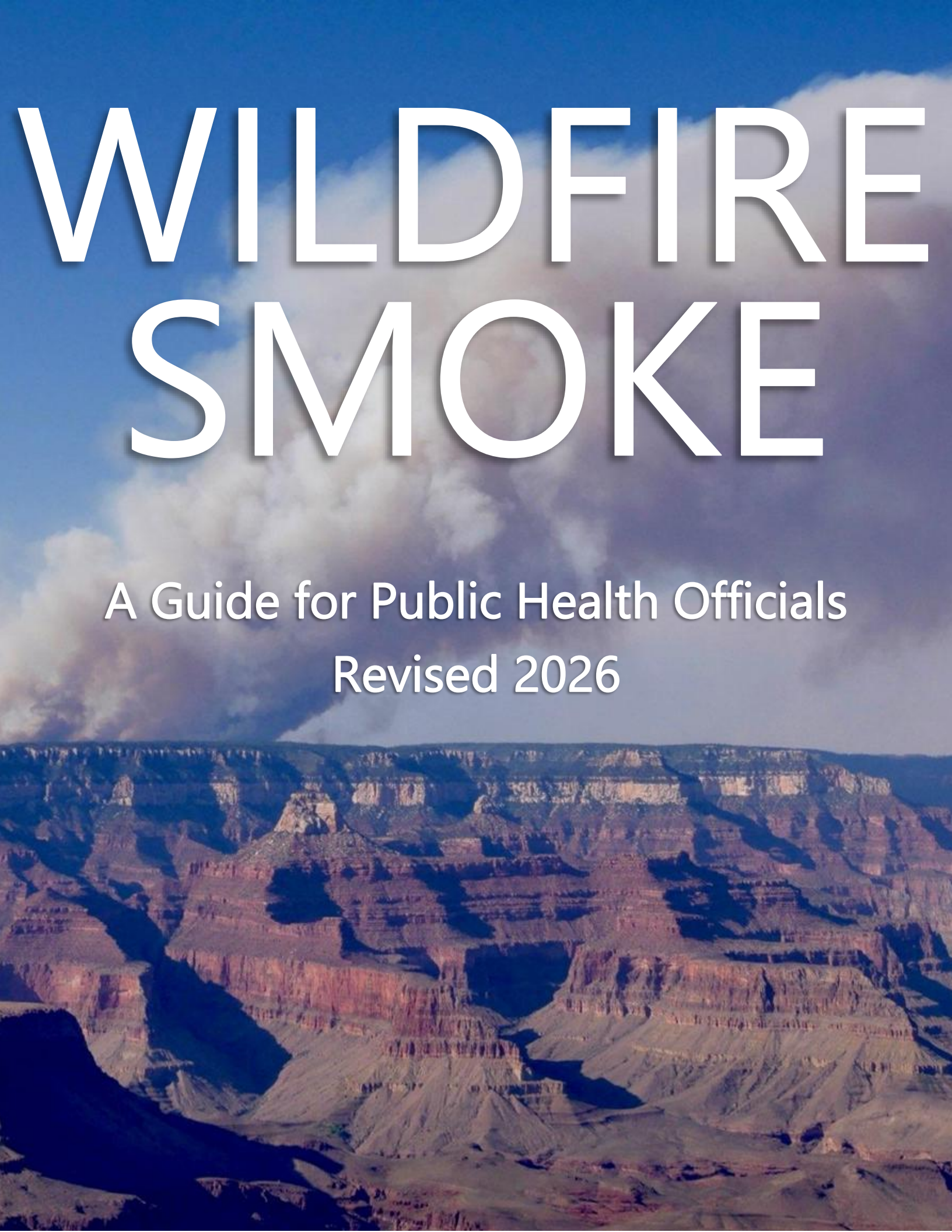

WILDFIRE SMOKE

A Guide for Public Health Officials

Revised 2026

EPA-452/B-26-001
June 2026

Wildfire Smoke

A Guide for Public Health Officials

Acknowledgements

The Wildfire Smoke Guide for Public Health Officials (Guide) was developed in part as the result of a meeting held in 2000 by the California Air Resources Board (CARB) to understand the risks of wildfire smoke and be able to communicate them to the public following the 1999 Hoopa Fire in California. A workshop held at the University of Washington in June 2001, under the auspices of the U.S. Environmental Protection Agency, Region 10, and the Department of Environmental Health, School of Public Health and Community Medicine of the University of Washington also helped formulate its initial recommendations. The Guide was first published in 2002 by CARB, which led a team of experts from the states of California, Washington, Montana and the U.S. Environmental Protection Agency. Subsequent updates in 2005 and 2008 were led by CARB.

In 2015, the composition of the Guide team expanded to include the U.S. Centers for Disease Control and Prevention and the U.S. Forest Service. The goal of the 2016 revision was to update the 2008 version by incorporating the new scientific evidence base, and then to take more time expanding the 2019 Guide by adding new sections and fact sheets. The 2019 version was the first to bear the logos of the partner agencies. The 2019 version of the Guide, the 2021 update related to the COVID pandemic, and this current 2026 version is the product of an inter-agency collaboration that includes: CARB; California Office of Environmental Health Hazard Assessment; U.S. Centers for Disease Control and Prevention; U.S. Forest Service; and U.S. Environmental Protection Agency. To date, fourteen fact sheets have been developed for public use, with links available in Appendix A. Team members and contributors are listed below.

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EXECUTIVE SUMMARY 2026

