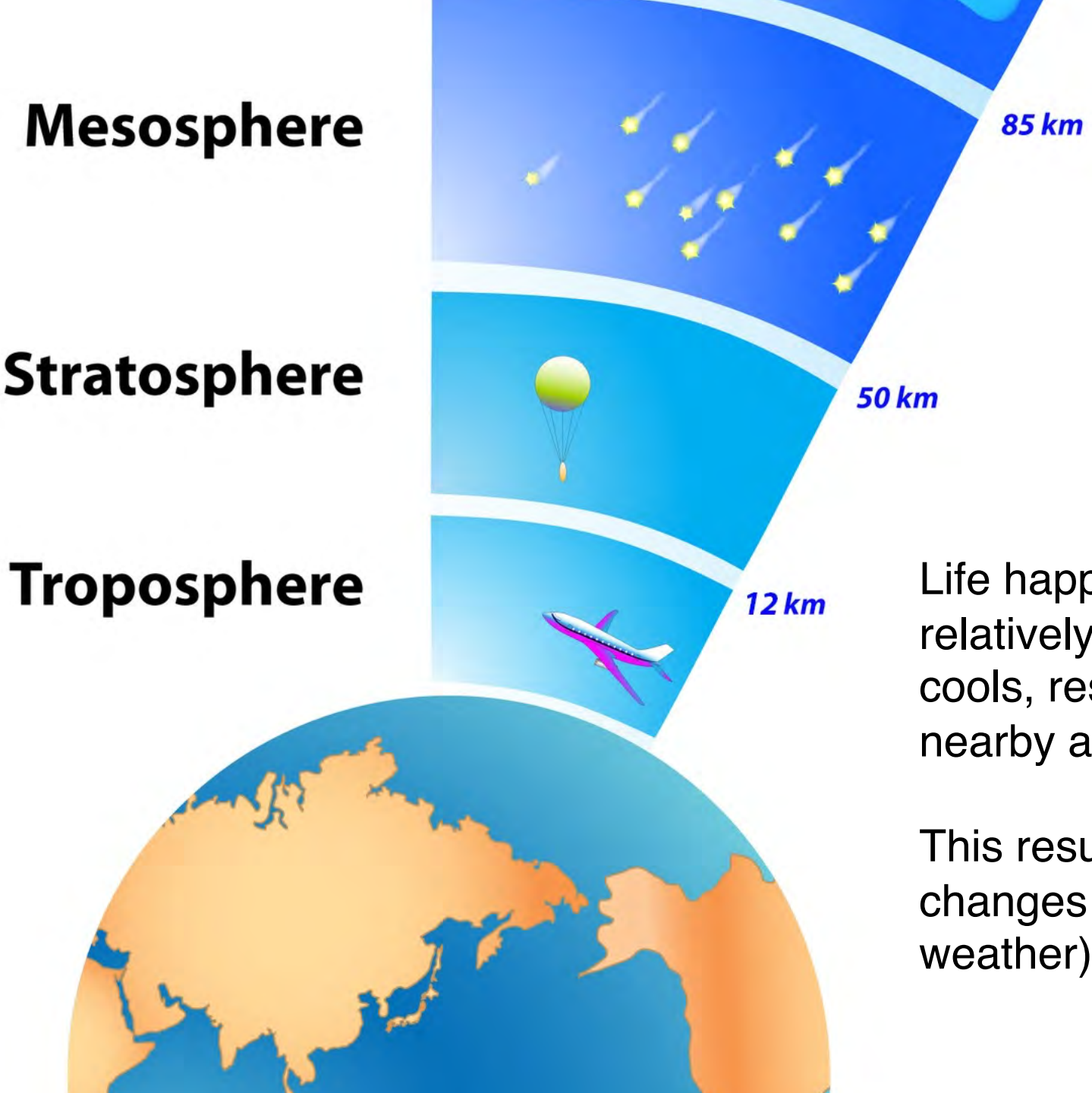
Atmospheric Structure

Layers defined by vertical temperature changes

In the troposphere – up to 10-15 km – temperature decreases as altitude increases. The surface is warm due to absorption of solar radiation.

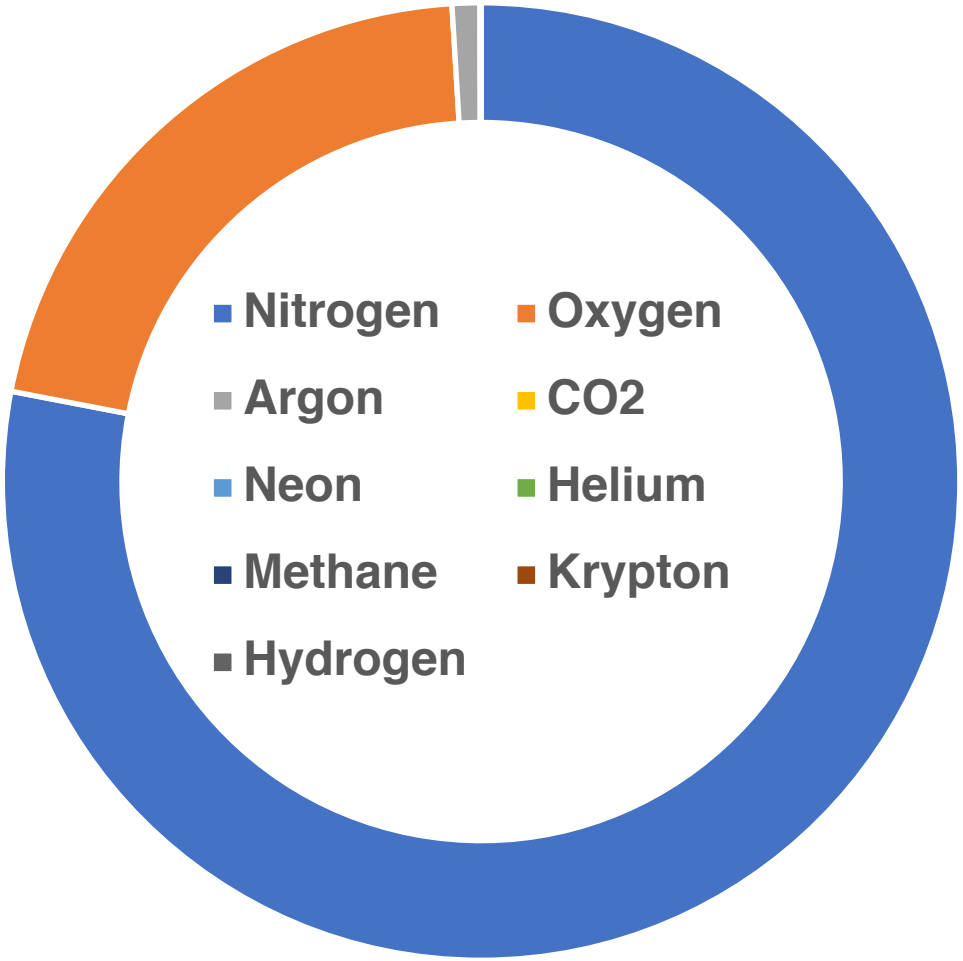
In the stratosphere, up to 45-50km, temperature increases as altitude increases. Partly due to the interaction of ozone and light.

Between the layers of the atmosphere are various **pauses**. Between the troposphere and the stratosphere is the **tropopause**, a relatively stable layer with little temperature change as altitude increases.



Life happens in the troposphere, which is relatively unstable – the surface heats and cools, resulting in heating and cooling of the nearby atmosphere.

This results in daily swings in temperature, changes in cloud cover, and precipitation (a.k.a. weather).



Atmospheric Composition

Mainly Nitrogen (78%) and Oxygen (21%)

Nitrogen, Oxygen, and Argon are permanent gases; CO2, Methane, Ozone, Water Vapor, SO2, and particulate matter are variable gases

Variable gases control the heat budget and moisture availability

What makes an atmosphere polluted?

EARL RECAMUNDA—AP

ROBERTO SCHMIDT—AFP/Getty Images

ROBERTO SCHMIDT—AFP/Getty Images

What makes an atmosphere polluted?

Changes in trace constituents

Increased emissions

Changes in removal mechanisms

- Wet and dry deposition
- Meteorological effects which inhibit mixing and dispersion
- Altered chemical equilibrium
  - Natural processes
  - Anthropogenic processes
  - Feedback loops

Primary pollutants are emitted directly into the atmosphere

Secondary pollutants are formed in the atmosphere through photochemistry or other processes

Natural Air Pollution

Volcanic activity, like the current eruption of Mayon in the Phillipines

Forest fires, like the recent Napa and Creek fires

Plant and animal decomposition

Ocean spray / sea salt

Volatile organics from plants

Dust storms

Geogenic and biogenic

“Trees cause more pollution than automobiles do.”

REAGANFOUNDATION.ORG

Natural Air Pollution

Outside of natural disasters, generally of less concern than anthropogenic air pollution, which happens closer to where people live

On balance, consequence from non-disaster natural air pollution from other sources tends to be low

Climate change poses challenges, as previously rare occurrences may increase in frequency and/or intensity

Anthropogenic Air Pollution

ROBERTO SCHMIDT—AFP/Getty Images

Smog

In London and other British cities, smoke from coal use mixed with fog to produce smog.

LA Basin is one of the best known cases, though there are others – Delhi, Beijing, Mexico City, Lima, etc

Inversions prevent mixing and dispersion of pollutants; the major source is light vehicle traffic. Known as photochemical smog.

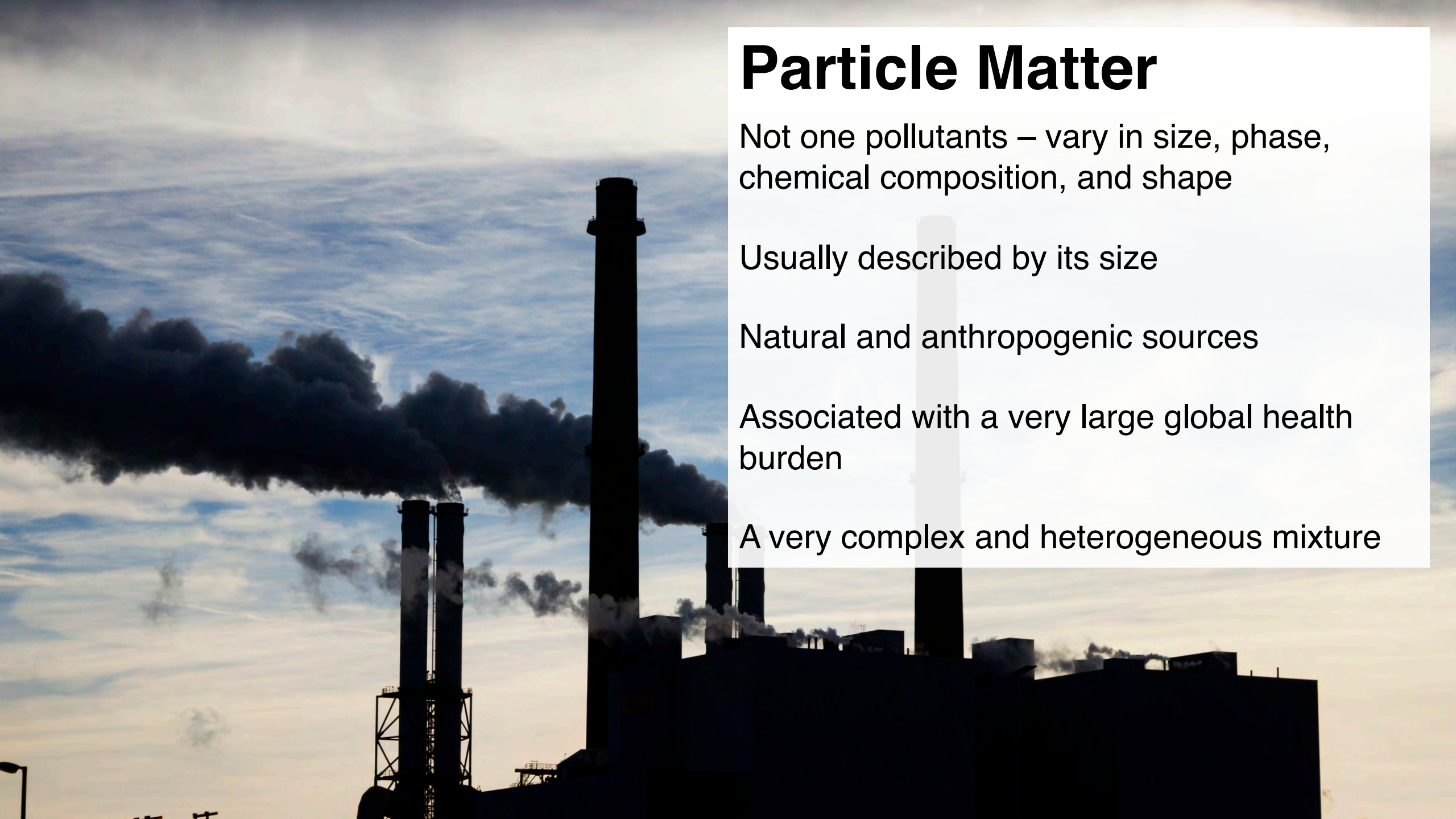
London, LA, Mexico City, and others provide policy pathways for emissions and exposure reductions

Gaseous Air Pollution

Hundreds of detectable pollutants in the atmosphere of urban areas; over 400 gases emitted as part of automobile exhaust

Thousands of detected compounds from biomass smoke in village households, including known carcinogens, dioxins, PCBs, and VOCs

Only a small number are present in the atmosphere for long enough or at high enough concentrations to impact humans directly



Particle Matter

Not one pollutants – vary in size, phase, chemical composition, and shape

Usually described by its size

Natural and anthropogenic sources

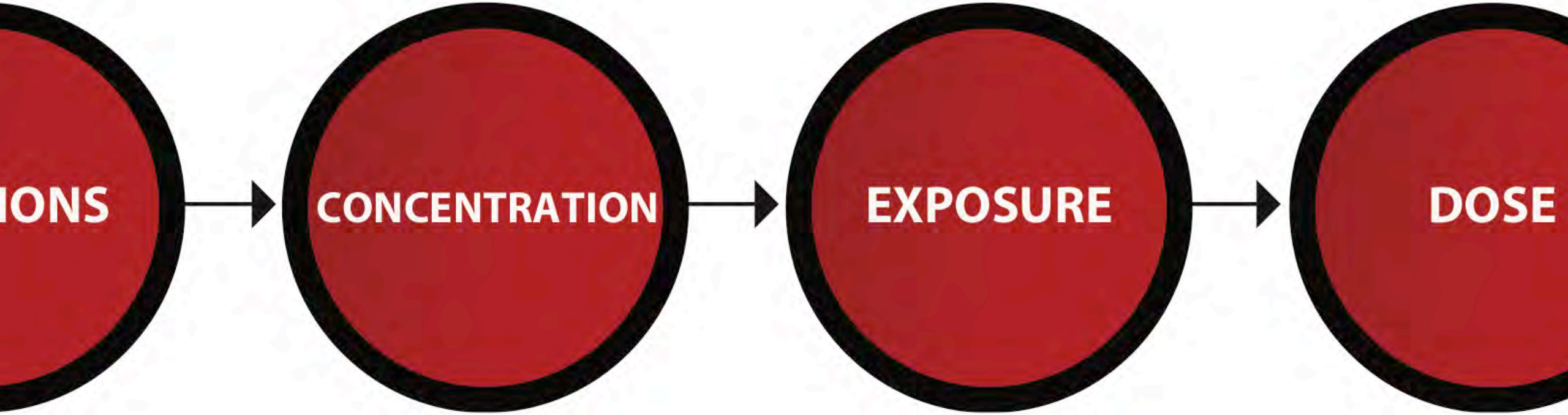
Associated with a very large global health burden

A very complex and heterogeneous mixture

How do we quantify pollutant levels?

Which pollutants do we worry about?

