# Health Guidelines for Smoke from Vegetation Fires

**Authors,** *Zifei Liu, Ph.D., Pat Murphy, Ronaldo Maghirang, Ph.D, Biological and Agricultural Engineering; and Daniel Devlin, Ph.D, Kansas Center for Agricultural Resources and the Environment, Kansas State University*

Vegetation fires, both planned and wild, usually include grassland, forest, agricultural crops, and crop residues. Smoke exposure is often an inevitable side effect of these open fires and is an important public health concern. Current knowledge of health impacts of particulate matter (PM) in air is obtained mainly from epidemiology studies of urban pollution. However, combustion-derived aerosols in vegetation fire smoke can be very different from urban aerosols in their constituents and characterizations, and thus can have different toxicological effects.

## Not all smoke is equal

Combustion conditions determine combustion efficiency and smoke components. In complete or highly efficient combustion, the fuel burns oxygen ($O_2$) and primarily yields carbon dioxide ($CO_2$) and water. The two main factors affecting combustion efficiency are combustion temperature and availability of $O_2$ (Figure 1). Hot flaming fires with sufficient $O_2$ are highly efficient and produce less carbon monoxide (CO), unburned hydrocarbons, and PM than non-flaming smoldering fires. Smoldering fire is the slow, low-temperature, flameless form of combustion. Compared with flaming conditions, smoldering fire can produce more than double the PM and a much greater quantity of incompletely oxidized toxic compounds. Incomplete combustion due to low temperatures and a low $O_2$ environment would result in the greatest quantities of smoke and toxic compounds. Smoke composition also depends on fuel type. Different types of vegetation are composed of varying amounts of cellulose, lignin, tannins, oils, and moisture, which produce different smoke compounds when burned.

## What could be in fire smoke?

Vegetation fire smoke is a complex mixture of airborne solid and liquid particulates, vapors, and gases, which can contain thousands of individual compounds involving a wide range of chemicals in categories such as PM, volatile and semi-volatile organic compounds (VOCs and SVOCs), inorganic gases, and water vapor. PM is the solid or liquid component of smoke, which is highly visible and is one of the principle public health concerns from smoke exposure. Fine particles are produced from the combustion, and larger particles are entrained into the smoke column as a result of the turbulence and buoyancy generated by the fire. About 70 to 90 percent of PM in smoke is $PM_{2.5}$,

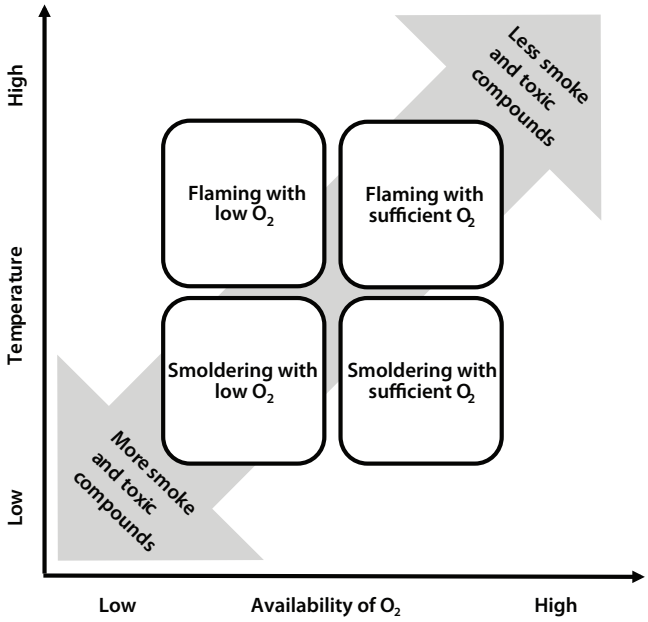


**Figure 1.** Four conditions of combustion and production of smoke.

meaning 2.5 μm (microns) or smaller in size (equivalent aerodynamic diameter). Particles of this size range are not easily removed by gravitational settling and therefore can be transported over long distances. The lifetime of $PM_{2.5}$ varies from days to weeks, and its travel distance ranges from 100 to more than 1,000 km. The size of particles in the air people breathe affects its potential to cause health problems. The depth of particle penetration into the lungs and the likelihood of them being exhaled depend on their size. Coarse particles affect the nasopharyngeal region, whereas fine particles can penetrate the large airways of the trachea, bronchi, and bronchioles, and even reach the alveoli. Inhaled fine particles can cause an inflammatory response in the respiratory system even though the material itself is inherently nontoxic. Smoke PM also acts as a vehicle to carry adsorbed hazardous compounds into the respiratory tract. The adsorbed hazardous compounds may include VOCs such as formaldehyde and acrolein, SVOCs such as polycyclic aromatic hydrocarbons (PAHs) and dioxin, gases such as nitrogen dioxide ($NO_2$), and toxic metal elements such as lead and mercury. The health and environmental impacts of various components in fire smoke are summarized in Table 1 on page 2.