Wildfire smoke events can occur without warning – but we can be prepared. This guide is intended to provide state, local, and Tribal public health officials with information they need to be prepared for smoke events and, when wildfire smoke is present, to communicate health risks and take measures to protect the public. Although developed for public health officials, the information in this document could be useful to many other groups including health professionals, air quality officials, and members of the public. The document is divided into five Chapters and two Appendices.

Wildland Fire Smoke Production

The science of wildland fire behavior and management is complex and technical. Wildland fire, which includes wildfire and prescribed fire, produces smoke that is a complex mixture of particulate matter, carbon dioxide, water vapor, carbon monoxide, hydrocarbons and other organic chemicals, nitrogen oxides, and trace minerals. The production of smoke from a wildland fire is highly dependent on several variables including fuel type, heat of the fire, and meteorology. A wildfire that moves into populated areas that border wildland areas, known as the wildland-urban interface (WUI), can result in the burning of human-made structures and materials in addition to natural fuels, adding complexity to the pollutants emitted.

Wildfire behavior will vary depending on natural fuel type; fires in forest fuels can range from mild to severe and can spread very slowly or extremely rapidly depending on weather and fuel conditions. While most wildfires in the United States are suppressed when they first start, those that continue past the initial suppression attempt can become large, of long duration, and a significant source of smoke. On these types of fires, an Incident Management Team (IMT) is usually engaged, which is then guided by the landowner/ manager/agency administrator and pre-existing land management plans. When smoke and air quality become a concern, the IMT can order an Air Resource Advisor (ARA) to the fire under the Interagency Wildland Fire Air Quality Response Program (IWFAQRP). ARAs are technical specialists who are trained on health effects of smoke, air quality monitoring, smoke dispersion and production modelling, and communication. When on a fire, ARAs produce smoke forecasts and communicate smoke impacts and air quality mitigation strategies with the IMT and the public.