What regulations are in place?



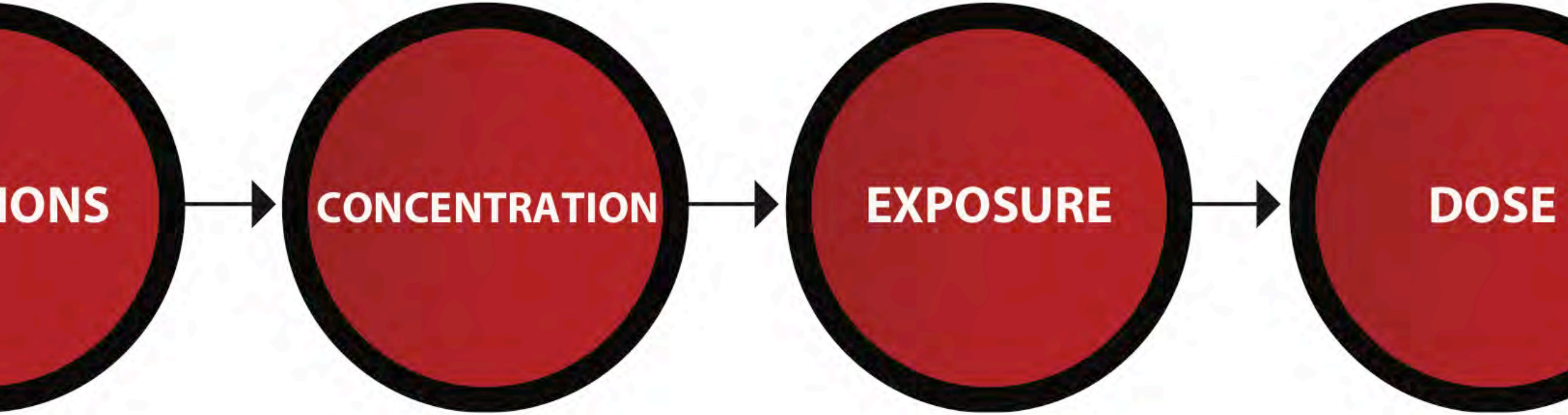
Describing pollutant levels

Mass per volume air

- ng, ug, mg per cubic meter of air (mg/m^3)
- commonly seen for particles and some gasses

Parts per million, billion, or trillion

- Volume of pollutant per million volumes of air
- Often expressed as ppmv, ppbv



Converting between the two

Assuming atmospheric pressure of 1 atm

$ppm_v = [(mg/m^3) \times K] / (12.187 \times MW)$

mg/m^3 = milligrams of gaseous pollutant per cubic meter air

MW = molecular weight of the gaseous pollutant

K = atmospheric temperature in Kelvin (K = 273.15 + C)

Regulatory Approaches

3000+ substances have been measured in air – from tailpipes, in the atmosphere, from biomass stoves, in urban areas, in rural areas

In the US, emissions of < 200 are regulated. Globally, standards vary widely, as does enforcement.

The US has model guidelines for six air pollutants

National Ambient Air Quality Standards

Last amended in 1990 as part of the Clean Air Act, which requires that US EPA set standards for pollutants harmful to public health and the environment

Primary standards provide public health protection, including protecting the health of sensitive populations, including children, asthmatics, and the elderly

Secondary standards provide public welfare protection, including against decreased visability and damage to animals, crops, and buildings

NAAQS exist for six pollutants: Carbon Monoxide, Lead, Nitrogen Dioxide, Ozone, Particulate Matter, and Sulfur Dioxide

National Ambient Air Quality Standards

Primary standards consider both acute and chronic health effects

Secondary standards take into account welfare related impacts, like visibility, material and property damage, etc

Pollutant [links to historical tables of NAAQS reviews]	Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)	primary	8 hours	9 ppm	Not to be exceeded more than once per year
		1 hour	35 ppm	
Lead (Pb)	primary and secondary	Rolling 3 month average	0.15 μg/m^3 (1)	Not to be exceeded
Nitrogen Dioxide (NO_2)	primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	primary and secondary	1 year	53 ppb (2)	Annual Mean
Ozone (O_3)	primary and secondary	8 hours	0.070 ppm (3)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years

Pollutant [links to historical tables of NAAQS reviews]		Primary/ Secondary	Averaging Time	Level	Form
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 µg/m^3	annual mean, averaged over 3 years
		secondary	1 year	15.0 µg/m^3	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb [(4)]	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Rules are great… what about enforcement?

https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=8fbf9bde204944eeb422eb3ae9fde765

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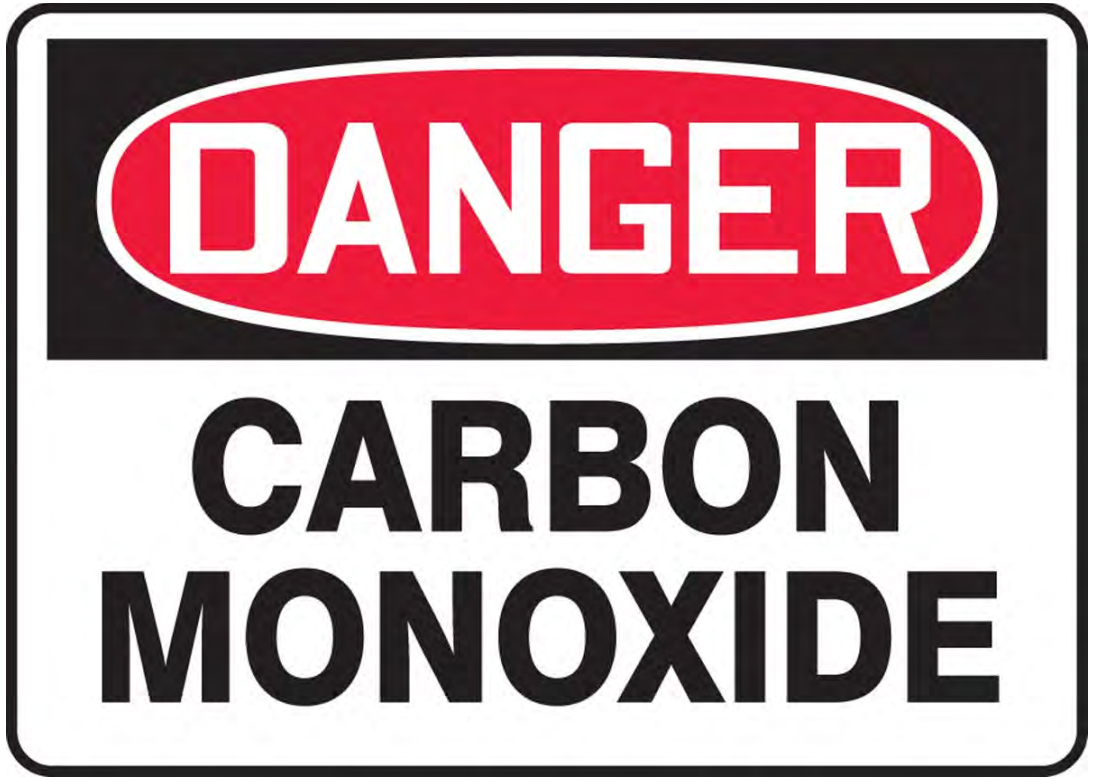
Any questions?

What about other countries?

Split into groups of 2. Take 10 minutes and look up guidelines from the following countries / regions:

Group 1: India
Group 2: China
Group 3: WHO Guidelines
Group 4: Cameroon

Find the agency in charge, the rules, and how they compare with the US NAAQS.

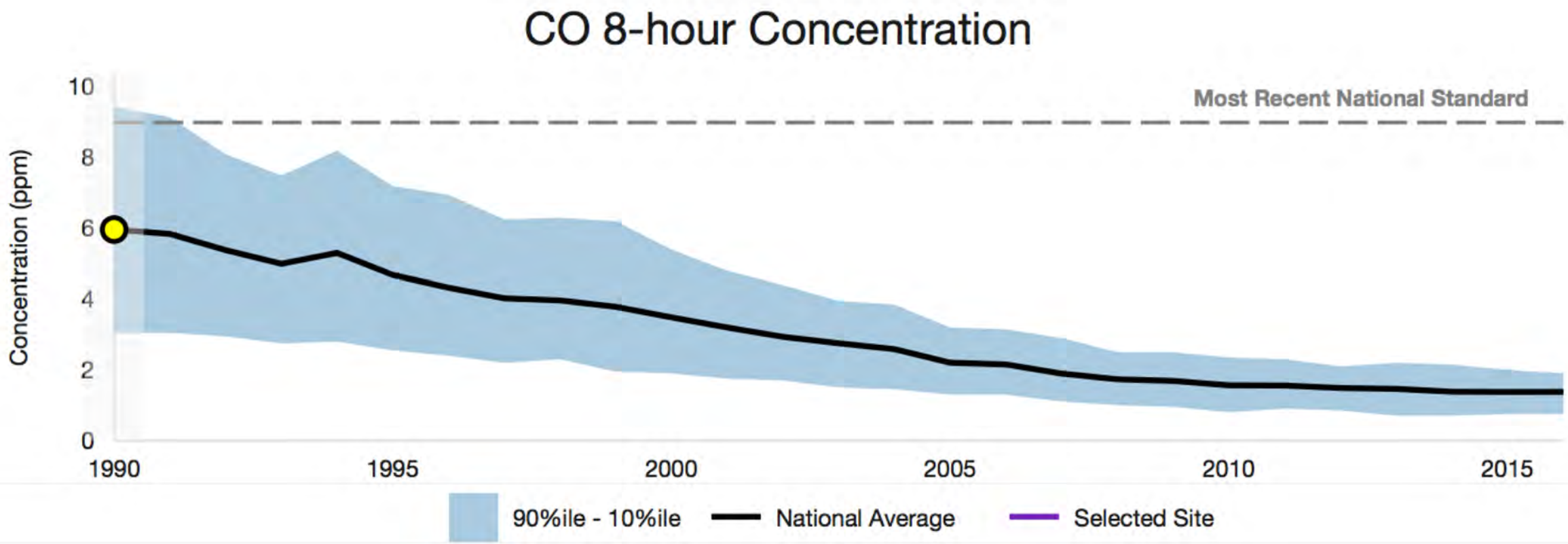


Colorless, odorless, tasteless gas

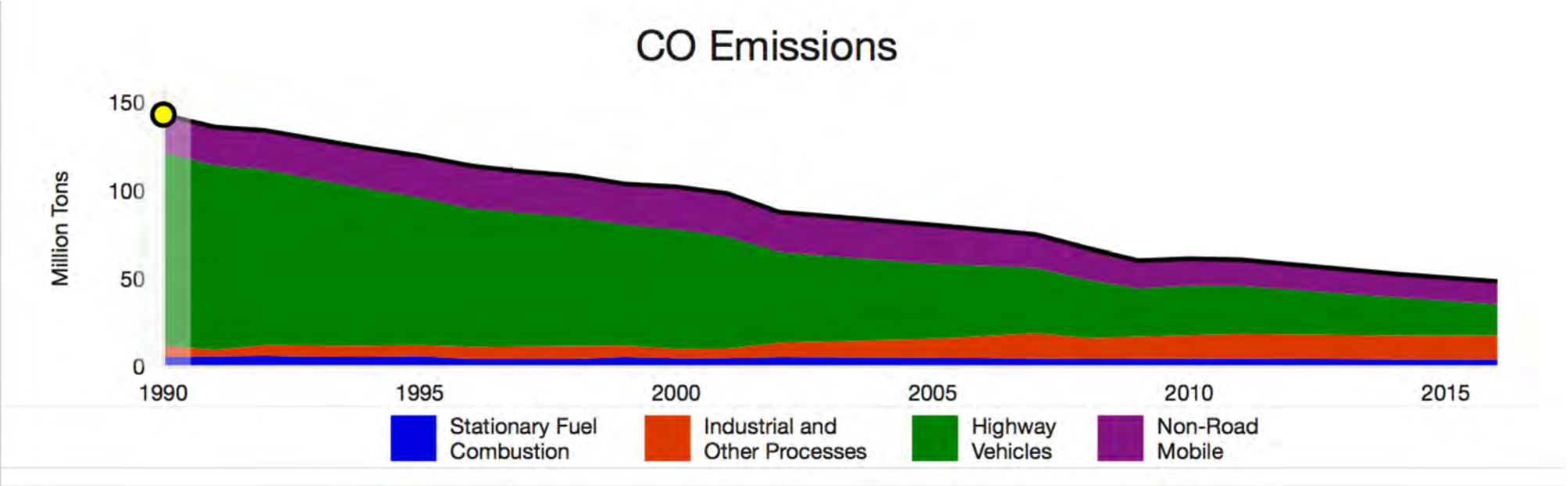
Emitted as a combustion and industrial byproduct

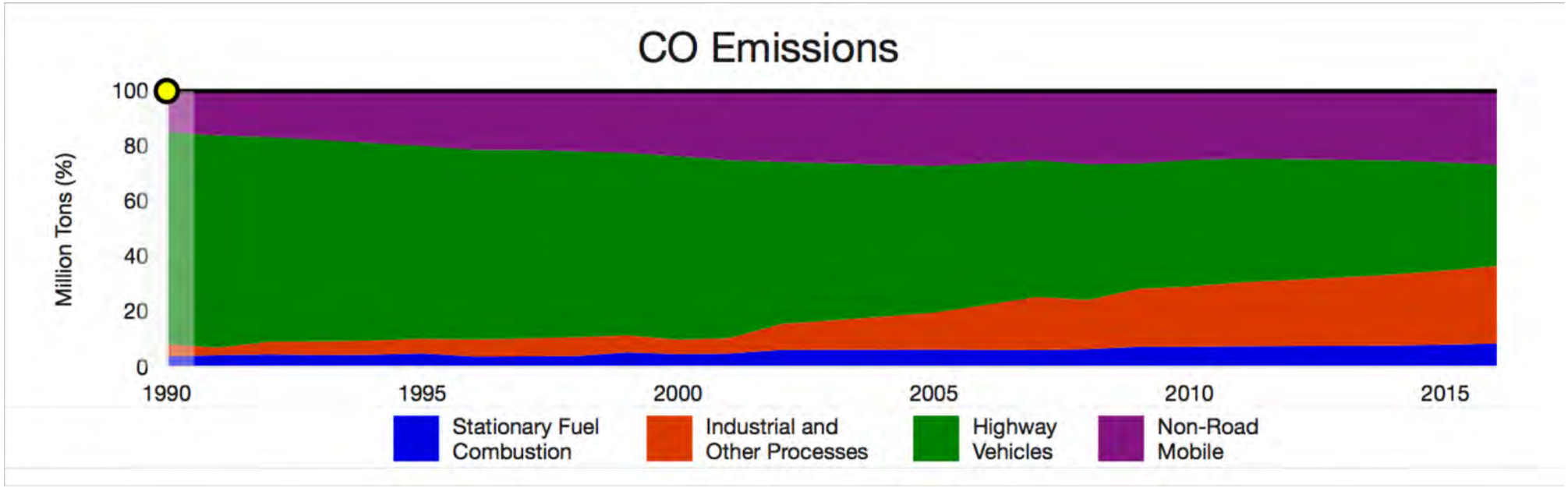
Produced in the atmosphere from oxidation of methane and other chemicals

