Intro to Particulate Matter

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Chemical and Biochemical Engineering

For GEOG:1020

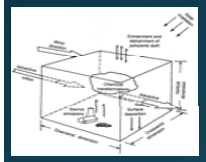
The Global Environment

Feb 28, 2017

What we'll cover

- "A" introduction to the health effects of pollution

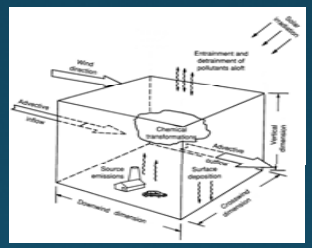
- "B" the chemical constituents that make up clean and polluted air



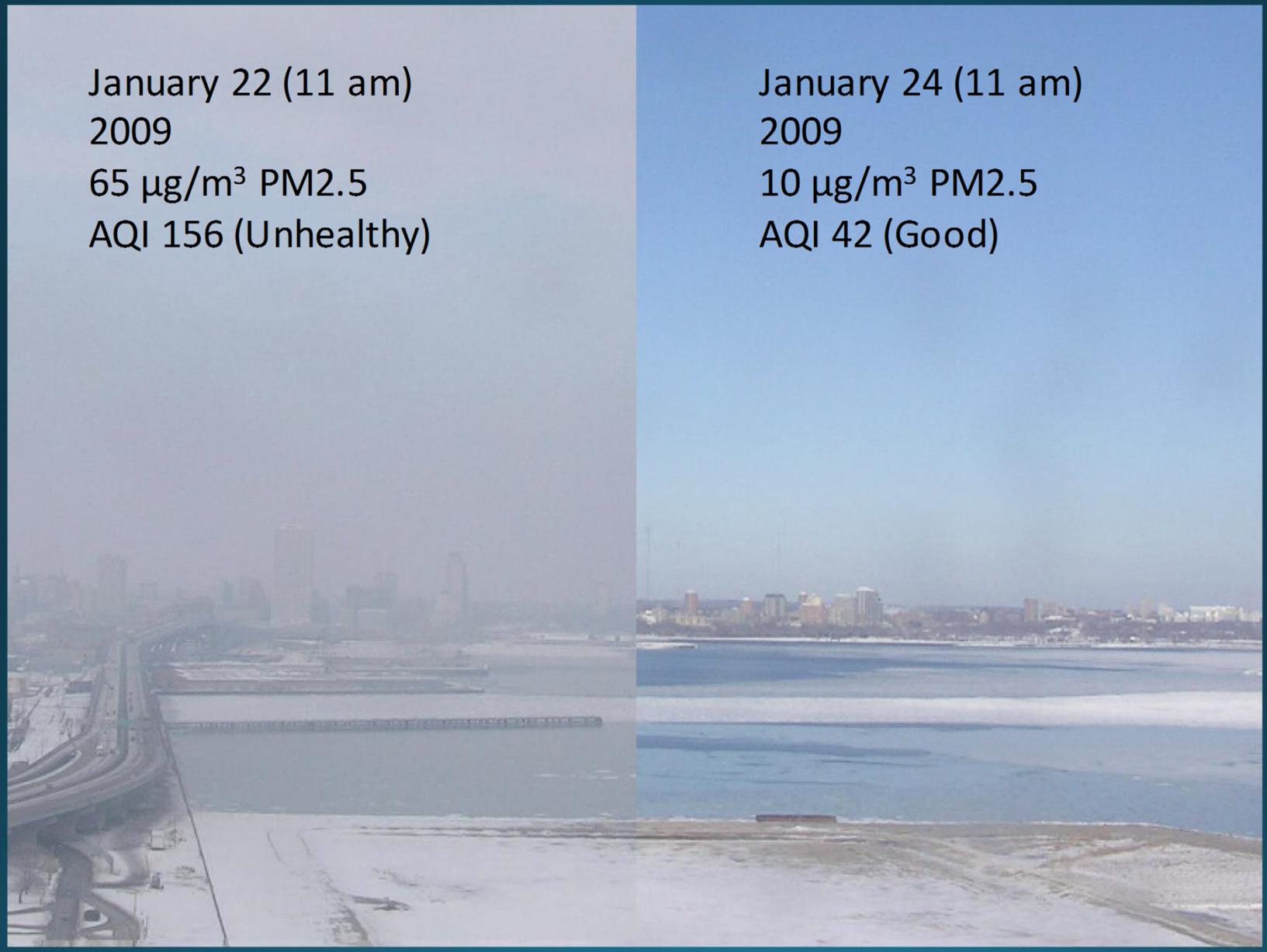
- "C" the processes that control concentrations in the atmosphere (emissions, chemical transformation, physical transformation, and meteorology)

- "D" Measurement and categorization of air quality – the Air Quality Index

“A” introduction to the health effects of pollution



Air Quality Index (AQI) Values	Levels of Health Concern
When the AQI is in this range:	*..air quality conditions are:*
0-50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151 to 200	Unhealthy
201 to 300	Very Unhealthy
301 to 500	Hazardous


January 22 (11 am)
2009
65 µg/m³ PM2.5
AQI 156 (Unhealthy)
January 24 (11 am)
2009
10 µg/m³ PM2.5
AQI 42 (Good)

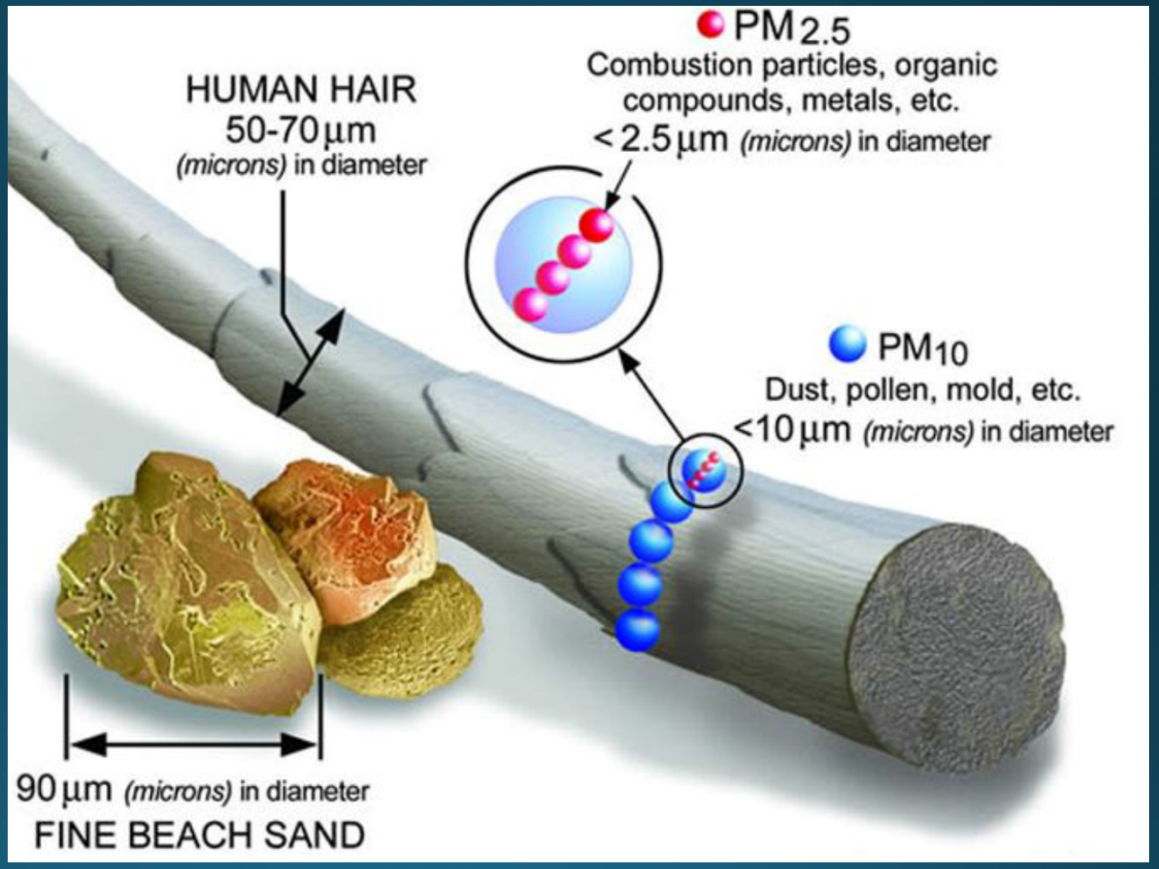
"Clean" vs. "Not Clean" is Defined by U.S. Law & Regulations

- Clean Air Act
  - Requires the U.S. EPA to establish health-based standards for criteria pollutants
  - National Ambient Air Quality Standards (NAAQS) (referred to as "Standards")

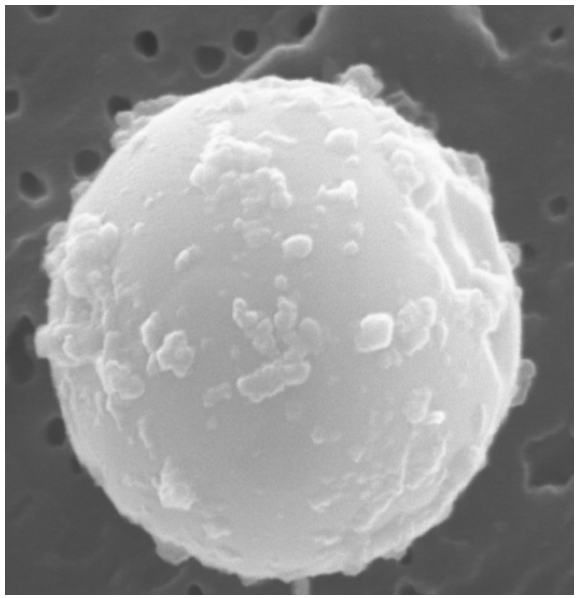
- NAAQS are set in order to protect the public health and welfare
  - Particulate Matter, Ozone, Lead, Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2)
  - Particulate matter (PM) broken into two size fractions
    - PM10
    - PM2.5

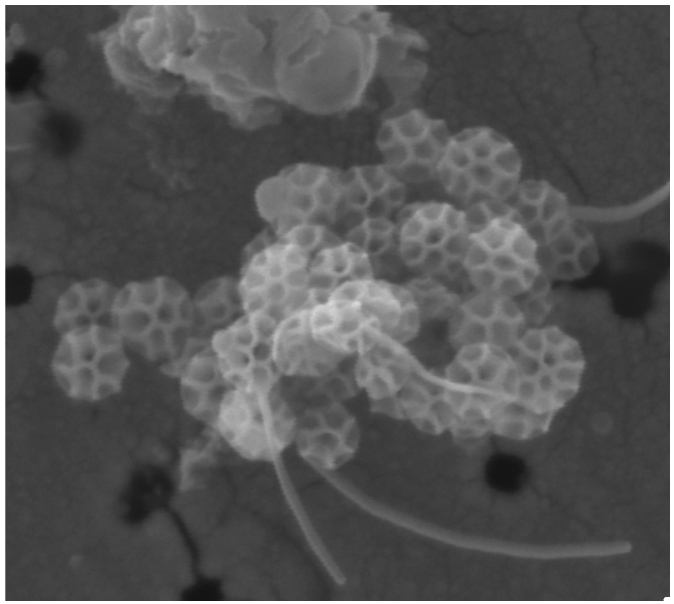
PM 2.5 Health Effects

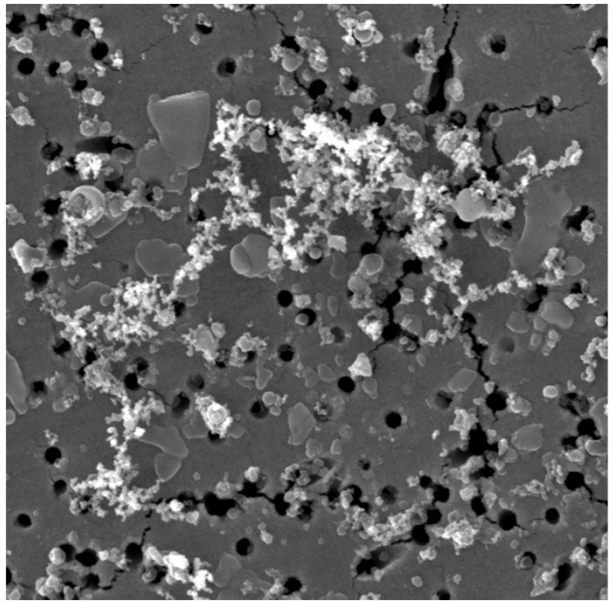
- Children
- Older Adults
- Active Adults
- People with heart & lung disease

