Biomass Pollution Basics

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Outline

- Biomass burning basics
  - combustion
  - pollutants emitted
- Particulate matter (PM)
  - types, sizes, and sources
  - human health effects
- Carbon monoxide (CO)
  - sources
  - human health effects

Wood is natural
Burning is natural

How can wood burning be a significant health hazard?

Wood is mainly just carbon, hydrogen, and oxygen: $[CH_2O]_x$

Combustion: $CH_2O + O_2 \rightarrow CO_2 + H_2O$ + heat

Why doesn't wood emit only CO_2 and H_2O when it is burned?

Answer: Incomplete combustion – unavoidably, some of the wood carbon is not completely combusted into CO_2

Pollutants in Solid Fuel Smoke

(many hundreds)

Biomass burning emits many products of incomplete combustion:

- Small particles, CO, NO_2
- Formaldehyde, Acrolein, Benzene, Toluene, Styrene, 1,3-Butadiene, etc.
- Polyaromatic hydrocarbons

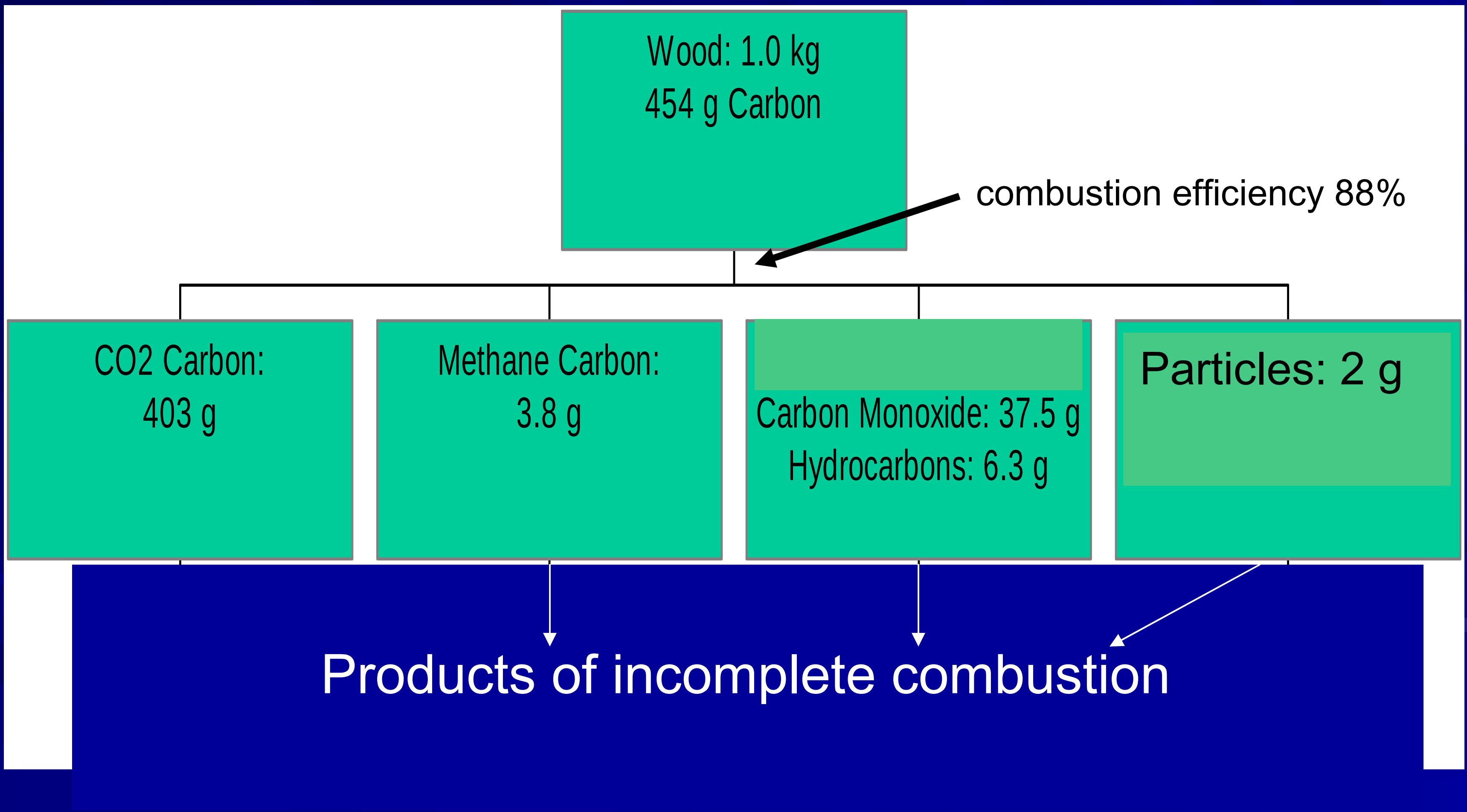
A Few of the Chemicals in Woodsmoke (~g/kg emission factors)

Carbon Monoxide	80-370
Methane	14-25
VOCs (C2-C7)	7-27
Aldehydes	0.65.4
– Formaldehyde	0.1-0.7
– Acrolein	0.02-0.1
– Propionaldehyde	0.1-0.3
– Butryaldehyde	0.01-1.7
– Acetaldehyde	0.03-0.6
– Furfural	0.2-1.6 1.6
Substituted Furans	*0.15-1.7*
Benzene	0.6-4.0
Alkyl Benzenes	1-6
Toluene	0.15-1.0
Acetic Acid	1.8-2.4
Formic Acid	0.06-0.08
Nitrogen Oxides (NO,NO2)	0.2-0.9
Sulfur Dioxide	0.16-0.24
Methyl chloride	0.01-0.04
Napthalene	0.24-1.6
Substituted Napthalenes	0.3-2.1
Oxygenated Monoaromatics	1 - 7
– Guaiacol (and derivatives)	0.4-1.6
– Phenol (and derivatives)	0.2-0.8
– Syringol (and derivatives)	0.7-2.7
– Catechol (and denvatives)	0.2-0.8
Particulate Organic Carbon	2-20
Chlorinated dioxins	1xl0-5 - 4x10-5
Particulate Acidity .	7x10-3 - 7x10-2
Normal alkanes (C24-C30)	1x10-3 - 6x10-3

