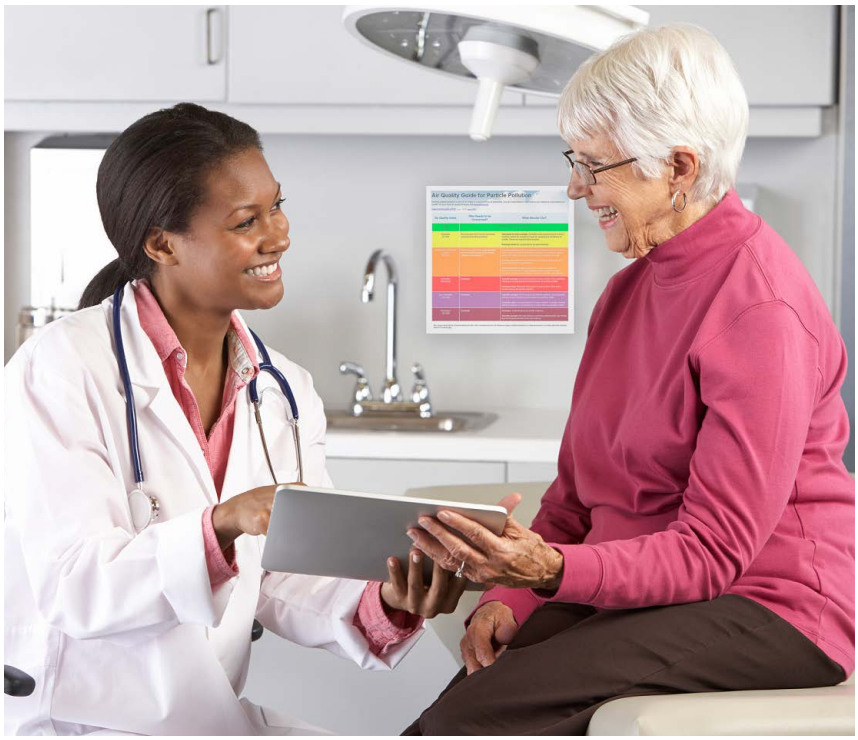
I. HEALTH EFFECTS OF WILDFIRE SMOKE



Wildfires expose populations to multiple environmental hazards, from combustion due to the fire itself to air pollution from smoke and byproducts of combustion such as ash. In addition, when wildfires move into communities, chemicals in plastics and other chemicals can be released into the air from burning structures and furnishings. Wildfires also cause mental health concerns and psychological stress. Recently, epidemiological (e.g., Reid et al. 2016, Tinling et al. 2016, Wettstein et al. 2018) and toxicological (e.g., Kim et al. 2018) studies have focused broadly on the health effects of wildfire smoke exposure and the toxicity of specific fuel sources, respectively. These studies consistently demonstrate a variety of respiratory-related health effects with more recent studies also providing some evidence of cardiovascular-related health effects in response to short-term (i.e., daily) wildfire smoke exposures. Although the body of literature specifically examining the health effects attributed to wildfire smoke exposure has grown, the initial understanding of potential health effects was derived from studies focusing on components of ambient air pollution, primarily in urban settings, that are also found in wildfire smoke (e.g., fine particulate matter and carbon monoxide).

Particulate matter is the principal public health threat from short-and longer-term exposure to wildfire smoke and is the focus of most of this document. While particles from wildfire smoke can vary in size (see Section II. Wildfire Smoke and Air Quality Impacts), approximately 90% of total particle mass emitted from wildfires consists of fine particles (i.e., $PM_{2.5}$, particles 2.5 µm in diameter or smaller) (Vicente et al. 2013; Groβ et al. 2013). The scientific evidence does not indicate that particles generated from wildfire smoke are more, or less, toxic than particles emitted from other sources (U.S. EPA 2009; DeFlorio-Barker et al. 2019). The effects of particulate matter exposure range from eye and respiratory tract irritation to more serious disorders including reduced lung function, bronchitis, exacerbation of asthma, heart failure, and premature death. Short-term exposures (i.e., days to weeks) to fine particles, a major component of smoke, are associated with increased risk of premature mortality and aggravation of pre-existing respiratory and cardiovascular disease. In addition, fine particles are respiratory irritants, and exposures to high concentrations can cause persistent cough, phlegm, wheezing, and difficulty breathing. Exposures to fine particles can also affect healthy people, causing respiratory symptoms, transient reductions in lung function, and pulmonary inflammation. Particulate matter may also affect the body's ability to remove inhaled foreign materials, such as pollen and bacteria, from the lungs. Specific lifestages and populations may potentially be at increased risk of health effects

due to particulate matter exposure (see next section) and actions should be taken to reduce their exposure to wildfire smoke.

Ground-level ozone, though less of a concern from wildfires than particulate matter, can cause effects such as reductions in lung function, inflammation of the airways, chest pain, coughing, wheezing, and shortness of breath – even in healthy people. These effects can be more serious in people with asthma and other lung diseases. Respiratory effects attributed to ozone exposure can lead to increased use of medication, school absences, respiratory-related hospital admissions, and emergency room visits for asthma and chronic obstructive pulmonary disease (COPD). Although the evidence of ozone's effects on the cardiovascular system (the heart, blood, and blood vessels) is more limited than the evidence of effects on the respiratory system, it indicates that short-term exposure to ozone may cause effects such as changes in heart rate variability and systemic inflammation. Additionally, evidence indicates that short-term ozone exposures can lead to premature mortality, as demonstrated by recent epidemiologic studies that consistently report positive associations between short-term ozone exposures and total non-accidental mortality, which includes deaths from respiratory and cardiovascular causes (U.S. EPA, 2013).

Carbon monoxide is also present in wildfire smoke. Typically, exposures to carbon monoxide from wildfire smoke do not pose a significant hazard to the public, except to some at-risk populations and firefighters very close to the fire line. This is because carbon monoxide does not travel far from the point of combustion. Carbon monoxide enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. People with cardiovascular disease may experience health effects such as chest pain or cardiac arrhythmias from lower levels of carbon monoxide than healthy people. At higher levels (such as those that occur in major structural fires), carbon monoxide exposure can cause headache, weakness, dizziness, confusion, nausea, disorientation, visual impairment, coma, and death, even in otherwise healthy individuals.

Wildfire smoke also contains significant quantities of respiratory irritants that can act in concert to produce eye and respiratory irritation and potentially exacerbate asthma. Additionally, Hazardous Air Pollutants (HAPs) (also referred to as Toxic Air Contaminants [TACs] by the California Environmental Protection Agency [CalEPA]) are also present in wildfire smoke (Reinhardt and Ottmar, 2010). HAPs may contribute to adverse health effects in infants, children, pregnant women and their fetuses, elderly persons, those with existing lung, heart, or liver diseases, and persons engaging in physical activity. Among the extensive list of HAPs, acetaldehyde, acrolein, formaldehyde and benzene, are of concern because of their differential impact on infants and children compared to adults. These HAPs overall contribute to the cumulative irritant properties of smoke and are present in concentrations that may be above regulatory health guidance values (e.g. OEHHA Reference Exposure Levels and U.S. EPA Reference Concentrations).

While most of the focus on health effects of wildfire smoke is on those attributed to short-term exposures (i.e. over a few days to weeks), it is also important to consider the health effects people may experience from cumulative exposures, whether due to repeated, multi-day exposures or multiple consecutive fire seasons. For example, there is concern that long-term exposures to chemicals in wildfire smoke at sufficient concentrations and durations might be a contributor to overall lifetime risk for heart disease, lung disease, and cancer. Unfortunately, there is little information on potential health effects from these types of exposures. The limited number of epidemiologic studies that have specifically examined the cumulative effect of wildfire smoke exposure on health have been studies of wildland firefighters. There is initial evidence that continuous occupational wildland fire smoke exposure (i.e., over multiple days) may have a cumulative effect on lung function, with some studies observing a progressive decline during burn seasons. However, it is unclear if this decline persists across off-seasons and it is difficult to compare a wildland

firefighter's occupational exposure and resulting health effects to those experienced by the general population (Adetona et al. 2016).

Overall, it is important to recognize that not everyone who is exposed to smoke from wildfires will experience health effects. The level and duration of exposure, age, individual susceptibility, including the presence or absence of pre-existing lung (e.g., asthma, COPD) or heart disease, and other factors play significant roles in determining whether someone will experience smoke-related health problems.

At-risk lifestages and populations

Most healthy adults and children will recover quickly from smoke exposure and will not experience long-term health consequences. However, certain at-risk lifestages and populations may be at greater risk of experiencing severe acute and chronic symptoms (See Chapter 5 for strategies to reduce exposure for at-risk lifestages and populations). Key risk factors that shape whether a population or individual is at increased risk of health effects from wildfire smoke have been identified primarily from epidemiologic studies examining exposure to fine particulate matter in urban settings. These studies provide evidence indicating the risk of health effects due to fine particulate exposures can vary based on lifestage (i.e., children, < 18 years of age; and older adults, ≥ 65 years of age), health status, and socioeconomic status. However, studies suggest that the health effects due to wildfire smoke exposure are likely to be similar to those of urban particle pollution (Adetona et al. 2016, Liu et al. 2015, Naeher et al. 2007, Reid et al. 2016).

It appears that the risk of fine particle-related health effects varies throughout a lifetime, generally being higher during early childhood, lower in healthy adolescents and younger adults, and increasing during middle age through old age as the incidence of heart and lung disease, hypertension, and diabetes increases. Therefore, certain lifestages (e.g., children) and populations (e.g., people with pre-existing respiratory and cardiovascular disease) should be particularly diligent about taking precautions to limit exposure to wildfire smoke. The following sections provide more specific information on subsets of the population that may be differentially affected by exposure to wildfire smoke.

While the focus of this section is on those groups at greatest risk of experiencing health effects from exposure to fine particles, as noted previously, pollutants emitted from wildfires can undergo atmospheric reactions and form secondary pollutants, such as ozone. Some of the same groups that are at increased risk of health effects due to fine particles are also at increased risk of health effects from exposure to ozone. This includes people with asthma and other lung diseases, children, older adults, and people who are active outdoors (e.g., outdoor workers).

Therefore, the lifestages and population groups considered as being at greatest risk of a health effect from exposure to fine particles and ozone should be aware of the potential effect of these pollutants on their health during wildfire events by checking the Air Quality Index (AQI) forecast each day and following recommendations to reduce fine particle and ozone exposure.