Health Effects of Wildfire Smoke

Wildfire smoke is a complex mixture of air pollutants of which particulate matter is the pollutant of greatest public health concern. The initial basis for understanding wildfire smoke health effects was derived primarily from studies of ambient air pollutants, specifically fine particulate matter (i.e., $PM_{2.5}$; particles with an aerodynamic diameter ≤ 2.5 μm). Extensive scientific evidence has demonstrated health effects in response to short-term (i.e., over a day or a few days) $PM_{2.5}$ exposure ranging from relatively minor (e.g., eye and respiratory tract irritation) to more serious health effects (e.g.,

exacerbation of asthma and heart failure, premature death), which are consistent with those reported in studies of wildfire smoke. More recently, studies have examined the health effects associated with longer duration smoke exposures, which are highly dynamic and vary within and across years, which differs from the relatively constant ambient (non-wildfire) $PM_{2.5}$ exposures people often experience. While fewer studies have been conducted examining these longer duration exposures, they indicate that the health effects from wildfire smoke exposure may not be limited to effects in response to short-term exposure. Additionally, some studies have examined the potential long-term health implications of smoke exposures to singular wildfire smoke events or repeated events and provide initial evidence of health effects such as increased risk of respiratory infection and impacts on lung development and lung function.

Although $PM_{2.5}$ garners much of the focus when discussing the health effects of wildfire smoke exposure, other pollutants found within the mixture (e.g., carbon monoxide [CO] particularly in close proximity to the fire), formed through atmospheric reactions (i.e., ozone), or emitted during WUI fires (e.g., metals, hazardous air pollutants [HAPs]) can also be of health concern. Additionally, other stressors, such as heat, may exacerbate the health effects associated with smoke exposure.

Most healthy people will recover quickly from smoke exposure, however, certain lifestages and populations may be at greater risk of experiencing health effects. These populations include people with respiratory or cardiovascular diseases, children and older adults, and pregnant women; and people that may experience higher smoke exposures including some ethnic and racial minority groups, people of lower socioeconomic status, and outdoor workers.

Specific Strategies to Reduce Exposure to Wildfire Smoke

In areas where the public is experiencing wildfire smoke, public health and air quality agencies should provide advice on strategies to limit exposure, which include:

- staying indoors,
- limiting physical activity,
- reducing indoor air pollution sources,
- adjusting air conditioners and ventilation systems to keep smoke out,
- using air filters and air cleaners indoors to remove particles in smoke,
- creating cleaner air spaces and shelters, and
- using respiratory protection when needed.

The most common advisory during a smoke episode is to stay indoors with doors and windows closed. While indoors, people should avoid activities that generate indoor air pollutants and air out the indoor environment once outdoor air quality improves. Reducing physical activity, especially in locations with poor air quality, can also reduce exposure to smoke.

Whether at home or in a public space, indoor environments with air filtration and climate control can provide relief from smoke and heat. Home air conditioners and ventilation systems should be adjusted to keep smoke out, for example by operating those with a fresh air intake on recirculate. High-efficiency heating, ventilation, and air-conditioning (HVAC) filters (rated MERV 13 or higher) in systems that can accommodate them can help reduce particle concentrations indoors. Portable air cleaners (PACs) appropriate for the size of the space can also reduce particle concentrations in individual rooms. Use only CARB-certified air cleaners, which are shown to produce little or no ozone. Do-it-yourself air cleaners are an effective alternative when PACs are unavailable or unaffordable. Individuals can create a cleaner air room at home by using a PAC in a designated room.

In public and commercial buildings, a building-specific smoke ready plan should be developed before a smoke event to adjust HVAC systems to minimize smoke intrusion and enhance indoor air filtration. Monitoring indoor air quality can be used to inform these strategies and adjust them as needed during a smoke event. Public cleaner air shelters and spaces can provide relief from smoke for individuals who do not have adequate air filtration or cooling equipment at home.

People can reduce particle levels in vehicles by keeping windows closed and operating the air conditioning in "recirculate" mode and upgrading to a high-efficiency particulate air (HEPA) cabin filter if possible.

People who must go outside during a smoke episode or who have health effects from smoke indoors may benefit from wearing a respirator. Properly wearing a NIOSH Approved® N95® or P100® particulate respirator that fits closely to the face can help reduce personal exposure to wildfire smoke and ash. People with heart or lung conditions should consult a healthcare provider before use. If respirators are unavailable, one-strap masks or surgical masks may provide some smoke protection. Do not use cloth face coverings for smoke protection.