Acutely toxic to humans

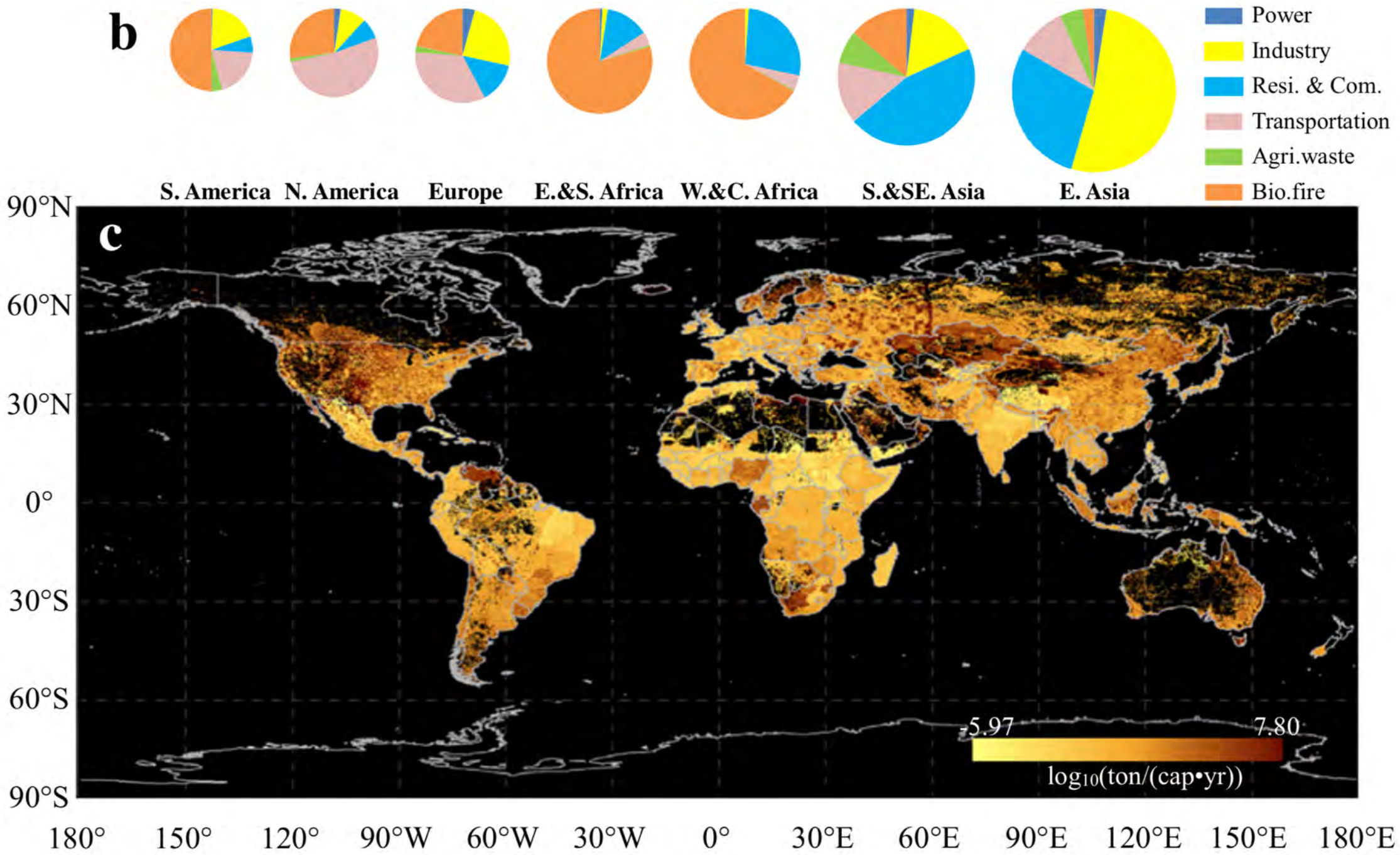

CO 8-hour Concentration
Most Recent National Standard
Concentration (ppm)
10
8
6
4
2
0
1990
1995
2000
2005
2010
2015
90%ile - 10%ile
National Average
Selected Site

US EPA


CO Emissions
Million Tons
150
100
50
0
1990
1995
2000
2005
2010
2015
Stationary Fuel Combustion
Industrial and Other Processes
Highway Vehicles
Non-Road Mobile


CO Emissions
Million Tons (%)
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Stationary Fuel Combustion
Industrial and Other Processes
Highway Vehicles
Non-Road Mobile

US EPA



Zhong et al 2017

Lead (Pb)

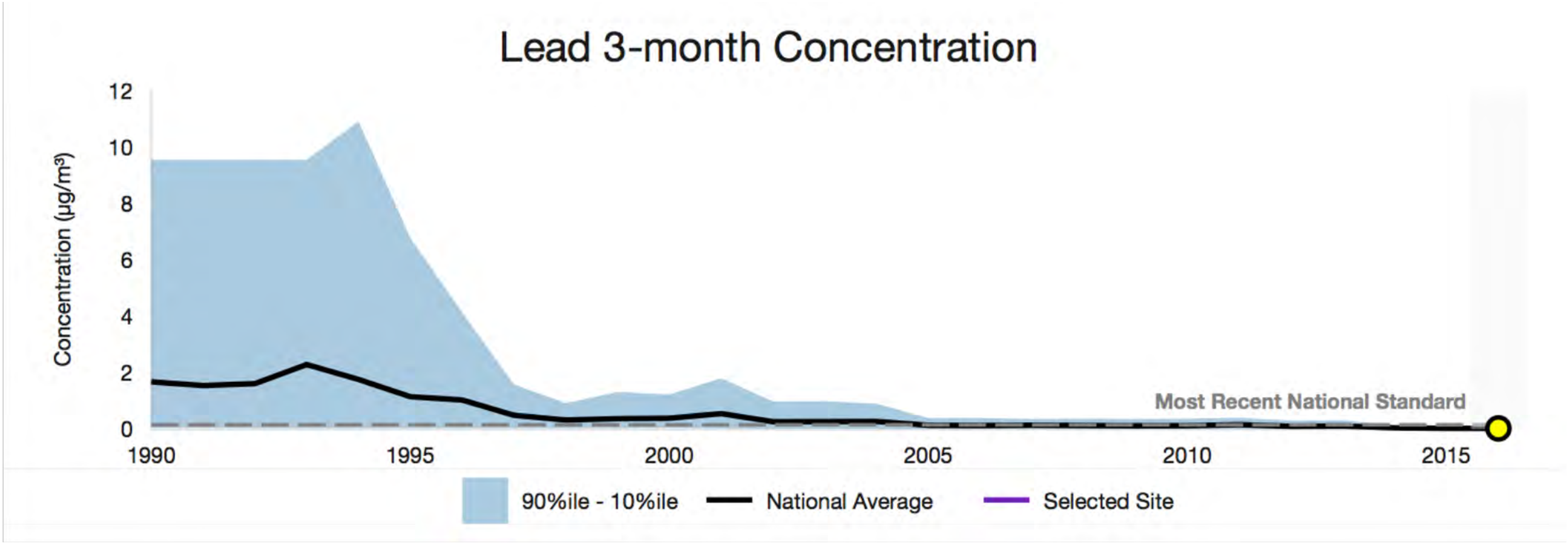
Occurs in soil, water, and air.

In use for thousands of years – humans have long been exposed to it and continue to be

In air, exposures used to come from the addition of lead to gasoline as an anti-knocking agent

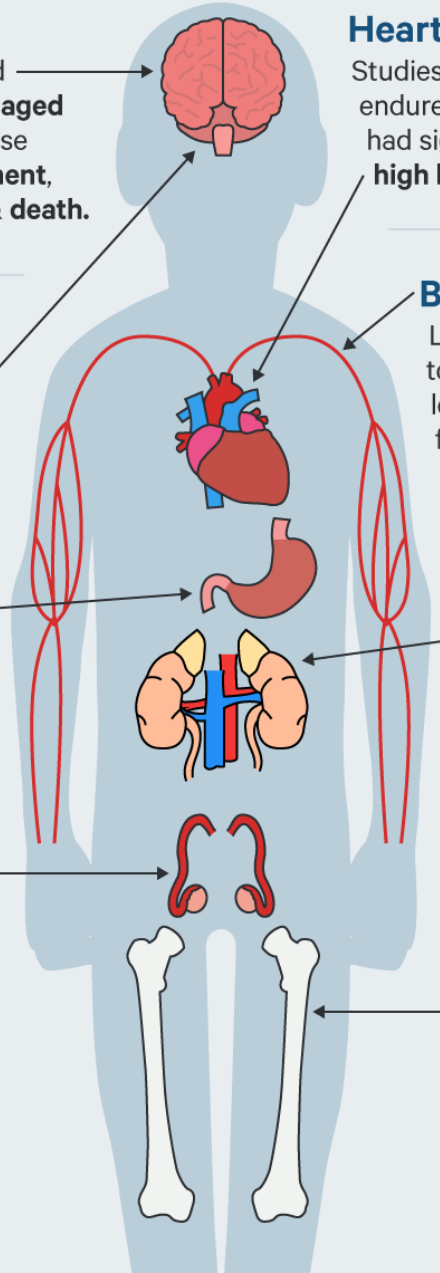
Still a problem in communities with smelters, in homes with lead paint, etc

Multiple routes of exposure



As a result of the permanent phase-out of leaded gasoline, controls on emissions of lead compounds through EPA's air toxics program, and other national and state regulations, airborne lead concentrations in the U.S. decreased 98 percent between 1980 and 2005. After 2005, the EPA methodology for estimating lead emissions changed and is not comparable to the 2005 and earlier numbers. Since 2008, emissions have continued to decrease by 23 percent from 2008 to 2014. In the 2014 NEI, the highest amounts of Pb emissions are from Piston Engine Aircrafts, and Ferrous and Non-ferrous Metals industrial sources.

How **lead** affects childrens' health



Brain

Any exposure is linked to lowered **IQ**, **ADHD**, **hearing loss**, and **damaged nerves**. Acute exposures can cause convulsions, **loss of body movement**, **coma**, **stupor**, **hyperirritability,** & **death.**

Hormones

Lead disrupts levels of vitamin D, which can **impair cell growth**, maturation, and tooth and bone development.

Stomach

Severe lead exposure can create intense **abdominal pain** and **cramping**.

Reproductive System

A moderate exposure can not only **lower sperm count**, but also **damage them**. Chronic exposures can diminish the concentration, total count, and motility of sperm, though it's unclear how long these effects last after the exposure ends.

Heart

Studies suggest that adults who endured lead poisoning as children had significantly higher risks of **high blood pressure** 50 years later.

Blood

Lead inhibits the body's ability to make hemoglobin, which can lead to anemia. This reduces oxygen flow to organs, causing **fatigue**, **lightheadedness**, **rapid heartbeat**, **dizziness,** & **shortness of breath.**

Kidneys

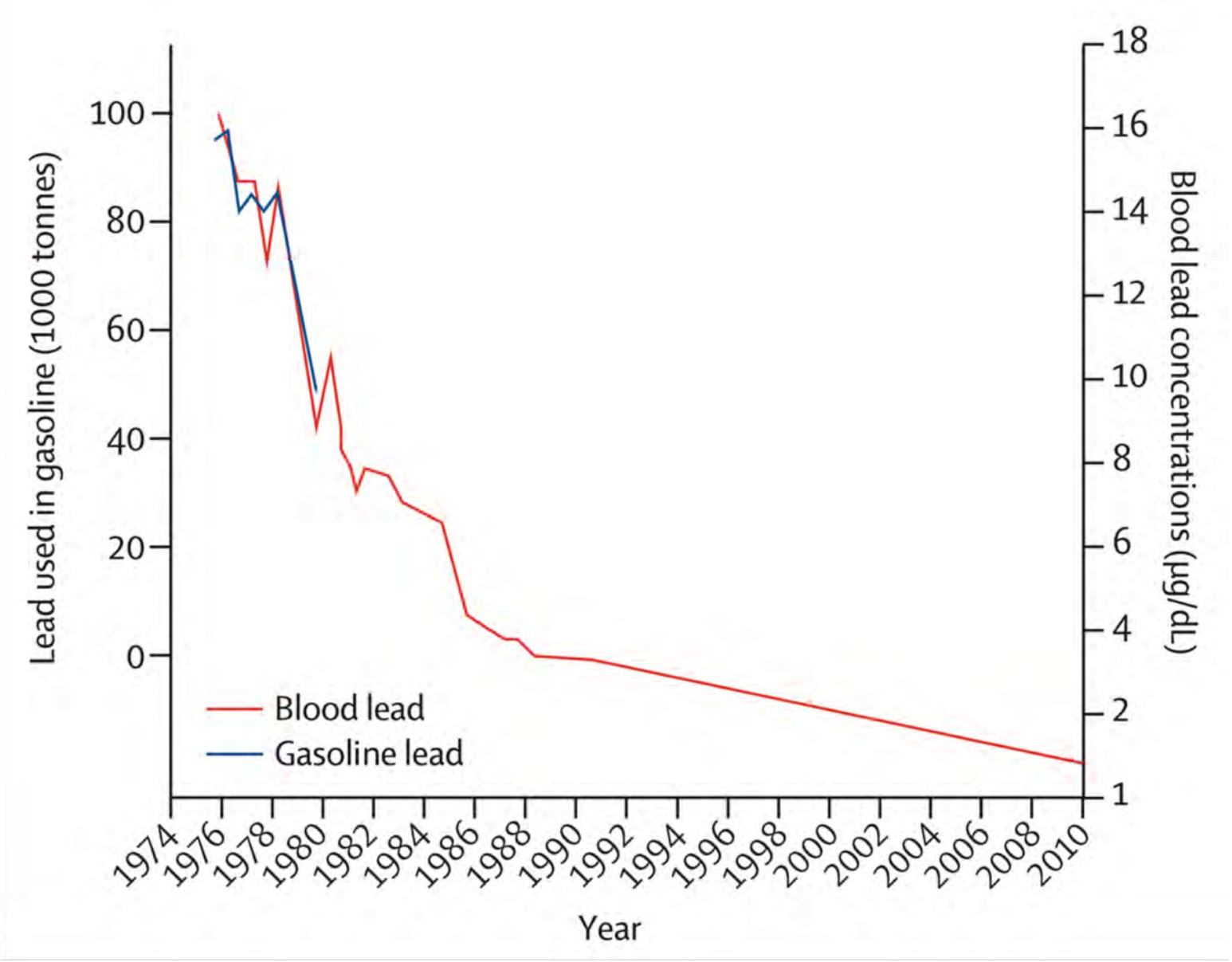
Chronic exposures can cause chronic inflammation, which can lead to **kidney failure**, **bloody urine**, **fever**, **nausea**, **vomiting**, **drowsiness**, **coma**, **weight gain**, **confusion**, **rash**, and **urinary changes**.

Bones

Lead may impair development and the health of bones, which can **slow growth in children**.