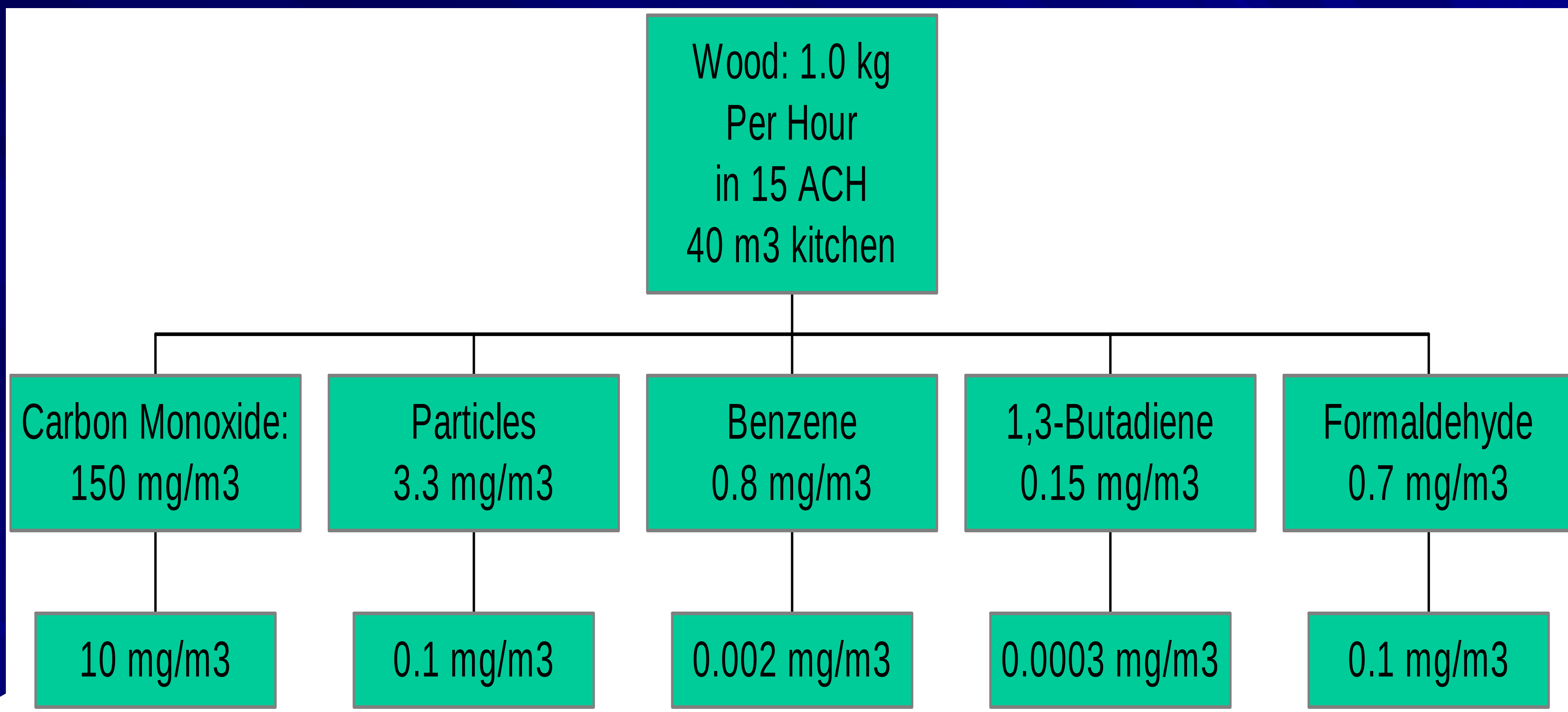
Oxygenated PAHs	0.15-1
Polycyclic Aromatic Hydrocarbons (PAH)	
Fluorene	4x10-5 - 1.7x10-2
Phenanthrene	2x10-5 - 3.4x10-2
Anthracene	5x10-5 - 2.1x10-5
Methylanthracenes	7xl0-5 - 8x10-5
Fluoranthene	7xl0-4- 4.2xl0-2
Pyrene	8x10-4 - 3.1x10-2
Benzo(a)anthracene	4x10-4 - 2x10-3
Chrysene	5x104- 1x10-2
Benzofluoranthenes	6x10-4- 5x10-3
Benzo(e)pyrene	2x104 - 4x10-3
Benzo(a)pyrene	3x104- 5x10-3
Perylene	5x10-5 - 3x10-3
Ideno(1,2,3-cd)pyrene	2xl0-4- 1.3x10-2
Benz(ghi)perylene	3x10-5- 1.lx10-2
Coronene	8x10-4- 3x10-3
Dibenzo(a,h)pyrene	3x104- lx10-3
Retene	7x10-3 - 3x10-2
Dibenz(a,h)anthracene	2x10-5 - 2xl0-3
Trace Elements	
Cr	2x10-5 - 3x10-3
Mn	7xl0-5 - 4x10-3
Fe	3x10-4 - 5x10-3
Ni	lxl0-6 - lx10-3
Cu	2x10-4 - 9x10-4
Zn	7xl0-4 - 8x10-3
Br	7x10-5 - 9x10-4
Pb	lx10-4 -3x10-3
Elemental Carbon	0.3 - 5
Cyclic di-and triterpenoids	
Dehydroabietic acid	0.01 - 0.05
Isopimaric acid	0.02 - 0.10
Lupenone	2x10-3 - 8x10-3
Friedelin	4x10-6 - 2x10-5

USEPA

Products of incomplete combustion: typical wood-fired cookstove (in India)



Typical indoor pollution concentrations from a typical wood-fired cookstove:



Typical standards to protect health

Clarifying Questions?

The best pollutants to measure for biomass combustion

1. Small particles (also called particulate matter, PM)
2. Carbon monoxide (CO)

Airborne Particles: *In Brief (1)*

- Particles are a mixture of dust (solids) and liquid droplets suspended in the air
  - *All* airborne solids and liquids (except pure water)
  - Size range 0.005-100 µm (micrometers, 10^{-6} m) in diameter
  - Importance of size has been demonstrated

    -- smaller ones are more health-damaging

- Broad range of chemical species
  - Role of composition still uncertain - sulfur, acidity, metals, organics, etc.

Airborne Particles: *In Brief (2)*

- Natural and human sources
- The first measured and regulated air pollutant
- Largest global impact, mechanisms still mysterious, new standards often proposed, much ongoing research

Important Particulate Matter (PM) Characteristics

- **Emissions Rate:**
  - Amount emitted per unit of time or fuel
- **Particle Size:**
  - Determines deposition properties and which particles can enter the lungs
- **Chemical Composition:**
  - Fractional abundance of different chemical elements and compounds in emissions
- **Temporal Variation:**
  - Emissions change on daily, weekly, seasonal, and annual cycles. The timing of emissions affects their transport, dilution, and human exposure to outdoor air pollution

Sources of Particulate Matter

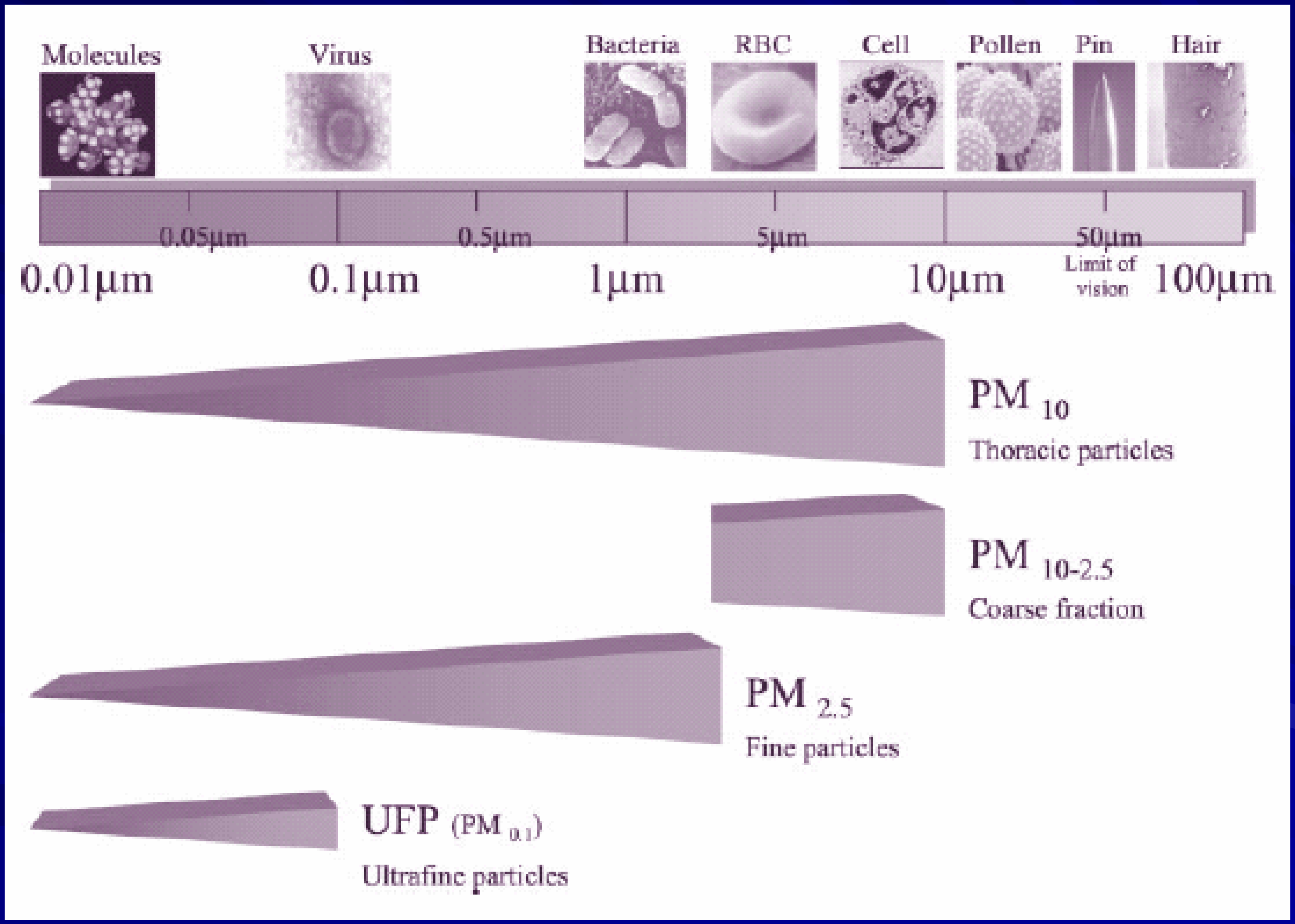
- Primary particles: emitted directly into the air
- Secondary particles: formed in the atmosphere through chemical and physical reactions
  - involving sulfur dioxide, nitrogen oxides, volatile organic compounds, and ammonia gases and sunlight

Sizes of Atmospheric Particles

- "Coarse" particles (>2.5 μm diameter)
- "Fine" particles (<2.5 μm diameter)
- "Ultrafine" particles (<0.1 μm diameter)

- How do they differ?
  - Source origins
  - Transformation
  - Removal mechanisms from the atmosphere
  - Chemical compositions
  - Optical properties
  - Respiratory tract deposition

Visualizing Particulate Matter Size



Source: Brook et al., Circulation 2004.