Smoke levels can vary throughout the day, so people may be able to plan necessary trips outside during times when the air is less smoky or minimize their time in smoke impacted areas. Smoke outreach and forecasting tools can help people make decisions about when and where they can go to minimize their smoke exposures. When smoke levels are especially high, local officials may take actions such as closing schools or canceling public events. Where evacuation is necessary, public health officials should consider appropriate strategies to reduce smoke exposure during the evacuation, at evacuation centers, and after allowing evacuees to return home.

Communicating Air Quality Conditions during Smoke Events

To communicate air quality conditions to the public during a smoke event two types of tools are required:

- Communication tools that interpret air quality data to tell the public what it could mean to their health and how to reduce exposure if needed. Resources are available at epa.gov/wildfires.
- Tools that measure or estimate current and forecast air quality data in a timely way, so people can make decisions about reducing exposure to protect their health. See the Fire and Smoke Map for data in your community.

In the United States, there is a nationally uniform index, the US Air Quality Index, or AQI, that is used by government agencies to report air quality in the past, present and future. It uses colors and health-based descriptors to provide easy to understand messages. It can be found on the Fire and Smoke Map, developed by the U.S Forest Service (USFS) and EPA, which is the smoke-focused part of the AirNow web site and App. Two programs related to AirNow, Enviroflash and the Air Quality Flag Program, can be helpful in getting out information about the daily AQI.

Tools for measuring, estimating, and forecasting air quality include the highly accurate national $PM_{2.5}$ monitoring network, the less accurate but more highly dispersed network of government agency and private $PM_{2.5}$ air quality sensors, and earth-observing satellites, which provide a vast array of important information about fires and their impacts on air quality on large aspatial scales. Modelling tools, including chemical transport models, statistical models, and data fusion products can estimate air quality in places between existing monitoring locations or for some point in the future. These tools and their strengths and weaknesses are discussed in this chapter and Appendix B. Air quality tools continue to evolve rapidly, so Appendix B has a link to an evergreen site that will be updated to help explain the uses of these new tools.

For communities that do not have access to continuous $PM_{2.5}$ monitoring, it may be appropriate to use visual range to assess smoke levels in the western US. With all the new tools and providers of air quality information, Chapter 4.6 discusses what to think about when faced with apparently conflicting air quality information.

Recommendations for Public Health Actions

Preparation is key to an effective response to wildfire smoke events. Wildfires can start and spread rapidly, and a smoke event may impact a community in a matter of hours. It is critical that public health officials have communication plans and response frameworks in place to prepare for, respond to, and recover from a smoke event.

Before a smoke event happens, public health officials should consider taking some or all the following steps:

1. Assess fire and smoke risks and identify at-risk populations.
2. Identify and form partnerships with community leaders and stakeholders such as air quality agencies, local health care providers, the media, and others.
3. Prepare a communication plan.
4. Facilitate education and outreach to increase awareness and preparation for smoke events in your community.
5. Consider how to implement actions in your community to reduce smoke exposure, such as by supplying NIOSH Approved® particulate respirators, PACs, or do-it-yourself (DIY) air cleaners, and designating cleaner air spaces or shelters.
6. Work with air quality agencies to identify gaps in monitoring coverage and opportunities to fill those gaps.

Communications planning should address not only messages and actions during a wildfire event, but preparations to make before fires occur and guidance for cleaning up after a fire. During a smoke event, messaging should focus on protective actions such as staying indoors, reducing outdoor activity levels, filtering indoor air, and using respiratory protection. Plain language messages, such as "limit outdoor activities" or "stay indoors" will be most effective and can include links to fact sheets or information like the locations and hours of local cleaner air spaces or shelters. Public advisories and recommendations based on air quality levels should address special needs of at-risk lifestages and populations (in the AQI the term "sensitive groups" is used), including people with heart or lung disease, older adults, children, pregnant women, and people of lower social economic status. Other concerns include advisories and recommendations for outdoor workers, prolonged smoke events, and protections for pets and livestock.