SOURCES: Centers for Disease Control; World Health Organization

Correlation between population mean blood concentration of lead and lead use in gasoline in the USA, 1974–91



Landrigan P, et al, Lancet Commission on Pollution and Health, *The Lancet*, Published online Oct 19, 2017
http://dx.doi.org/10.1016/S0140-6736(17)32345-0

Nitrogen Dioxide and NO_x

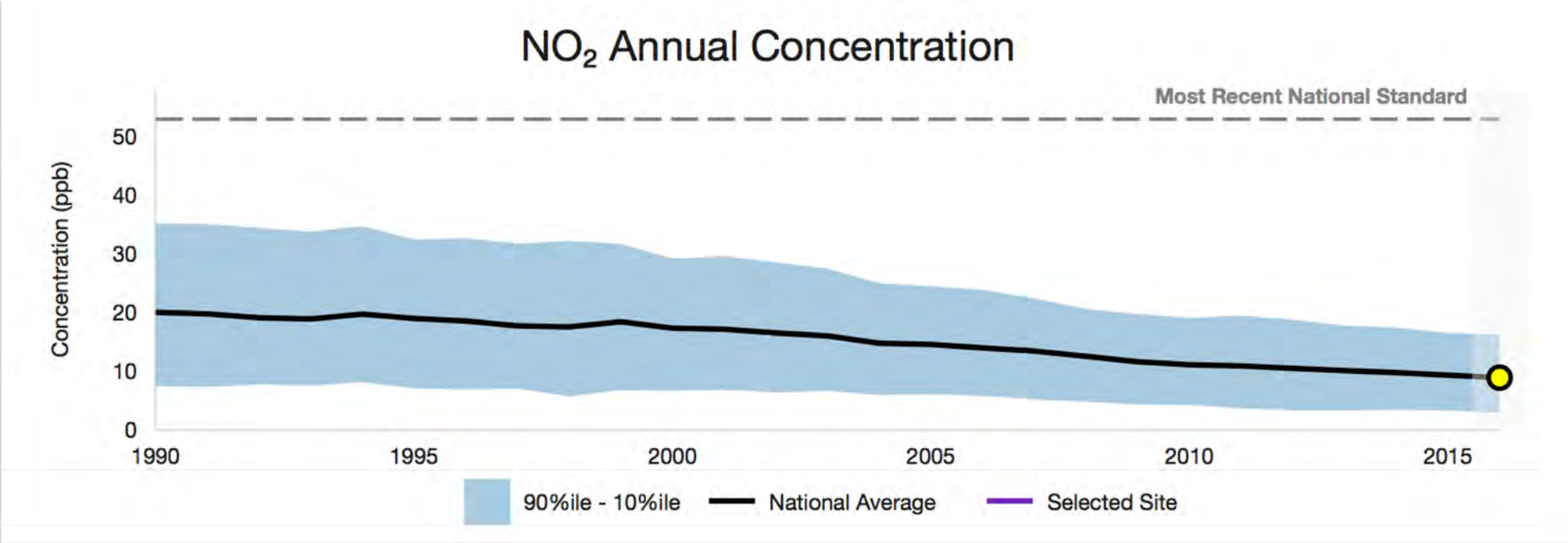
NO_2 is a yellow/brown, pungent gas

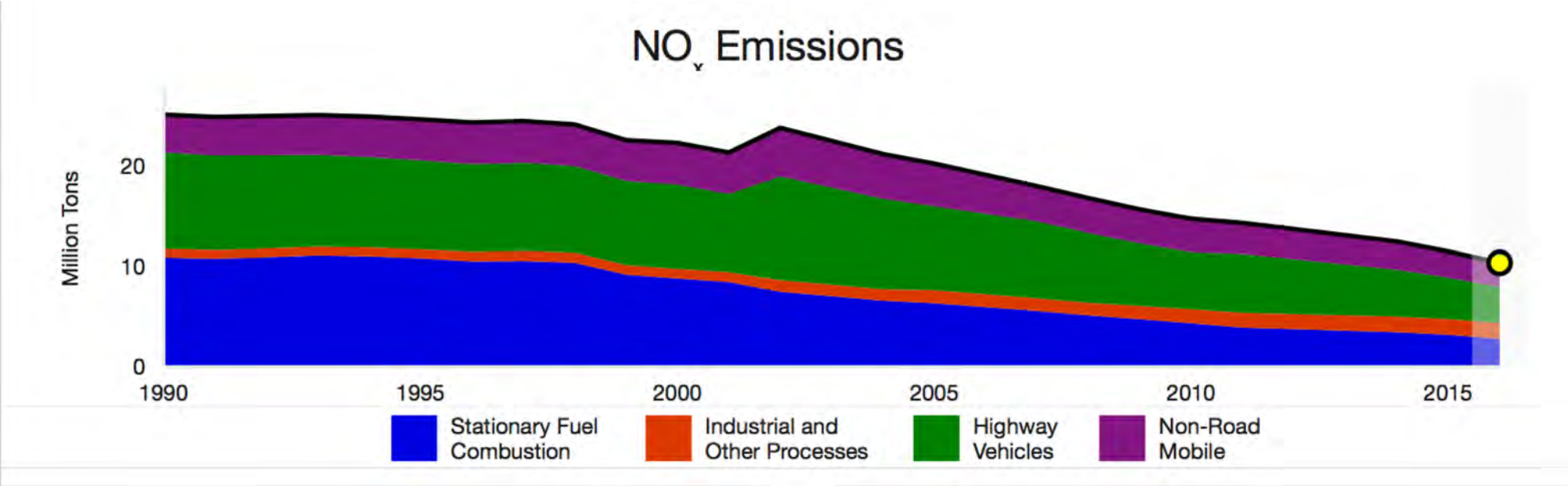
Emitted from high temperature combustion, automobiles, trucks

Can arise from biogenic soil sources and from lightning and forest fires

NO_2 is used as an indicator for the large group of NO_x

NO_x central to ground-level ozone formation; can react to form nitrate particles and acidic aerosols


NO_2 Annual Concentration
Most Recent National Standard
Concentration (ppb)
50
40
30
20
10
0
1990
1995
2000
2005
2010
2015
90%ile - 10%ile
National Average
Selected Site


NO_x Emissions
Million Tons
20
10
0
1990
1995
2000
2005
2010
2015
Stationary Fuel Combustion
Industrial and Other Processes
Highway Vehicles
Non-Road Mobile

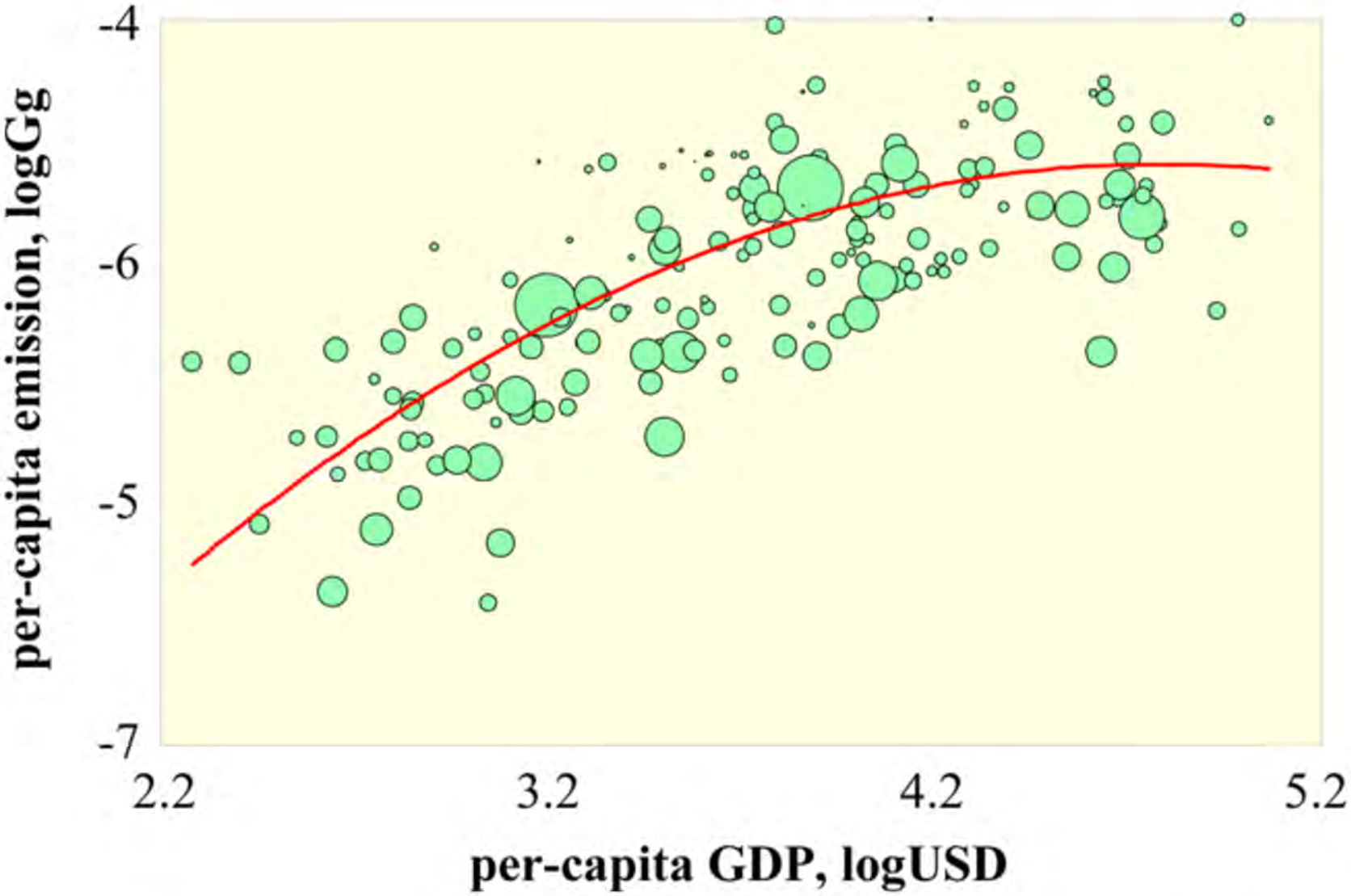


Figure 1. Relationship between per capita emission of NO_x and per capita GDP, both of which have been log-transformed.

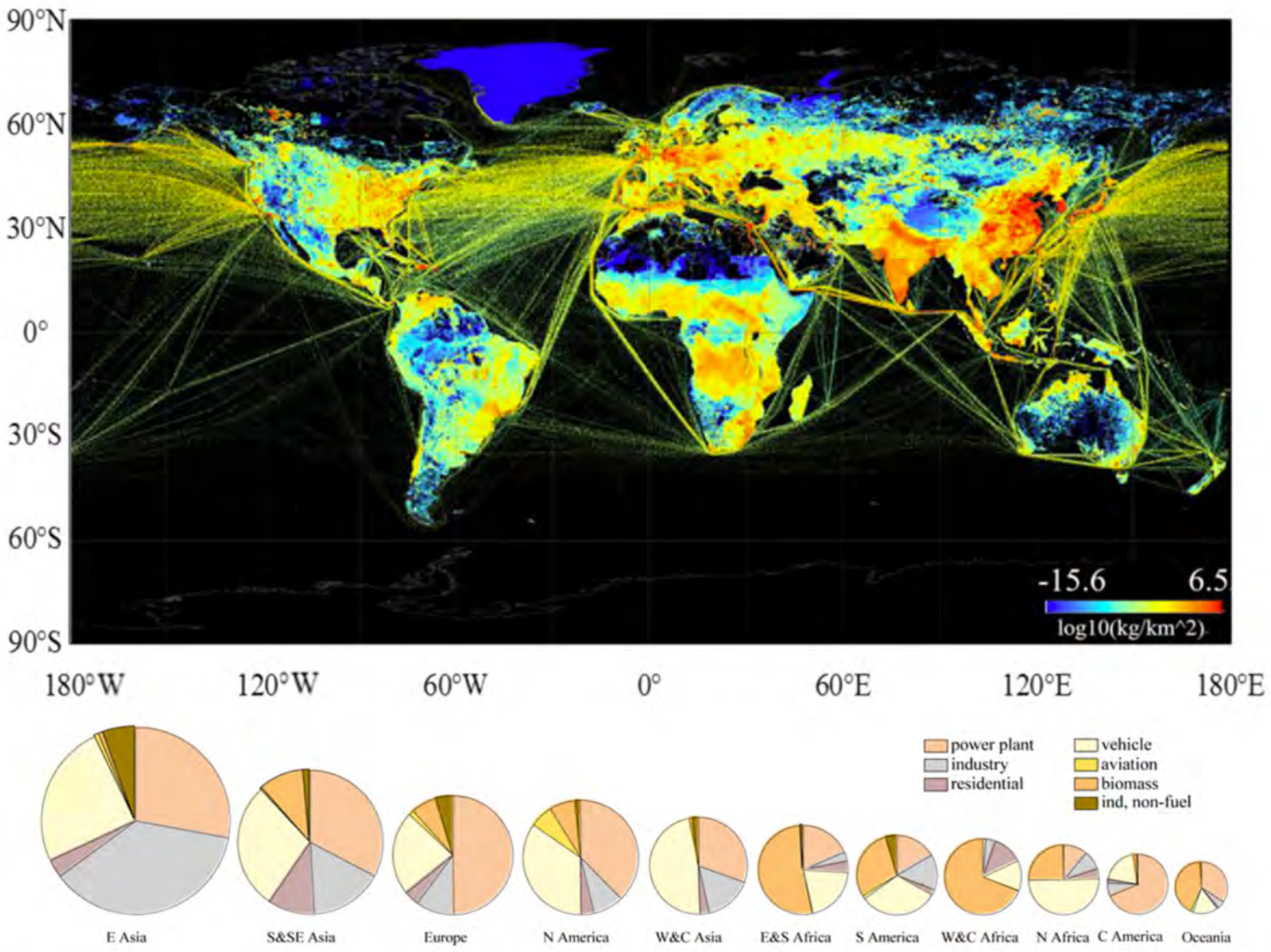


Figure 2. Geospatial distributions of NO_x emission densities, with the exception of aviation in 2014. The source profiles of the emissions in various regions are shown as pie charts.

Ozone (O_3)

Ozone is typically considered a secondary pollutant produced by a complex interaction of hydrocarbons, NOx, and sunlight

There are some natural sources of hydrocarbons which play a role in ozone formation, including plants and trees

Ozone exposure is thought to contribute to approximately 250,000 deaths per year globally.

Ozone (O_3)

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Figure 5. Seasonal average population-weighted ozone concentrations in 2015.