People with asthma and other respiratory diseases. More than 25 million people in the United States, including more than 6 million children, experience chronic lung diseases such as asthma with another 16 million experiencing COPD (CDC 2017, CDC 2018). Air pollution, such as wildfire smoke, can lead to breathing difficulties for people with chronic lung diseases, such as asthma and COPD, and potentially trigger exacerbations of their disease. Extensive evidence from epidemiologic studies focusing on exposure to fine particles demonstrates increased risk of emergency department visits and hospital admissions for asthma and COPD (U.S. EPA, 2009).

Asthma is a condition characterized by chronic inflammation of the bronchi and smaller airways, with intermittent airway constriction, causing

shortness of breath, wheezing, chest tightness, and coughing, sometimes accompanied by excess mucus production. During an asthma attack, the muscles tighten around the airways and the lining of the airways becomes inflamed and swollen, constricting the free flow of air. Because children's airways are narrower than those of adults, irritation, such as from wildfire smoke, that might create minor problems for an adult may result in significant obstruction in the airways of a young child. Additionally, minority and impoverished children and adults bear a disproportionate burden associated with asthma and other diseases, which may increase their susceptibility to the health effects of wildfire smoke (Brim et al. 2008, CDC 2014). However, these diseases affect all age and sociodemographic groups.

A significant fraction of the population may have airway hyper responsiveness; an exaggerated tendency of the large and small airways (bronchi and bronchioles, respectively) to constrict in response to respiratory irritants including cold air, dry air, and other stimuli, including wildfire smoke. While airway hyper responsiveness is considered a hallmark of asthma, this tendency may also be found in many individuals without asthma for example, during and following a lower respiratory tract infection. In such individuals, wildfire smoke exposure may cause asthma-like symptoms.

Individuals with COPD -- generally considered to encompass emphysema and chronic bronchitis -- may also experience worsening of their conditions because of exposure to wildfire smoke. Patients with COPD often have an asthmatic component to their condition, which may result in their experiencing asthma-like symptoms. However, because their lung capacity has typically been seriously compromised, additional constriction of the airways in individuals with COPD may result in symptoms requiring medical attention. Researchers have reported that individuals with COPD run an increased risk of requiring emergency medical care after exposure to particulate matter or wildfire smoke. In addition, because COPD is usually the result of many years of smoking, individuals with this condition may also have heart and vascular disease and are potentially at risk of health effects due to wildfire smoke exposure from both conditions.

People with cardiovascular disease. Cardiovascular diseases are the leading cause of mortality in the United States, comprising approximately 30 to 40 percent of all deaths each year (Xu et al. 2018). Most of these deaths occur in people over 65 years of age. Diseases of the circulatory system (e.g., high blood pressure, heart failure, vascular diseases such as coronary artery disease, and cerebrovascular conditions) can put individuals at increased risk of cardiovascular-related events triggered by air pollutants.

Following exposure to particulate matter, people with chronic heart disease may experience one or more of the following symptoms: palpitations, unusual fatigue, or lightheadedness; shortness of breath, chest tightness, pain in the chest, neck, or shoulder. Chemical messengers released into the blood because of particle-related lung inflammation may increase the risk of blood clot formation, angina episodes, heart attacks, and strokes. Studies have linked fine particulate matter to increased risks of heart attacks, and sudden death from cardiac arrhythmia, heart failure, or stroke (U.S. EPA, 2009). Despite this evidence regarding fine particulate matter effects and cardiovascular effects, wildfire-related cardiovascular studies have been inconsistent, although several recent investigations have identified elevated risks of specific health outcomes (Wettstein et al. 2018, Deflorio-Barker et al. 2019).

Children. All children, even those without pre-existing illnesses or chronic conditions, are considered at-risk of experiencing a health effect due to air pollution, including wildfire smoke. Compared to adults, children spend more time outside, tend to engage in more vigorous activity, and inhale more air (and therefore more smoke constituents) per pound of body weight — all of which can affect the developing lungs (Sacks et al. 2011). For these reasons, it is important to try to limit children's vigorous outdoor activities during wildfire events. Although the focus of this document is wildfire

smoke, children may encounter other environmental hazards including air pollutants from burning structures and furnishings, and exposure to fire ash if children are present during fire clean up.

Wildfire smoke can persist for days or even months, depending on the extent of the wildfire. Symptoms of wildfire smoke inhalation, which can include coughing, wheezing, difficulty breathing, and chest tightness, are supported by evidence from epidemiologic studies of particulate matter that report increased respiratory symptoms and decreased lung function (U.S. EPA, 2009). Air pollution from wildfires can exacerbate asthma symptoms and trigger attacks. Research has shown a higher rate of asthma emergency department visits and hospital admissions for children, especially infants and very young children, during and after wildfires (Hutchinson et al., 2007). Even children without asthma could experience respiratory symptoms, resulting in school absences and other limitations of normal childhood activities.

In addition to the overt health effects and underlying physiologic differences between children and adults, children may also experience significant emotional distress, resulting from anxiety and grief following a wildfire. It is important to consider not only the potential physical health implications of wildfire smoke on children, but also the potential longer-term psychological implications.

See factsheet Protecting Children from Wildfire Smoke and Ash.

Pregnant women. During pregnancy, physiologic changes, such as higher respiratory rates and increases in blood and plasma volumes, increase a woman's vulnerability to environmental exposures. Additionally, during critical windows of human development, a mother's exposure to wildfire smoke may harm the developing fetus. A few studies have examined potential health effects of wildfire smoke exposure during pregnancy. Holstius et al. (2012) examined the effect of wildfire smoke on pregnancy outcomes in Southern California and reported some evidence indicating a potential reduction in birth weight due to *in utero* exposure to wildfire smoke. In addition, psychosocial stress exacerbated by wildfires is another mechanism through which wildfire events may affect the health of pregnant women and their fetuses (Kumagai et al. 2004). While there are few studies examining the health effects of exposure to wildfire smoke on pregnancy outcomes, there is some available evidence of health effects due to exposures to other combustion-related air pollutants. Specifically, there is substantial evidence of low birth weight due to repeated exposures to cigarette smoke, including both active and passive smoking and an emerging, but still inconsistent body of literature on the health effects of prenatal exposure to ambient air pollution. Specifically, studies examining chronic maternal exposure to ambient particulate matter (U.S. EPA 2009) and indoor biomass smoke (e.g., Amegah et al. 2014) from wood-fired home heating devices have provided some evidence of adverse birth and obstetrical outcomes (e.g., decreased infant birth weight, preterm birth).

Older adults. The number of U.S. adults 65 years of age and older will nearly double between 2012 and 2050 (Ortman et al. 2014). Older adults are at increased risk of health effects from short-term exposures to wildfire smoke because of their higher prevalence of pre-existing lung and heart diseases, and because important physiologic processes, including defense mechanisms, decline with age. Epidemiologic studies of short-term exposures to fine particles have reported greater risks of emergency department visits and hospital admissions and mortality, in older adults (U.S. EPA, 2009). Additional evidence from animal toxicological studies and human clinical studies provides biological plausibility and further support that older adults should limit exposures to fine particle pollution, such as wildfire smoke.

Low socioeconomic status (SES). SES is often defined in epidemiologic studies using a variety of indicators such as educational attainment, median household income, percentage of the population in poverty, race/ethnicity, and location of residence. It is well-recognized that SES is a composite measure that encompasses multiple individual indicators along with other factors and is often measured at the population- or community-level. Epidemiologic studies of fine particulate matter using indicators of SES provide initial evidence that individuals of low SES may be at increased risk of mortality due to short-term exposures. With respect to wildfire smoke the evidence is much more limited, although Rappold et al. (2012) and Reid et al. (2016) reported some evidence that locations classified as having the lowest SES were at the greatest risk of health effects attributed to wildfire smoke.

In addition, SES may contribute to differential exposures to wildfire smoke across communities. For example, access to air conditioning reduces infiltration of particle pollution indoors. Less access to air conditioning may lead to greater exposure to wildfire smoke and greater sensitivity to extreme heat and, subsequently, health disparities across communities. People of color and impoverished children and adults bear a disproportionate burden of asthma and other respiratory diseases and therefore they may be at increased risk of health effects due to wildfire smoke exposure (Brim et al. 2008, CDC 2014). As a result, additional outreach activities and support may be required to properly communicate the actions that people of low SES should take to both reduce and protect themselves from wildfire smoke exposures.

Outdoor workers. Working outdoors during periods of wildfire smoke exposure could result in a range of health effects depending on the underlying health status of the worker. Effects of exposure to wildfire smoke range from eye and respiratory tract irritation to the triggering of an asthma exacerbation or cardiovascular event. For workers that encompass a previously identified at-risk population or lifestage, and workers who are negatively impacted by smoke exposure, some of the same recommendations listed in this document for the general public apply when working outdoors in a smoky environment. See Chapter 5 (Protecting Outdoor Workers) for more information.

Summary

Particulate matter is the principal public health threat from exposure to wildfire smoke. The effects of particulate matter exposure range from eye and respiratory tract irritation to more serious disorders including reduced lung function, bronchitis, exacerbation of asthma and heart failure, and even premature death. Although exposure to fine particles can lead to a range of health effects, certain lifestages and populations are at greatest risk of health effects due to fine particle exposures (Table 1). While evidence about the implications of repeated or prolonged smoke exposures on health is very limited, when smoke exposure is expected to be prolonged, public health officials should consider all options in communicating the importance of actions that can be taken to reduce smoke exposure.

Table 1. Summary of lifestages and populations potentially at-risk of health effects from wildfire smoke exposures.