Coarse Particles (> 2.5 μm)

- Formed from mechanical processes
  – weathering, volcanic activities, wind blown soil, sea salt spray, pollen, grinding operations (mining)
- Given their heavy mass, they usually settle out of the air within a few hours to days

Fine Particles: (< 2.5 μm)

- Formed from:
  - Combination of smaller particles
  - Condensation of vapors onto particles that then grow
- Greatest *surface area* and most of *mass* concentration
- 0.1-2.5 μm particles are very hard to remove from the atmosphere, persisting days to weeks
- Precipitation accounts for 80% of removal
- Highly visible

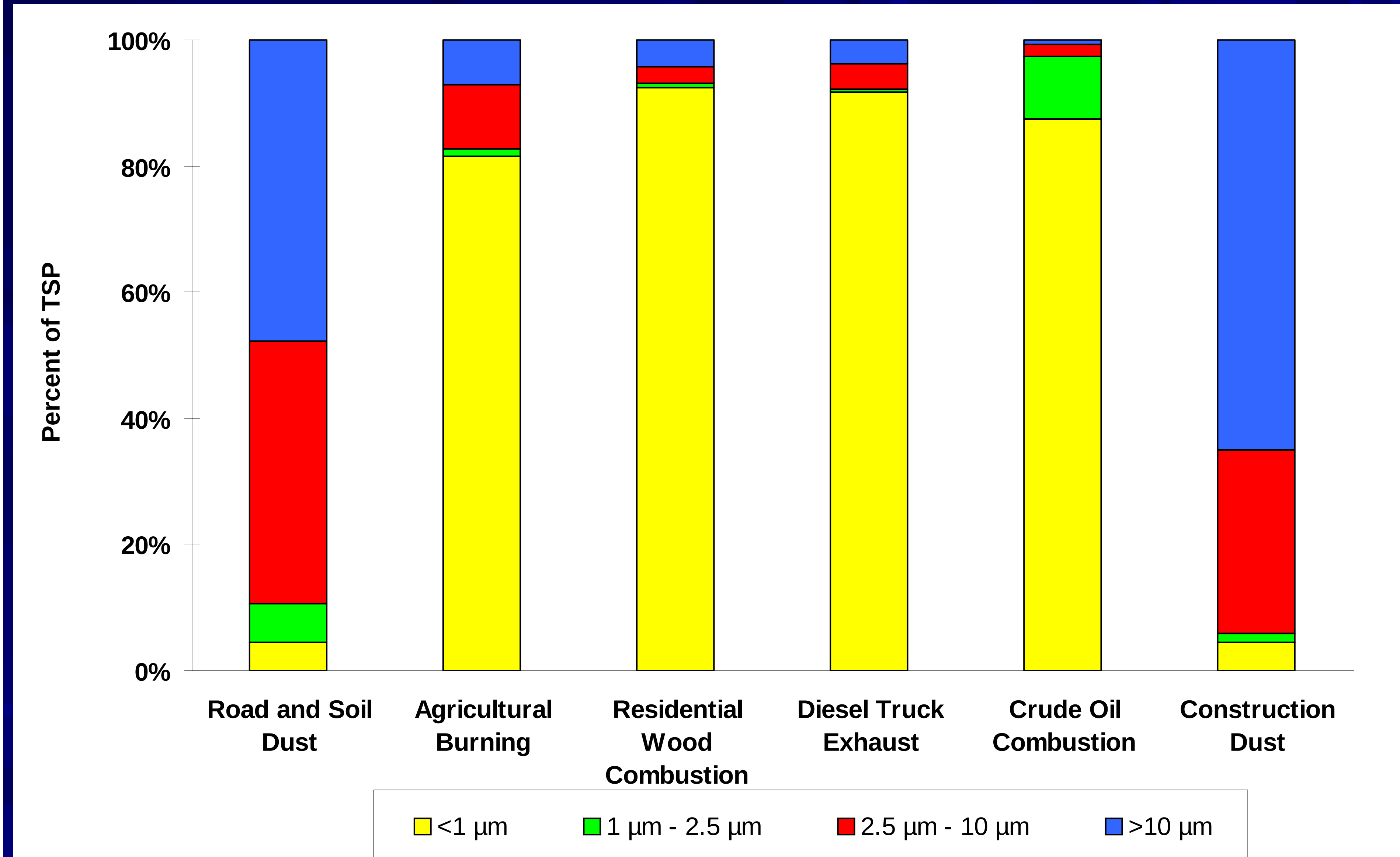
Ultrafine Particles (< 0.1 μm)

- Formed from:
  - condensation of vapors during very high temperature combustion (motor vehicles, diesel, organic vapors, fly ash)
  - combination and growth of atmospheric particles
- Greatest *number* concentration, very little mass concentration due to small size
- Short atmospheric residence time due to random motion and collisions (combining with and forming other particles)
- Not visible

Four Major Human Sources of Particulate Matter (PM)

1. Fuel combustion (including biomass burning)
2. Industrial production
3. Non-industrial sources (road dust, cropland wind erosion, construction)
4. Transportation (cars)

Size Distributions of Several PM Source Emissions



from Particulate Matter Science for Policy Makers: A NARSTO Agreement.