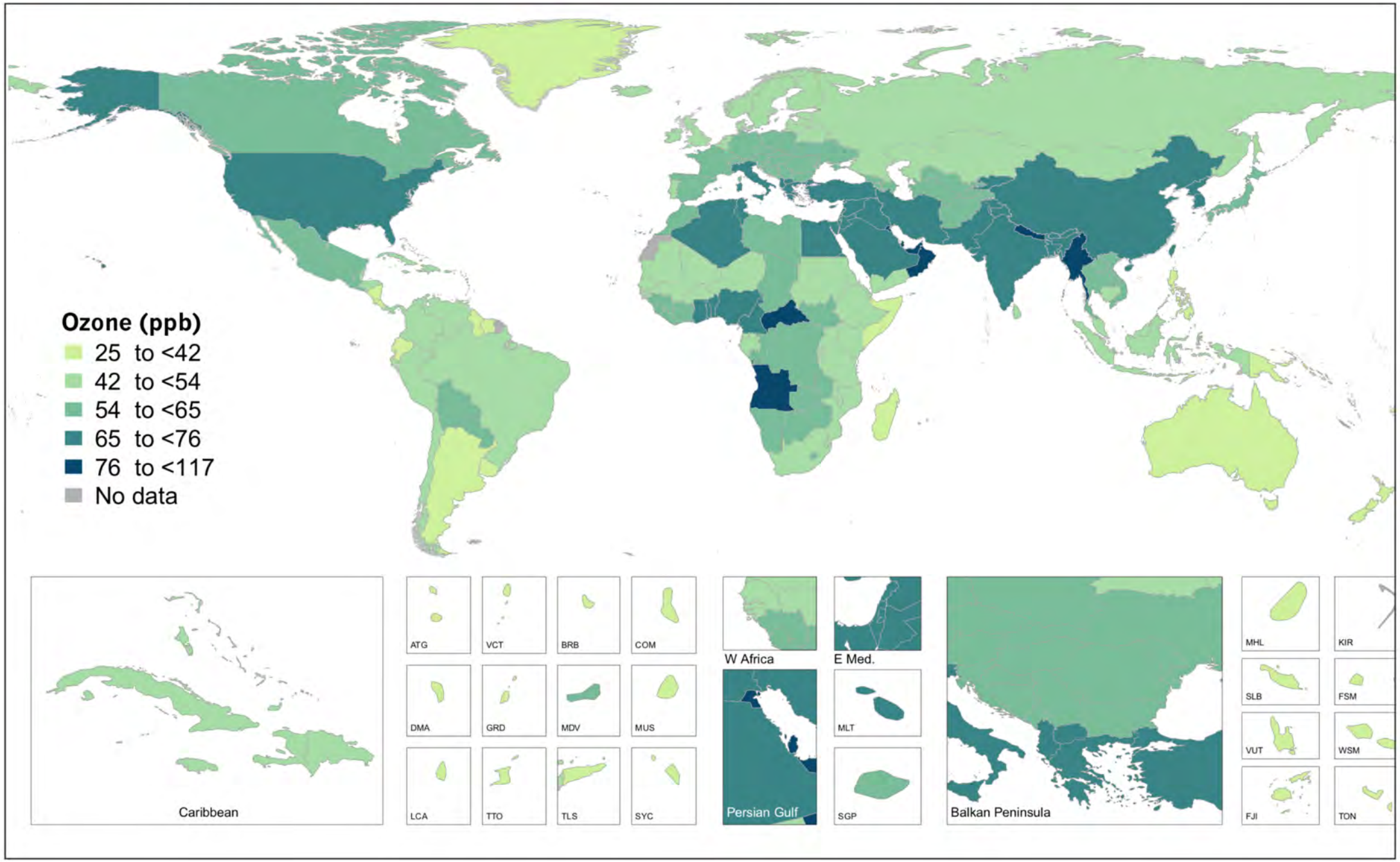
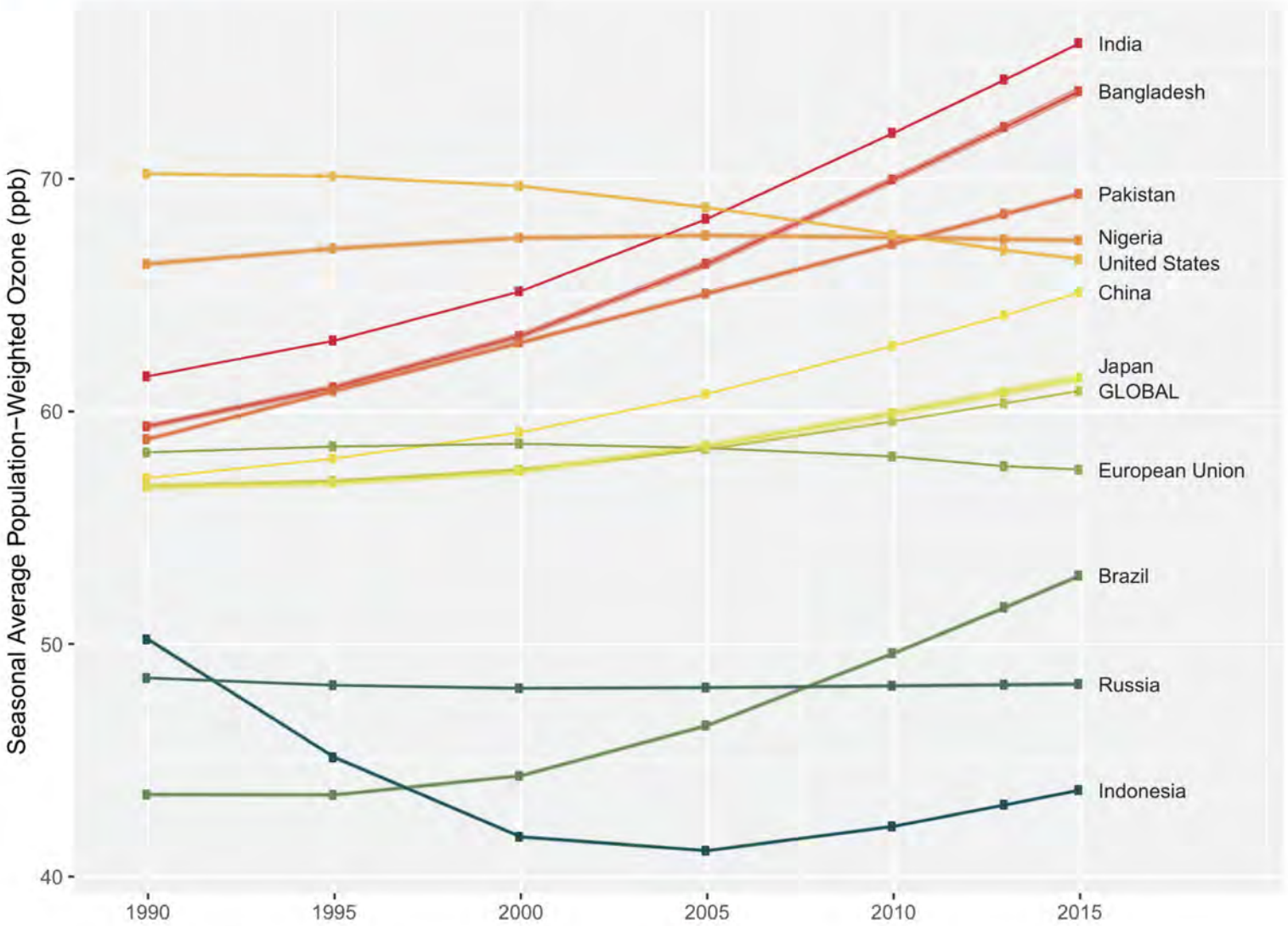
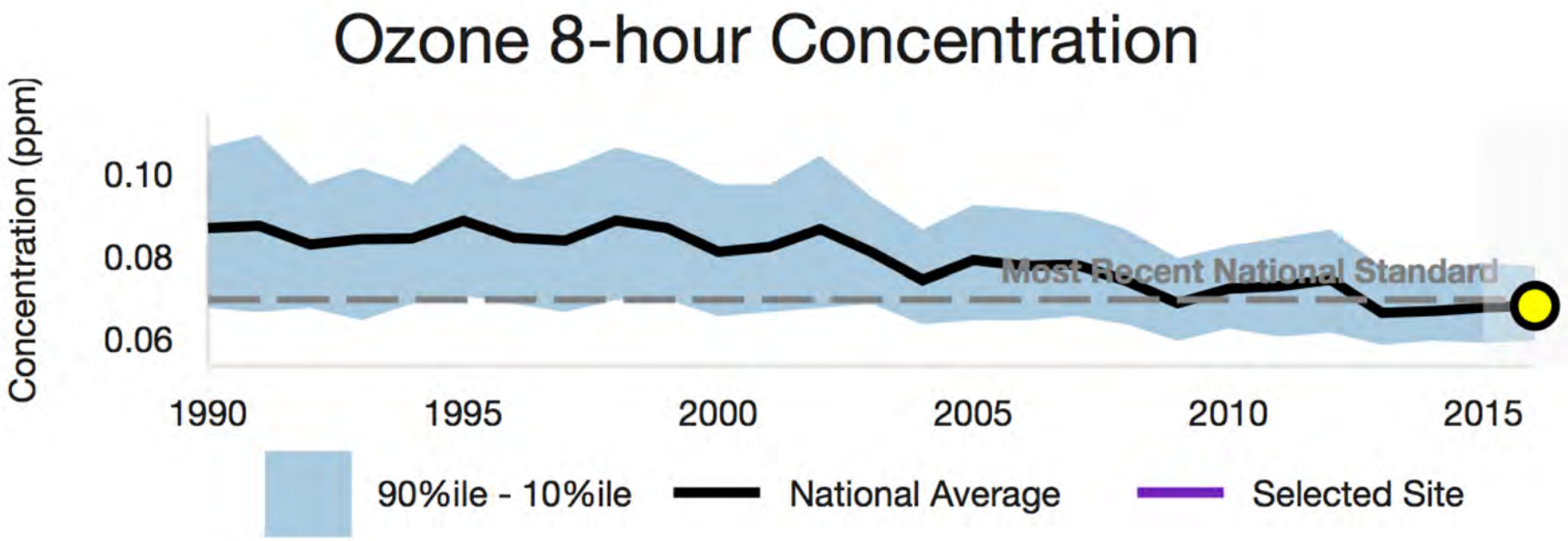
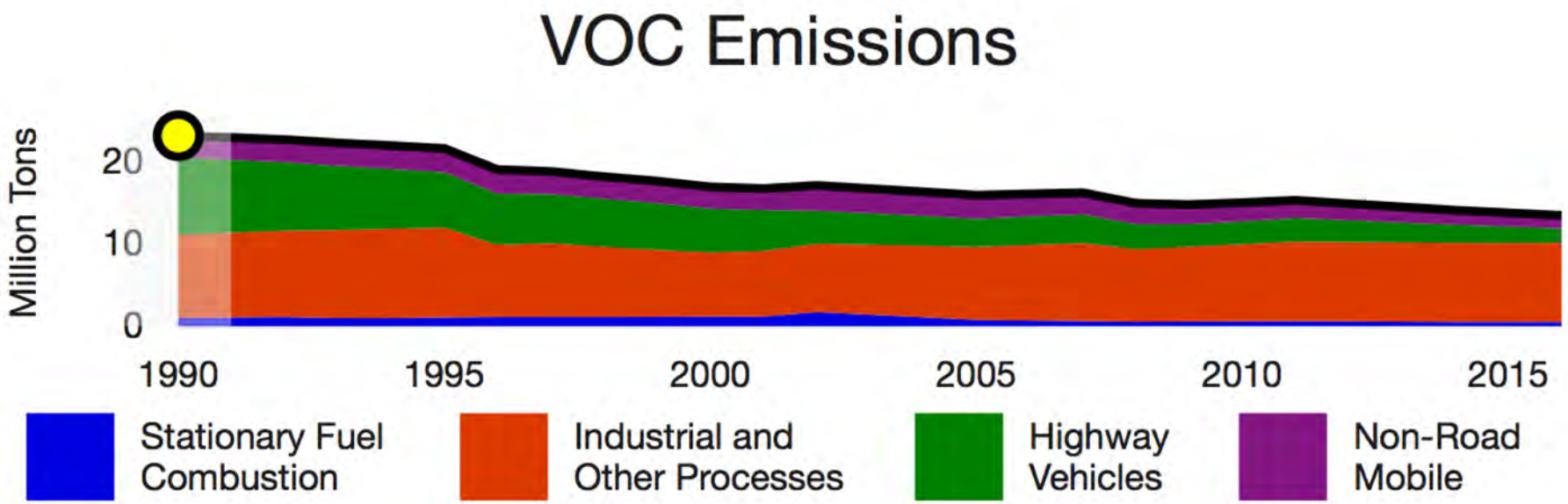


Figure 6. Trends in seasonal average population-weighted ozone concentrations in the most populous countries.




Ozone 8-hour Concentration
Concentration (ppm)
0.10
0.08
0.06
Most Recent National Standard
1990
1995
2000
2005
2010
2015
90%ile - 10%ile
National Average
Selected Site


VOC Emissions
Million Tons
20
10
0
1990
1995
2000
2005
2010
2015
Stationary Fuel Combustion
Industrial and Other Processes
Highway Vehicles
Non-Road Mobile

The complex interactions between VOCs, O3, NOx, and sunlight

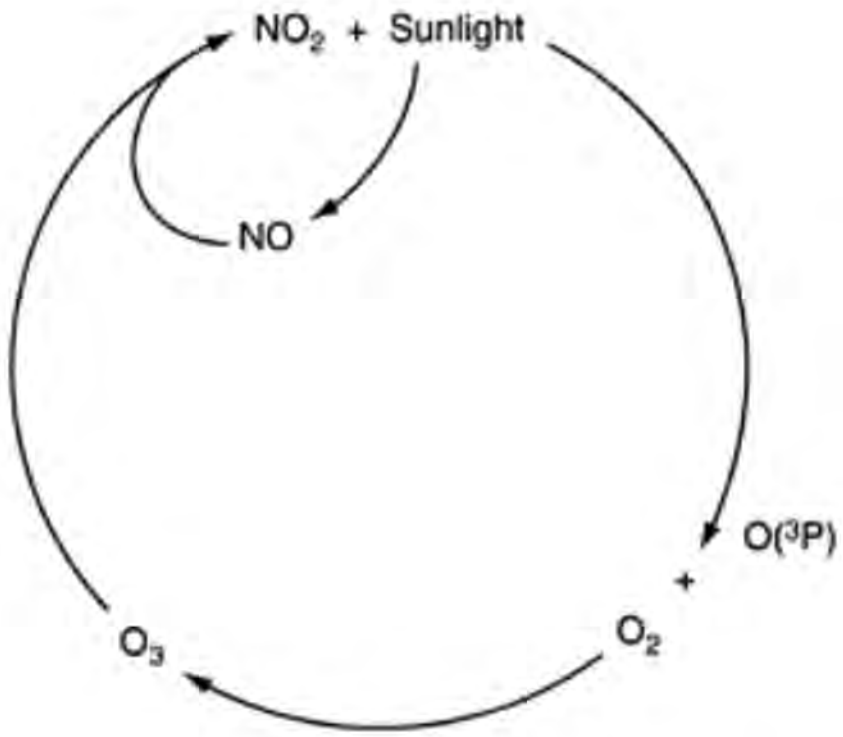


Figure 2.6 Photolysis of NO_2 to produce O_3.

The complex interactions between VOCs, O3, NOx, and sunlight

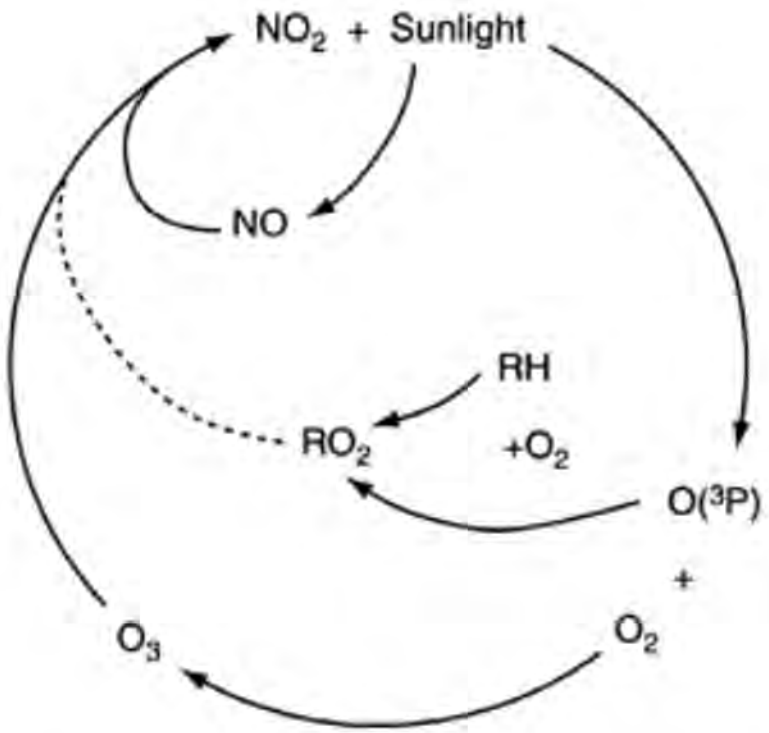


Figure 2.7 Photochemical reactions between NO_x and hydrocarbon radicals resulting in the production of O_3.