At-risk Lifestage/ Population	Rationale and Potential Health Effects from Wildfire Smoke Exposure
People with asthma and other respiratory diseases	Rationale: Underlying respiratory diseases result in compromised health status that can result in the triggering of severe respiratory responses by environmental irritants, such as wildfire smoke. Potential health effects: Breathing difficulties (e.g., coughing, wheezing, and chest tightness) and exacerbations of chronic lung diseases (e.g., asthma and COPD) leading to increased medication usage, emergency department visits, and hospital admissions.
People with cardiovascular disease	Rationale: Underlying circulatory diseases result in compromised health status that can result in the triggering of severe cardiovascular events by environmental irritants, such as wildfire smoke. Potential health effects: Triggering of ischemic events, such as angina pectoris, heart attacks, and stroke; worsening of heart failure; or abnormal heart rhythms could lead to emergency department visits, hospital admissions, and even death.
Children	Rationale: Children's lungs are still developing and there is a greater likelihood of increased exposure to wildfire smoke resulting from more time spent outdoors, engagement in more vigorous activity, and inhalation of more air per pound of body weight compared to adults. Potential health effects: Coughing, wheezing, difficulty breathing, chest tightness, decreased lung function in all children. In children with asthma, worsening of asthma symptoms or heightened risk of asthma attacks may occur.
Pregnant women	Rationale: Pregnancy-related physiologic changes (e.g., increased breathing rates) may increase vulnerability to environmental exposures, such as wildfire smoke. In addition, during critical development periods, the fetus may experience increased vulnerability to these exposures. Potential health effects: Limited evidence shows air pollution-related effects on pregnant women and the developing fetus, including low birth weight and preterm birth.
Older adults	Rationale: Higher prevalence of pre-existing lung and heart disease and decline of physiologic process, such as defense mechanisms. Potential health effects: Exacerbation of heart and lung diseases leading to emergency department visits, hospital admissions, and even death.
People of low socioeconomic status	Rationale: Less access to health care could lead to higher likelihood of untreated or insufficient treatment of underlying health conditions (e.g., asthma, diabetes). Less access to measures to reduce exposure (e.g., air conditioning) could lead to higher levels of exposure to wildfire smoke. Potential health effects: Greater exposure to wildfire smoke due to less access to measures to reduce exposure, along with higher likelihood of untreated or insufficiently treated health conditions could lead to increased risks of experiencing the health effects described above.
Outdoor workers	Rationale: Extended periods of time exposed to high concentrations of wildfire smoke. Potential health effects: Greater exposure to wildfire smoke can lead to increased risks of experiencing the range of health effects described above.

II. WILDFIRE SMOKE AND AIR QUALITY IMPACTS

Composition of wildfire smoke

Smoke from combustion of natural biomass is a complex mixture of particulate matter, carbon dioxide, water vapor, carbon monoxide, hydrocarbons and other organic chemicals, nitrogen oxides, and trace minerals. The individual compounds present in smoke number in the thousands. Most research on wildland fire emissions has centered on natural biomass fuels—the vegetative materials comprised of trees, needles, leaves, branches, litter, duff, stumps, grasses, shrubs, and downed trees. Wildfires may also move into the WUI burning homes and structures in the process and thus consuming man made materials in addition to natural fuels. More research is needed to understand potential health impacts of breathing this complex mix of natural and man made material emissions.

The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment. EPA has set NAAQS for six principal pollutants, including three pollutants that may be of concern during wildfire smoke events: particulate matter (regulated in two size categories: PM_{10} and $PM_{2.5}$), ground level ozone (O_3), and carbon monoxide (CO).

In wildfire smoke, **particulate matter**, especially the smallest size component **$PM_{2.5}$**, is the principal air pollutant of concern for public health. Particulate matter is a generic term for particles suspended in the air, typically as a mixture of both solid particles and liquid droplets. The size of the particles (Figure 1) affects their potential to cause health effects. Particles larger than 10 micrometers in diameter do not usually reach the lungs though they can irritate the eyes, nose, and throat. Particles with diameters less than 10 micrometers (PM_{10}) can be inhaled into the lungs and affect the lungs, heart, and blood vessels. The smallest particles, those less than 2.5 micrometers in diameter ($PM_{2.5}$) are the greatest risk to public health because they can reach deep into the lungs and may even make it into the bloodstream. Most of the effort to quantify, describe, and monitor smoke and health effects from wildfires focuses on

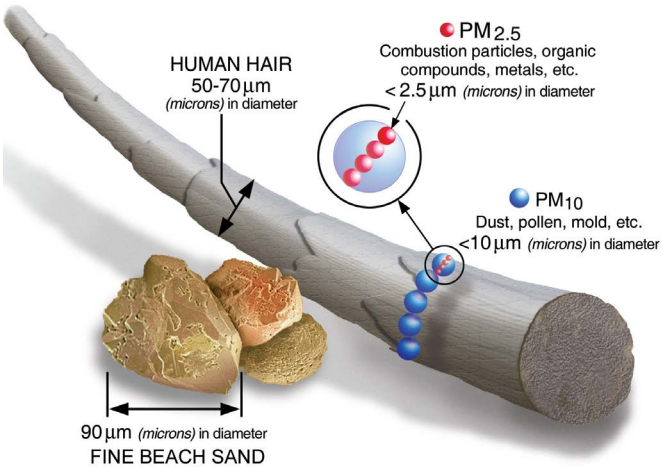


Figure 1. Fine, inhalable particulate matter ($PM_{2.5}$) is the air pollutant of greatest concern to public health from wildfire smoke because it can travel deep into the lungs and may even enter the bloodstream.

$PM_{2.5}$. Particles from smoke tend to be very small, with a size range near the wavelength of visible light (0.4–0.7 micrometers), and therefore efficiently scatter light and impact visibility, which can pose a serious safety risk when smoke crosses roads or impacts airports.

Two other pollutants that may be of concern during wildfire smoke events are carbon monoxide and ozone. **Carbon monoxide** is a colorless, odorless gas produced by incomplete combustion of wood or other organic materials. Carbon monoxide dilutes rapidly so is rarely a concern for the general public, or people with heart disease who are at-greater risk from exposure, unless they are in very close proximity to the wildfire (generally within three miles of the fire line and when smoldering fuels are present). Carbon monoxide can be a concern to firefighters close to the fire line. Smoke episodes can also be associated with elevated levels of **ozone**. Ozone is not emitted directly from a wildfire but forms in the plume as smoke moves downwind. It can be further enhanced if given the opportunity to mix with urban sources of nitrous oxides. Note that ozone is not always enhanced downwind of a fire as the formation and breakdown of ozone is a complex photo-chemical process.

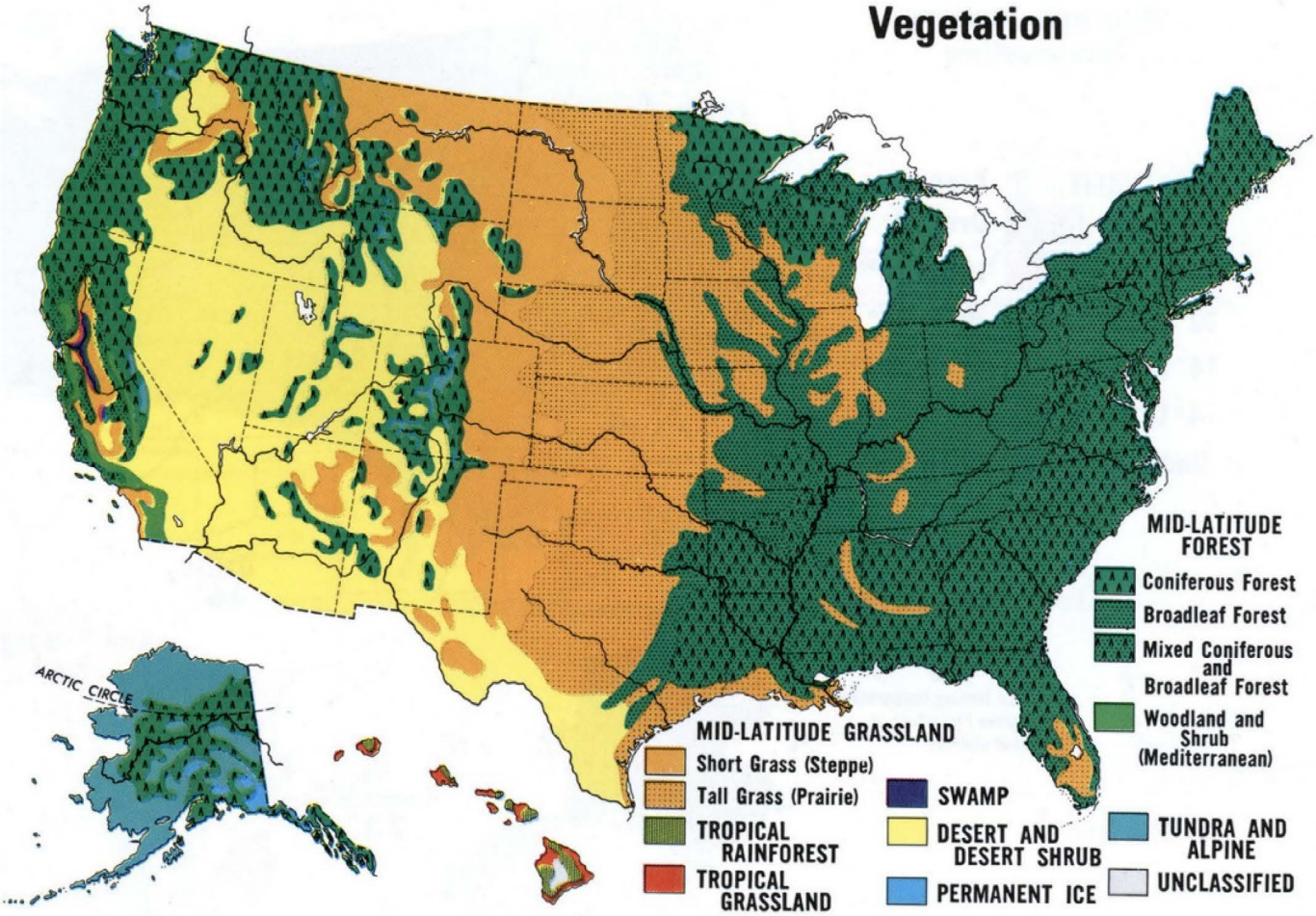


Figure 2. Wildfire rate of spread, fuel consumed, smoke produced, and duration are all influenced by vegetation type. Fires in grass fuels tend to spread quickly and burn out quickly. Fires in brush fuel types can burn hot and spread fast if weather conditions are right. Fires in forest fuel types can range from slow moving to rapidly spreading; long lasting fires in this fuel type tend to produce the most serious and prolonged smoke impacts but smoke can cause problems from wildfires in all fuel types.