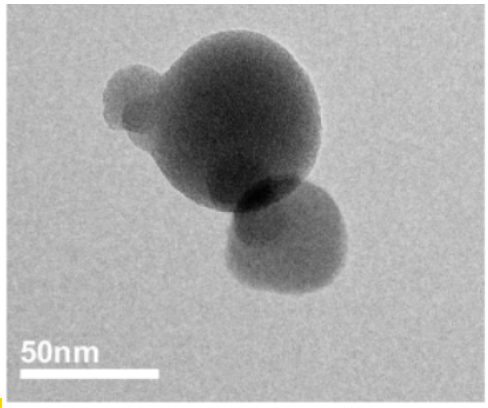


What are Atmospheric Aerosol Particles
What is “Particulate Matter” (PM)?



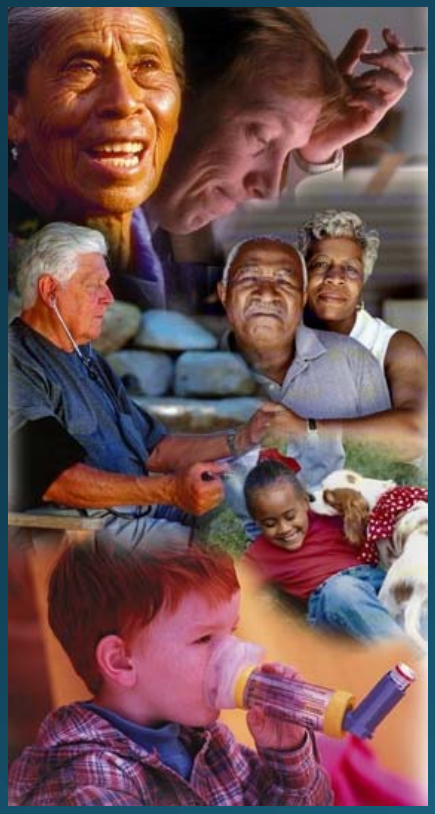






SEM Images:
Gary Casuccio, R.J. Lee Group, Monroeville, PA; Sylvia Lee Joun, University of Iowa

Some Groups Are More at Risk



- People with heart or lung disease
  - Conditions make them vulnerable
- Older adults
  - Greater prevalence of heart and lung disease
- Children
  - More likely to be active
  - Breathe more air per pound
  - Bodies still developing

USC *Children's Health* Study

- Between about 1995 and 2008, in 6 LA communities studied by Gauderman et al.
  - the average NO2 level decreased by 14 ppb
  - PM2.5 concentrations decreased by about 13 ug/m3
  - PM10 concentrations decreased by about 9 ug/m3

- In the 1990's the study looked at lung capacity in 11-yr old children and then followed these children with followup measurements until they were 15
- This was repeated in ~2008 with a new group of 11-15 year olds
- Comparisons are possible between clean and dirty communities
- Comparisons are possible between the same communities in the polluted state of the 1990s and the clean state of the 2000s

Gauderman, W. J., et al. *N. Engl. J. Med.* **2015**, *372* (10), 905–913.

What does your intuition say? The pollution decrease was associated with

- No statistical difference in the lung capacity of 15 year olds
- 0-2% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA
- 2-4% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA
- 4-6% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA

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- 4-6% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA
- (p values < 0.001)
- Also
  - in the recent groups of children, fewer children have doctor-diagnosed low lung capacity. Results hold true across race/ethnicity, community, and asthma/inhaler use status.
  - Growth of children is not accelerated overall. Lung capacity does not predict height.

Gauderman, W. J., et al. *N. Engl. J. Med.* **2015**, *372* (10), 905–913.

$PM_{2.5}$ is Regulated Because

- $PM_{2.5}$ is linked in dozens of studies (both long and short term) to:
  - Symptom aggravation and/or death from cardiac diseases:
    - Cardiac arrhythmias, angina, and cardiac arrest, heart disease
  - Hospital admissions and/or death from respiratory diseases
    - Lung disease, emphysema, Chronic obstructive pulmonary disease (COPD), asthma
  - Progression of atherosclerosis (hardening of arteries)
  - Changes in lung and blood chemistry and biology consistent with many of the above diseases
  - Work absence, disability, and medication use for the above diseases
- And possibly
  - Low birthweight, developmental problems in children, diabetes, neurogegenerative diseases such as Alzheimer's

What are the Standards?

- Fine Particulate Matter (PM2.5) NAAQS
  - Fine particulate matter first regulated in 1997 (and the limits were 15 and 65, respectively)
  - The 24-hour standard was revised in 2006
  - The Annual standard was revised in 2012

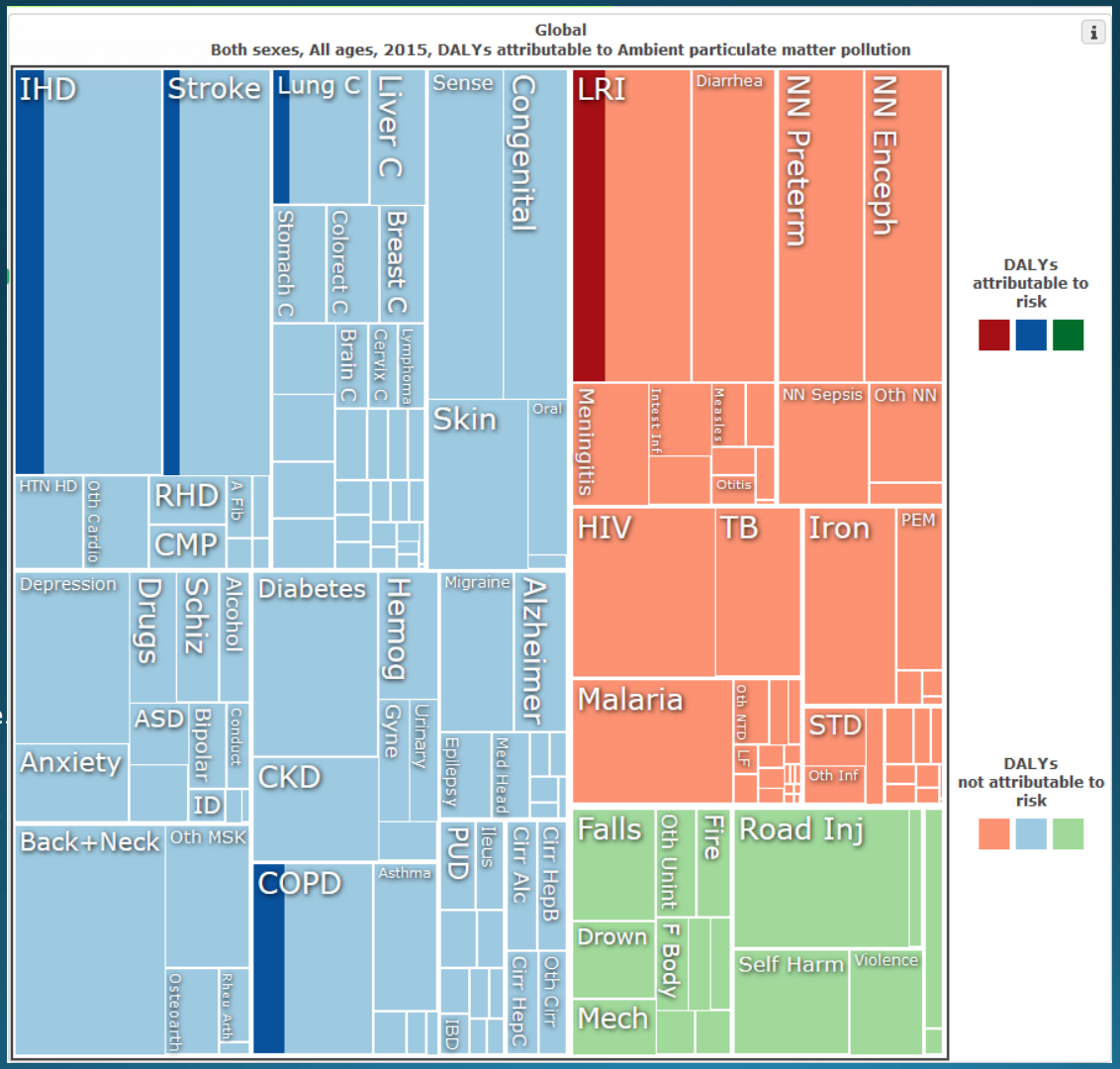
	2012 Standards	
	Annual	24-hour
$PM_{2.5}$ (Fine Particles)	12 µg/m3 Annual arithmetic mean, averaged over 3 years	**35 µg/m^3** 24- hour average, 98th percentile, averaged over 3 years

Mentimeter Q1

$PM_{2.5}$ is Regulated Because It Causes Disease and Death

Pictorial representation of disability-adjusted years of life lost due to various causes