Even after the worst of the fire and smoke is over, individuals who return after the fire should be aware of health and safety hazards. Exposure to lingering smoke and ash can cause significant health effects in both healthy individuals and those in at-risk groups. People may experience symptoms including respiratory irritation, heat-related illness, and emotional stress after a fire. Physical stress from cleanup activities, exposure to toxic chemicals, damaged power lines, and equipment such as portable generators can cause injuries during cleanup.

Public health officials should work closely with officials from affected counties to warn residents of health and safety concerns during cleanup and to provide information on best practices for homeowners returning after a fire. In post-fire situations in which air quality is poor due to smoke and ash residue in or near affected structures, ventilation and other protective measures are advised during cleanup.

1. Wildland Fire Management and Interagency Smoke Response

1.1 Composition of Wildland Fire Smoke

Smoke from wildland fire, which includes wildfire and prescribed fire, 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 which are the vegetative materials comprised of trees, needles, leaves, branches, litter, duff, stumps, grasses, shrubs, and downed trees. Prescribed fires are conducted to consume specific natural biomass in order to prevent wildfires, support endangered species, and to maintain the ecological role of fire. Wildfires may also move into the wildland-urban interface (WUI), which is the line or area where communities border wildland areas, burning human-made structures and materials in addition to natural fuels. Human-made materials can vary depending on the WUI burned leading to variability in the pollutants emitted. To date, there is not a clear set of pollutants emitted during a WUI fire.

In wildfire smoke, particulate matter (PM) is a main component. PM is a generic term for particles suspended in the air, typically as a mixture of both solid particles and liquid droplets. PM is characterized into size fractions based on the size of the particles which are measured by their aerodynamic diameter (Figure 1.1), and each size fraction represents a distribution of particles. Within wildland fire smoke, fine particles ($PM_{2.5}$; particles with an aerodynamic diameter less than or equal to 2.5 µm), are the principal air pollutant of concern for public health. Most of the effort to quantify, characterize, and monitor smoke focuses on $PM_{2.5}$ due to the well-documented health effects attributed to $PM_{2.5}$ exposure from anthropogenic sources (e.g., industrial operations, vehicles, etc.) (See Chapter 2). 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 it is rarely a concern for the general public unless in very close proximity to the wildfire

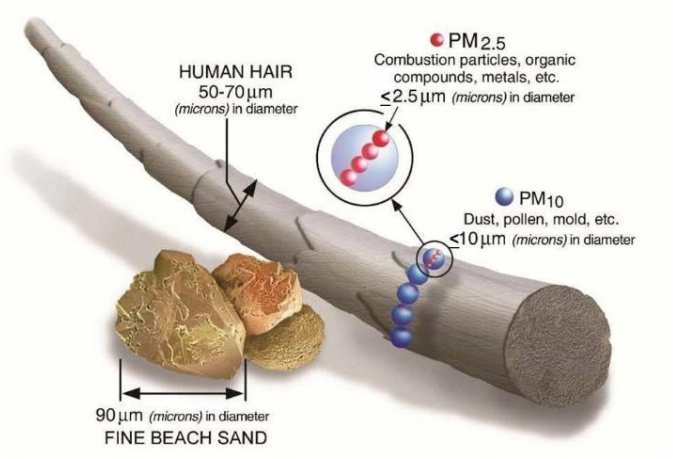


Figure 1.1 Comparison of different size fractions of PM. *(U.S. EPA)*

(generally within three miles of the fire line and when smoldering fuels are present). As such, carbon monoxide is a concern for firefighters close to the fire line. Smoke episodes can also be associated with elevated levels of ozone. Ozone is not emitted directly from wildland fires, but ozone precursors are, which result in ozone formation in the presence of sunlight downwind of the fire. The precursors can mix with urban sources of nitrous oxides leading to higher ozone levels. Ozone is not always enhanced downwind of a fire and has been shown to be highly variable spatially and temporally. Many other chemicals are present in wildfire smoke but at lower concentrations than particulate matter and carbon monoxide. These chemicals are further detailed in context of human health impacts in Chapter 2.