Size Distribution of Biomass Smoke Particles

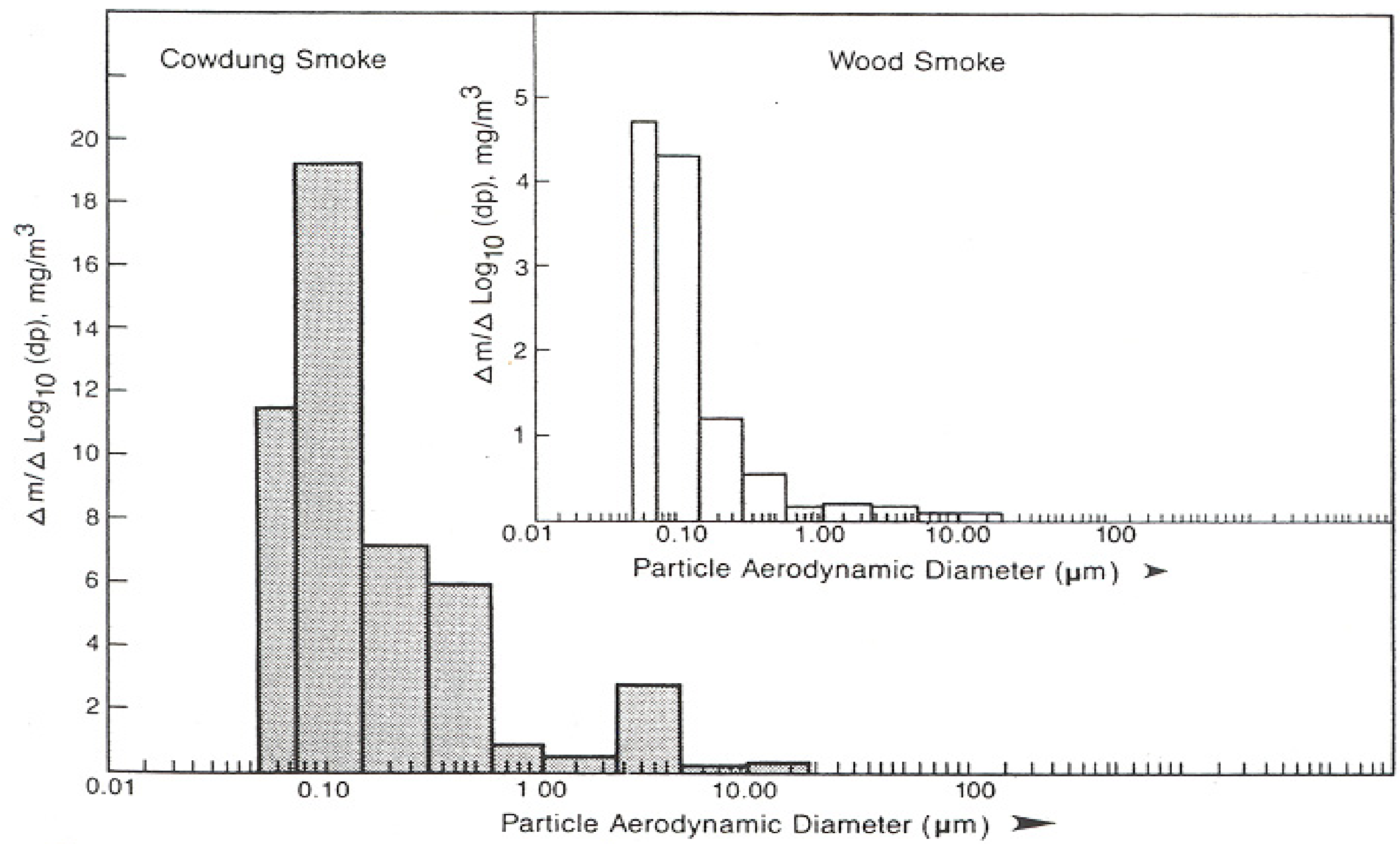
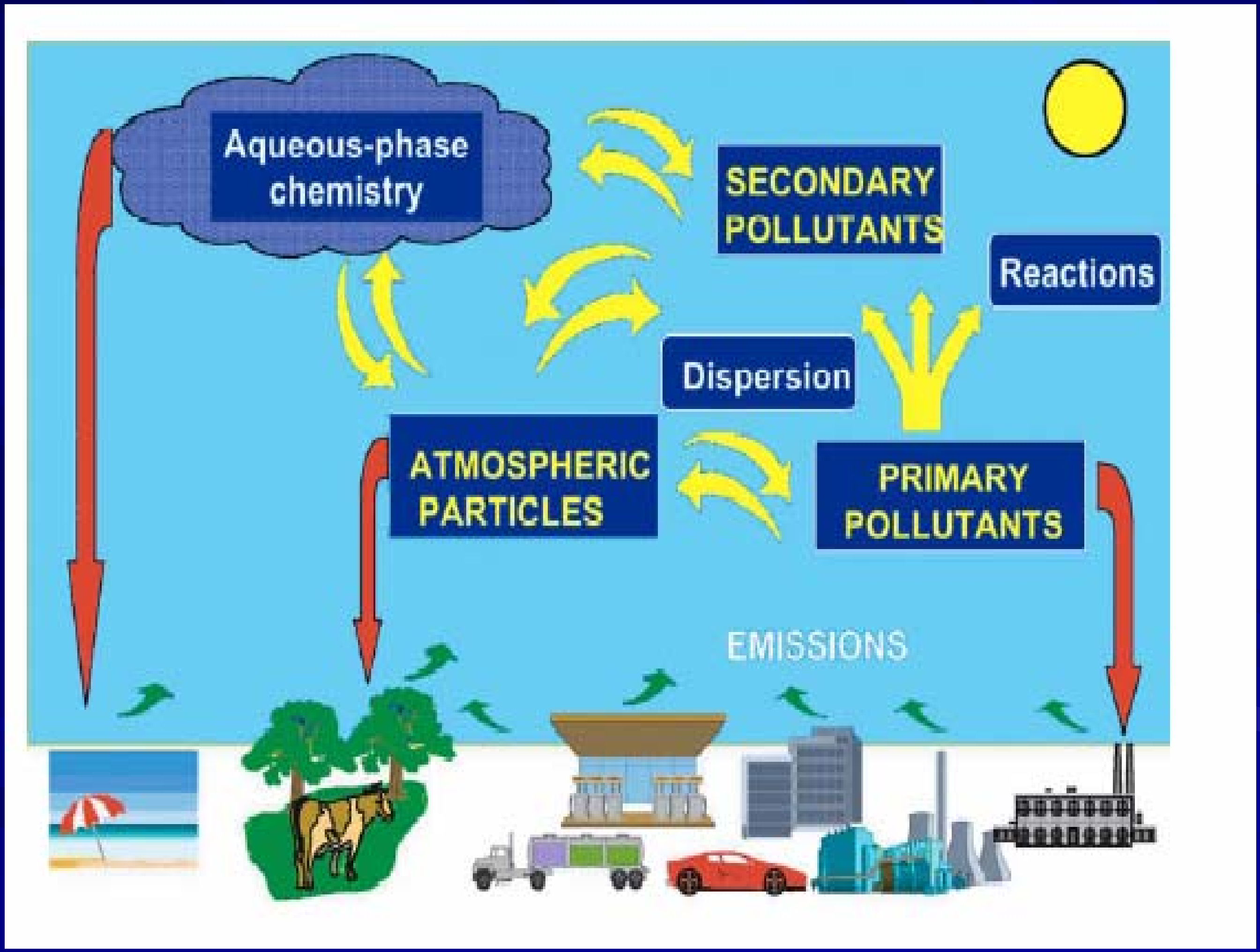


Figure 2.2. Size distribution of woodsmoke and dungsmoke particles. Measurements taken in the East–West Center simulated village house as reported in Smith *et al.* (1984b). (Figure prepared by Premlata Menon.)

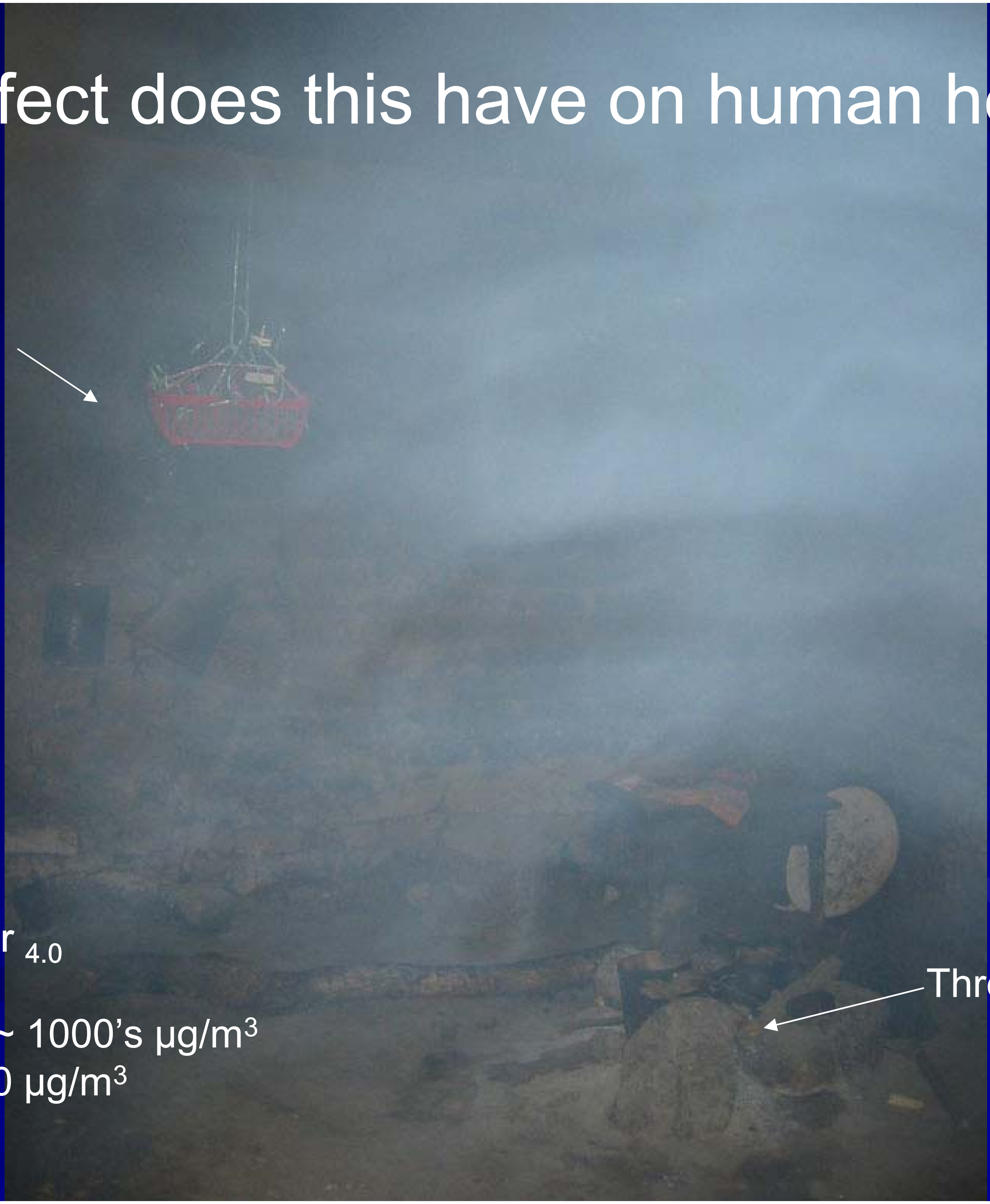
Source: KR Smith, 1987

Ambient Particulate Matter System



from Particulate Matter Science for Policy Makers: A NARSTO Agreement.