Non-communicable diseases

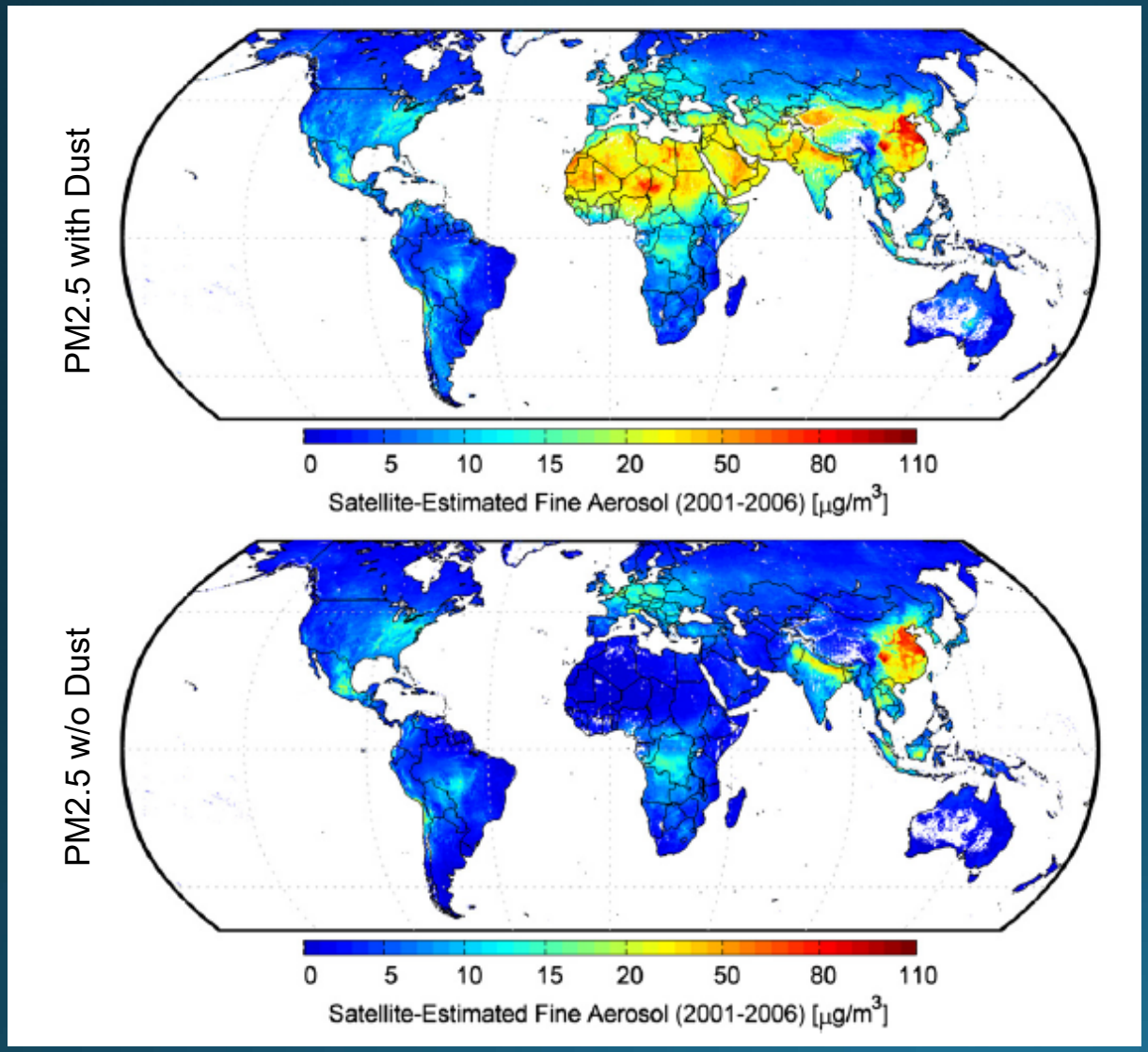


Communicable, maternal, neonatal, and nutritional disorders

Injuries

Institute for Health Metrics and Evaluation (IHME). **GBD Compare**. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed Jan 2016)

Globally, aerosol concentrations are estimated by a combination of satellites and computer simulations

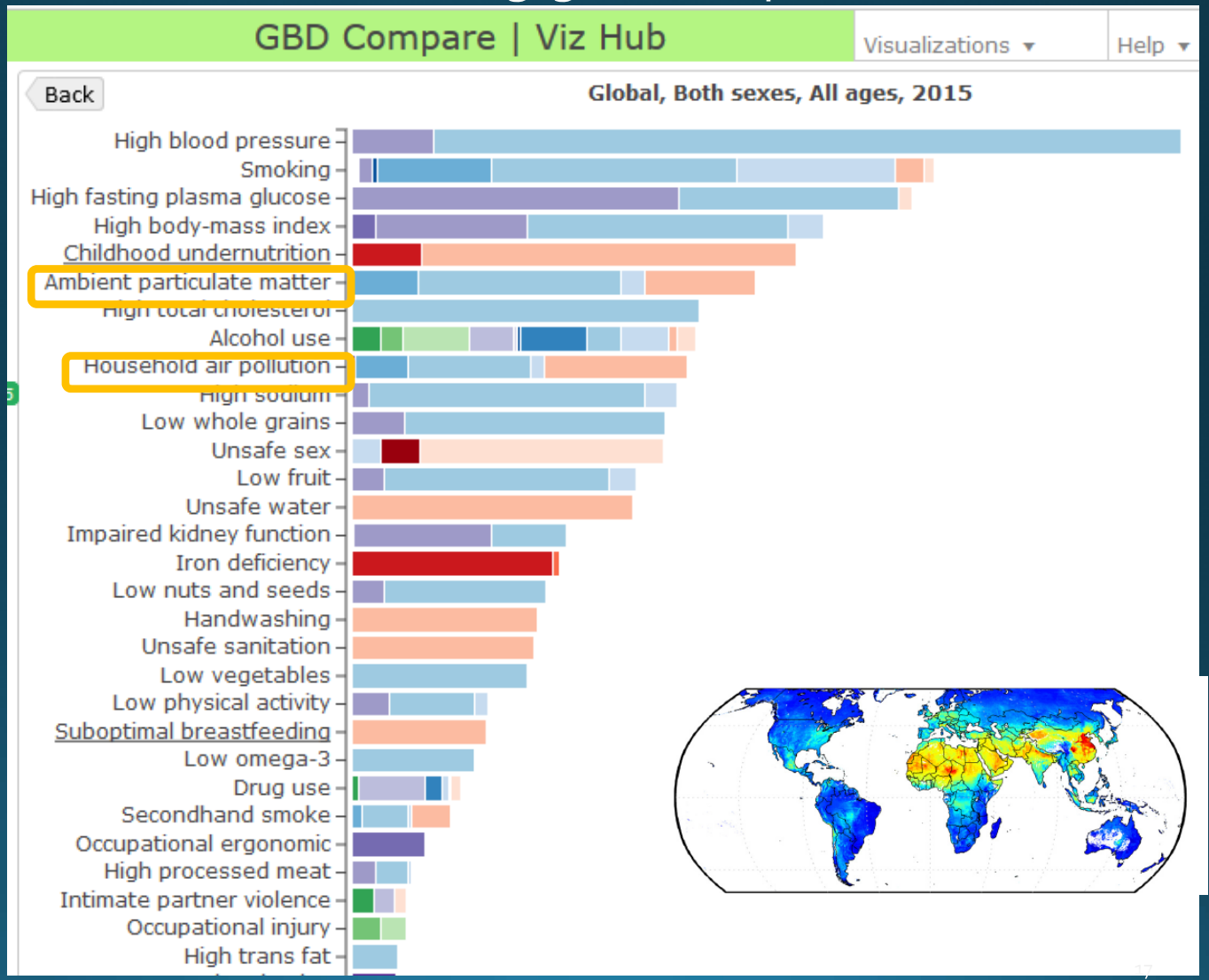


Evans et al. Environmental Research (2013).

Aerosol concentrations use 2001-2006 MODIS/MISR composite fields and aerosol properties from GEOS Chem.

See van Donkelaar et al. (2010) Environmental Health Perspectives for PM2.5 method

Globally – ambient air pollution is #9 environmental risk factor http://vizhub.healthdata.org/gbd-compare/



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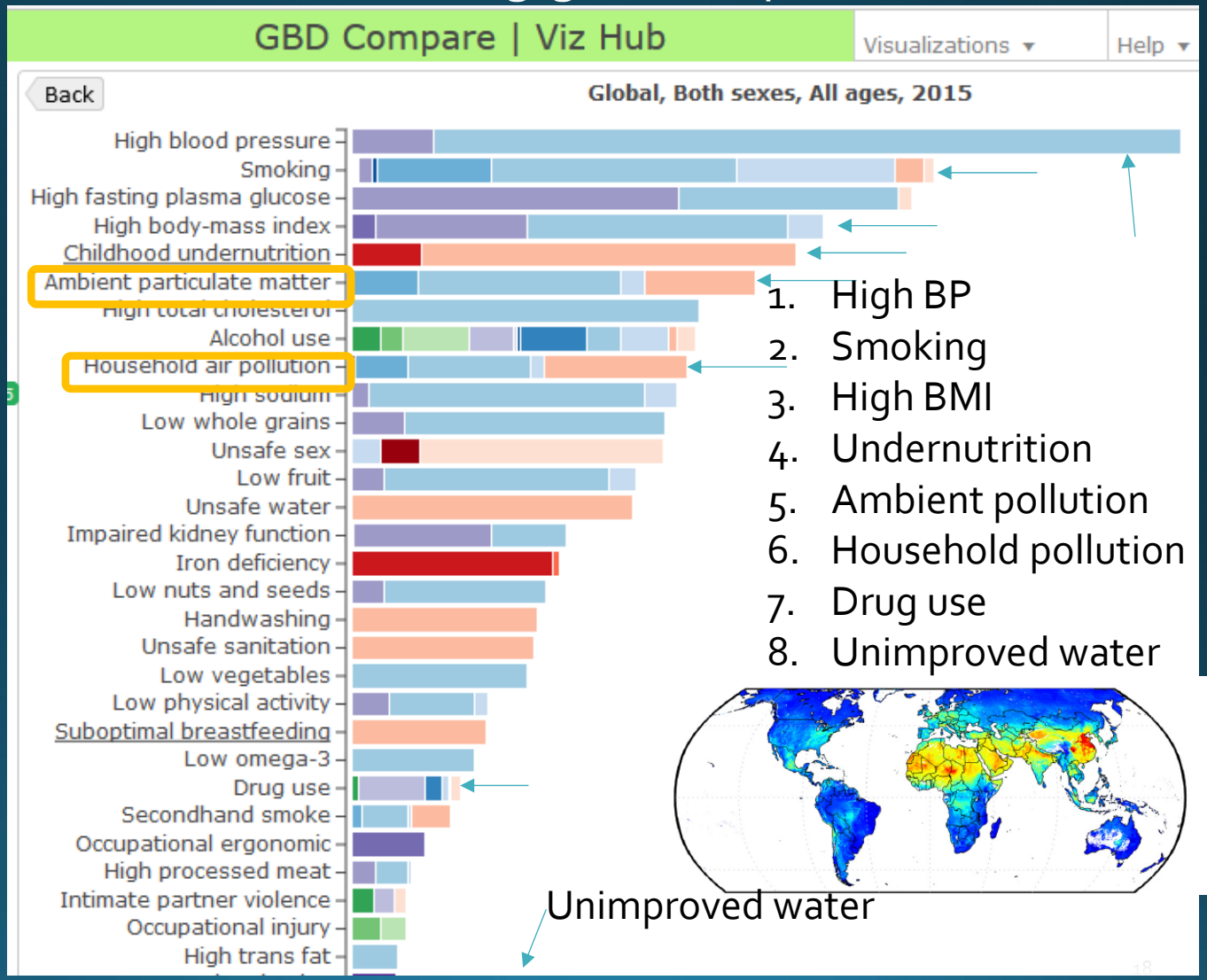
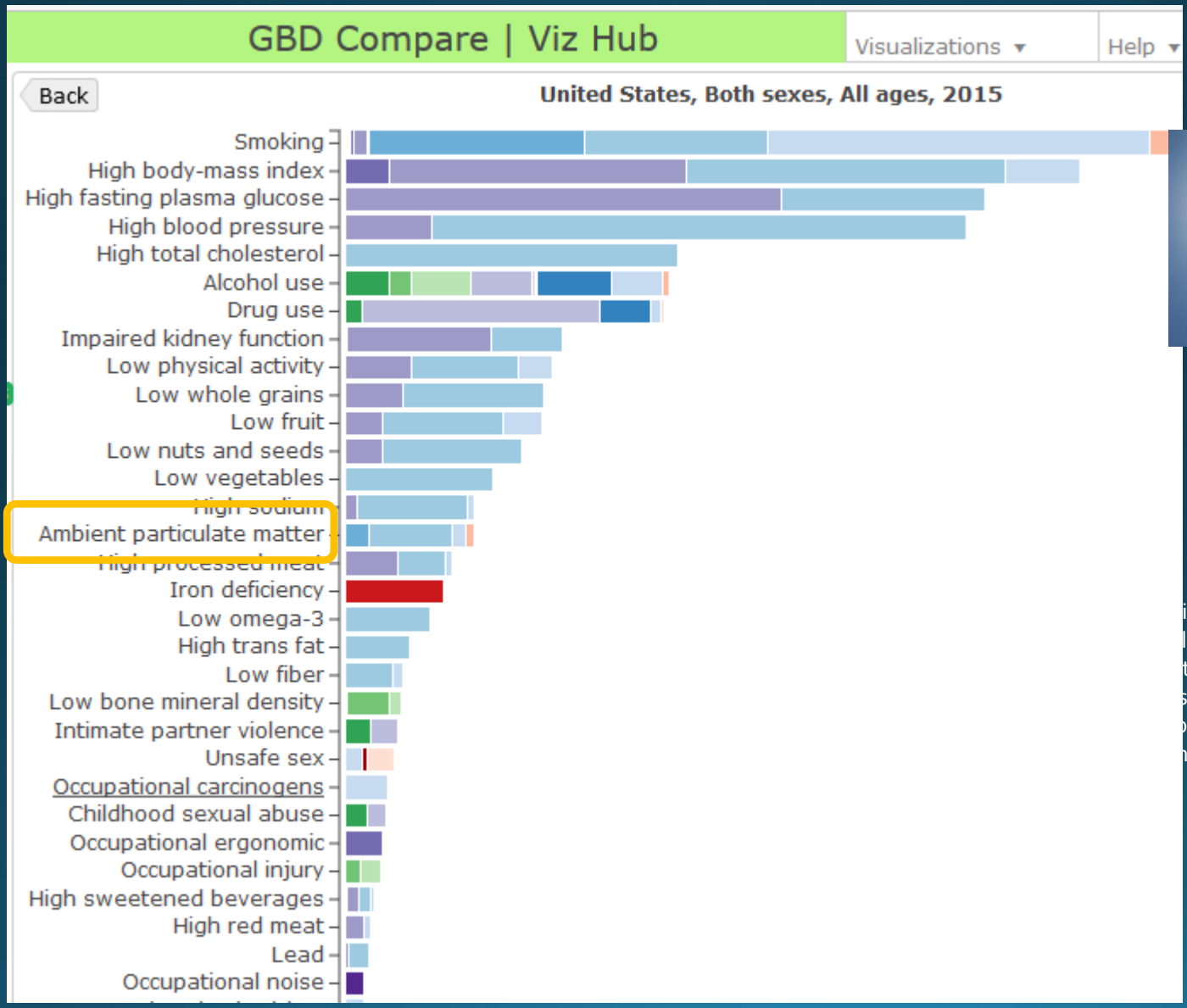