## Observed concentrations

Concentrations of smoke components from vegetation fires reported in literature are summarized in Table 2. Results from different studies are highly variable because of the variability in fuel and combustion conditions. The $PM_{10}$ and $PM_{2.5}$ concentrations at downwind communities affected by vegetation fire smoke can be significantly higher than the corresponding air-quality standards. Concentrations of acrolein were below the National Institute for Occupational Safety and Health (NIOSH) 8-hour exposure limits, while concentrations of formaldehyde were higher than the NIOSH 8-hour exposure limits, both at the fires and at downwind communities. Some hazardous compounds in smoke, such as CO, are only present in significant quantities in the immediate vicinity of the fire, while ozone ($O_3$) is present downwind over long distances. The contribution of vegetation fire smoke on downwind $O_3$ concentrations is a big concern, since it can be as high as 67 percent of the current 8-hour $O_3$ standard (Table 2). Organic irritants (acrolein, formaldehyde, etc.), complex molecules (PAHs, dioxins, etc.), and $PM_{2.5}$ can travel long distances and be present in the smoke plume far away from the source.

**Table 1.** Main components in vegetation fire smoke

| Category | Components | Characterization | Health and environmental impacts |
|---|---|---|---|
| Particles | PM | Complex mixtures of EC, OC, and inorganic ash; 70–90% of PM is $PM_{2.5}$; can transport over long distances. | Act as vehicles to carry adsorbed hazardous compounds into the respiratory tract; increases respiratory and cardiovascular mortality and morbidity, including asthma and emphysema; contributes to regional haze and impairs visibility. |
| | EC | Primary particles; 2–20% of PM mass. | Scatters and absorbs solar radiation thus affecting climate. |
| | OC | Primary or secondary particles; 60-70% of PM mass. | Some are carcinogens or irritants. |
| | Trace elements | Concentrate in the fine particles. | Some metal elements are toxic. |
| VOCs | Acrolein | Can be absorbed on particles. | An organic irritant and a potent lachrymatory agent. |
| | Formaldehyde | Can be absorbed on particles. | An organic irritant and a carcinogen linked to nasal and throat cancer and leukemia. |
| | Isocyanic acid | Found in both cigarette smoke and vegetation fire smoke. | Contribute to cardiovascular problems and inflammation. |
| SVOCs | PAHs | Specific species varies with composition of vegetation; condense or absorbed onto fine particles or as volatiles in the vapor phase. | Potentially carcinogenic and mutagenic. |
| Permanent gases | $CO_2$ | Dependent on availability of $O_2$. | Greenhouse gas |
| | CO | Dependent on availability of $O_2$; abundant only in immediate vicinity of fire. | Toxicity due to reducing oxygen-carrying capacity of the blood, known as hypoxia. |
| | $CH_4$ | Global warming potential 21 times higher than $CO_2$. | Greenhouse gas |
| | $NO_x$ | Reactive; concentrations change with distance from fire. | Irritant and precursors of $O_3$. |
| Water vapor | Can condense onto fine particles. | Contributes to regional haze and impairs visibility. | |
| Secondary products | $O_3$ | Secondary product of $NO_x$, VOCs and CO; can transport over long distances. | Causes chest pain and respiratory problems. |

**Note:** PM = particulate matter; $PM_{2.5}$ = particulate matter less than 2.5 µm in equivalent aerodynamic diameter; EC = elemental carbon; OC = organic carbon; VOCs = volatile organic compounds; SVOCs = semi-volatile organic compounds; PAHs = polycyclic aromatic hydrocarbons; $CO_2$ = carbon dioxide; CO = carbon monoxide; $CH_4$ = methane; $NO_x$ = nitrogen oxides; $O_3$ = ozone.

# Health impacts

Air pollution in general interferes with heart and lung processes. In fire smoke exposure, people are exposed to a complex mixture rather than many isolated components. The actual health effect of smoke exposure is the combined effects of all hazardous smoke components. Reduced resistance to infection is linked to smoke exposure. Smoke harms the cellular membrane, slows down immune system activity, damages the inflammatory cells that protect and clean the respiratory tract, and also disrupts enzyme levels (Quebec Lung Association, 2012).