Many other chemicals are present in wildfire smoke but at much lower concentrations than particulate matter, ozone, and carbon monoxide. These include an extensive list of HAPs that can be potent respiratory irritants and carcinogens. Given that the specific effects of these pollutants are hard to quantify and measure during an active smoke incident, $PM_{2.5}$ is typically the pollutant that is tracked and monitored, and the pollutant that is used to estimate public health effects from wildfire smoke

Characteristics of wildfires

Wildfires need three conditions to start—fuel, oxygen and a heat source—these three together are known as the fire triangle. Fuel is anything that can burn such as grass, brush, trees and even homes and other structures. The more fuel there is to burn, the more intense a fire can be. Fire needs oxygen to grow and winds increase oxygen supply and fire intensity. Plus, winds can push heat from the fire into new areas, preheating and drying fuels and moving the fire rapidly forward. Heat sources spark the fire and bring fuel temperatures hot enough to ignite and burn. The sun, lightning, burning campfires, cigarettes, sparks, and hot winds are all examples of heat sources

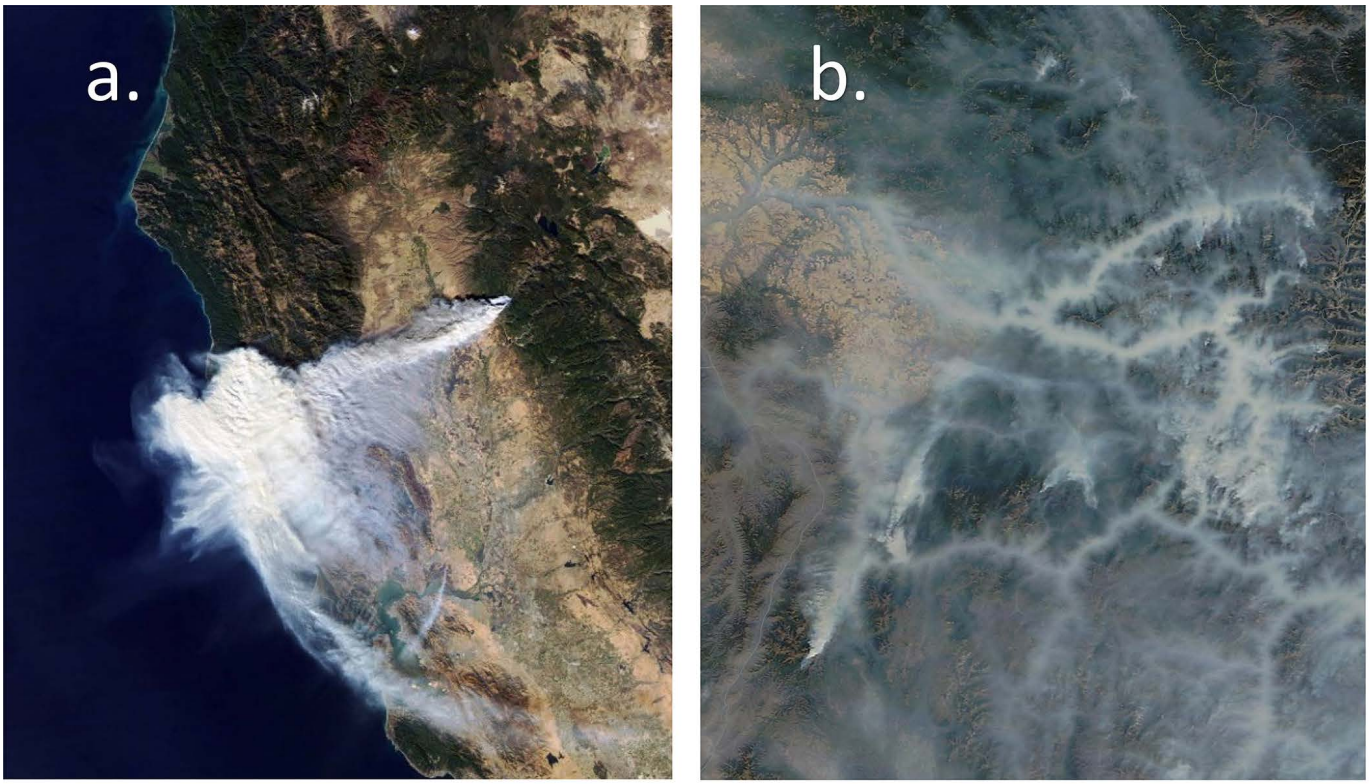


Figure 3. Strong winds can cause rapid fire spread and move smoke into communities far from a wildfire. In 2018, smoke from the Camp fire caused weeks of poor air quality in the San Francisco Bay area (a). Light winds and stable atmospheric conditions cause smoke to pool near a wildfire and flow down valleys to nearby communities as seen in central Idaho in 2012 (b).

necessary to start and promote growth of wildfires. Once ignited, fuels, weather. and topography govern fire behavior and determine how fast the fire spreads, how intensely it burns, and how much smoke it will put into the air on a given day. The changing climate is also influencing the frequency, duration, and severity of wildfires due to a warming climate, longer fire seasons, and increases in drought conditions (Westerling et al. 2003; USGCRP 2018).

Wildland fuels

The general characteristics of wildland fuels help predict some of what will happen during a wildfire smoke incident. Very generally, natural fuel fires can be described in three large and diverse categories: grass, brush, and forest (Figure 2). Wildfires in grass typically spread very rapidly but generally burn themselves out and are brought under control within hours to days of ignition. Brush-type fuels, for example chaparral, gallberry, and ceanothus often contain volatile compounds that result in hot, fast moving fires that are very difficult to control especially if the brush is growing on slopes or in dense clusters. Wildfires in forest fuel types can range from mild to severe in intensity and can spread very slowly or extremely rapidly depending on weather and fuel conditions. Fires in forests can last for weeks or months and are often the wildfire type that results in the most severe and longest duration air quality impacts. Fires in forest fuel types are more likely to be in remote and inaccessible areas making firefighting more difficult. Wildfires of course often burn over multiple fuel types and may start in one fuel type before moving into another.

The amount and type of fuel and its moisture content affect smoke production, as does the stage of combustion (flaming and smoldering). The smoldering phase of a fire when large rotten logs and duff or peat are consumed, can sometimes result in high particle emissions due to less complete combustion than when flames are present. Smoldering fuels are the sign of a cooler fire so smoke generally stays closer to the source and closer

to the ground, and air quality impacts are often closer to the fire, especially at night and downslope of smoldering activity.

Meteorology and smoke

Weather conditions such as wind, temperature, and humidity contribute to fire behavior and smoke accumulation. Winds brings a fresh supply of oxygen to the fire and pushes the fire into new fuels. Strong, hot, and dry winds can cause a wildfire to grow very rapidly or "blow up". Winds also move smoke away from the fire and contribute to atmospheric mixing meaning smoke impacts to the public may be lessened near the fire although winds can move smoke long distances into communities far from where the wildfire is burning (Figure 3).

Once smoke enters the atmosphere, its concentration at any one place and time depends on mechanisms of transport and dispersion. Transport refers to whatever process may carry a plume vertically or horizontally in the atmosphere. Vertical transport is controlled by the buoyancy of the smoke plume and stability of the atmosphere. Horizontal transport is controlled by wind. The larger the volume of space that smoke is allowed to enter and the farther it can be transported, the more dispersed and less concentrated it will become.
The intense heat generated by an active wildfire drives smoke high into the air where it remains until it cools and begins to descend. As smoke moves downwind, it becomes more dilute and often more widespread, eventually reaching ground level. Terrain also affects localized weather. For example, as the sun warms mountain slopes, air is heated and rises, bringing smoke and fire with it. After sunlight passes, the terrain cools and the air begins to descend. This creates a down-slope airflow that can alter the smoke dispersal pattern seen during the day. These daily cycles sometimes help predict repeating patterns of smoke impacts in communities.

In the evening, especially in mountain valleys and low-lying areas, temperature inversions in which the air near the ground is cooler than the air above are common. Temperature inversions prevent upward air movement. The lid effect of inversions, coupled with a drop in wind speed, can favor smoke and pollutant accumulation in valleys close to the fire at night. Strong inversions can also allow for smoke to accumulate in an area for days or weeks with little opportunity for clean air to help improve smoke concentrations.

Smoke levels in populated areas can be difficult to predict and will often depend on a suite of local terrain, weather, and fire-behavior-based factors. A wind that usually clears out a valley may simply blow more smoke in or may fan the fires, causing a worse episode the next day. Smoke concentrations change constantly. Sometimes, by the time officials can issue a warning or smoke advisory, the smoke may already have cleared.

Wildland fire management

Most of the tens of thousands of wildfires in the United States are suppressed during initial attack efforts. For many jurisdictions, from federal to private lands, there are specific plans in place addressing fire suppression efforts and response. For federal land managers, land management plans are created with annually updated fire management plans that help guide the appropriate response to a wildfire in a specific area. When these land management plans are revised, they undergo public review, which provides an opportunity for input on how the land is managed by a federal agency.

When there is an ignition, whether human caused or from lightning, the first order of business is always protecting the safety of the public and fire fighters. Some wildfires continue past the initial attack or occur in areas where the risks of attack are high or the likelihood of suppression success is low. Such fires can become large, of long duration, and a significant source of smoke. When these wildfires elude initial attack efforts, exceed local firefighting capabilities, or become large quickly, the land owner or, for federal lands, the agency administrator, has

the opportunity to engage external assistance for additional resources to assist their local efforts. On these types of fires, an Incident Management Team (IMT) is usually engaged. The land owner/manager/agency administrator where the wildfire is burning advises the IMT on strategies, constraints, and priorities so that fire management and suppression efforts align with other land management goals in the area.

Fire management strategies designed for a remote wildfire in a wilderness area will be much different from tactics used on lands adjacent to or in communities. Wildfires in remote areas with no risk to public resources may be monitored and largely left to take a natural course and eventually burn themselves out, especially when firefighting resources are scarce. Similarly, only sections of a wildfire may be suppressed due to resource capabilities or threats to public and private resources. Wildfires that threaten homes or other infrastructure will be attacked aggressively. This may include retardant drops from aircraft, bulldozers, fire engines, and multiple 20-person fire crews. Public and firefighter safety is considered above all else in determining the fire management or suppression approach that will be implemented.

Incident Management Teams

An IMT is a group of trained professionals that respond to national, regional, or local emergencies. IMTs are used to manage large-scale, complex wildfire incidents. Team members have expertise in finance, logistics, operations, information, safety, planning, public information, and other areas needed to manage a wildfire. Every incident management team has an incident commander to oversee and control the infrastructure of the team. IMTs work, eat, and sleep in a safe location near the wildfire frequently in camps or nearby public facilities. The IMTs hold both public and cooperator meetings where updates about the fire, upcoming fire tactics, and concerns are discussed. These are important opportunities for engagement on smoke issues.