Institute for Health Metrics and Evaluation (IHME). **GBD Compare**. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed Feb 2017)

US – ambient air pollution is #15 environmental risk factor
http://vizhub.healthdata.org/gbd-compare/



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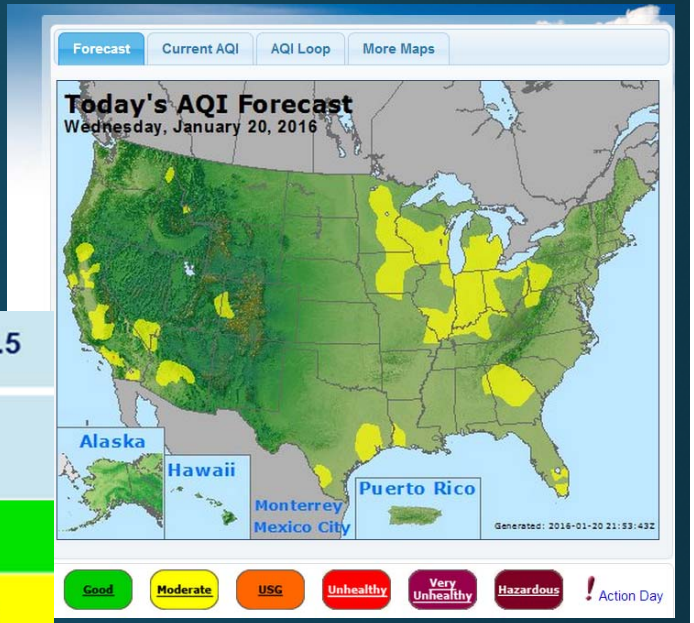
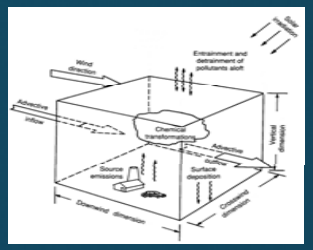
Air Quality Index

Air Quality Index (AQI) Values	Levels of Health Concern	Colors	24 hr ave PM2.5
When the AQI is in this range:	*..air quality conditions are:*	*...as symbolized by this color:*	*ug/m3*
0-50	Good	Green	0 - 12
51-100	Moderate	Yellow	12.1 -35.4
101-150	Unhealthy for Sensitive Groups	Orange	35.5 – 55.4
151 to 200	Unhealthy	Red	55.5 – 150.4
201 to 300	Very Unhealthy	Purple	150.5 – 250.4
301 to 500	Hazardous	Maroon	250.5 – 500.4



Air Quality Index (AQI) is used by government agencies to tell the public how clean or polluted the air currently is.

http://www.airnow.gov/



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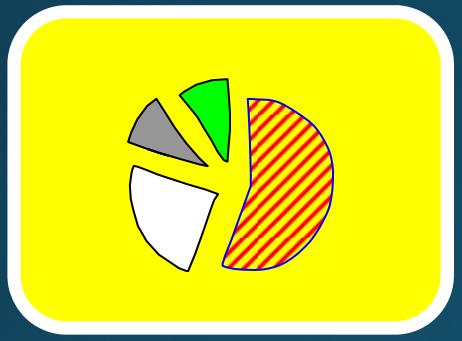
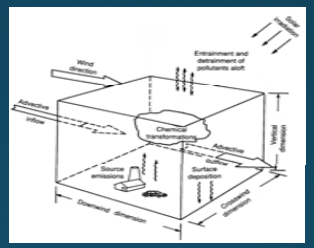
- The Clean Air Act sets standards for the concentration of 6 pollutants – ozone (O_3), lead, sulfur dioxide (SO_2), Nitrogen Dioxide (NO2), Carbon Monoxide (CO), and Particulate Matter (PM)
  - PM is divided into two size classifications PM2.5, and PM10
- There are significant respiratory and cardiovascular health benefits to low PM and significant risks to high PM
- The health effects of PM are robust and are supported by the number of studies that have found association, and the variation in the types of studies (long term, short term, natural experiment, case crossover, biomarkers, lung function, etc.)
- Globally, ambient and household Air Pollution are the #6 and #9 largest causes of disability and death

“B” chemical constituents that make up clean and polluted air





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Classification of Major Air Pollutants

- **NAAQSs**
  - **Six Criteria Pollutants [Nitrogen Dioxide (NO_2), Ozone, Sulfur Dioxide, Carbon Monoxide, Lead, PM]**
  - **Non-Criteria Pollutants**
- **Chemical Properties**
  - **Inorganic**
  - **Organic**
- **Chemical Groups**
  - **Sulfur-Containing Compounds (SO_2, H_2SO_4)**
  - **Nitrogen-Containing Compounds (NO, NO_2, HNO_3)**
  - **Carbon-Containing Compounds (CH_4, Alkanes, Alkenes, Alcohols)**
  - **Halogen-Containing Compounds (CFCs, CH_3Cl, CH_3Br)**
  - **Atmospheric Oxidants (O_3, H_2O_2, OH radical, NO_3 radical)**
  - **PM (sulfate, nitrate, OC, EC, dust, sea-salt)**
  - **Air Toxics (Lead, Mercury, Asbestos, Dioxins, Benzene)**
- **Residence Time (or Lifetime)**
  - **Long-Lived Species (CFCs, CH_4, N_2O)**
  - **Moderately Long-Lived Species (CO, SO_2, NO_x, PM, Tropospheric Ozone)**
  - **Short-Lived Species (Radicals: OH, NO_3, HO_2)**

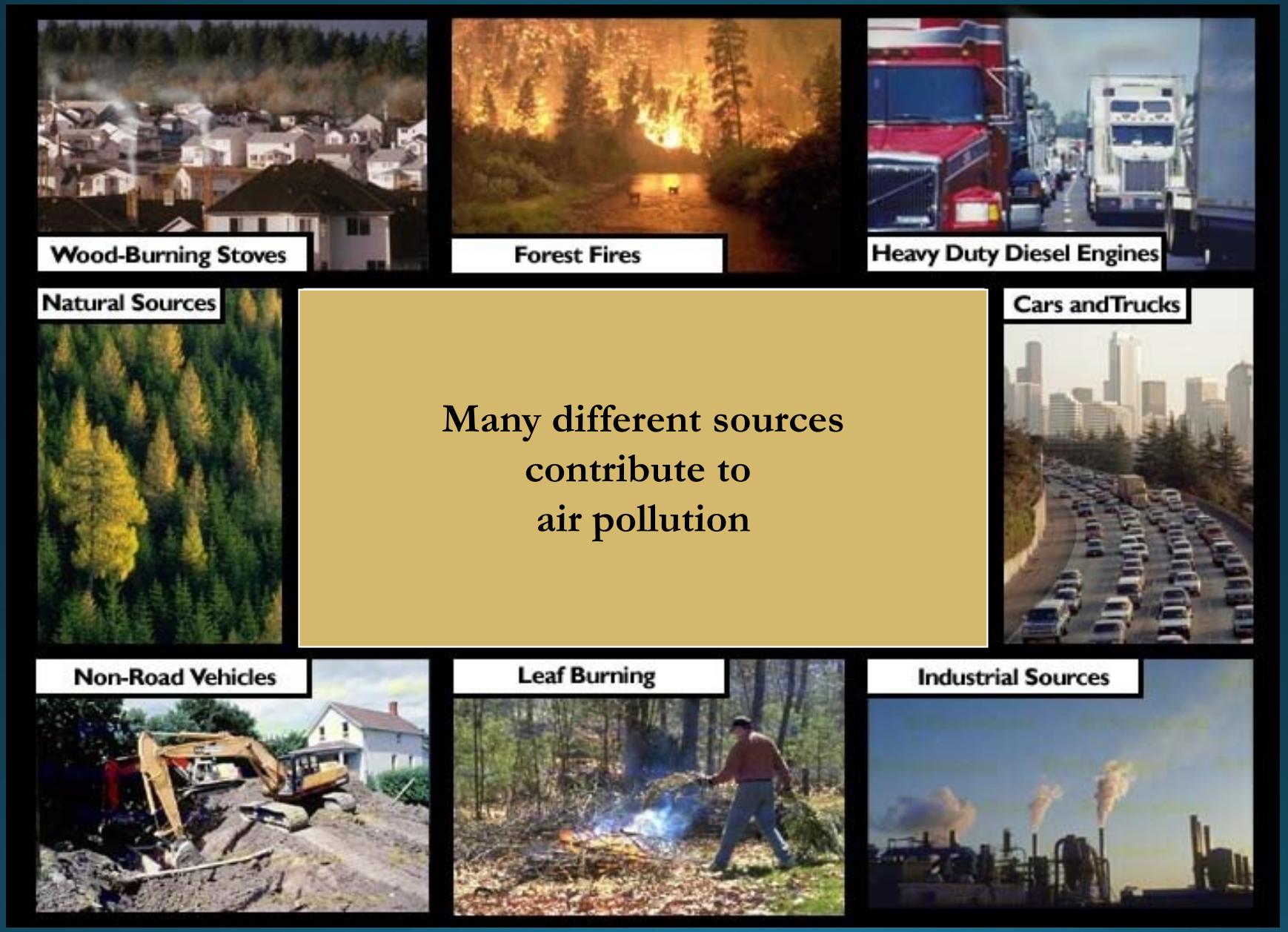
Credit: Yang Zhang, NC State

O_3: Good Up High and Bad Nearby

- **Tropospheric Ozone** (ground-level) – Bad, it is harmful to breathe and it damages crops, trees and other vegetation
- **Stratospheric Ozone** – Good, it protects life on Earth from the sun's harmful ultraviolet (UV) rays