What effect does this have on human health?



Particulate Matter $_{4.0}$

Indoor open fire ~ 1000's μg/m^3
This room = 8670 μg/m^3

Particulate Matter Deposition in the Lungs

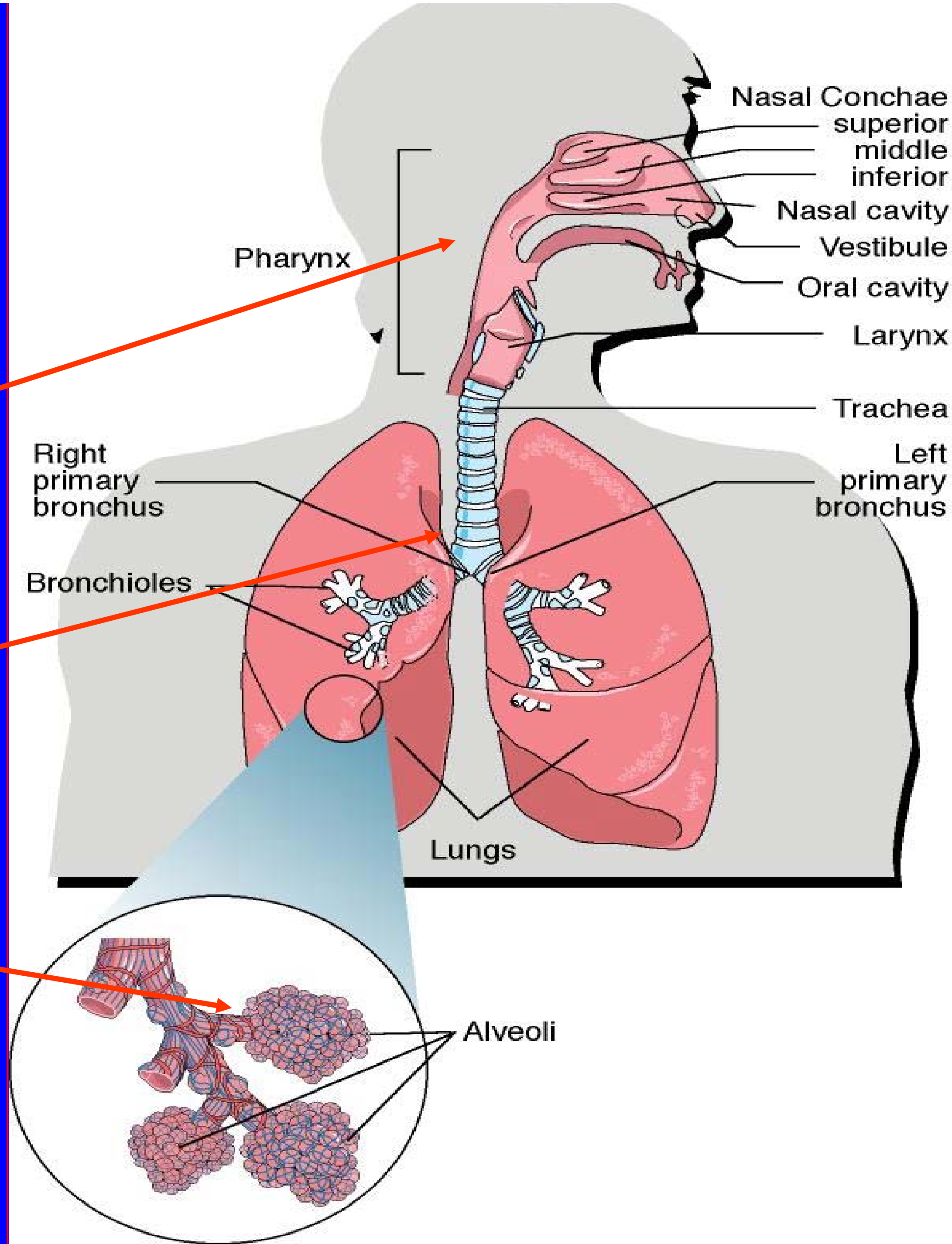
- Depends on:
  - Particle size range
  - Physical mechanisms that favor deposition at different regions which include:
    - Brownian diffusion
    - Impaction
    - Sedimentation
  - Lung structure and physiology:
    - Airway diameter, branching angles, filtration in prior compartments, ventilation rate

PM Uptake in the Human Body

Naso-oropharangeal region: large fraction of ultrafines and coarse PM removed

Tracheo-bronchial region: smaller percentages of ultrafines and coarse PM deposit

Alveolar region: fine PM penetrates and can be absorbed into the blood stream



How Does PM Effect the Respiratory System?

(1) inhibiting and inactivating mucociliary streaming

(2) killing or neutralizing alveolar macrophages

(3) constricting airways

(4) causing vasodilation and excess mucous secretion

(5) causing changes in alveolar cell wall structure through abscesses and thickening which causes scar formation

(6) traveling to other parts of the body, e.g., blood and heart

Particulate Matter Standards

PM Standards

	Time Period	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
United States EPA[a]	Daily	150	65
United States EPA[a]	Annual	50	15
California	Daily	50	Under discussion in 2002
California	Annual	20	12 (Proposed in 2002)
European Union[b]	Daily	50	Not set
European Union[b]	Annual	20	Not set

[a] Under revision.

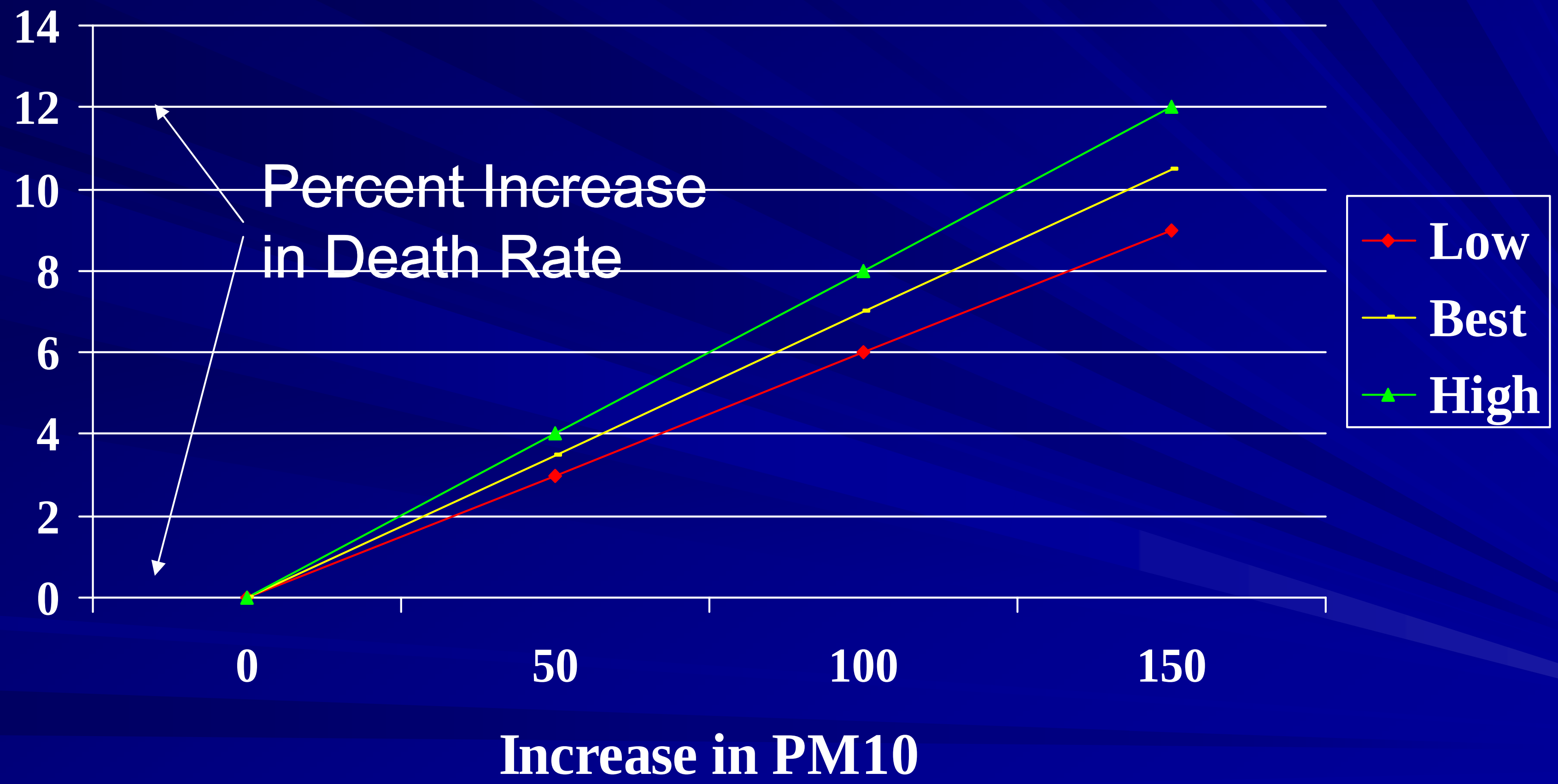
[b] To be met in 2010 (to be reviewed in 2003).