Sulfur Dioxide

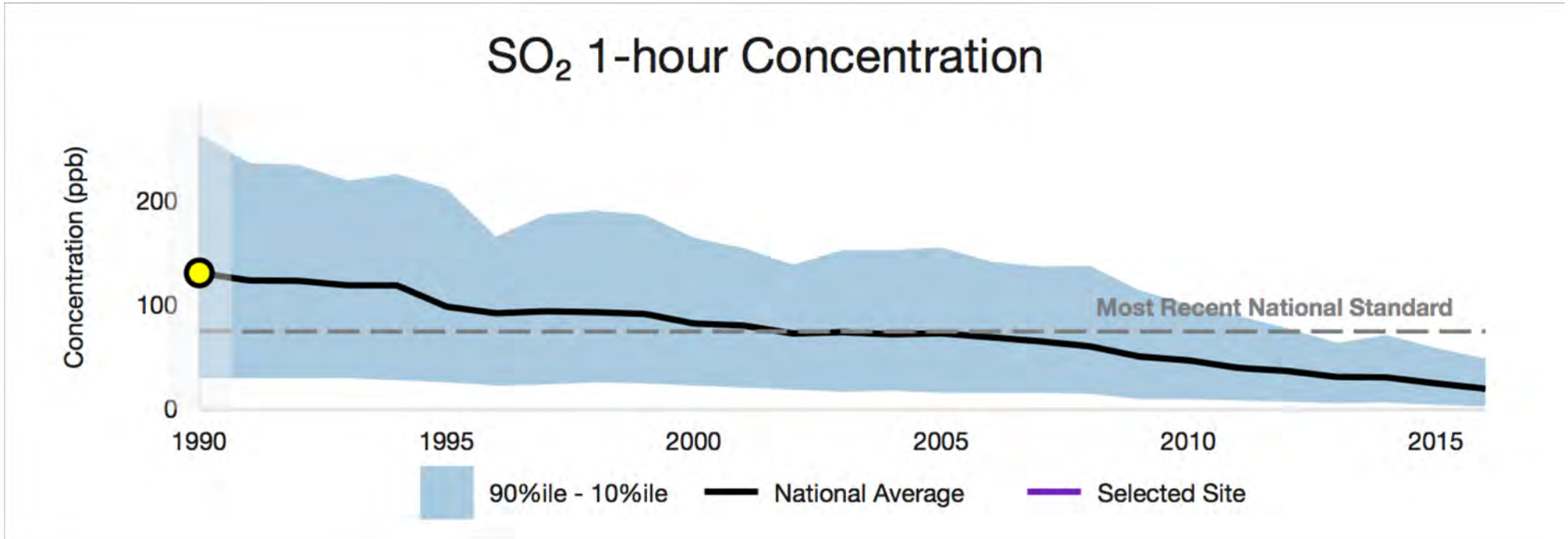
Colorless gas, “sulfury” odor. Above 3 ppm, it is extremely pungent and can be a respiratory irritatant

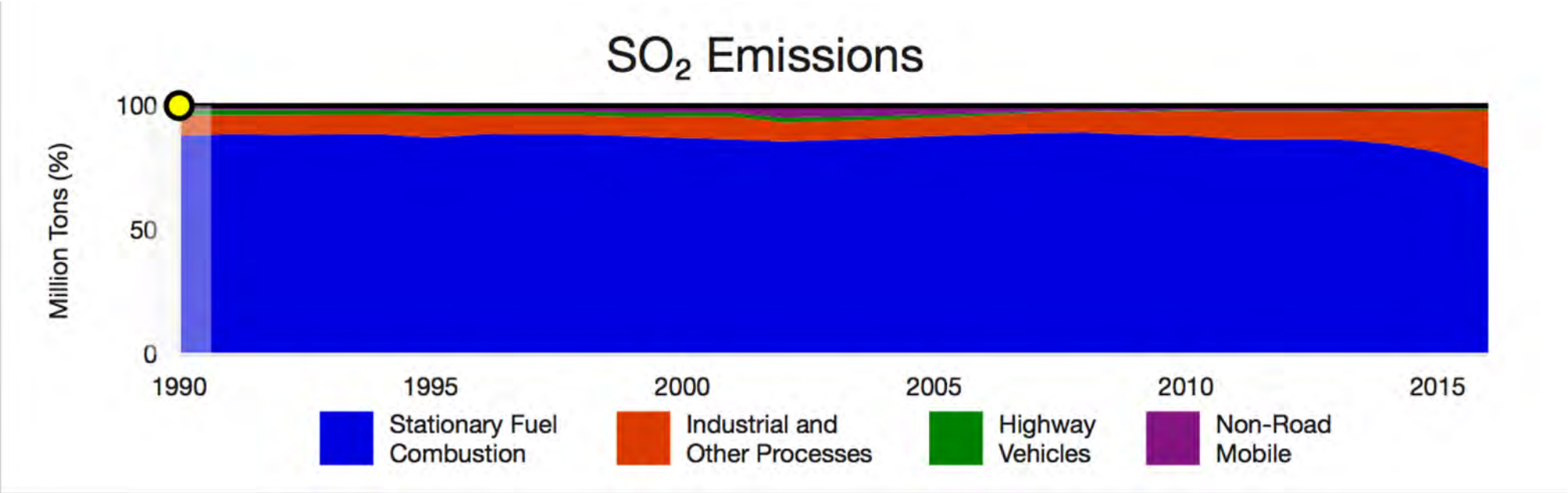
Predominantly from the combustion of fossil fuels and industrial processes

Biogenic sources and volcanoes

Significant source of secondary particles

Long range transport


SO_2 1-hour Concentration
Concentration (ppb)
200
100
0
1990
1995
2000
2005
2010
2015
Most Recent National Standard
90%ile - 10%ile
National Average
Selected Site


SO_2 Emissions
Million Tons (%)
100
50
0
1990
1995
2000
2005
2010
2015
Stationary Fuel Combustion
Industrial and Other Processes
Highway Vehicles
Non-Road Mobile

Coal

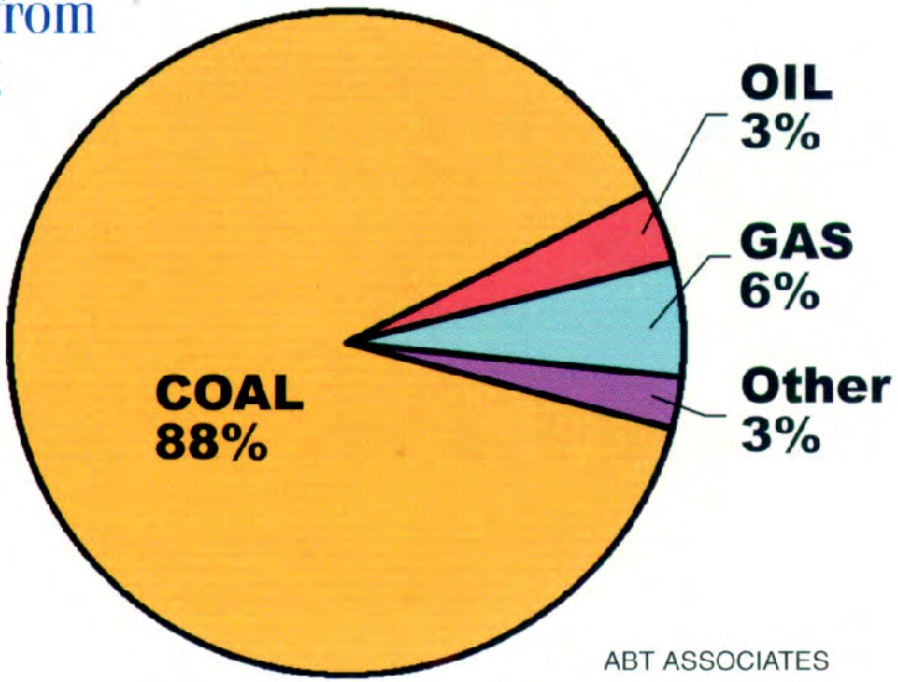
Wood

Gas

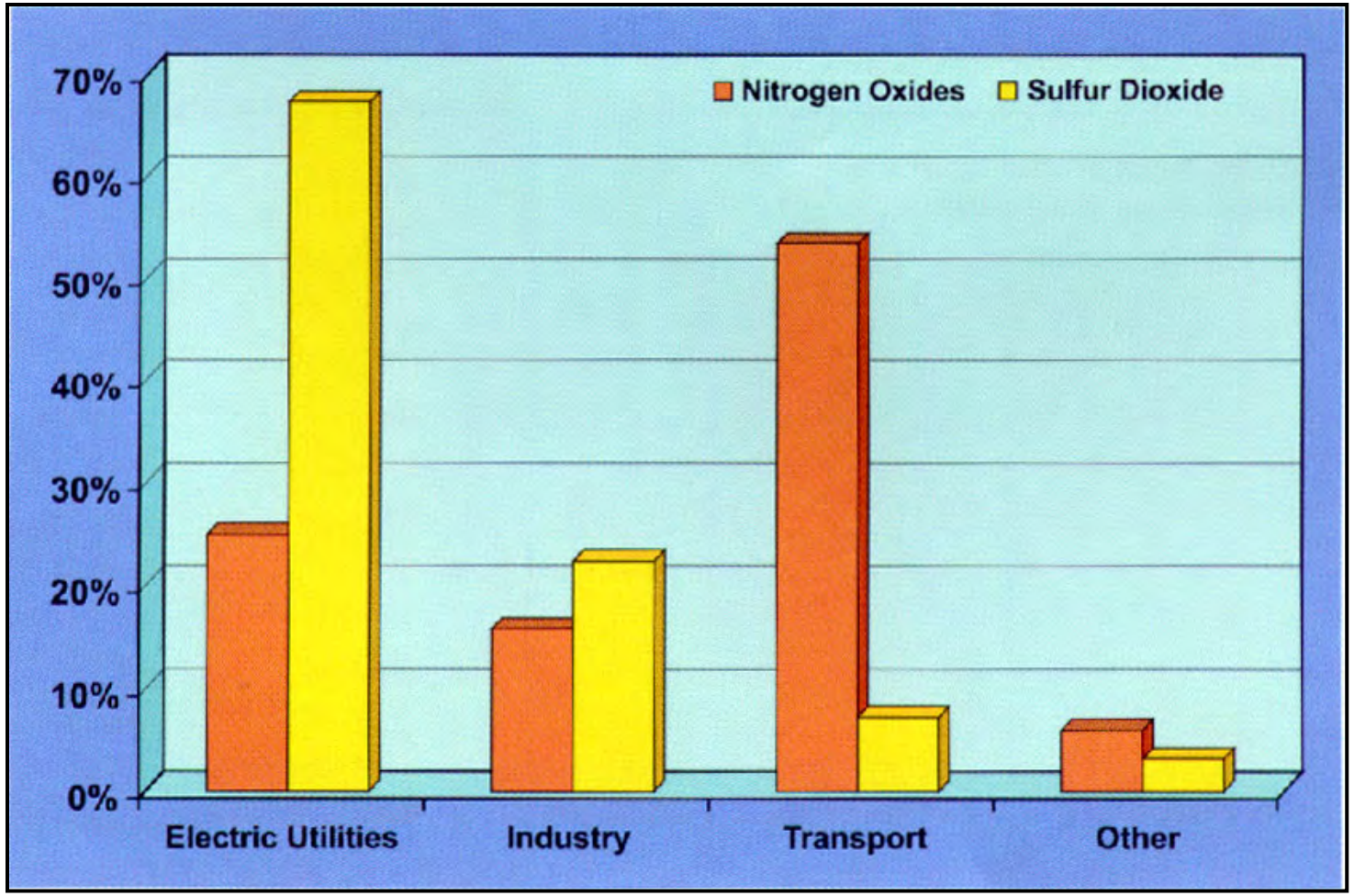
Natural Gas

Increasing sulfur content

Most of the sulfur dioxide pollution from power plants comes from burning coal.



ABT ASSOCIATES


Nitrogen Oxides
Sulfur Dioxide
70%
60%
50%
40%
30%
20%
10%
0%
Electric Utilities
Industry
Transport
Other

Aerosols + Particulate Matter

An aerosol: a stable suspension of solid or liquid particles in air (cigarette smoke, welding fumes, sea mist)

Many types – dusts, mists, smoke, fumes, bioaerosols, fibers

Usually described the size of the particle

Arise from industrial processes and fuel combustion

Removal mechanisms include wet and dry deposition and coagulation

Dust

Solid aerosols generated by abrasion, grinding, handling, or cutting

Size depends on the process and energy used during its creation. Typically, high energy processes result in smaller particles

Saw dust, coal dust

Mists

Liquid aerosols generated by condensation from a gaseous state or by the breaking up of a bulk liquid into a dispersed state

Metal working fluids, paint spray, liquid mixing operations

Smoke

Solid aerosols resulting from the incomplete combustion of carbonaceous materials

Wide range of particle sizes

Size related to combustion

Wood smoke, diesel exhaust

Fumes

Solid aerosols generated by the condensation of vapors or gases from combustion or other high temperature processes

Very small, spherical

Welding, foundry and smelting operations, hot cutting or burning tasks

Bioaerosols

Solids or liquids from biological sources

May be infectious, allergenic, or simply irritating

Wide range of sizes (viruses, very small – 0.002 to 0.03 μm; tree pollent, 10 to 100 μm)

Mold spores, animal allergens, anthrax

Fibers

A kind of dust that is longer than wide

Defined aspect ratios (length:width) like 3:1 or 5:1

Toxicity a function of composition, size, and number of fibers

Asbestos, fiberglass, refractory ceramic fibers

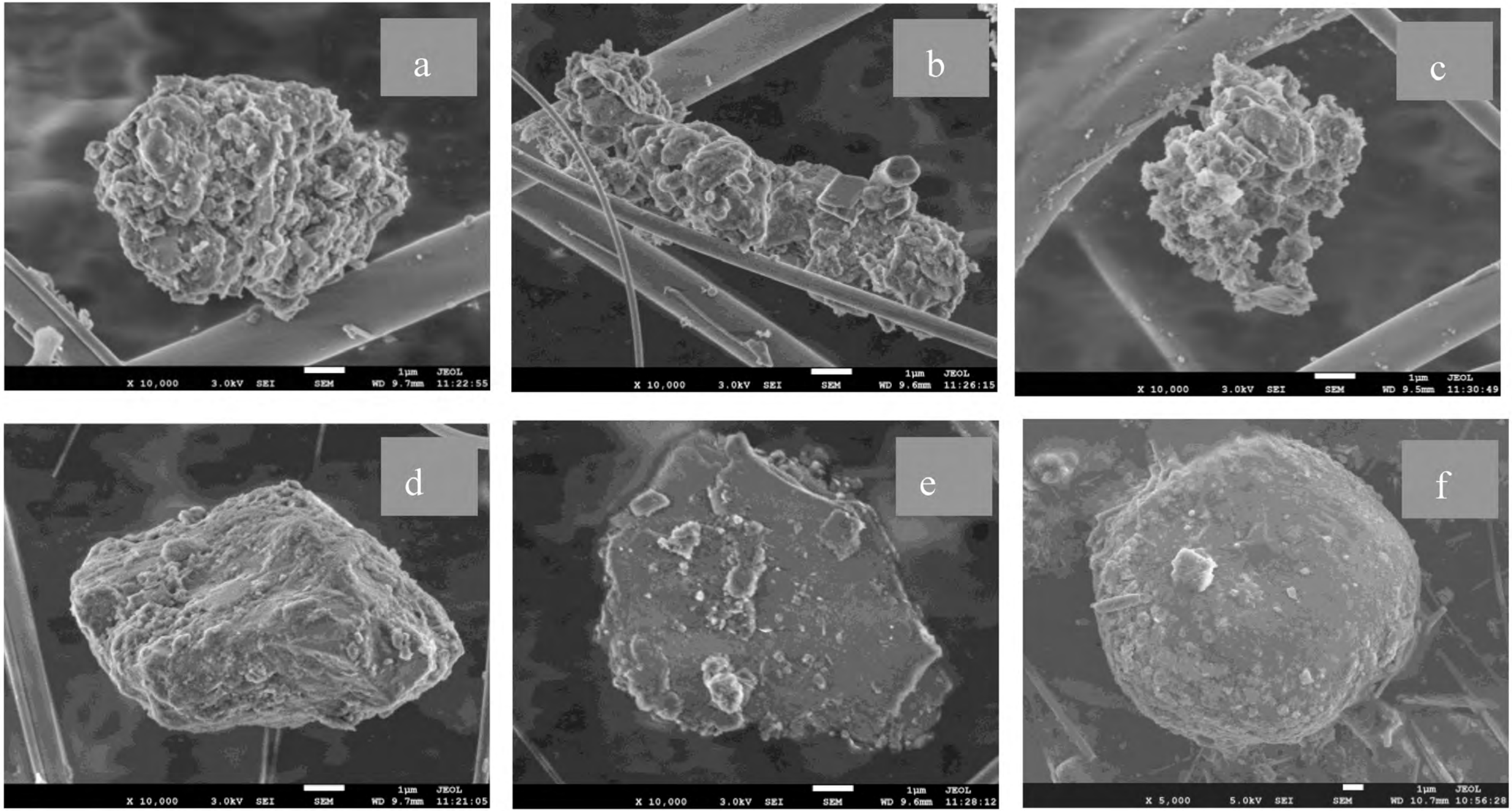
Smoke

Solid aerosols resulting from the incomplete combustion of carbonaceous materials