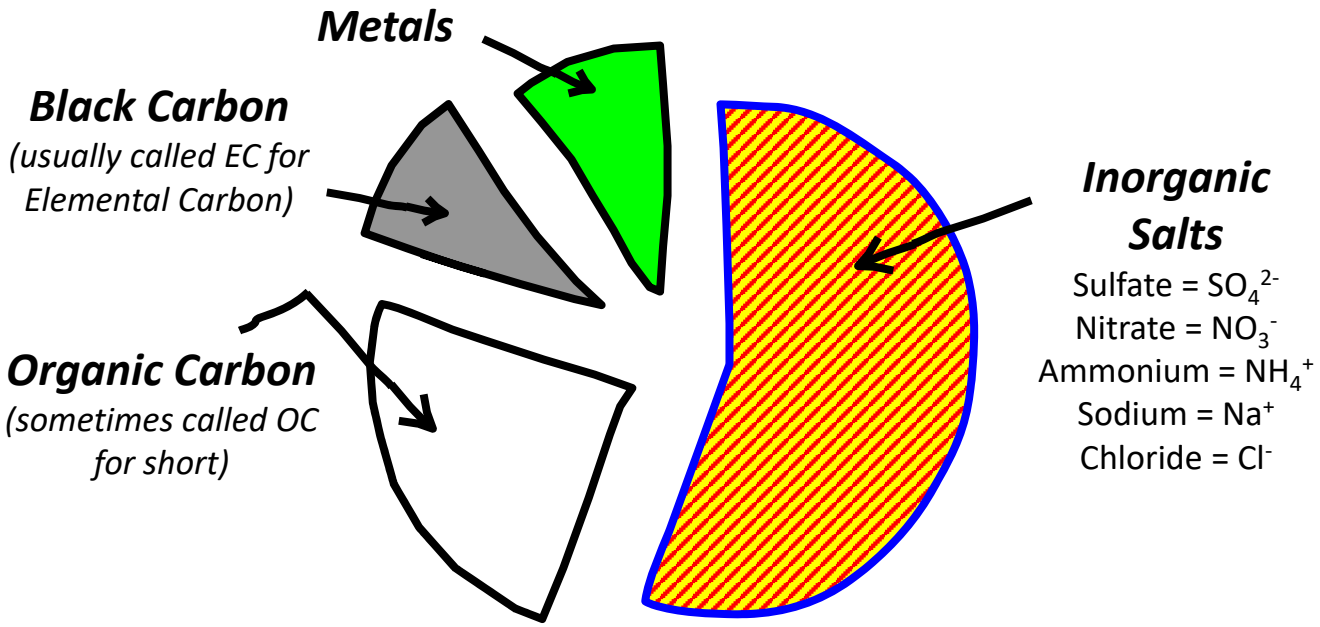
NAAQS: 65 ppb

Source: http://www.epa.gov/oar/oaqps/gooduphigh/ozone.html#good Credit: Yang Zhang, NC State



Source: Jim McGraw, IDNR

Typical Chemical Makeup



#1 Chemical Contribution = “Salts”

Ammonium Nitrate

Ammonium Sulfate

- **Formed IN THE ATMOSPHERE – called <u>Secondary</u> Particulate Matter**
- Ultimate sources
  - Ammonia
  - Nitrogen Oxides (NOx, NO and NO_2)
  - Sulfur Dioxide

<u>Image Sources</u>
www.hottdealss.com/Ammonium%20nitrate.html
www.irmteam.com/html/prod_210024sfluid.html

#2 Chemical Contribution = Carbonaceous Materials

Organic Carbon (OC)

Black Carbon (EC)

- Primary and Secondary
- Ultimate Sources: Incomplete Combustion, Solvent and Fuel Vapors, Vegetation

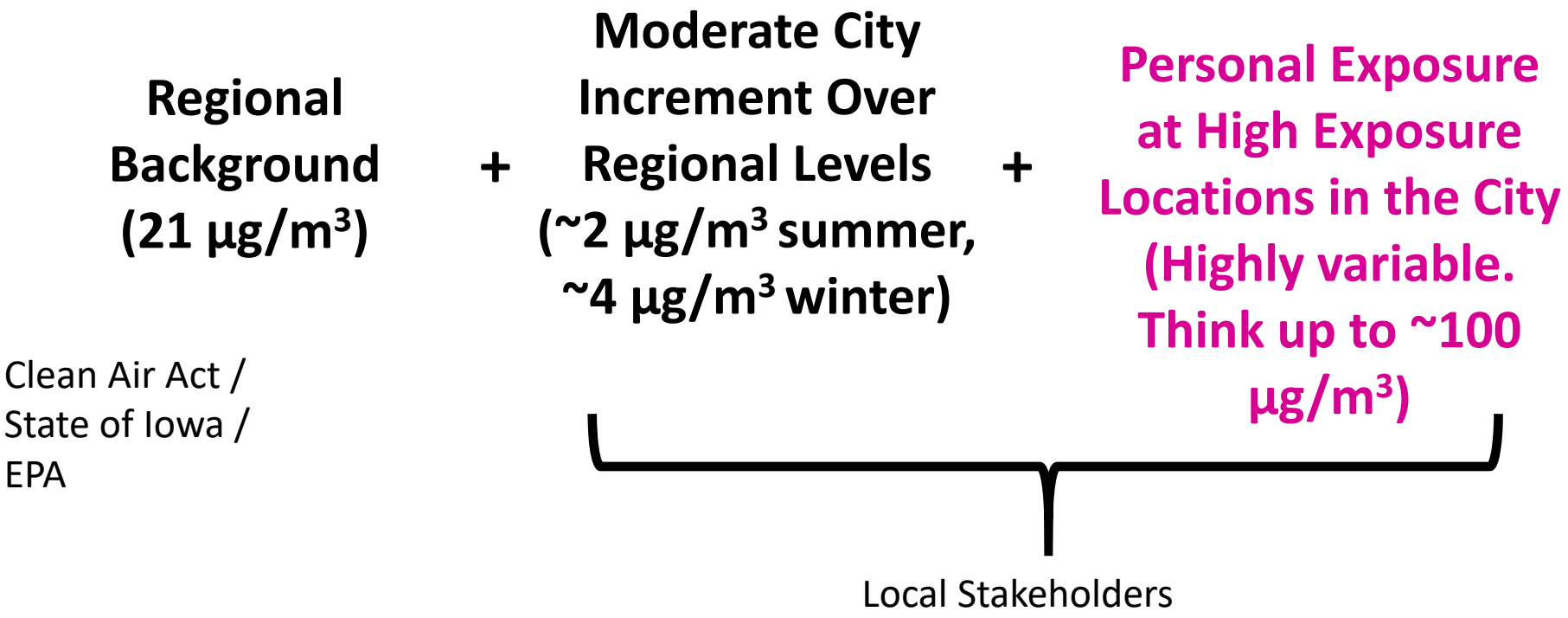
- Primary
- Ultimate Source: Incomplete Combustion

Image Sources www.honorrunchem.com/Sodium_Benzoate.html
www.jiaodakaida.com/cpshow.php?id=57
www.allproducts.com/manufacture100/sfsd/product1.html

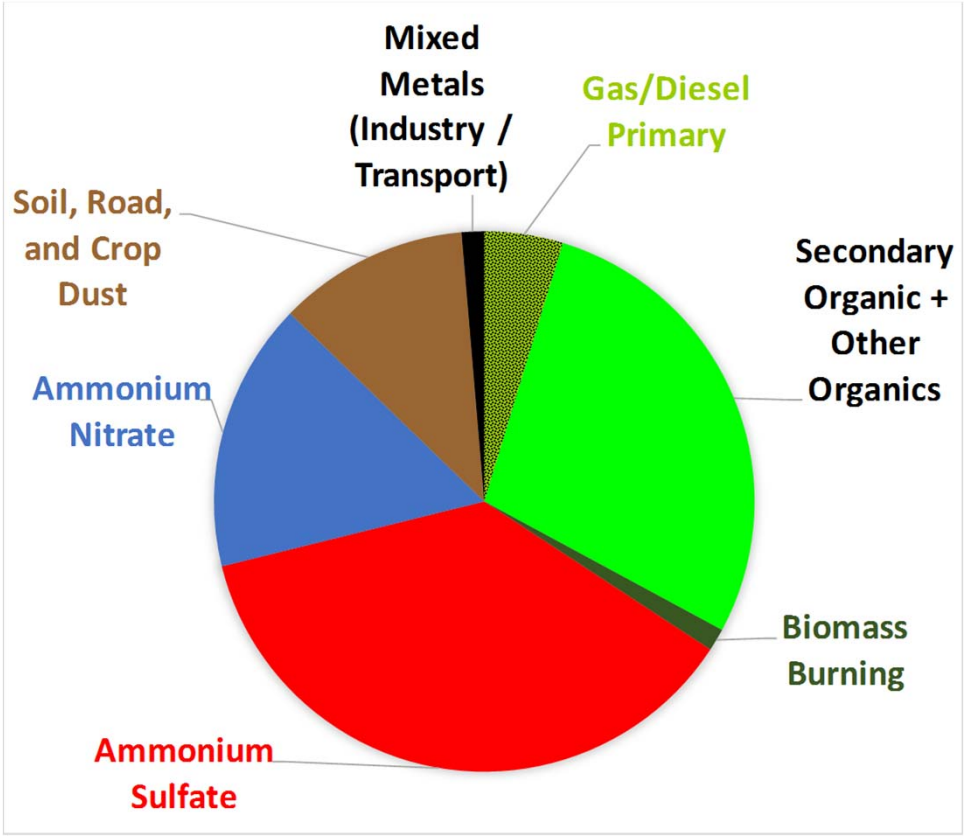
Quick Review…

PM2.5 Species	Primary or Secondary?	Notes
Nitrate	Secondary	#1 in winter Ultimate source: NOx from combustion
Organic Carbon (OC)	Secondary and Primary	#2 year round Variety of sources
Sulfate	Secondary	#1 in summer Ultimate source: Sulfur dioxide (SO2) from combustion
Ammonium	Characteristics of both secondary and primary	Important year round Ultimate source: ammonia gas emissions from fertilizer, manure, automobiles, and wastewater
Metals	Primary	Road and soil dust; Combustion; Industrial emissions; Tire and brake wear
Black Carbon (EC)	Primary	Incomplete Combustion

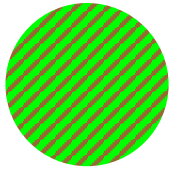
Where does PM come from and how to reduce it?