Source: Health Effects Institute Perspectives. April 2002.

Epidemiologic Evidence for Human Health Effects of PM

- Time-series studies in 90 cities in the U.S.
- Measure daily changes in ambient PM and daily morbidity and mortality patterns
- Outcome: 0.27% increase in mortality per 10 $\mu g/m^3$ increase in PM_{10}

Daily Excess Mortality from Daily PM_{10} Exposures



WHO Air Quality Guidelines, 1999

Future Epidemiologic Research Needs for Particulate Air Pollution

- How do the effects of PM differ across locations? What is the magnitude and the heterogeneity of these effects?
- What is the magnitude of "life shortening" with particle exposures? How much of this is due to "harvesting" effect?
- What are the toxic elements of the particle?
- What are the pathophysiological mechanisms or pathways that describe the exposure-outcome?

Source: Samet & Arden Pope (2003). Epidemiologic research needs for particulate air pollution. J Toxic. Environ. Health, 66: 1873-6.

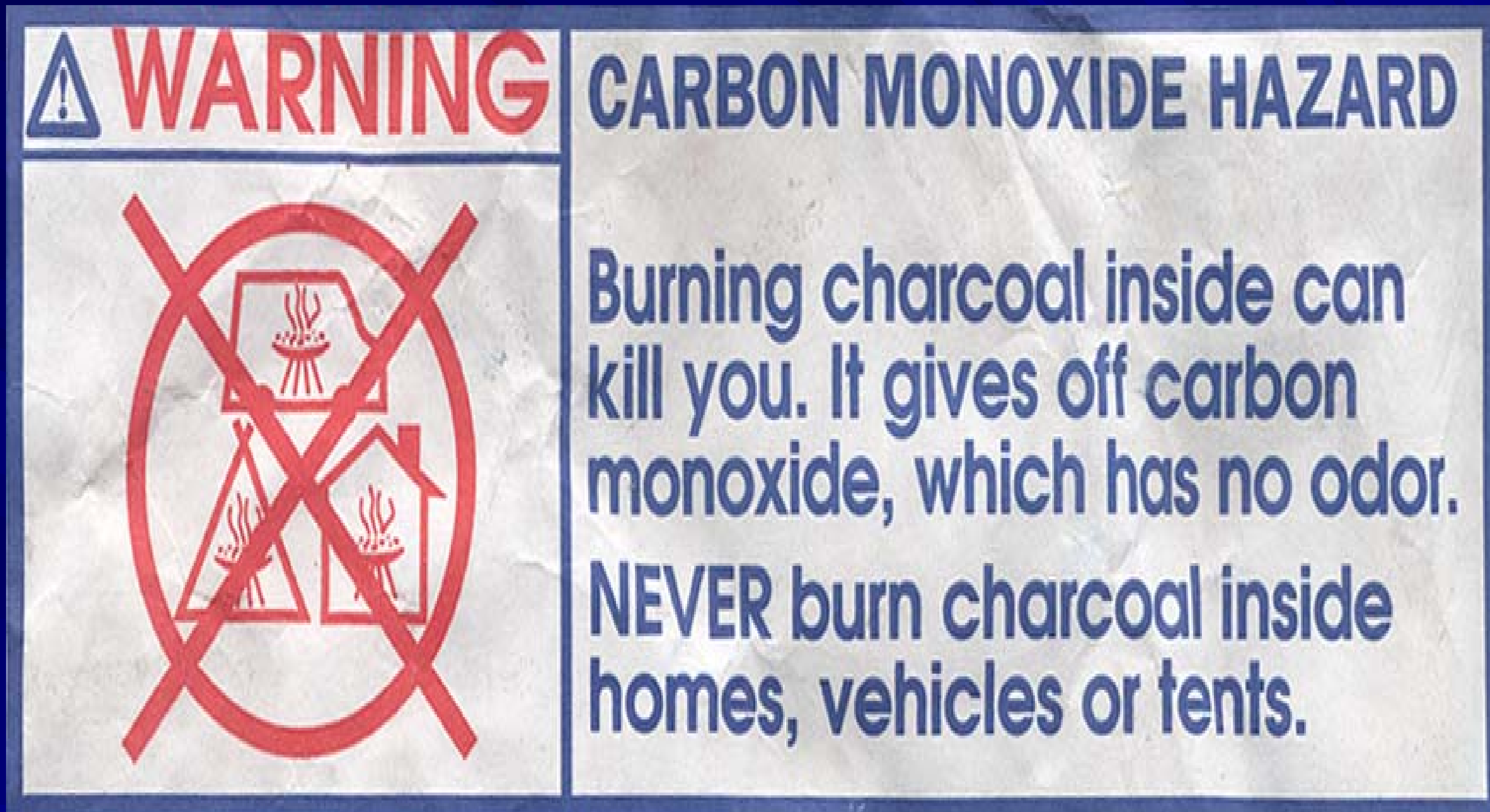
Clarifying Questions about PM?

The second major biomass combustion pollutant:

Carbon Monoxide (CO)

The Carbon Monoxide Story

- Colorless, odorless, tasteless
- Acute effects - poisoning:
  - in USA, 600 unintentional deaths per year and 20,000 emergency room visits (home heating appliance failures)
- Chronic effects
  - cardiovascular system