If smoke and air quality issues become a concern, the IMT can order a technical specialist called an Air Resource Advisor (ARA). ARAs come from a variety of backgrounds but have specialized training in health effects of fine particles, air quality monitoring, smoke dispersion modeling, predicting future air quality, and communicating this information to the public in an understandable and consistent way. Much of the work of an ARA fits well with the work of public health officials because ARAs produce a "Smoke Outlook" that tells when and where smoke levels will be high during the next couple of days. Further discussion and an example outlook can be found in Chapter 4.

III. SPECIFIC STRATEGIES TO REDUCE EXPOSURE TO WILDFIRE SMOKE

In areas where the public is experiencing wildfire smoke exposure, public health and air quality agencies should provide advice on actions that can be taken to reduce smoke exposure. The following strategies to reduce wildfire smoke exposure can be used individually or in combination by individuals and communities, as feasible and appropriate for the smoke event they are experiencing. Recommendations for communicating these strategies to the public are provided in Chapter 5 and summarized in Table 4.

Individuals with heart or lung disease who are concerned about the potential health implications of exposure to wildfire smoke and actions they can take to limit exposures, should be advised to discuss this with their primary health care provider. They should also check the Air Quality Index (AQI, discussed below) each day for the air quality forecast and for information about ways to reduce exposure.

Stay indoors

The most common advisory issued during a smoke episode is to stay indoors. The effectiveness of this strategy depends on how well the building limits smoke from coming indoors, and on efforts to minimize indoor pollution sources. Staying indoors will provide some protection from smoke, especially in a tightly closed, air-conditioned home in which the air conditioner recirculates indoor air. Generally, newer homes are "tighter" and keep ambient air pollution out more effectively than older homes.

Staying inside with the doors and windows closed can reduce the entry of outdoor air into homes, in some cases by a third or more (Howard-Reed et al., 2002). Homes with central air conditioning generally recirculate indoor air, though some smoky outdoor air can still be drawn inside (e.g., when people enter or exit or when the central system can be set to bring in outdoor air). In homes without air conditioning, indoor concentrations of fine particles can approach 70–100% of the outdoor concentrations; however, it is more common that the indoor concentrations of fine particles that come from outdoors are 50% or less of outdoor concentrations when windows and doors are closed (Allen et al. 2012, Chen and Zhao 2011, Singer et al. 2016). In very leaky homes and buildings, outdoor particles can easily infiltrate the indoor air, so guidance to stay inside may offer little protection. In any home, if doors and windows are open, particle levels indoors and outdoors will be about the same.

Sometimes smoke events can last for weeks or even months. These longer events are usually punctuated by periods of relatively clean air. When air quality improves, even temporarily, residents should "air out" their homes to reduce indoor air pollution. People who wish to clean their residences after or between wildfire smoke events should use cleaning practices that reduce re-suspension of particles that have settled, including damp mopping or dusting and using a high-efficiency particulate air (HEPA) filter-equipped vacuum.

Staying indoors is a recommended strategy for avoiding both heat and smoke exposure, as long as the indoor air environment is protected. In high-heat conditions, people are advised to stay cool, stay hydrated, and stay inside. An important caveat about advising people to stay inside and close windows and doors of homes without air conditioning is the increased risk of heat stress. Even without smoke exposure, extreme heat poses a substantial health risk, especially for at-risk groups, including young children, the elderly, those with chronic diseases or disabilities, and pregnant women. These at-risk groups largely overlap with those at higher risk from smoke exposures. Heat-related illnesses include heat exhaustion, heat stroke and death. Warning signs include heavy sweating, muscle cramps, weakness, headache, nausea, vomiting, paleness, confusion, fainting (passing out), and dizziness. To prevent overheating, use cool compresses, misting, showers, baths, and drink plenty of water. In some high-heat conditions, windows and doors will need to be opened to allow cooling even if smoke enters.

People who do not have air conditioning at home should be advised to visit family members, neighbors, or public buildings with air conditioning and appropriate air filtration (such as a shopping mall, library, cooling center, or movie theatre) during high

smoke conditions to cool off for a few hours each day. Public health officials should get information about cooling and filtration status of buildings before recommending where people can seek shelter from heat or smoke. Some public buildings may have older heating, ventilating, and air-conditioning (HVAC) systems that use low-efficiency filters (see section below on air conditioners and filters).

In preparation for the fire season or a smoke event, it is a good idea to have enough food on hand to last several days, to minimize driving and trips outdoors. Foods stored for use during the fire season should not require frying or broiling, since these activities can add particles to indoor air. It is also important to have at least a several-day supply of medication for the same reason.

Guidance on protecting office and other indoor workers from wildfire smoke has been developed by the California Division of Occupational Safety and Health (Cal/OSHA), in consultation with technical staff from several other California agencies (Appendix D) . This guidance describes how to maximize the protection provided by HVAC systems common in public and commercial buildings, as well as other steps to protect occupants.

Reduce activity

Reducing physical activity lowers the dose of inhaled air pollutants and reduces health risks during a smoke event. When exercising, people can increase their air intake 10 to 20 times over their resting level. Increased breathing rates bring more pollution deep into the lungs. People tend to breathe through their mouths during exercise, bypassing the natural filtering ability of the nasal passages and delivering more pollution to the lungs. They also tend to breathe more deeply, modifying the usual patterns of lung particle deposition. This guidance addresses outdoor exercise during smoky periods; residents need not be discouraged from indoor exercise in an environment with acceptable air quality.

Reduce other sources of indoor air pollution

Indoor sources of air pollution such as smoking cigarettes, using gas or wood-burning stoves and furnaces, spraying aerosol products, frying and broiling meat, burning candles and incense, and vacuuming can all increase indoor particle levels. Some of these same pollutants are also present in wildfire smoke. Reducing indoor air pollutant emissions during smoke events can decrease indoor particle levels.

Cigarette smoke significantly increases levels of particles and other pollutants. For instance, in a closed room of 125 square feet, it takes only 10 minutes for the smoke of four cigarettes to generate hazardous levels of particles (644 micrograms per cubic meter of air or $\mu g/m^3$ $PM_{2.5}$). The second largest source of indoor air pollutants is indoor combustion sources without proper ventilation to the outdoors. “Room-vented” or “vent-free” appliances such as unvented gas or propane fireplaces, decorative logs, and portable heaters can contribute substantial quantities of particles to indoor air and are of significant concern. Frying or broiling some foods also can produce high levels of particles in the kitchen and dining areas. These sources can also increase the levels of polycyclic aromatic hydrocarbons (PAHs), carbon monoxide, acrolein, and nitrogen oxides, all of which are potentially harmful to health. In addition, small sources such as candles and incense burning can produce surprisingly large quantities of particles and should not be used during wildfire smoke events. To avoid re-suspending particles, do not vacuum during a smoke event, unless using a HEPA-filter-equipped vacuum. When cleaning, use a damp mop or damp dust cloth to minimize re-suspending settled particles.

Use air conditioners and filters

When wildfire risk rises, and before the smoke arrives, public health agencies can help their communities prepare by developing public service announcements with information about upgrading the filters in their central air systems. The message should include information about different filter

types, the importance of stocking up on filters ahead of wildfire season, and how to turn off fresh air intakes. Highlight the importance of creating clean air spaces in homes with individuals in at-risk groups and encourage residents to install high-efficiency filters (MERV 13 or higher), if possible. Engage with local health care professionals and provide information they can pass on to their patients. A fact sheet on indoor air filtration and air cleaners is available at: https://www3.epa.gov/airnow/smoke_fires/indoor-air-filtration-factsheet-508.pdf

Homes with central air conditioners generally have lower concentrations of particles from the outdoors compared to homes that use open windows for ventilation. Much less is known about the effect of using various types of room air conditioners (e.g., window units) and their air filters on smoke concentrations in homes. Most air conditioners are designed by default to recirculate indoor air. Those systems that have both "outdoor air" and "recirculate" settings need to be set on "recirculate" during smoke events. Other types of air conditioners, such as swamp coolers, can actually bring in large quantities of outdoor air. Below is a brief overview of common types of cooling systems.

Central air systems

Central heating and air conditioning systems (and some room air conditioners) contain filters that remove some airborne particles with different degrees of efficiency. The most helpful parameter for understanding the efficiency of HVAC filters is the fractional removal efficiency. The most widely used test method for HVAC filters in the United States is the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 52.2, which evaluates the removal efficiency for particles 0.3 to 10 µm in diameter. Results are reported as a Minimum Efficiency Reporting Value (MERV) ranging from MERV 1 to MERV 16 based on the average removal efficiency across three particle size ranges: 0.3–1 µm, 1–3 µm, and 3–10 µm (Table 2). Other commercially common proprietary rating systems for in-duct air filters include the Microparticle Performance Rating (MPR) and Filter Performance Rating (FPR). In general, the higher the filter rating, the higher the filter's removal efficiency for at least one particle size range.

If possible, the HVAC filter should be replaced with a pleated medium- or high-efficiency particle filter. Higher-efficiency filters (e.g., filters rated at MERV 13 or higher) are relatively inexpensive and preferred because they can capture more of the fine particles associated with smoke and can reduce the amount of outdoor air pollution that gets indoors. However, caution must be taken to ensure that the central system is able to handle the increased airflow resistance from a higher-efficiency filter. Consultation with an HVAC technician or the central air system manufacturer may be necessary to confirm if or which high-efficiency filters will work with an individual system. Filters need to be replaced regularly and should fit the filter slot snugly. Filters only remove particles while the system fan is operating and passing air through the filter. Regardless of whether a filter upgrade has been performed, during a wildfire smoke event, the central system's circulating fan can be set to operate continuously (i.e., fan switch on the thermostat set to "ON" rather than "AUTO") to obtain maximum particle removal by the HVAC filter, although this will increase energy use and costs (Fisk and Chan 2017). The thermostat can be reset back to "AUTO" after the wildfire smoke clears.

In addition to high- and medium-efficiency filters, electrostatic precipitators (ESPs) or other electronic particle air cleaners can sometimes be added by a technician to central air conditioning systems to keep particle levels in indoor air within acceptable levels during a prolonged smoke event. However, **ESPs may produce some amount of ozone as a byproduct**, so only ESPs that have been independently tested and produce little or no ozone should be used.

For newer air conditioners with a "fresh air ventilation system" that brings in outdoor air continuously or semi-continuously, the "fresh air" setting for the system should be turned off during smoke events. This may require closing the outdoor

air damper or sealing off outdoor air intakes, setting the system on "recirculate" only, or turning off the energy- or heat-recovery ventilator or exhaust fans that are part of the system. If the control system instructions are not clear or accessible, residents should contact their builder or heating and cooling contractor to help temporarily adjust the system. However, residents should also place a reminder tag in a visible spot so that they reset the system once the smoke clears.