Where does PM come from and how to reduce it? (Summer during an episode)



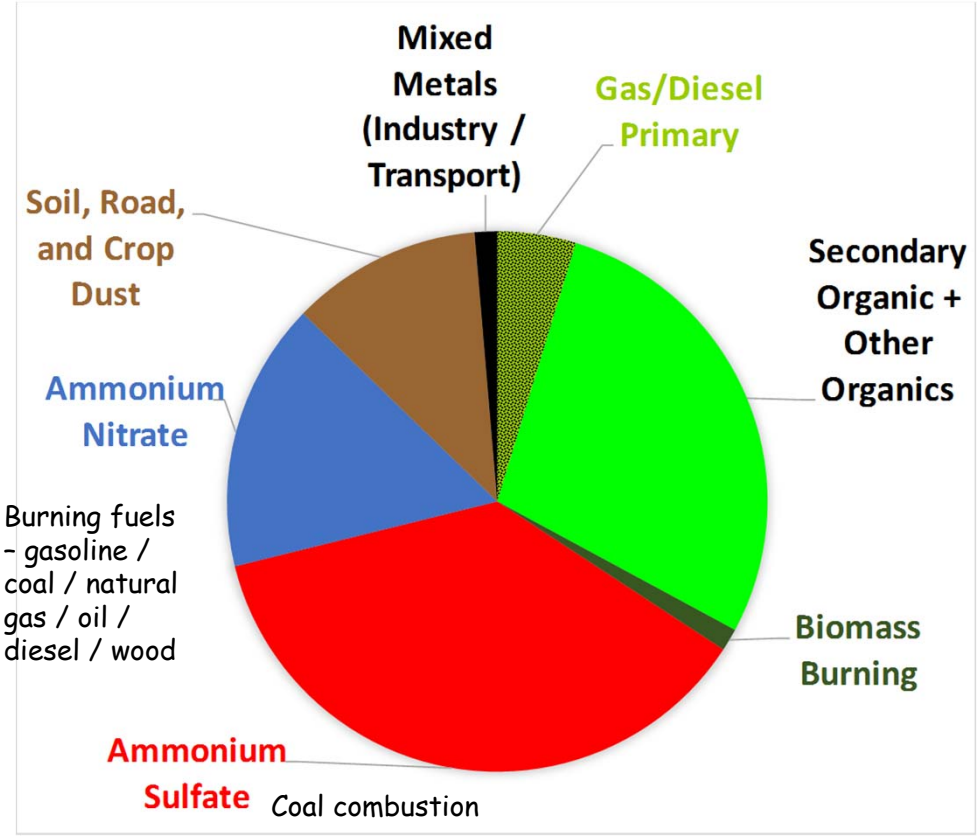
Regional Background (21 µg/m3)



Moderate City Increment Over Regional Levels (~2 µg/m3)

Personal Exposure at Hot Spots In the City

Where does PM come from and how to reduce it? (Summer during an episode)



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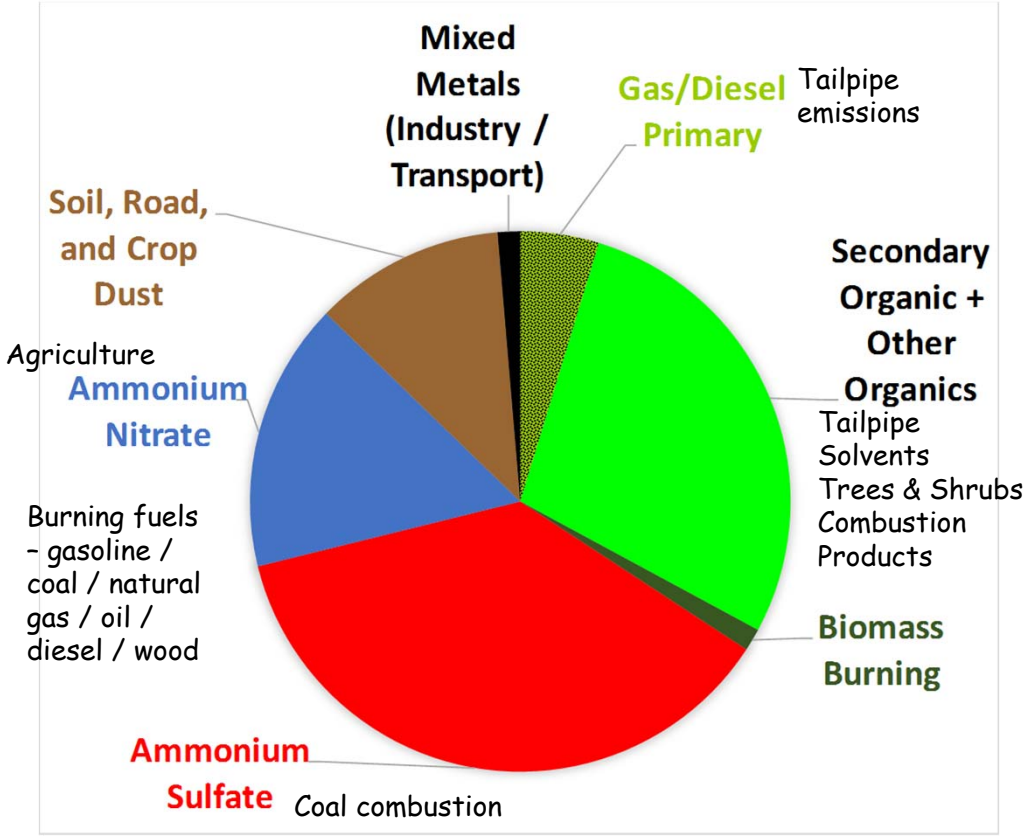

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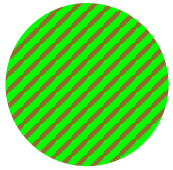

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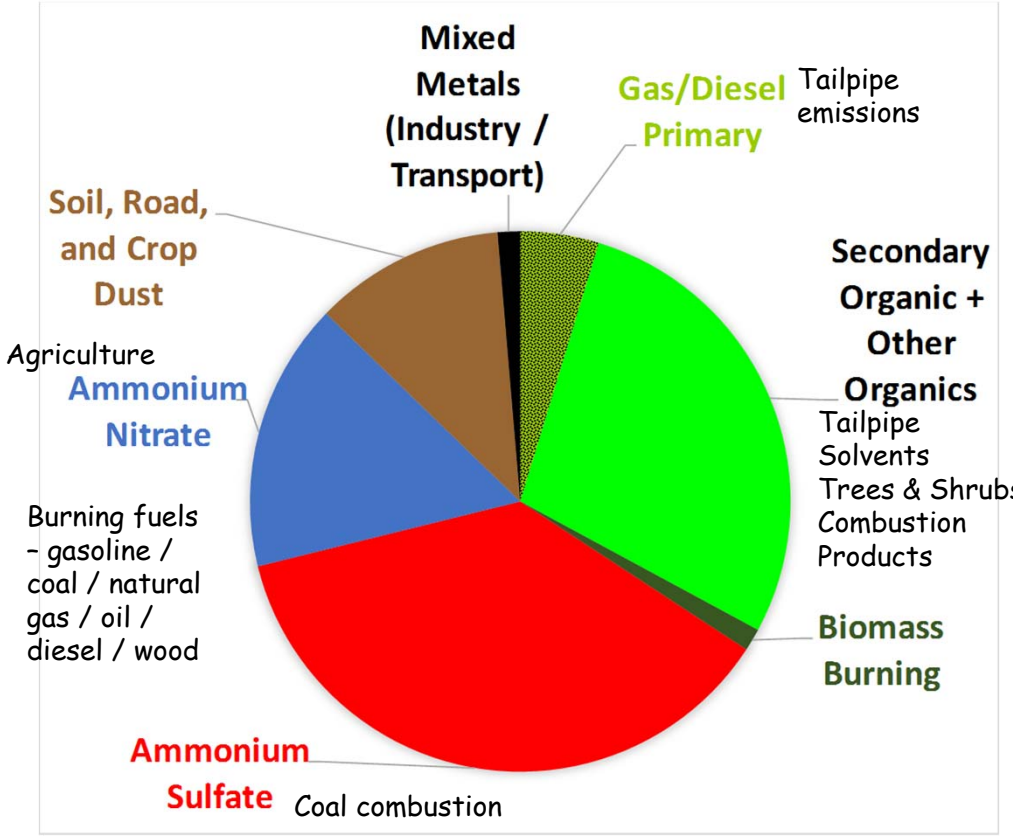
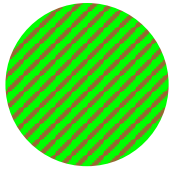


Regional Background (21 µg/m3)

- Burning (Wood, Charcoal, Trash, Brush, etc)
- Food Cooking
- On Road Vehicles
- Off Road Vehicles
- Small & Recreational Engines
- Cigarette Smoke
- Dust
- Construction Activity
- Local Industrial Emissions
- Fireworks



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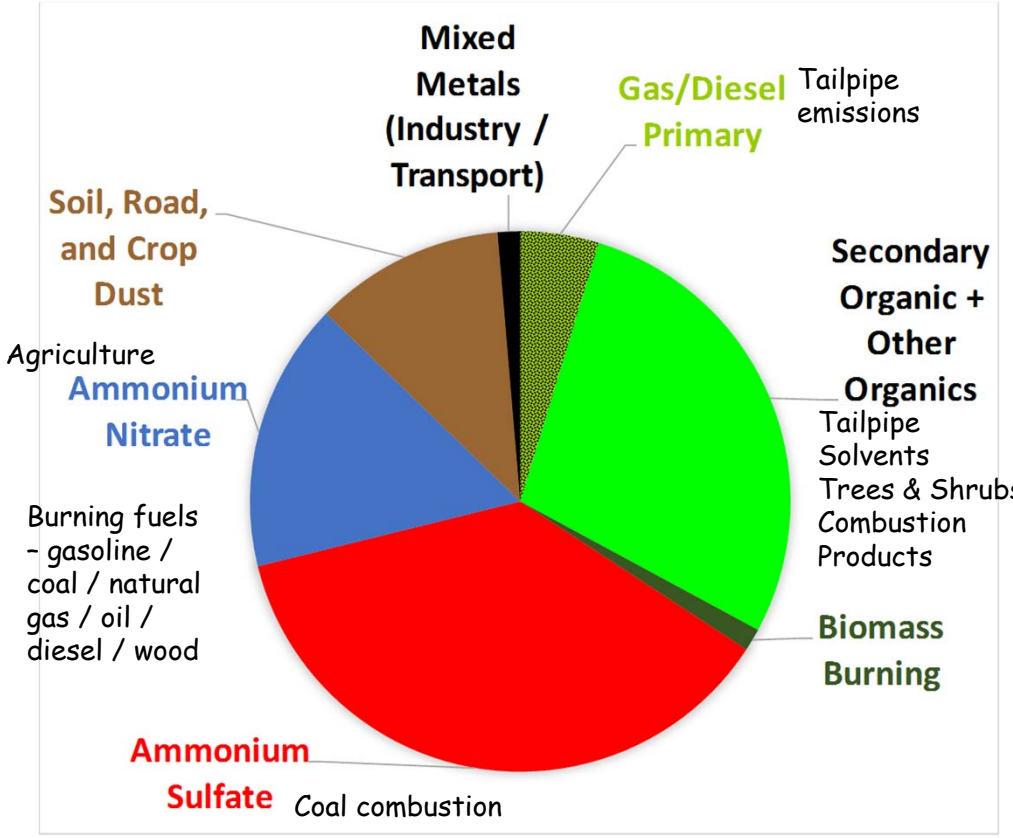