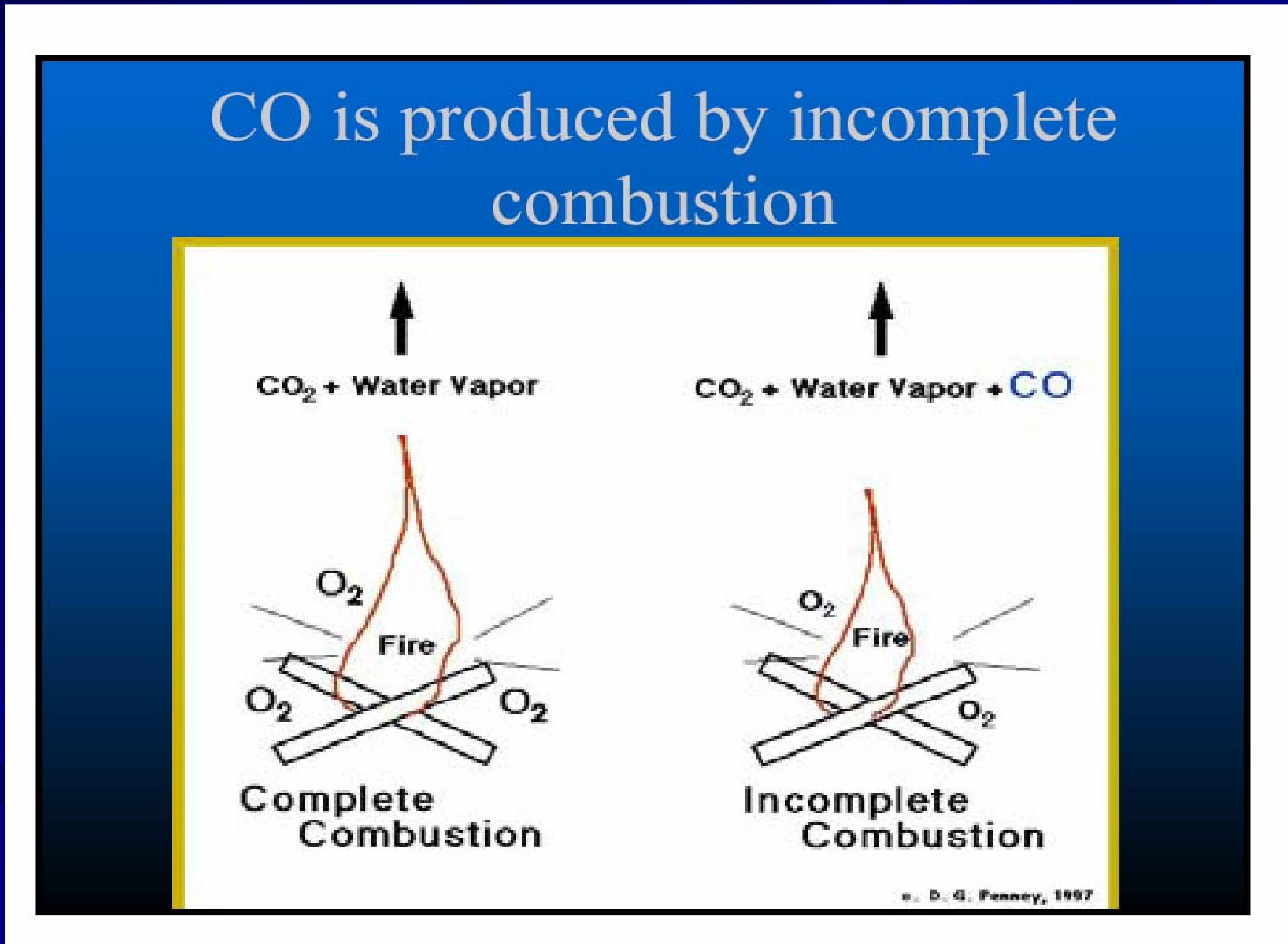


Required warning on bags of charcoal in USA

CO Emissions

- Direct emissions from fossil fuel and **<u>biomass burning</u>**
- Indirect production through photochemical reactions in the atmosphere
- 70% of global CO emissions are from human activities
  - emissions in developing countries are thought to be significant, but are not well described

A reminder:


CO is produced by incomplete combustion
CO2 + Water Vapor
CO2 + Water Vapor + CO
O2
Fire
O2
O2
O2
Fire
O2
Complete Combustion
Incomplete Combustion
©. D. G. Penney, 1997

Carbon Monoxide Uptake in the Human Body

- When inhaled, CO binds with hemoglobin in the blood (displacing O_2), forming carboxyhemoglobin [COHb]
- High levels of carboxyhemoglobin cause poor oxygenation of cells/tissues around the body
- CO-hemoglobin affinity (binding) is 250 times stronger than O_2-hemoglobin affinity

Acute (Toxic) Effects of CO

Dose = Ambient Concentration x Length of Exposure

200 ppm for 2-3 hours	Mild headache, fatigue, nausea, dizziness
400 ppm for 1-2 hours	Serious headaches, symptoms intensify
800 ppm for 45 minutes	Nausea, dizziness, convulsions, unconscious within 2 hours
1600 ppm for 20 minutes	Death within one hour
3200 ppm for 5-10 minutes	Death within one hour

Source: http://www.coheadquarters.com/

Considering Chronic CO Effects: WHO's CO Exposure Guidelines

Four averaging times:

- 100 mg/m^3 for 15 min
- 60 mg/m^3 for 30 min
- 30 mg/m^3 for 1 h
- 10 mg/m^3 for 8 h

- Determined so that a carboxyhemoglobin level of 2.5% is not exceeded

For comparison:

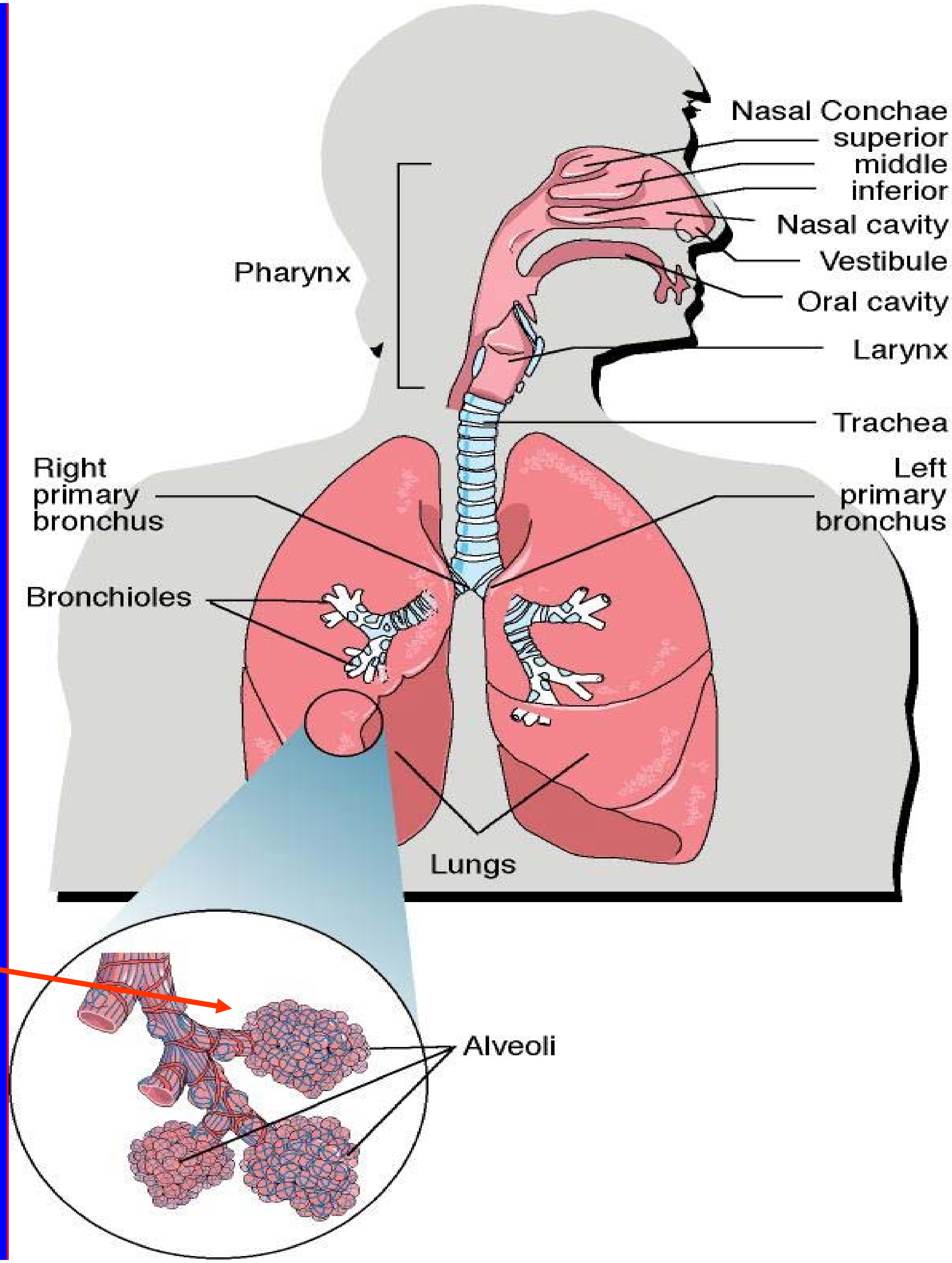
- Cigarette smokers average 4% carboxyhemoglobin
- Non-smokers average 1% carboxyhemoglobin

Source: World Health Organization. Environmental Health Criteria 213: Carbon Monoxide. 1999

CO Uptake in the Human Body

Does not diffuse into upper airway lung tissue; not a pulmonary irritant

CO penetrates into the alveolar region where it can be absorbed into the blood stream