The health effects considered to be associated with vegetation fire smoke include chronic obstructive pulmonary disease (COPD), reduced lung function, asthma, heart disease, bronchitis, rhinitis, and various respiratory problems. Many components of vegetation fire smoke are irritants. Symptoms from acute exposure to smoke include teary and burning eyes, runny nose, and scratchy and sore throat.

Individuals react differently to air pollutants. Studies indicated that children, elderly people, pregnant women, smokers, and people with pre-existing respiratory problems are especially vulnerable to health effects from fire smoke. Children are more likely to be affected because their airways are still developing and they breathe more air per pound of body weight than adults. In areas where annual or seasonal burning is practiced, effects of constant exposure to vegetation fire smoke could pose a potential health risk. However, little is known about the long-term effects of smoke exposure. For the range of identified effects, much is unknown on whether the effects are reversible or permanent.

# The visibility guide

Air pollutants are rarely measured in rural areas where fire occurs. Since smoke is highly visible, it is possible to visually estimate smoke levels using a visibility index. Visibility can be determined by facing away from the sun and looking for landmarks at known distances. The visibility range is the distance at which even high-contrast objects cannot be seen (e.g., a dark building viewed against the sky at noon). Once visibility has been determined, Figure 2 on page 4 can be used to estimate the equivalent $PM_{2.5}$ levels and the associated air quality category. The visibility index is not effective at night or when humidity is high.

**Table 2.** Concentrations of smoke components from vegetation fires as reported in literature

| Air Pollutants | Observed daily concentrations as reported in literature | | Standards or exposure limits |
|---|---|---|---|
| | At the fires | At downwind communities | |
| Total PM | 200–47600 µg/m$^3$ | 100–600 µg/m$^3$ | - |
| $PM_{10}$ | 1300–1800 µg/m$^3$ | 6.4–852 µg/m$^3$ | [1]150 µg/m$^3$ |
| $PM_{2.5}$ | 148–6865 µg/m$^3$ | 63–400 µg/m$^3$ | [1]35 µg/m$^3$ |
| Acrolein | 0.018–0.071 ppm | 0.009 ppm | [2]0.1 ppm |
| Formaldehyde | 0.03–0.468 ppm | 0.02–0.047 ppm | [2]0.016 ppm |
| Isocyanic acid | - | 600 ppb | - |
| PAHs | - | - | [3]200 µg/m$^3$ |
| BaP | 0.102–0.161 µg/m$^3$ | 0.0071 µg/m$^3$ | - |
| Acenaphthene | 0.57–1.53 µg/m3 | 0.83-0.89 µg/m$^3$ | - |
| Naphthalene | 0–3.27 µg/m3 | 0-3.53 µg/m$^3$ | - |
| Phenanthrene | 0.38 µg/m$^3$ | - | - |
| $CO_2$ | 350–1000 ppm | - | [2]5000 ppm |
| CO | 1–140 ppm | 1–6 ppm | [4]9 ppm<br>[2]35 ppm |
| $CH_4$ | - | - | - |
| $NO_x$ | - | Slight increase | [5]100 ppb |
| $O_3$ | - | Up by 50 ppb | [4]75 ppb |

**Note:** PM = particulate matter; $PM_{10}$ = particulate matter less than 10 µm in equivalent aerodynamic diameter; $PM_{2.5}$ = particulate matter less than 2.5 µm in equivalent aerodynamic diameter; PAHs = polycyclic aromatic hydrocarbons; BaP = benzo(a)pyrene; $CO_2$ = carbon dioxide; CO = carbon monoxide; $CH_4$ = methane; $NO_x$ = nitrogen oxides; $O_3$ = ozone.

**References:** [1] National Ambient Air Quality Standards (NAAQS) 24-hr standards; [2] National Institute for Occupational Safety and Health (NIOSH) 8-hr exposure limits; [3] Occupational Safety and Health Administration (OSHA) 8-hr exposure limits; [4] NAAQS 8-hr standards; [5] NAAQS 1-hr standards.