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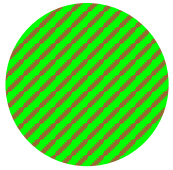
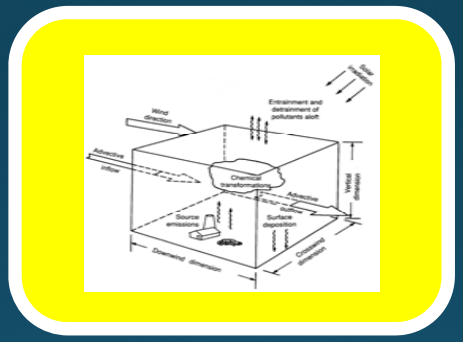


Moderate Increment Over Regional Levels (~2 µg/m3)

- Being in close proximity to sources at left
- Indoor Air Pollution (e.g. smoking, cooking, candles incense, crafts, kerosene heat)

Personal Exposure at Hot Spots In the City

"C" the processes that control concentrations in the atmosphere



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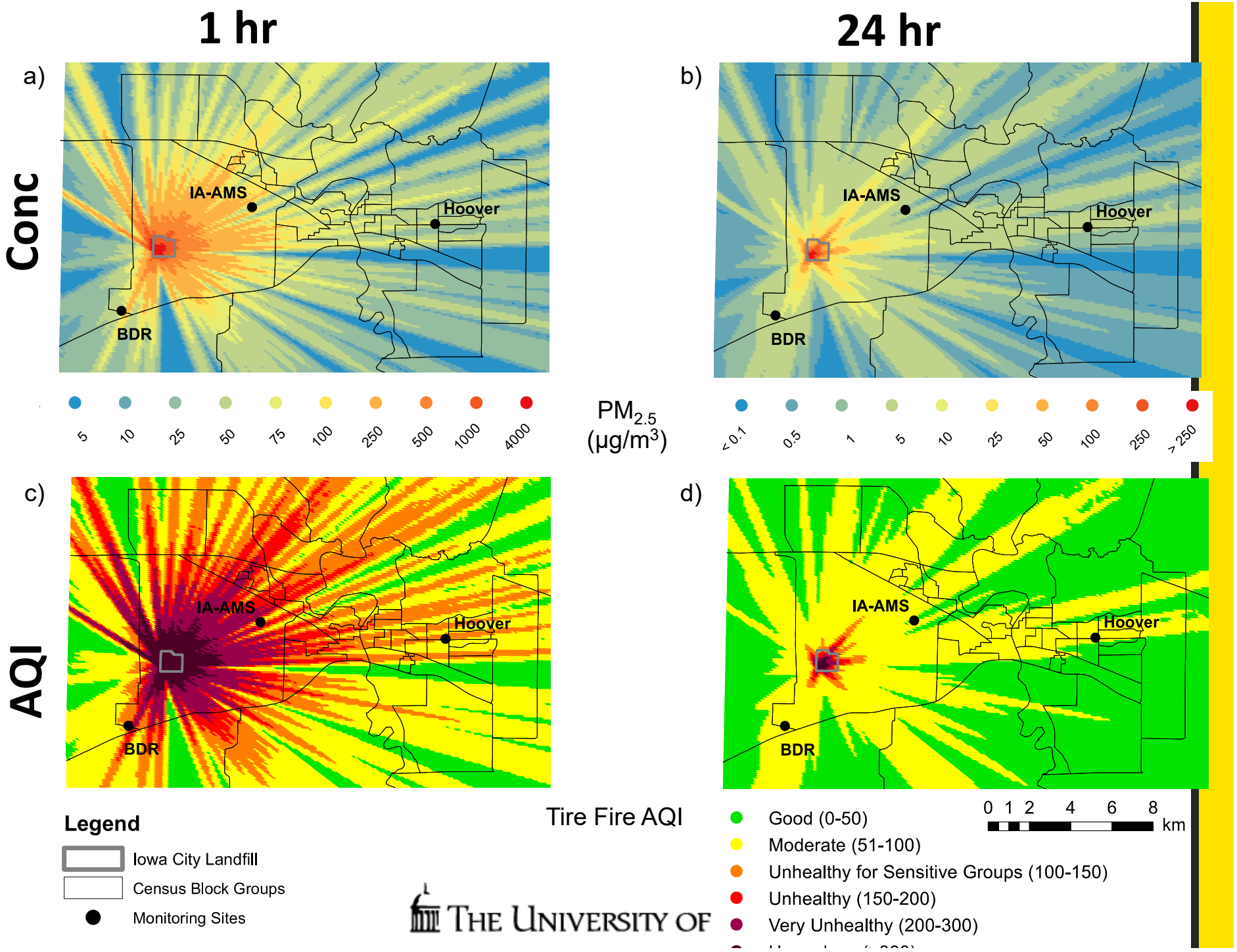
2012 Iowa City Landfill Fire

1. In a populated area
2. $PM_{2.5}$: 2000 µg/m^3 < 1 mile radius (for short term < 5 min) and 71 µg/m^3 7 miles downwind site (1 hr avg.)
3. Carcinogenic VOC enhanced from background by factor of 10.
4. Total PAH enhanced from background by factor of 180.

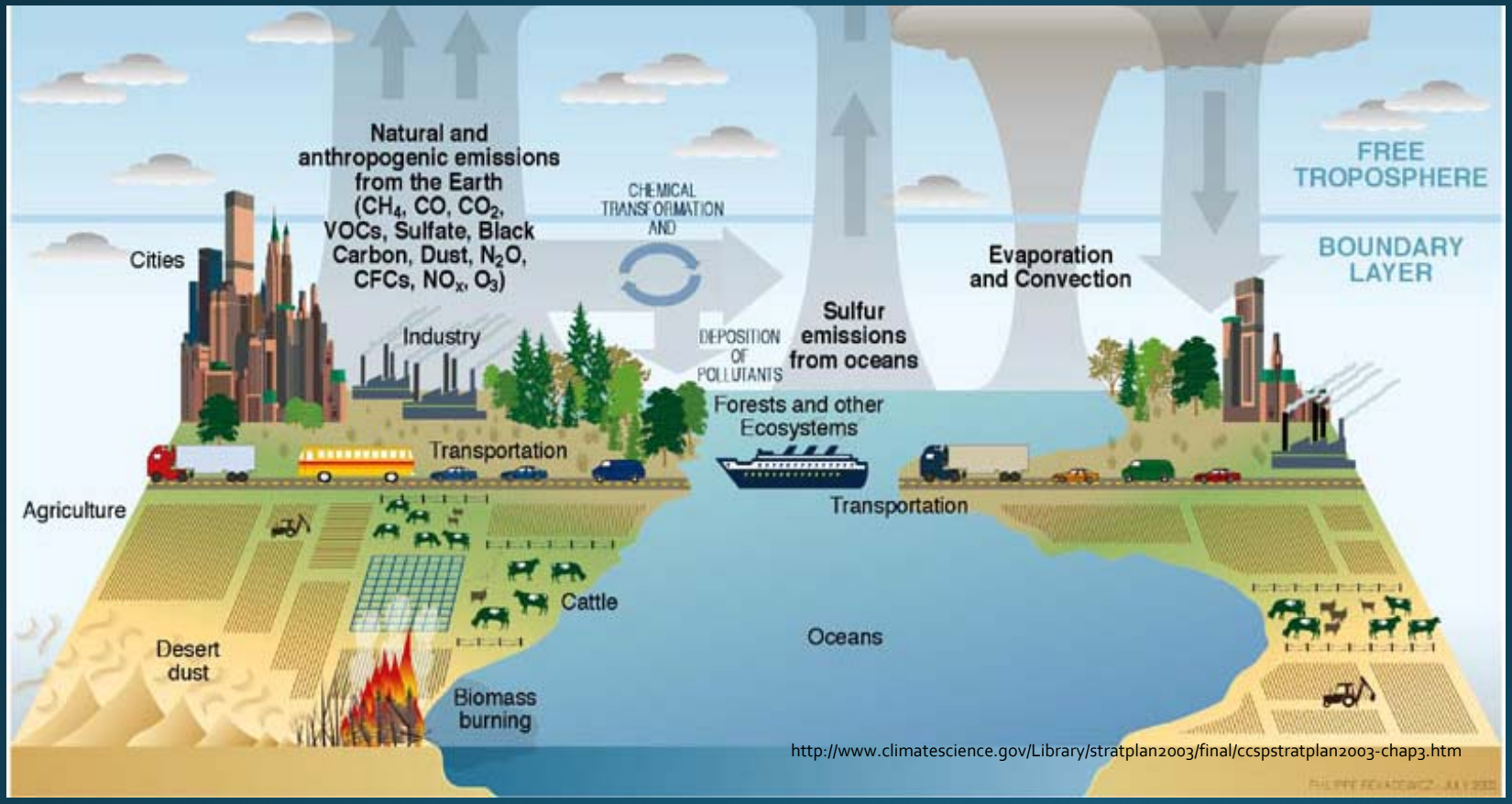





Charles Stanier


1 hr
24 hr
a)
b)
c)
d)
Conc
AQI
IA-AMS
Hoover
BDR
5
10
25
50
75
100
250
500
1000
4000
PM2.5 (µg/m3)
< 0.1
0.5
1
5
10
25
50
100
250
> 250
Legend
Iowa City Landfill
Census Block Groups
Monitoring Sites
Tire Fire AQI
Good (0-50)
Moderate (51-100)
Unhealthy for Sensitive Groups (100-150)
Unhealthy (150-200)
Very Unhealthy (200-300)
0 1 2 4 6 8
km
THE UNIVERSITY OF

Air Pollution Processes

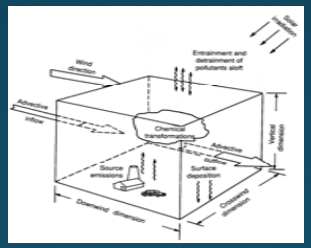


Key processes:

- Boundary layer height / mixing height
- Radiation
- Clouds and Precipitation
- Emissions
  - Anthropogenic vs. Biogenic vs. Biomass Burning
  - Primary vs. Secondary
- Deposition
- Chemical Transformations
  - Those that control ozone concentrations
  - Those that create sulfate aerosol
  - Those that create secondary organic aerosol
  - Those that create ammonium nitrate aerosol
- Aerosol Thermodynamics

Mentimeter Q2

“D” Measurement and categorization of air quality – the Air Quality Index



Air Quality Index (AQI) Values	Levels of Health Concern
When the AQI is in this range:	*...air quality conditions are:*
0-50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151 to 200	Unhealthy
201 to 300	Very Unhealthy
301 to 500	Hazardous

Measurement Stations (Certified Data)

New smaller electronic sensors exist but with significant accuracy, precision, calibration, and drift issues

Figure 2.1.6-1. Met One model 831 oriented in its shelter with the lid up.

Williams, R., Kaufman, A., Hanley, T. & Rice, J. *Evaluation of Field-deployed Low Cost PM Sensors*. (2014).