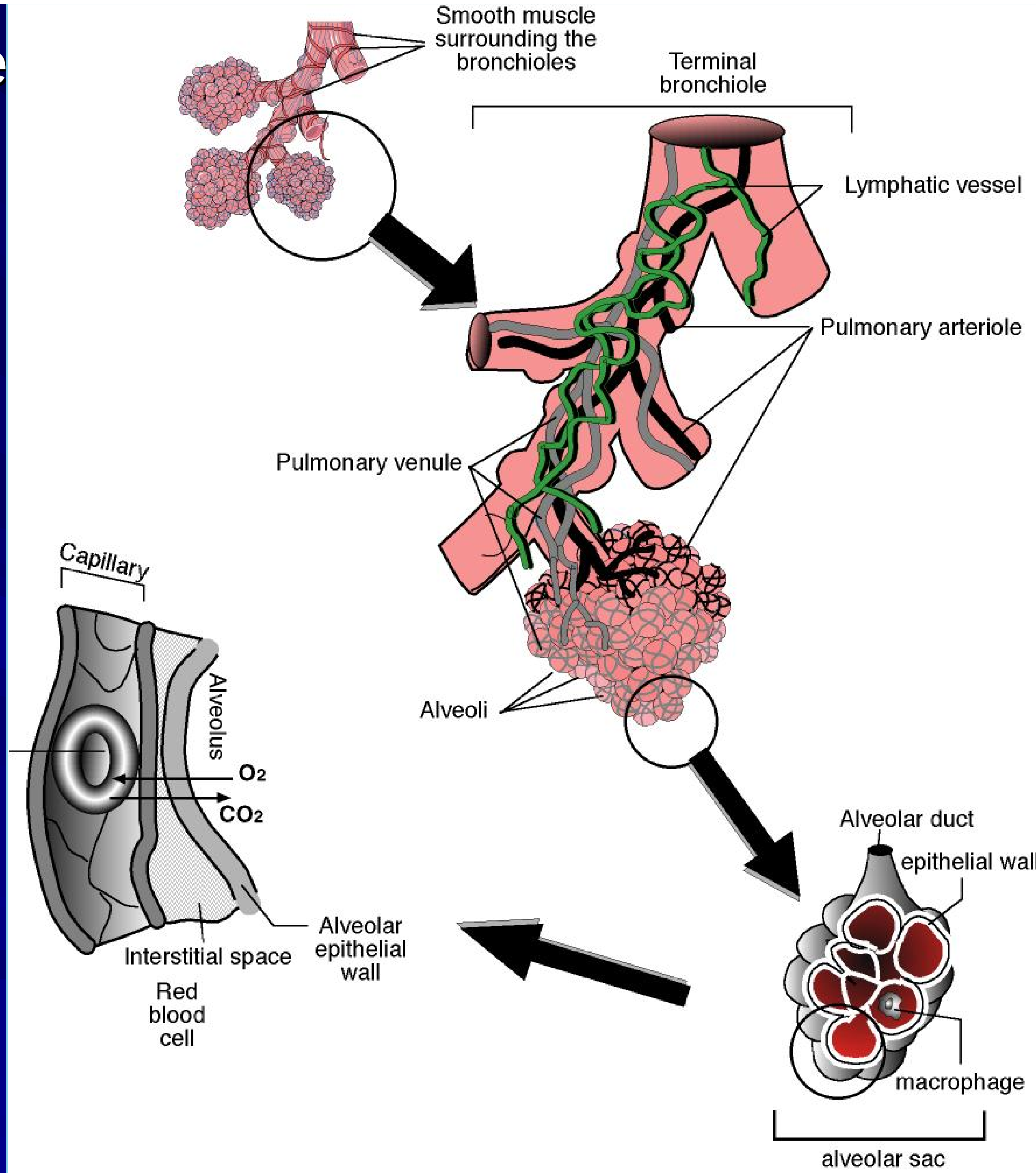
CO Uptake in the Human Body:

-CO diffuses from the alveoli into the capillaries

-binds with hemoglobin

-travels throughout the body

-leads to tissue hypoxia (heart and skeletal muscle)



Epidemiological Evidence for Human Health Effects of CO

- Acute experimental studies→ many published studies
- Accidental exposures → case studies
- Chronic exposures to low concentrations→ few studies to date

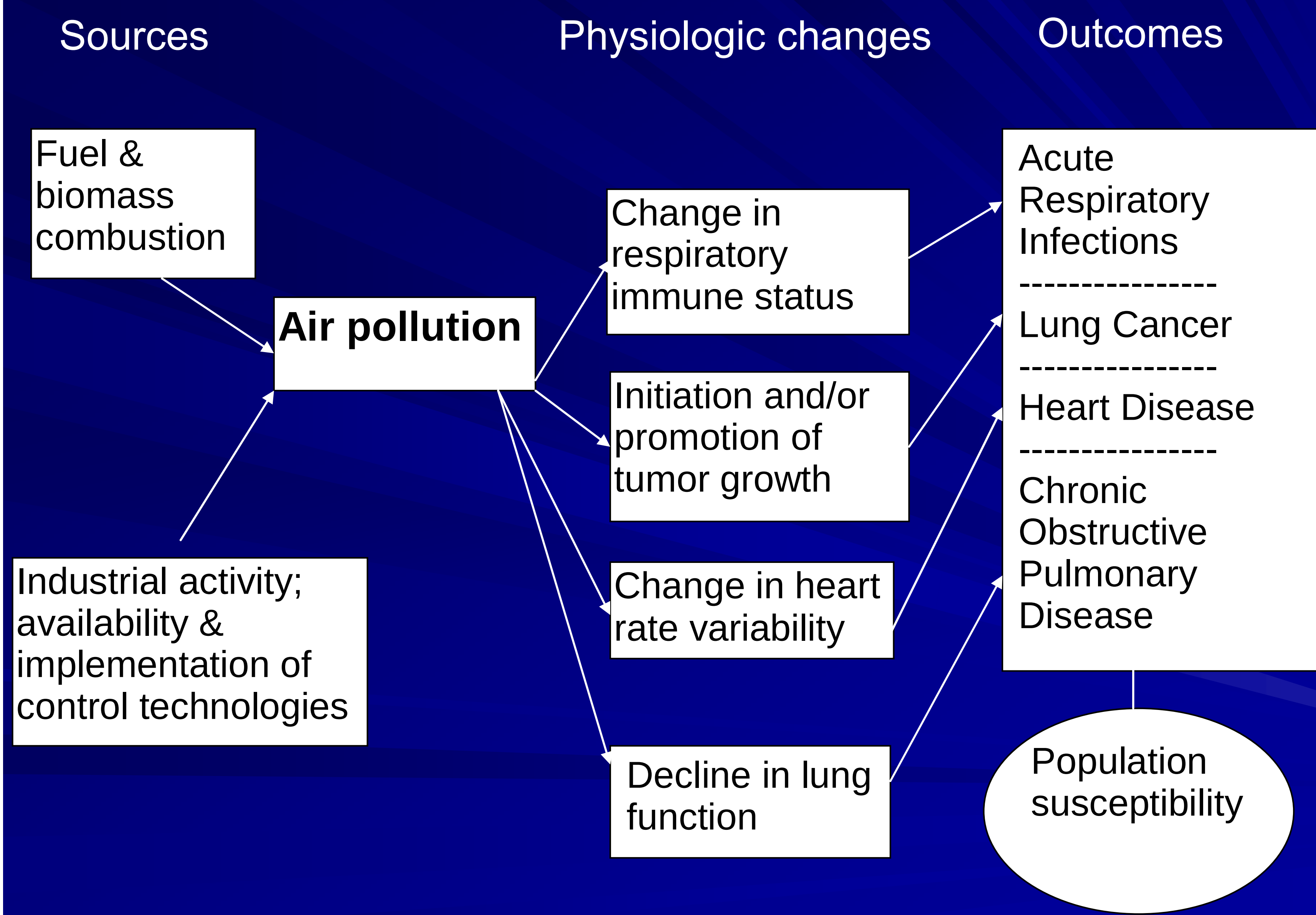
- Based on findings, *sensitive populations:* elderly, pregnant women, fetuses, young infants, and people with anemia, cardiovascular, or pulmonary disease

Epidemiological Evidence for CO (2):

- Cardiovascular effects are of greatest concern
  - 11+ major studies show heart disease exacerbation
  - Mix of pollutants, identifying CO effect is difficult
- Studies also show some evidence for daily mortality, respiratory effects, fetal effects, and neurobehavioral effects

Clarifying Questions about CO?

Causal Web for Air Pollution Health Effects



Thank you

What is the most surprising fact you learned about biomass pollution?