Many newer homes currently have whole-dwelling mechanical ventilation systems that intentionally bring outdoor air inside, often designed to meet the requirements of ASHRAE Standard 62.2. This can be achieved through dedicated supply ductwork (creating positive pressure in the building), controlled exhaust ventilation (creating negative pressure in the building), or "balanced" ventilation strategies that typically employ a heat recovery or energy recovery ventilator (HRV/ERV). Mechanical ventilation in new homes is now required by building codes in some jurisdictions. These systems may need to be turned off or adjusted during periods of high outdoor air pollution from wildfires to avoid entry of outdoor air pollutants, especially exhaust ventilation systems. Mechanical ventilation systems used in public and commercial buildings differ and are discussed further in appendices B and D.

Swamp coolers

Many older homes use evaporative coolers, known as "swamp coolers," to condition the air in the home. A cooler unit operates by evaporating water off large pads located in the cooler housing. The unit also contains the fan motor, fan, water tray, and pump and is usually located on the roof of a house. The coolers rely on bringing large volumes of outside air into the home and they will not cool effectively if the home is sealed up and the incoming air cannot be exhausted from the home. Although a laboratory study has shown that evaporative coolers can reduce PM_{10} up to 50%, and $PM_{2.5}$ by 10–40% (Paschold et al., 2003), other outdoor pollutants such as ozone are not filtered out and can reach indoor levels that are nearly equal to the outdoor levels. Therefore, unless there is a heat emergency, evaporative coolers should not be used during periods when there is heavy smoke outside.

Ductless mini-split systems

Some new or recently renovated homes may have ductless mini-split heat pumps or air conditioning systems. Ductless mini-split systems, which use an air handling unit mounted inside the home's pressure boundary, will still cool effectively in a home that has been sealed up to minimize smoke infiltration and generally do not compromise indoor air quality. These systems have the advantage of not requiring

Table 2. Particle size efficiency for select MERV ratings*

MERV Rating	Average Particle Size Removal Efficiency (%)		
	Particle Size (µm)		
	0.3–1.0	1.0–3.0	3.0–10.0
Low (1–4)	n/a	n/a	<20
Medium (5–8)	n/a	>20+	20 to >70
Medium (9–12)	20 to >35++	35 to >80	75 to >90
High (13–16)	50 to >95	>85	>90
HEPA (17–20)**	≥99.97		

*Adapted from ANSI/ASHRAE Standard 52.2

**Not part of the official ASHRAE Standard 52.2 test but added for comparison purposes

n/a: Not applicable to MERV rating (not tested)

+ Not applicable for MERV 5–7

++Not applicable for MERV 9–10

ductwork throughout the attic or basement space. From an air-balance standpoint, these systems do not significantly affect the air pressure in the home and do not result in extra air being brought into or exhausted from the home. Some mini-split systems include ducts connected to a low-profile air handler, which may be installed in an unconditioned area and may be susceptible to outdoor air exchange issues, depending on the effectiveness of the duct sealing during installation.

Window-mounted and portable air conditioners

Some residences are cooled or heated using window-mounted air conditioners. To function properly and efficiently, these units must form a tight seal with the window frame in which they are mounted. People who have window units should be advised to check the quality of the seal by looking around the perimeter of the window unit for any visible gaps. Light or air leaking in from the outside is an easy way to determine whether the seal is tight. Also, window units can be operated in recirculation mode or fresh air mode. During a high smoke event, people should be advised to set the window AC unit to operate in recirculation mode.

Use of a single-hose portable air conditioner might result in outdoor smoke being drawn into the home. Portable air conditioners are usually used to condition the air in a single room of the home. These units have a cooling capacity that can range from 6,000 to 15,000 BTU and many of these units also have a heating mode of operation. Depending on the make and model, a portable air conditioner will have either a single- or dual-hose configuration. The single-hose configuration expels hot exhaust air to the exterior of the home, but the supply air is taken from the home itself, so the net effect is that the room is placed under slight negative pressure. This means that air is drawn into the home through any leaky points in the building envelope. This is not a problem with dual-hose configurations, because they draw and deliver supply air from the outside so the air pressure inside the room remains balanced.

Use room air cleaners

Choosing to buy an air cleaner is a decision that ideally should be made ***before*** a smoke emergency occurs, particularly in homes with occupants in at-risk groups. During a smoke emergency, it may be hazardous to go outside or drive, and appropriate devices may be in short supply. It is unlikely that local health officials or non-governmental organizations will be able to buy or supply air cleaners to those who might need them. Note that air cleaners are frequently referred to as "air purifiers" by retailers and the general public.

Choose an air cleaner appropriate for the size of the indoor environment

Air cleaners can help reduce indoor particle levels, provided the specific air cleaner is properly matched to the size of the indoor environment. Room air cleaners are available as portable units designed to clean the air in a single room ($90–$900). Central air cleaners, which may be large portable units or in-duct units installed by an HVAC professional, are intended to clean the whole house ($450–$1,500). Central air cleaners can be more effective than room air cleaners (depending on how much they are operated), although two or more well-placed portable air cleaners can be equally effective, and their cost may still be less than a large central air cleaner.

Room air cleaner units should be sized to provide a filtered airflow at least two to three times the room volume per hour. Most portable units will state on the package the unit's airflow rate, the room size it is suitable for, its particle removal efficiency, and perhaps its Clean Air Delivery Rate (CADR). The CADR is a rating that combines efficiency and airflow.

The Association of Home Appliance Manufacturers (AHAM) maintains a certification program for air cleaners. The AHAM seal on the air cleaner's box lists separate CADR numbers for tobacco smoke, pollen, and dust. Higher numbers indicate faster filtration of the air. For wildfire smoke, choose a unit with a tobacco smoke CADR at least 2/3 of the room's area. For example, a 10' x 12' room (120 square feet) would require an air cleaner with a tobacco smoke

CADR of at least 80. If the ceiling is higher than 8', an air cleaner rated for a larger room will be needed.

Choose an air cleaner that effectively removes particles without producing ozone

The two common mechanisms for particle removal include:

- Mechanical air cleaners that contain a fiber or fabric filter. The filters need to fit tightly in their holders and be cleaned or replaced regularly. HEPA filters (and Ultra-Low Penetration Air [ULPA] filters, which are not generally available for residential use) are most efficient at removing particles.
- Electronic air cleaners, such as electrostatic precipitators (ESPs) and ionizers. ESPs use a small electrical charge to collect particles from air pulled through the device. Electronic air cleaners usually produce small amounts of ozone (a respiratory irritant) and some, especially those that are combined with other technologies, may produce substantial levels of ozone (see next section on Ozone Generators). Only ESPs that have been independently tested and documented to produce little or no ozone should be used. Ionizers, or negative ion generators, cause particles to stick to materials (such as carpet and walls) near the device and are also often a source of ozone. Ionized particles deposited on room surfaces can cause soiling and, if disturbed, can be resuspended into the indoor air.

Only portable (room) air cleaners that do not produce ozone above 0.050 ppm should be used (see below). The California Air Resources Board (CARB) certifies air cleaners that produce little or no ozone and only CARB-certified air cleaners may be sold in California.

A list of CARB-certified air cleaners can be found at: https://www.arb.ca.gov/research/indoor/aircleaners/certified.htm.

Place and operate the air cleaner to maximize particle removal

Room air cleaners will provide the most protection when placed where people spend the most time, such as a bedroom. A good portable air cleaner placed in a bedroom may be particularly helpful to a person with asthma or COPD. For retired or homebound individuals, the portable room air cleaner should be set up in whichever room is used the most. To maximize air cleaner effectiveness, operate it continuously, or as often as possible. Use the highest fan speed and make sure the air flow to the air cleaner is not obstructed. Keep outside doors and windows closed to prevent additional particles from entering the room.

Air cleaners can be used in combination with central air system filter upgrades described in the preceding section to maximize the reduction of indoor particles. Air cleaners alone can effectively reduce particle concentrations even in homes that do not have central air conditioning if windows and doors remain closed and excessive heat is not a concern. Under normal (non-smoky) conditions, portable air cleaners fitted high-efficiency filters can reduce indoor particle concentrations by as much as 90 percent (Singer et al. 2016). During a wildfire smoke event, portable air cleaners fitted with high-efficiency filters may reduce indoor particle concentrations by as much as 45% (Fisk and Chan 2017).

Air cleaners for gases and odors

Most air cleaners are not effective at removing gases and odors, although some specialized models that perform this task well are available. Devices that remove gases and odors can cost more than particle air filters, both to purchase and maintain. They force air through materials such as activated charcoal or alumina coated with potassium permanganate. However, with smaller-sized air cleaners, the filtering medium can become quickly overloaded and may need to be replaced often. Large gas-removing devices may be useful for individuals that encompass an at-risk lifestage or population and may require less-frequent replacement of the filtering medium. New models that combine particle and gas removal are available in both portable and in-duct models.

Do-it-yourself box fan air cleaners

Some organizations provide instructions to assemble a do-it-yourself (DIY) box fan air cleaner by

attaching a high-efficiency filter to a box fan. There is currently some limited evidence to support the filtration efficacy of these DIY devices. However, concerns have been raised that the box fan motor may overheat when operated with a filter attached. We expect there will be more research conducted on the safety and efficacy of DIY air cleaners in the coming years. In the meantime, though there is not enough evidence for us to endorse their use, we acknowledge that during a wildfire smoke event some people may choose to assemble a DIY air cleaner to reduce their exposure to wildfire smoke. Those who make this choice should be advised to use the device with caution and not to operate it unattended or when sleeping, to avoid any potential fire or electrical hazard.

For more information about residential air cleaners:

https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home-0

https://www.arb.ca.gov/research/indoor/aircleaners/consumers.htm

http://ahamverifide.org

Avoid ozone generators

Some devices, known as ozone generators, personal air purifiers, "super-oxygen" air purifiers, and "pure air" generators, are sold as air cleaners, but the position of public health agencies, including the California Air Resources Board and U.S. Environmental Protection Agency, is that they do more harm than good. These devices are designed to intentionally produce large amounts of ozone gas. Ozone generator manufacturers claim that ozone can remove mold and bacteria from the air, but this occurs only when ozone is released at levels many times higher than those that are known to harm human health.