1.2 Characteristics of Wildfires

Wildfires need three conditions to start—fuel, oxygen and a heat source—these three together are known as the fire triangle (Figure 1.2).
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. Winds can also 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 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 (Figure 1.3). Changing meteorological conditions (i.e., hotter and drier) also influences the frequency, duration, and severity of wildfires.

Figure 1.2 The fire triangle. *These three elements, fuel, oxygen and heat must be present and combined before combustion can occur and continue supporting a fire (National Wildfire Coordinating Group, 2022. S-190 Basic Concepts of Wildland Fires).*

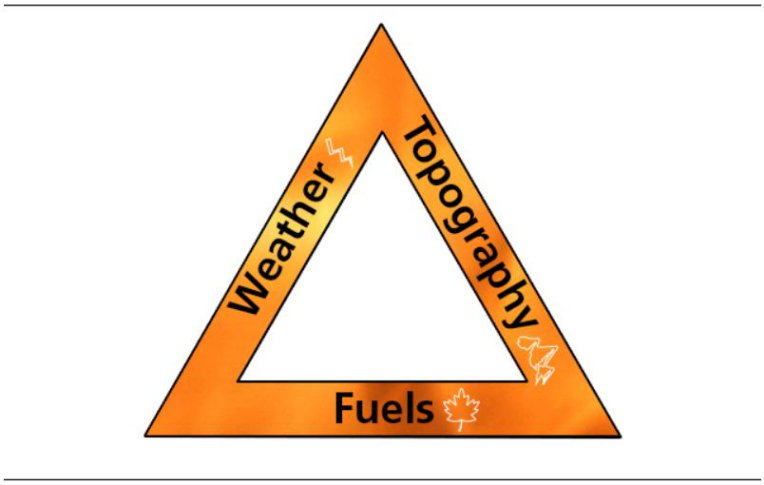


Figure 1.3 The fire behavior triangle. *The fuels, topography and weather will influence fire behavior which in turn influences smoke quantity and movement (National Park Service, https://www.nps.gov/articles/wildland-fire-behavior.htm).*

1.2A 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 1.4). Wildfires in grass typically spread rapidly but generally burn themselves out and are brought under control within hours to days of ignition. Brush-type fuels, for example chaparral, often contain volatile compounds that result in hot, fast-moving fires that are difficult to control, especially if the brush is growing on slopes or in dense clusters. Wildfires in forests can range from mild to severe in intensity and can spread slowly or rapidly depending on weather and fuel conditions. Additionally, wildfires that occur in forests can last for weeks or months and are often the type that results in the most severe and longest duration of air quality impacts. Wildfires in forests are more likely to be in remote and inaccessible areas, making firefighting more difficult. Wildfires are not limited to one fuel type and often burn over multiple fuel types.