NPR
http://www.npr.org/sections/alltechconsidered/2015/07/29/427462846/some-google-street-view-cars-now-track-pollution-levels?utm_medium=RSS&utm_campaign=news

Foobot, Indoor Air Quality Monitor Oct 1, 2015
by Foobot
$199.00 Prime
Get it by Tomorrow, May 21
More Buying Choices
$199.00 new (4 offers)
$999.99 used (1 offer)

Dylos DC1100 Standard Laser Air Quality Monitor
by Dylos
$199.99
Prime
Get it by Tomorrow, May 21
More options available:
$199.99 Other Sellers

Awair: Smart Air Quality Monitor with LED display
by Bitfinder
$199.00 Prime
Get it by Tomorrow, May 21
More Buying Choices
$199.00 new (2 offers)

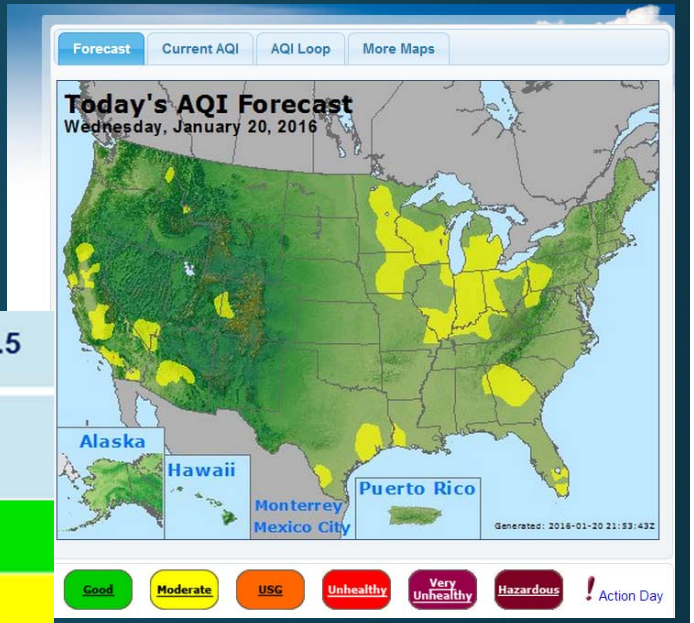
Air Mentor PRO A 6-in-1 Indoor Air Quality Monitor (8096-AP)
by Coasia
$183.00 used (1 offer)

Air Quality Egg

Featured
$169 USD + Shipping

Air Quality Index

Air Quality Index (AQI) Values	Levels of Health Concern	Colors	24 hr ave PM2.5
When the AQI is in this range:	*..air quality conditions are:*	*...as symbolized by this color:*	*ug/m3*
0-50	Good	Green	0 - 12
51-100	Moderate	Yellow	12.1 -35.4
101-150	Unhealthy for Sensitive Groups	Orange	35.5 – 55.4
151 to 200	Unhealthy	Red	55.5 – 150.4
201 to 300	Very Unhealthy	Purple	150.5 – 250.4
301 to 500	Hazardous	Maroon	250.5 – 500.4



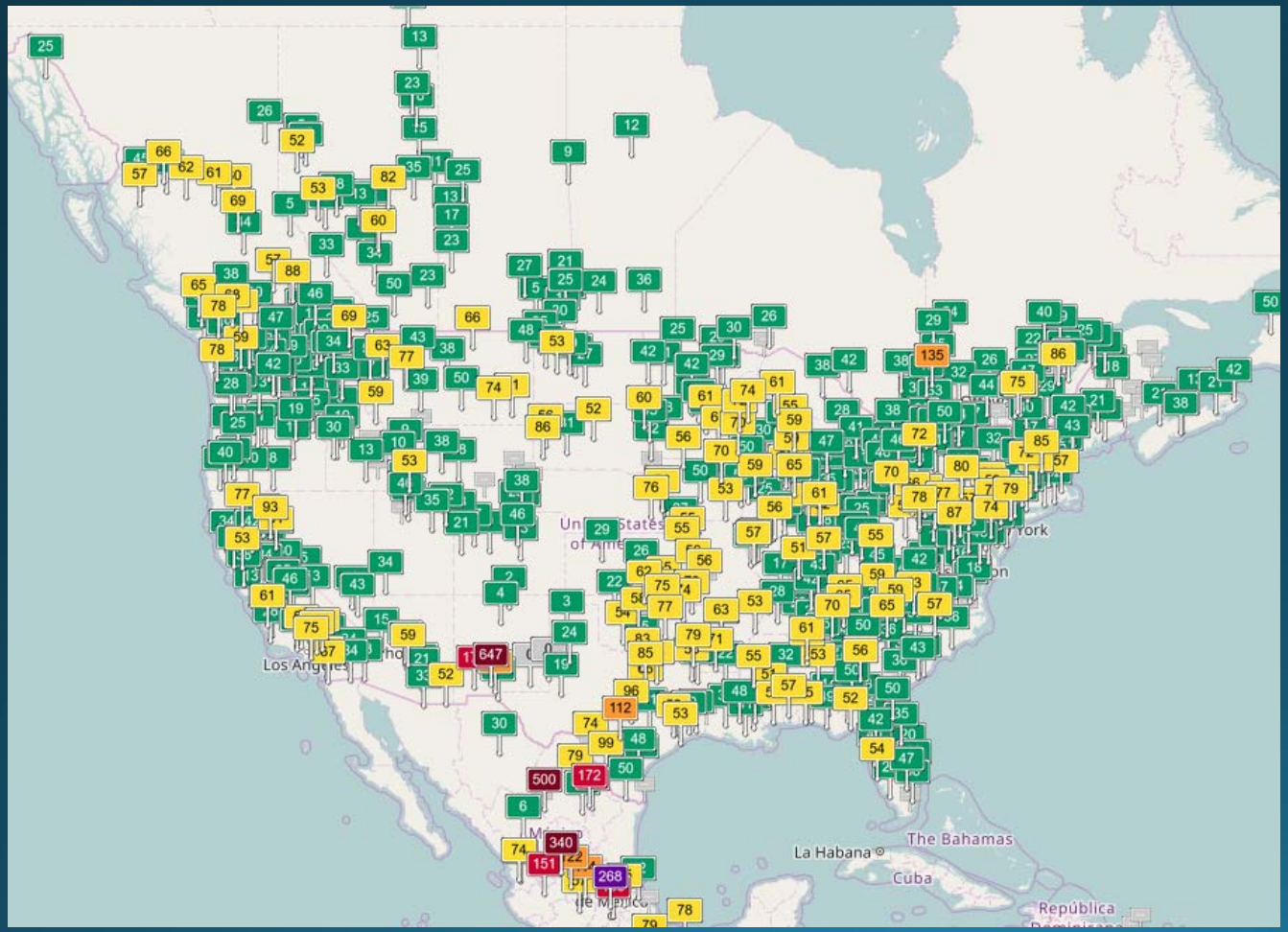
Air Quality Index (AQI) is used by government agencies to tell the public how clean or polluted the air currently is.

http://www.airnow.gov/

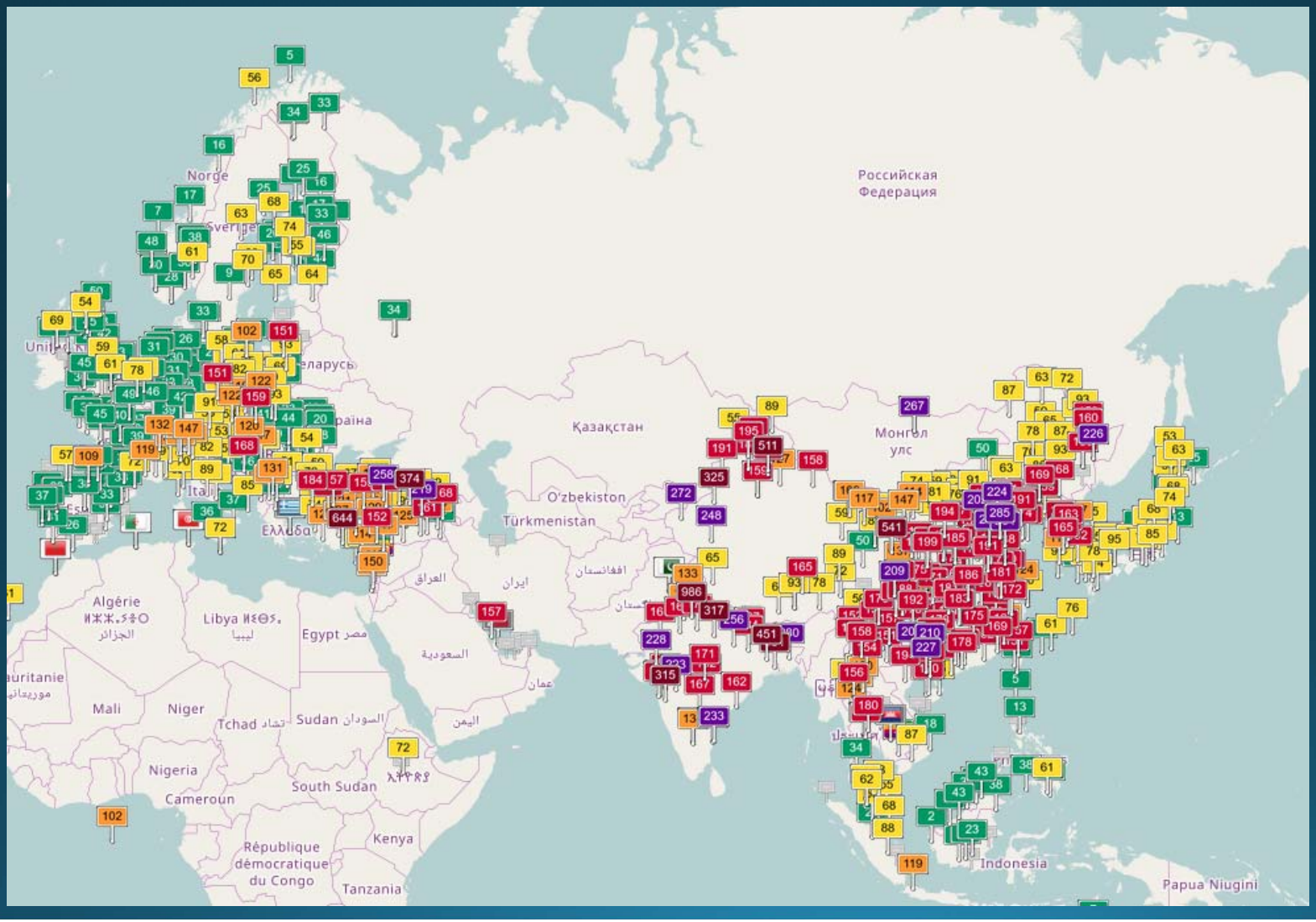
Recommendations for each level of AQI

Category	Health Effects	Caution Statement	Other Protective Actions
Good	None Expected	None	None
Moderate	Possible aggravation of heart or lung disease	Unusually sensitive individuals should consider limiting prolonged or heavy exertion • Pay attention to symptoms • If symptoms, contact health care provider (repeated cough, shortness of breath, difficulty breathing, wheezing, chest tightness or pain, palpitations, nausea, unusual fatigue or lightheadedness)	If symptomatic, reduce exposure to particles by • Closing doors and windows • Avoid using exhaust fans • Keep garage-to-home door closed • If using central air, turn to "recirculate" if that's an option • Avoid using whole house fans • Avoid indoor air pollutants (tobacco smoke, heating with wood stoves and kerosene heaters, frying or broiling food, burning candles, vacuuming, paints, solvents, cleaning products, adhesives)
Other levels – see our CLE4R Website			

AQI Values – North America 12:30 PM Today (Iowa City AQI 36)



Asia and Europe at the Same Time



Charles.stanier@gmail.com

CLE4R

CLEan Air in the River Valley

Environmental Education | Technology
Partnerships | Planning

Thank You!