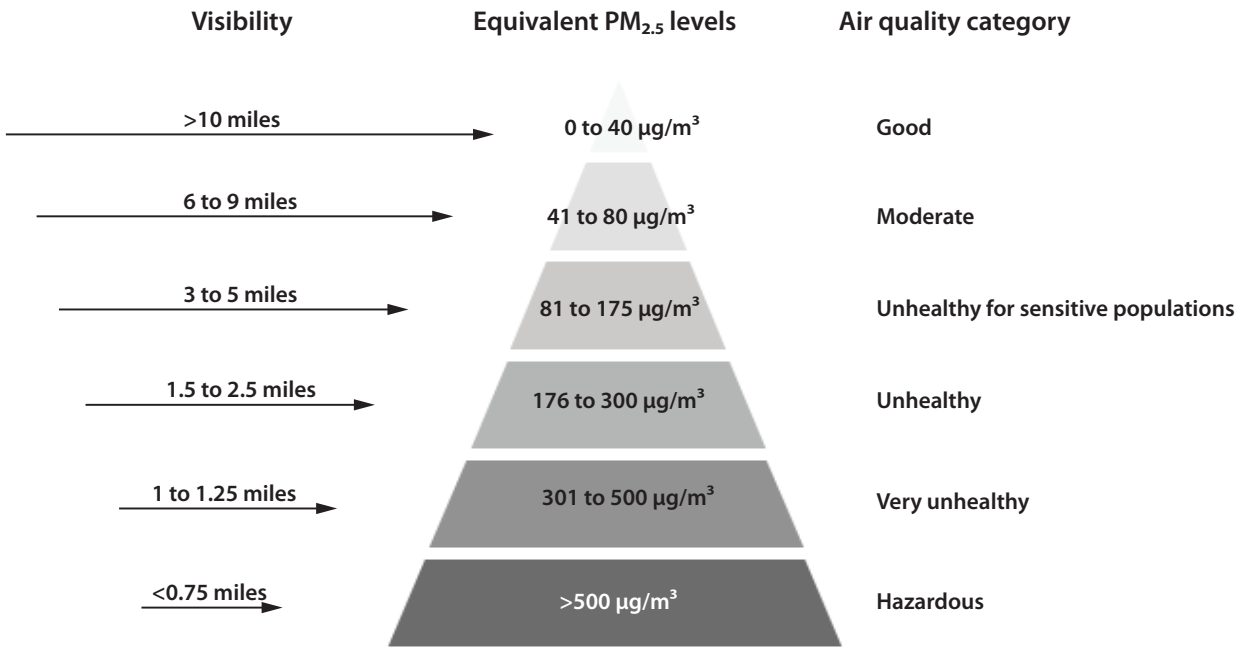


**Figure 2.** Assessing $PM_{2.5}$ levels and air quality based on visibility index (Data from EPA, 2001)

## Protecting yourself from smoke exposure

It's a good idea to avoid breathing smoke even though it may smell good, especially if you have pre-existing conditions that make you more susceptible. When smoke is nearby, it's probably not a good time to go for a run, or let your children play outdoors. Smoke particles can be very small. Common available paper dust masks designed to trap larger particles are generally inadequate to protect your lungs from the fine particles in smoke. Some masks (N95 or N99) are designed to filter out 95 percent to 99 percent of test particles as small as 0.3 µm. If properly fitted, these masks will offer some protection. For more information about effective masks, see the *Respirator Fact Sheet* (*www.cdc.gov/niosh/docs/2003-144/pdfs/2003-144.pdf*) provided by NIOSH.

You can limit your exposure to smoke by remaining indoors and reducing physical activities that increase your air intake. Staying indoors with windows closed can usually reduce exposure by about a third. When smoke levels are high for a prolonged period of time, fine particles can build up indoors even though you may not be able to see them. When smoke is thick, susceptible people may need to leave the area and stay in buildings equipped with air conditioning and particle filtration systems. To keep indoor particle levels lower, avoid cooking or using anything that burns, such as wood fireplaces or even candles. Vacuuming should also be avoided, since it stirs up particles in the air. Some types of air cleaners can be used to reduce indoor particle levels. For more information about effective home air cleaners, see the summary (*www.epa.gov/iaq/pubs/residair.html*) provided by the Environmental Protection Agency (EPA).

## Resources and references

EPA. 2009. *Residential Air Cleaners (2nd Edition): A Summary of Available Information*. Available at *www.epa.gov/iaq/pubs/residair.html*

NIOSH. 2003. *Respirator Fact Sheet.* Available at *www.cdc.gov/niosh/docs/2003-144/pdfs/2003-144.pdf*

EPA. 2001. *Wildfire smoke: a guide for public health officials*. Available at *www.epa.gov/ttn/amtic/files/ambient/smoke/wildgd.pdf*

Quebec Lung Association. 2012. *Wood heating: Air pollution problems and their adverse health effects.* Available at *www.pq.lung.ca/environment-environnement/wood_smoke-fumee_bois/*



**Kansas State University Agricultural Experiment Station and Cooperative Extension Service**
MF3179 February 2015