Relatively low levels of ozone can irritate the airways, causing coughing, chest pain and tightness, and shortness of breath. Low levels of ozone can also worsen chronic respiratory diseases such as asthma and compromise the body's ability to fight respiratory infections. As a result, using an ozone generator during a smoke event may actually increase the adverse effects from the smoke. In addition, ozone gas does not remove particles from the air and can lead to particle formation; ozone reacts with certain chemicals commonly found indoors to produce particles and formaldehyde. California now prohibits the sale of air cleaners that emit potentially harmful amounts of ozone. A list of air cleaners that California has certified to emit little or no ozone is available at:

https://www.arb.ca.gov/research/indoor/aircleaners/certified.htm

For more information about ozone generators marketed as air cleaners:

https://www.epa.gov/indoor-air-quality-iaq/ozone-generators-are-sold-air-cleaners

https://www.arb.ca.gov/research/indoor/ozone.htm

Humidifiers

Humidifiers are not air cleaners and will not significantly reduce the number of particles in the air during a smoke event. Nor will they remove gases like carbon monoxide. However, humidifiers and dehumidifiers (depending on the environment) may slightly reduce pollutants through condensation, absorption, and other mechanisms. In an arid environment, one possible benefit of running a humidifier during a smoke event might be to help the mucous membranes remain comfortably moist, which may reduce eye and airway irritation. However, if not properly cleaned and maintained, some humidifiers can circulate mold spores and other biological contaminants. The usefulness of humidification during a smoke event has not been studied.

Create a clean room at home

Creating an in-home "clean room" is a good exposure reduction strategy for people who live in areas regularly affected by wildfire smoke—especially those with pre-existing conditions that increase the risk of air pollution-related health effects. It is also a good strategy for those who must work outside so that they can breathe cleaner air while indoors at home after work. A good choice for a clean room is an interior room with few windows and doors, such as a bedroom. Anyone who cannot create an adequate clean room in their own home should be encouraged to seek out cleaner air shelters or cleaner air spaces located in their communities for periods of respite from the smoke (see discussion below).

Some suggestions for creating and maintaining a clean room:

- Keep windows and doors closed.
- Set up a properly sized room air cleaner (see above) to help remove particles from the air while emitting little or no ozone.
- Run an air conditioner or central air conditioning system. If the air conditioner provides a fresh air option, keep the fresh-air intake closed to prevent smoke from getting inside. Make sure that the filter is clean enough to allow good airflow indoors.
- Do not vacuum anywhere in the house, unless using a HEPA-filter equipped vacuum.
- Do not smoke or burn anything, including candles or incense, anywhere in the house.
- Keep the room clean by damp mopping or dusting with a damp cloth.
- Long-term smoke events usually have periods when the air is better. When air quality improves, even temporarily, air out your home to reduce indoor air pollution.
- People in homes that are too warm to stay inside with the windows closed or who are at-risk of smoke-related health effects should seek shelter elsewhere. Keep in mind that many particles will enter the home even if all of these steps are taken.
- For additional information, see the EPA website Create a Clean Room to Protect Indoor Air Quality During a Wildfire.

Cleaner air shelters and cleaner air spaces

Public health officials in areas at risk from wildfire smoke episodes should identify and evaluate public spaces where people can seek relief from wildfire smoke. For the purposes of this guide, these public spaces are defined as either cleaner air shelters or cleaner air spaces. People should be made aware that driving to and from a public shelter or cleaner air space for short-term relief and the stress of evacuating for an extended stay in a shelter can also have health consequences. Therefore, whether to create a clean room at home or leave for a public shelter or cleaner air space will depend on factors that the individual must assess.

Cleaner air shelters

Cleaner air shelters are public spaces for people who are displaced by wildfire or smoke. People who take refuge in these shelters may only need to stay overnight or may need the shelter for extended periods (days or even weeks). Some examples of cleaner air shelters are school gymnasiums, buildings at public fairgrounds, and civic auditoriums. A cleaner air shelter may also be considered an evacuation shelter but be aware that not all evacuation centers provide cleaner air for the occupants. Therefore, public health officials in areas at risk from wildfire smoke episodes should identify and evaluate public spaces where people can shelter from wildfire smoke well in advance of fire season. Guidance for identifying or setting up a cleaner air shelter is provided in Appendix B.

Cleaner air spaces

During severe smoke events, it is often impractical or impossible for people to set up a clean room in their homes. Individuals who cannot create an adequate clean room should be encouraged to seek out cleaner air spaces located in their communities for periods of respite from the smoke. People can find temporary relief from smoke, heat, or cold at public cleaner air

spaces for several hours, or perhaps for the better part of a day; however, many of these commercial spaces and public facilities are unlikely to be open at night. Examples of cleaner air spaces could include libraries, museums, shopping malls, theaters, sports arenas, senior centers, and any indoor area with effective particle filtration and air conditioning.

Inside vehicles

Individuals can reduce the amount of smoke in their vehicles by keeping the windows and vents closed, and, if available, operating the air conditioning in "recirculate" mode. However, in hot weather, a car's interior can heat up very quickly to temperatures that far exceed that outdoors and heat stress or heat exhaustion can result. Children and pets should **never** be left unattended in a vehicle with the windows closed. The ventilation systems of older cars typically remove a small portion of the particles coming in from outside. Newer models may have better air filters that remove more particles from the air, but the vehicle owner should not assume that they will get the same level of protection they would get from a dedicated clean room or cleaner air space. Most vehicles can recirculate the inside air, which will help keep the particle levels lower.

Drivers should check the owner's manual and assure that the system is set correctly to minimize entry of outdoor smoke and particles. However, studies have shown that carbon dioxide levels can quickly accumulate to very high levels (possibly exceeding 2500 parts per million) in newer cars due to occupants' exhaled breath when vents and windows are closed and the recirculation setting is used (Fruin et al. 2011, Hudda and Fruin 2018, Lee and Zhu 2014). Therefore, if driving a recent model vehicle for more than a short period of time, it may be a good idea to briefly open windows or vents occasionally when smoke levels are low to avoid the build-up of carbon dioxide. Finally, vehicles should not be used as a shelter, but rather as a means of transportation to indoor locations with cleaner air.

Respiratory protection for wildfire smoke and ash

Respiratory protection (commonly referred to as "masks") can be useful for reducing personal inhalation of wildfire smoke or ash. Respirators are widely available and offer some protection for adults if selected and used properly, although the public should be advised to take more effective measures first to limit their exposures. Information provided in this section describes selection and proper use of tight-fitting particulate respirators certified by the National Institute for Occupational Safety and Health (NIOSH).

Drawbacks to recommending the use of respirators include the possibility that users will select the wrong type or use them incorrectly. A stand-alone factsheet, Protect Your Lungs from Wildfire Smoke or Ash, has been designed for the public and includes links to other resources. The use of respiratory protection without first ensuring that no medical conditions exist that would make use of respiratory protection a risk or first providing users with "fit tests" to ensure a reliable seal to the face is not ideal although inevitable in the case of public wildfire smoke exposure. A fit test is a procedure that quantitatively or qualitatively evaluates the fit of a specific model and size of respirator on an individual and is required in workplace settings. However, the respirators described in this section are available in multiple sizes and are likely to provide some protection to users who can achieve a reasonably close fit to the face, even without fit testing.

Respirators described in this section would also help to protect the public involved in cleaning up fire ash. There is additional guidance in this document on wildfire ash, and a factsheet for the public on cleaning up ash, Protect Yourself from Ash.

Respiratory protection use in workplace situations is beyond the scope of this section, see Chapter 5, Protecting Outdoor Workers. Employers who anticipate that their workers may need to wear respiratory protection are expected to put in place a full respiratory protection program prior to use.

In emergency situations, employers should consult the applicable Occupational Safety and Health Administration (OSHA) program for current guidance. Where respirator use is not required by OSHA regulations or by the employer, the employer may provide respirators at the request of employees or permit employees to use their own respirators, if the employer determines that such respirator use will not in itself create a hazard and provides some basic information about proper use and the limitations of respirators.

Children and respirator use

Respirators are not made to fit children and will not protect them from breathing wildfire smoke. Children are especially at risk from exposure to wildfire smoke because their lungs are still developing. Reduce children's exposure to wildfire smoke by checking air quality, keeping them indoors, creating a clean air room, and being ready to evacuate if necessary. See also the factsheet Protecting Children from Wildfire Smoke or Ash.

NIOSH does not currently certify respirators for children. As new research findings on efficacy become available, guidance by U.S. government agencies may be issued on the proper use of respirators by older children.

Who may need to wear a respirator

The most effective action the public can take to reduce the risk of health effects from inhalation of wildfire smoke or ash is to stay indoors or limit the time spent outdoors during wildfire smoke emergencies. People at higher risk of adverse effects, such as those with heart or lung disease and older adults, should check with their health care providers before using a respirator, since using a respirator can make it harder to breathe. If the smoke event is expected to be prolonged, these groups should consider temporary relocation out of the smoky area.

People who must be outdoors for extended periods of time in smoky air or in an ash-covered area may benefit from using tight-fitting, NIOSH-approved N95 or P100 respirators to reduce their exposures. People experiencing health effects from a smoky environment, even if indoors, may also benefit from using N95 or P100 respirators if they cannot move to locations with better air quality or take other steps to clean their indoor air.

For people who wish to wear respirators, learning how to select respirators and use them correctly is important for achieving the best protection possible.

Figure 4. Two types of N95 disposable particulate respirators. Note the presence and placement of the two straps above and below the ears. Photos courtesy of the California Department of Public Health

Choosing the correct respirator

Tight-fitting "particulate" respirators are designed to capture or filter out particles from contaminated air before the user can breathe them in. A "filtering facepiece" respirator, commonly called a disposable N95 or P100 respirator, has two straps and a facepiece made entirely of filtering material (Figure 4). Respirators must be certified by NIOSH, and the words "NIOSH" and either "N95" or "P100" will be printed on the facepiece by the manufacturer. The user should select a size and model that fits over the nose and under the chin and seals tightly to the face. Any leakage around the face seal causes unfiltered air to enter and be inhaled by the wearer, reducing or eliminating the ability of the respirator to provide protection. A good seal is not possible if the user has a beard or other excess facial hair where the respirator seals to the face.