Wide range of particle sizes

Size related to combustion

Wood smoke, diesel exhaust


a
X 10,000 3.0kV SEI SEM 1μm JEOL WD 9.7mm 11:22:55
b
X 10,000 3.0kV SEI SEM 1μm JEOL WD 9.6mm 11:26:15
c
X 10,000 3.0kV SEI SEM 1μm JEOL WD 9.5mm 11:30:49
d
X 10,000 3.0kV SEI SEM 1μm JEOL WD 9.7mm 11:21:05
e
X 10,000 3.0kV SEI SEM 1μm JEOL WD 9.6mm 11:28:12
f
X 5,000 5.0kV SEI SEM 1μm JEOL WD 10.7mm 10:56:28

PM Size Fractions

Irregular shapes, sizes, densities

Use the concept of aerodynamic equivalent diameters to describe sizes

The AED is the size of a spherical particle of a specified density that settles at a standard velocity

It is a measure of the behavior of the particle in air, and helps determine / approximate where the particle(s) would settle in the lungs

Most easily thought of a sphere of water corrected for density that would fall through the atmosphere at the same speed as the particle of interest

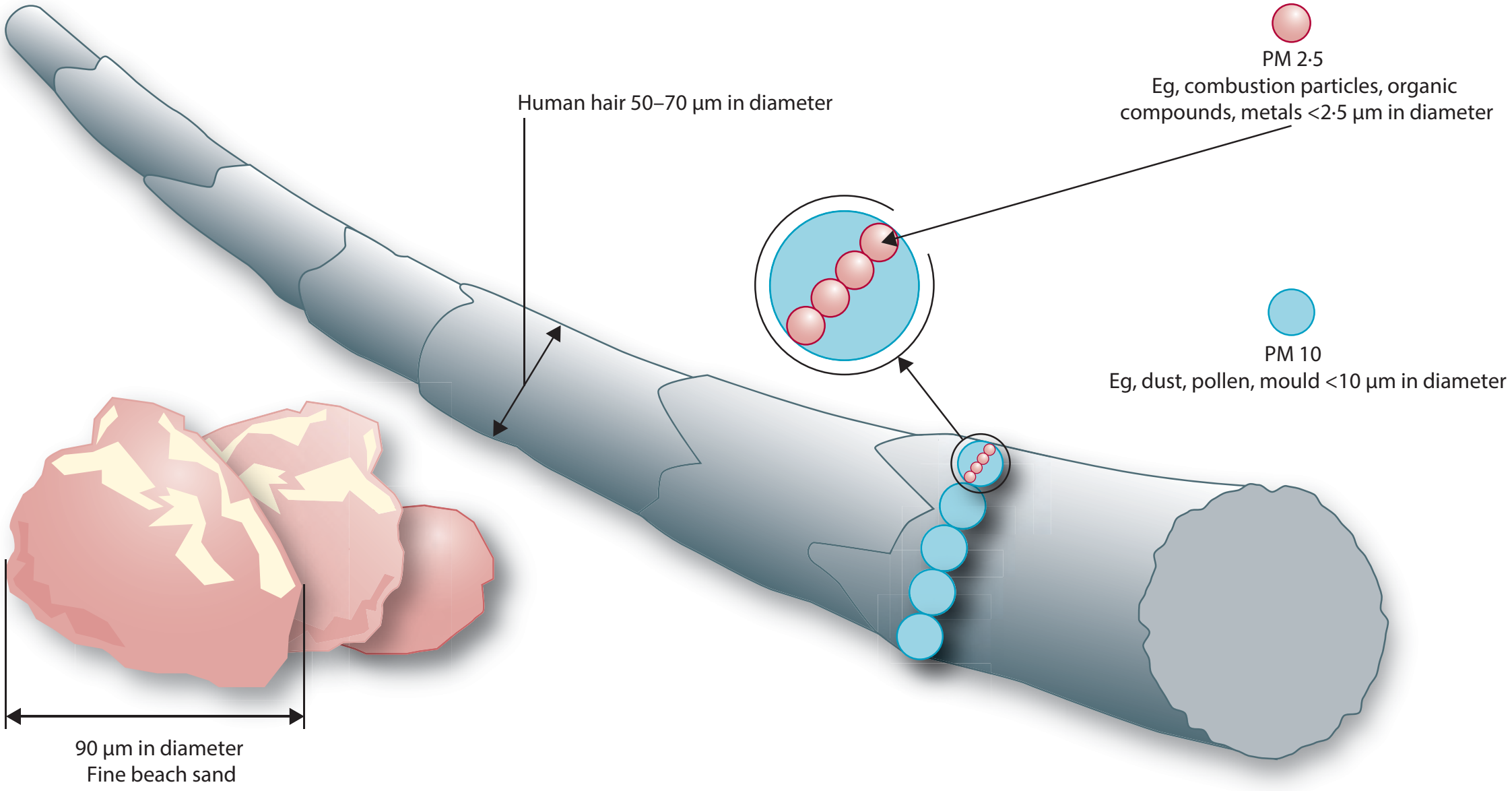
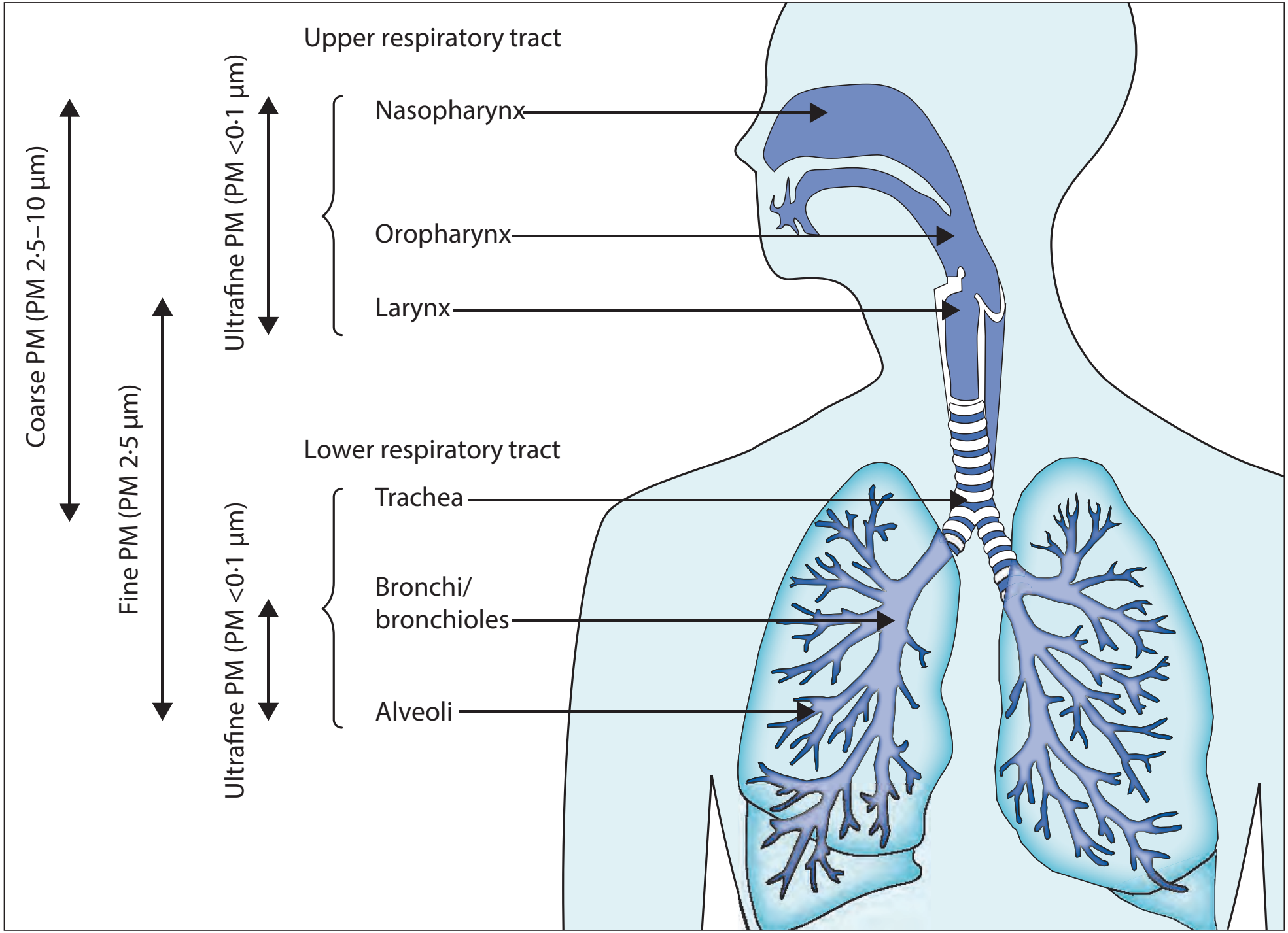


Figure 3: Particulate matter size
Image modified with permission from the US Environmental Protection Agency.
PM=particulate matter.


Upper respiratory tract
Nasopharynx
Oropharynx
Larynx
Lower respiratory tract
Trachea
Bronchi/
bronchioles
Alveoli
Coarse PM (PM 2·5–10 µm)
Fine PM (PM 2·5 µm)
Ultrafine PM (PM <0·1 µm)
Ultrafine PM (PM <0·1 µm)

Inhale some particles… what happens?

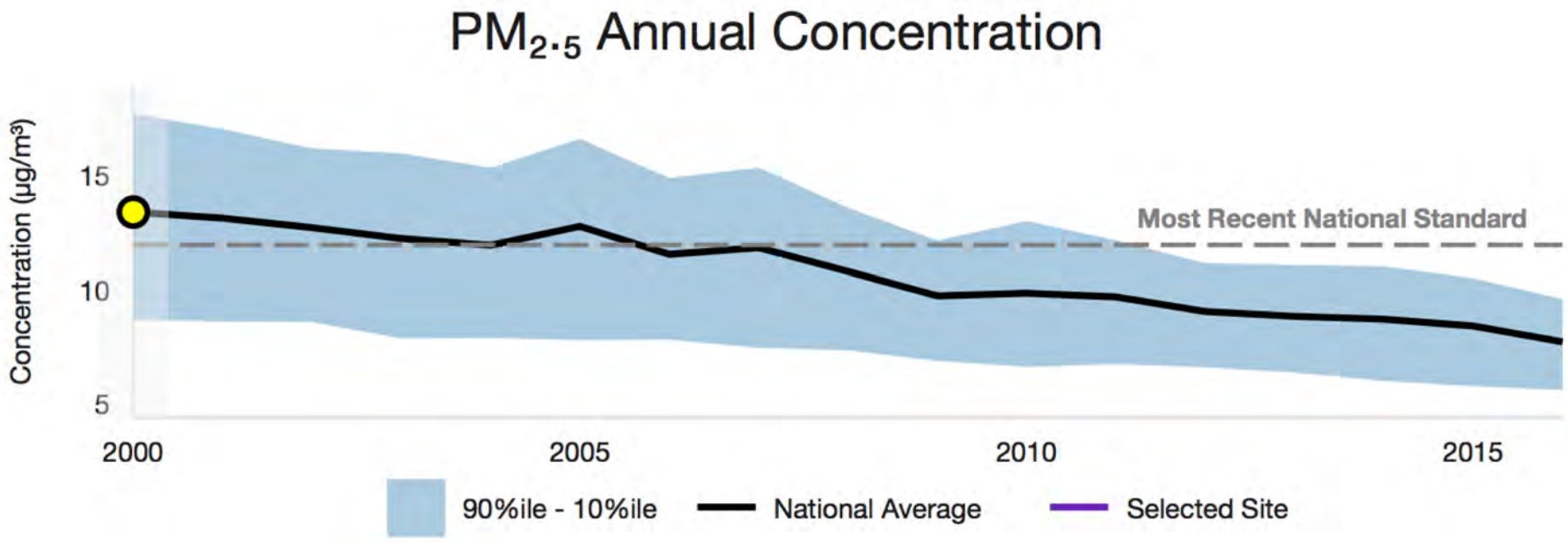
Inertial Impaction
Depending on the size and speed of the particle, it may impact upon a surface as the aerosol moves through the environment or through your lungs

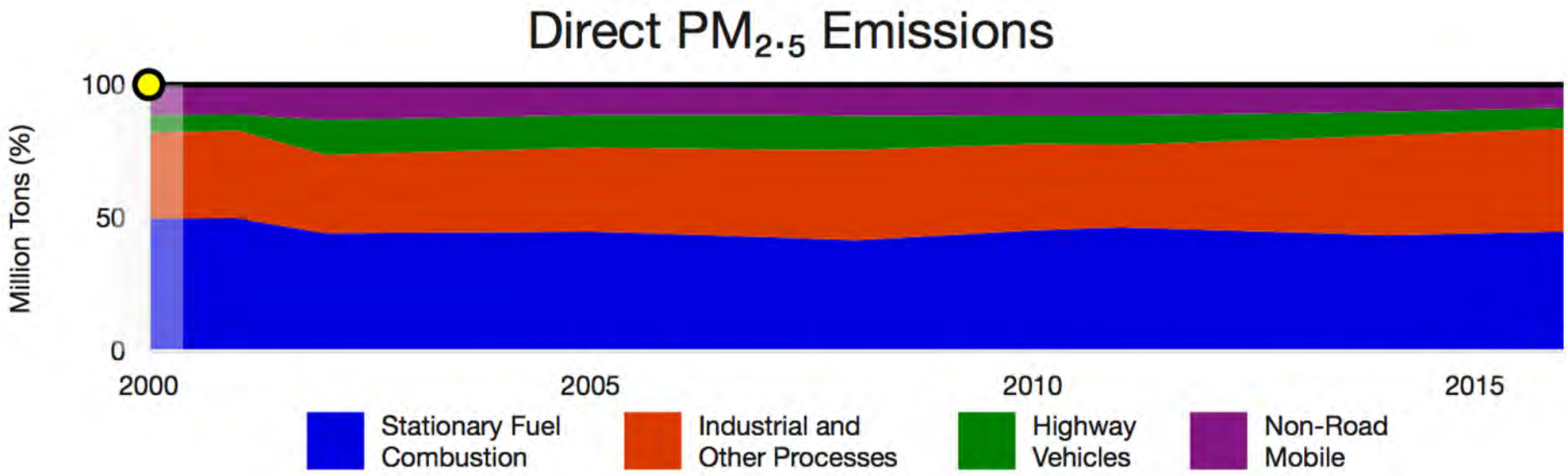
Sedimentation / gravitational settling
Depending on the speed and mass of the particle, forces of gravity may act on it to have it settle on a surface

Interception
Even if the particle is small enough, its shape may result in it being intercepted by a surface

Diffusion
Depending on the size, number, speed, and distance traveled, the particles may diffuse through and eventually strike a surface

https://aerosol.ees.ufl.edu/respiratory/section04-4.html


PM2.5 Annual Concentration
Concentration (µg/m³)
15
10
5
2000
2005
2010
2015
Most Recent National Standard
90%ile - 10%ile
National Average
Selected Site


Direct PM2.5 Emissions
Million Tons (%)
100
50
0
2000
2005
2010
2015
Stationary Fuel Combustion
Industrial and Other Processes
Highway Vehicles
Non-Road Mobile

Executive Summary Figure 1. 2013 Chinese provincial-level population-weighted $PM_{2.5}$ concentrations.