The numbers "95" and "100" on a respirator facepiece indicate that the filter material captures 95% or 99.97%, respectively, of particles passing through it when tested using particles 0.3 micron in diameter that are the hardest to capture. However, when used by the public without individual user fit testing, there is likely little difference in effectiveness between N95 and P100 respirators, as leakage around the face seal will be a more significant factor determining effectiveness than filtration efficiency. "N" indicates filter material that is not resistant to degradation in the presence of oil mist; "P" identifies filters that are resistant. In environments where smoke or ash are present, N95 or P100 respirators can be used. Both types can be found in retail pharmacies, in hardware and home repair stores, or online. NIOSH-approved respirators with filters designated as N99, N100, R95, P95, and P99 are far less common, but would also be appropriate.

Other non-disposable NIOSH-certified respirators, such as elastomeric half-masks, can also be used for wildfire smoke or ash. They have a tight-fitting, flexible, re-useable half-mask facepiece and replaceable filters or cartridges; these provide similar protection from particles when they are used with N95 or P100 particulate filters. This type of respirator may also be purchased with a combination filter and organic vapor cartridge, which can reduce exposure to irritating gases in smoke, such as aldehydes. (Disposable N95 or P100 respirators remove only particles, not gases or vapors.)

How to use a tight-fitting respirator

To get a secure fit, a respirator user should put the facepiece over the nose and under the chin and position one strap at the back of the neck below the ears, and the other at the crown or top of the head, above the ears. Incorrect strap placement is a common problem with untrained respirator users and may compromise the face seal and reduce effectiveness.

Users must be clean-shaven where the respirator touches the skin. A good face seal is not possible with facial hair. Care should be taken so that hair, eyeglasses, or other objects do not interfere with the seal of the respirator to the face.

Some N95 or P100 respirators have a metal nose clip that should be pinched around the bridge of the nose to fit securely. The user should follow any instructions provided by the manufacturer for checking for a tight face seal.

Disposable respirators should be discarded when they become dirty, wet, deformed in shape, or when it gets harder to breathe through them.

Possible risks from wearing a respirator

Wearing a respirator can make it harder to breathe. Public health officials should encourage members of the public who have heart or lung problems to consult their health care provider before using a respirator.

Anyone who has difficulty breathing while wearing a respirator, feels dizzy, faint, or claustrophobic or has other symptoms, should remove it and go to a place with cleaner air.

Wearing a respirator, especially if a person is physically active or in a hot environment, may increase the risk of heat-related illness. Users should take periodic breaks from physical activity or, if possible, rest in a location with cleaner air where the

Figure 5. A one-strap paper mask is not a respirator and provides little or no protection from smoke particles. Photo courtesy of the California Department of Public Health

Figure 6. A surgical mask is designed to capture infectious particles generated by the wearer, is not a respirator, and provides little or no protection from smoke particles. Photo courtesy of the California Department of Public Health

respirator can be removed. Rest in a cooler area such as in shade and adequate hydration are important for heat illness prevention, as is gradually acclimating to physical activity in hot locations. Symptoms such as dizziness, nausea, or feeling faint should prompt the user to remove the respirator and seek medical attention or emergency care as appropriate.

Certain "masks" do not provide protection

The public should be cautioned that masks with one-strap nuisance dust masks (Figure 5) or surgical or procedure masks with two straps that loop around the ears (Figure 6) are not respirators. They are not designed to seal tightly to the face and will not provide protection from wildfire smoke or ash. Bandanas (damp or dry), handkerchiefs, and tissues held over the mouth and nose also should not be relied on for protection.

Handling respirator shortages

In a large-scale wildfire smoke emergency, local supplies of N95 and P100 respirators may become limited or exhausted. Local health officials might want to monitor respirator availability and consider ways to increase the supply if necessary. Extra respirators may be available from regional or state stockpiles of personal protective equipment, or directly from respirator manufacturers and distributors of safety equipment.

Respiratory protection resources

An excellent (but fairly technical) NIOSH article, Non-occupational Uses of Respiratory Protection – What Public Health Organizations and Users Need to Know, discusses common mistakes of untrained users as well as best practices and provides references to relevant studies.

NIOSH has a searchable website entitled Approved N95 Particulate Filtering Facepiece Respirators that lists NIOSH-approved N95s alphabetically by manufacturer.

Public health officials can find additional information on the NIOSH Respirator Trusted-Source Information website.

Avoiding smoky periods

Smoke levels from wildfires often change substantially over the course of the day, so there may be opportunities for the public to plan necessary trips outside at times of day that avoid the worst periods of smoke. Ground-level smoke impacts are often forecasted and posted on state smoke blogs in states that use these outreach tools. For example, officials in California, Idaho, Oregon, Washington, currently post forecasts to smoke blogs during fire season. Forecasts can also be found on the Inciweb site by specific named wildfire incidents and at the Wildland Fire Air Quality Response Program page (https://wildlandfiresmoke.net). For communities near active wildfires, smoke impacts often follow a pattern such as nighttime smoke draining downhill and settling into valleys before lifting out the next day. Communities farther downwind of a fire may see smoke arrive in the mid-to-late afternoon and occasionally linger overnight. Either way, it is sometimes possible for people to plan their days around the smokiest times in order to minimize exposure. Public health officials can recommend the use of NowCast AQI (current air quality in terms of the AQI) values from nearby or representative monitors to help people identify and avoid the smokiest times of day (see). Visual range-based estimation can be used if no monitoring is representative of the impact areas. Links to smoke forecasts can be disseminated to provide daily smoke impact patterns in your local Public Service Announcements (PSAs) (see Chapter 5). Chaper 5 describes the Wildland Fire Air Quality Response Program and provides an example of a smoke forecast from a large wildfire.

Closures

The decision to close schools, curtail business activities, or cancel public events is made at the local level and will depend upon predicted smoke levels and other local conditions. Check to see if your state or local air quality or public health agencies have developed guidance that local health officials can reference when trying to evaluate when or where closures should occur. Other factors to consider are whether pollutant levels inside schools and businesses are likely to be similar to or lower than those in homes. Children's physical activity may be better controlled in schools than in homes. On the other hand, smoky conditions may make travel to school hazardous. In many areas, it will not be practical to close businesses and schools, although partial closures may be beneficial. Closures and cancellations can target specific groups (e.g., the at-risk groups described earlier) or specific high-risk activities, such as outdoor sporting events and practices. Curtailing outside activities can reduce exposures, as can encouraging people to stay inside and restrict physical activity.

Evacuation

The most common reason for evacuation during a wildfire is the direct threat of engulfment by the fire, rather than exposure to smoke. Leaving an area of thick smoke may be a good protective measure for members of at-risk groups, but it is often difficult to predict the duration, intensity, and direction of smoke, making this an unattractive option to many people. There is stress associated with evacuation and most people do not want to leave their homes. Even if smoky conditions are expected to continue for weeks, it may not be feasible for a large percentage of the affected population to evacuate. Moreover, the process of evacuation can entail serious risks, particularly if poor visibility makes driving hazardous. In these situations, the risks posed by driving need to be weighed against the potential benefits of evacuation. Therefore, in areas where fires are likely to occur, public health officials are encouraged to develop plans to help at-risk groups shelter locally.

Where individuals are evacuated to a common center because of fire danger, public health officials need to pay particular attention to the potential for smoke to affect the evacuation center itself. It is not always possible to locate evacuation centers far away from smoky areas, or to expect that evacuees will be able to take the steps necessary to reduce their exposures in their new surroundings. Public health officials should consider informing incident commanders if this situation could arise and supplying evacuees with information and materials to further reduce

exposures, including provision of a cleaner air shelter within the evacuation center, if possible, as well as other means of respiratory protection. (See "Respiratory Protection" above.) It is important to consider smoke levels when allowing those evacuated for fire safety reasons to return to their homes. Medical capability (from available transport to urgent care and hospital capacity) to address smoke induced medical situations should be assessed if smoke levels are predicted to be high. Additionally, the smoke from smoldering natural and (if structures are burned in fires) possibly manmade materials pose ongoing hazards that should be considered.

Summary of strategies to reduce smoke exposure

The public should be encouraged to prepare to minimize trips out of the home before fire season arrives by having food and medicine on hand to last several days. Foods stored for use during a smoke event should not require frying or broiling, since these activities can add particles to indoor air.

When smoky conditions are expected, people can pursue a number of strategies to reduce their exposure. Those with moderate to severe heart or lung disease might consider staying with relatives or friends who live away from the smoke impact area. If smoke is already present in substantial quantities, such individuals may want to evaluate whether their exposure during evacuation would be greater than staying at home and using other precautions described above. Depending on how sensitive they are to smoke, as smoke levels increase it may be appropriate for some people to stay in a clean room in the home, relocate temporarily to a cleaner air shelter, or to leave the area entirely if it is possible and safe to do so.

Everyone in a smoky area should avoid strenuous work or outdoor exercise to the greatest extent possible. They should avoid driving or if driving is necessary, run the air conditioner on recirculate mode to avoid drawing smoky air into the car. Smoke can also impair roadway visibility making driving hazardous. Guidance on protecting outdoor workers from wildfire smoke has been developed by the California Division of Occupational Safety and Health (Cal/OSHA). More information about the protection of outdoor workers can be found in Chapter 5.

Closing up a home by shutting windows and doors can give some protection from smoke. Most air conditioners are designed by default to recirculate indoor air. Systems that have both "outdoor air" and "recirculate" settings need to be set on "recirculate" during fire/smoke events to prevent smoke-laden air from being drawn into the building (note: this does not apply to HVAC systems in office and commercial buildings; see Appendix D). Additional protection in homes can be achieved by operating properly-sized air cleaners and upgrading the filtration efficiency of air filters in central air conditioning systems. High-efficiency filters (rated at MERV 13 or higher) should be installed when feasible. When filters have been upgraded, central air conditioning fans can be set to operate continuously during a wildfire event, and not cycle on and off, although this will increase energy use and costs.

Once people have closed up the building in which they live, they should avoid strenuous activity, which can make them breathe harder and faster. They should drink plenty of fluids to keep their respiratory membranes moist. Vacuuming (except with HEPA filter-equipped vacuums) should also be avoided, since most vacuum cleaners disperse very fine dust into the air.

Smoke levels can change substantially over the course of the day, so it may be possible to plan your day around the smokiest times to minimize exposure using tools and information in this Guide.

NIOSH-approved disposable particulate respirators (e.g., N95 or P100) available in hardware stores and online provide some level of protection from exposure to particles in smoke as long as a close-fitting model and size is selected, and they are used properly. One-strap paper masks, surgical masks, or other face coverings are not recommended since they provide little or no protection.