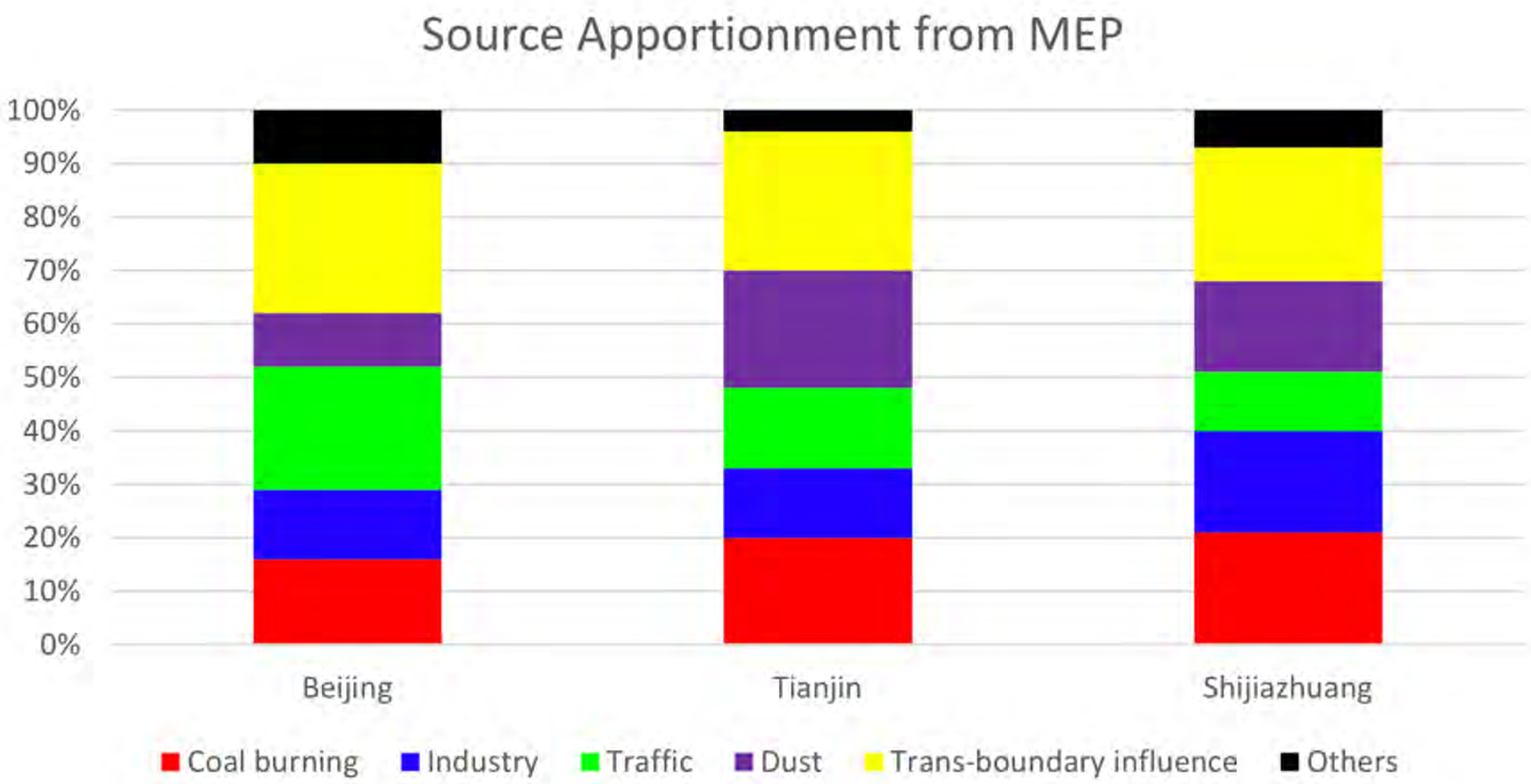
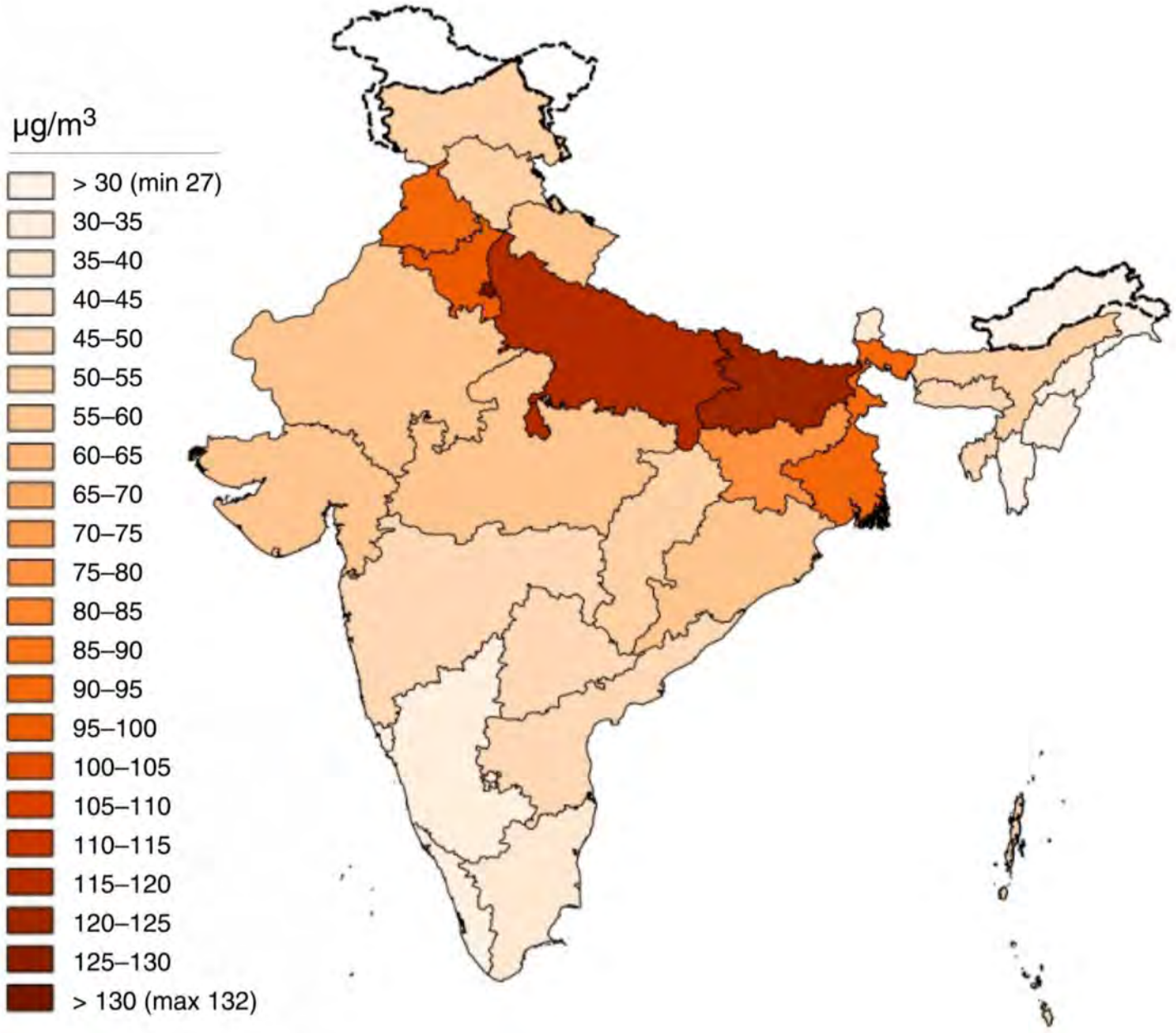
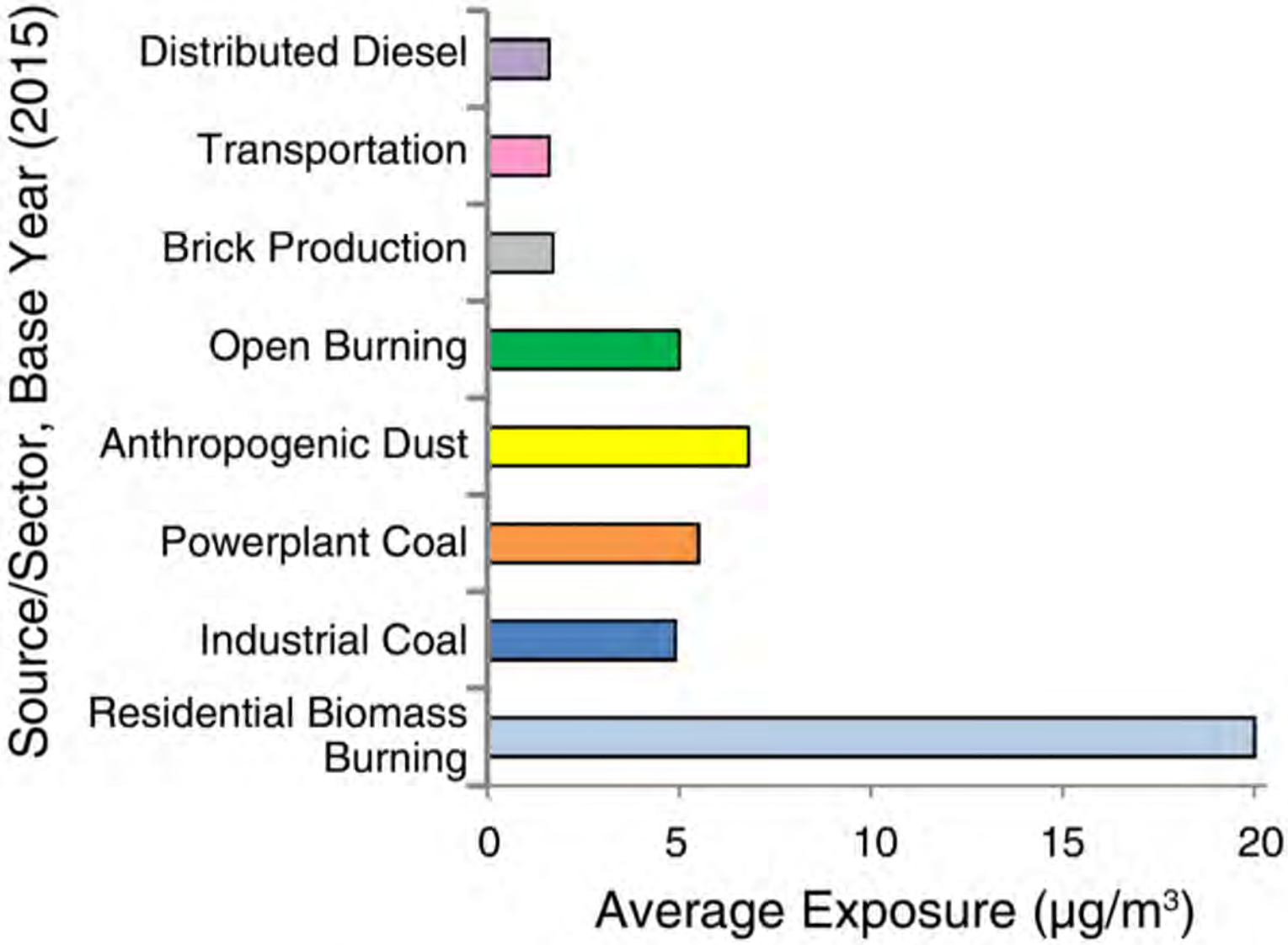


Figure 16. Source apportionment for cities in northern China from MEP.



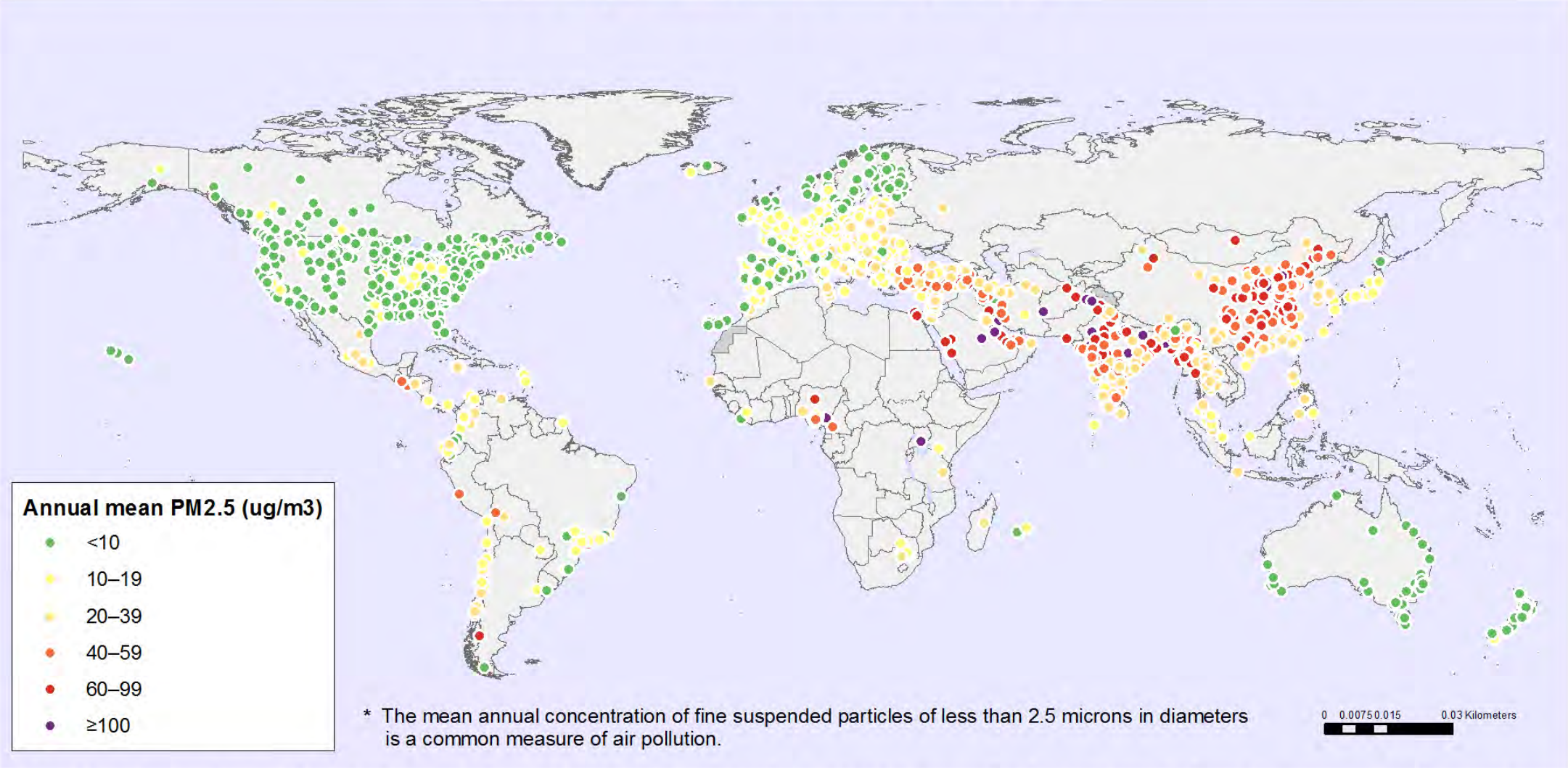
Summary Figure 1. Population-weighted state-level mean $PM_{2.5}$ concentrations in 2015 across India. These state-level means are created by aggregating up from the 11-by-11-km-grid population and ambient $PM_{2.5}$ concentration data developed for GBD 2015 (see text for details).



Summary Figure 4. Contribution by selected sources to average population exposure to $PM_{2.5}$ in India for 2015 (see Table 3 in the main report).

http://gamapserver.who.int/gho/interactive_charts/phe/oap_exposure/atlas.html

Concentration of particulate matter with an aerodynamic diameter of 2.5 µm or less (PM2.5) in nearly 3000 urban areas*, 2008–2015



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Information Evidence and Research (IER)
World Health Organization

World Health Organization

Data!

Split into groups of 2. Take 5-10 minutes and look up guidelines from the following countries / regions:

Group 1: India
Group 2: China
Group 3: Brazil
Group 4: Cameroon

Try Google, openaq.org, aqicn.org, stateofglobalair.org, etc