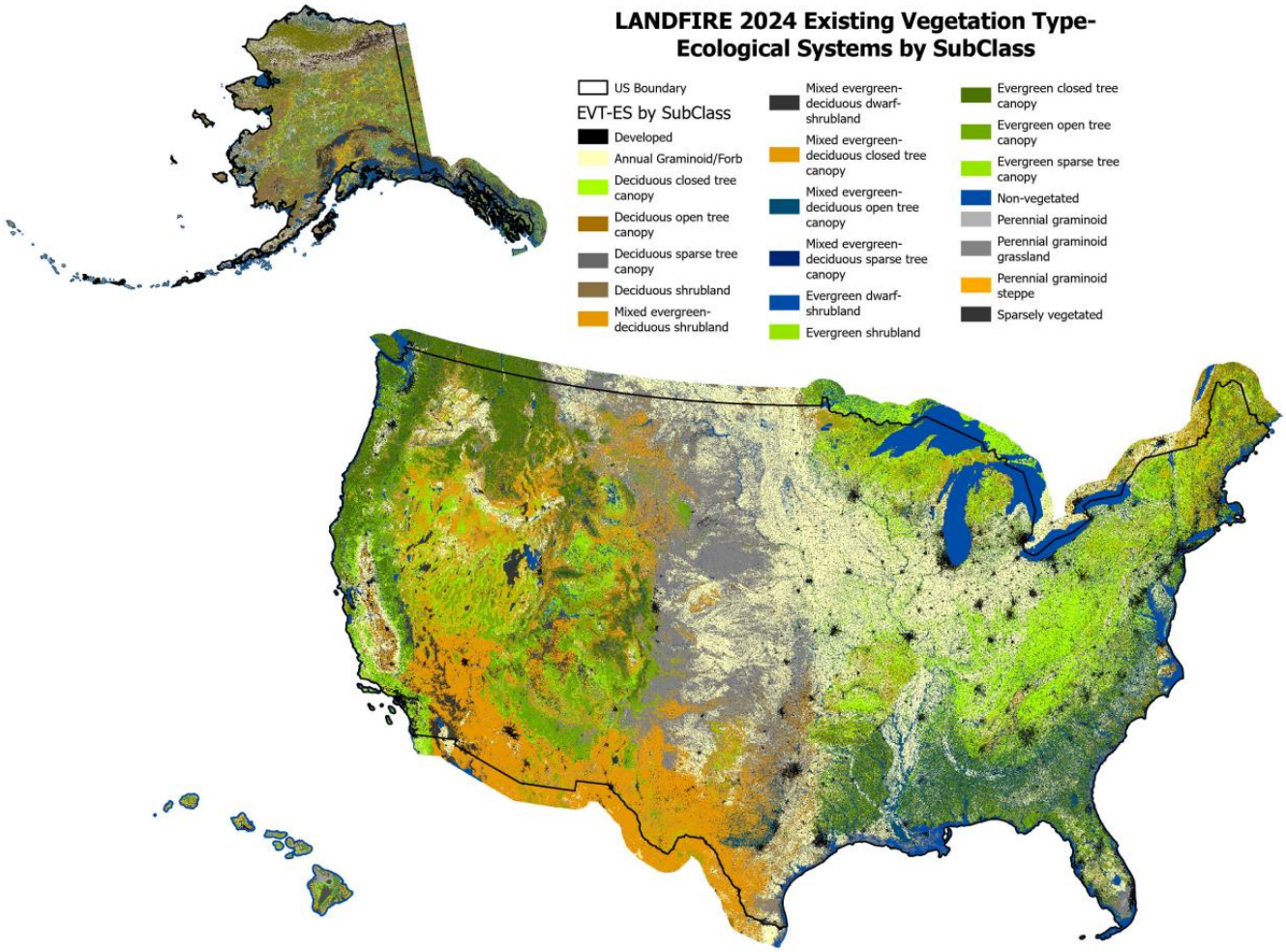


Figure 1.4 Existing vegetation types in the United States. *Wildfire rate of spread, fuel consumed, smoke produced, and duration are all influenced by vegetation type. Fires in grass (graminoids and forbs) fuels tend to spread quickly and burn out quickly. Fires in brush (shrubland) fuel types can burn 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 due to their higher fuel loads with residual smoldering but smoke can cause problems from wildfires in all fuel types (LANDFIRE, https://landfire.gov/vegetation/evt).*

The amount, type, and moisture content of fuel affects smoke production, as does the stage of combustion (flaming, smoldering, and/or residual smoldering) (Table 1.1). The smoldering and residual smoldering phases of a fire, such as when large rotten logs and duff or peat are dry and consumed, will result in high particle emissions due to less complete combustion than when flames are present. Smoldering fuels are the sign of a cooler fire, which results in smoke generally staying closer to the

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

Table 1.1 Available fuel (Mg/ha), consumption (Mg/ha) and PM2.5 emissions from wildfire conditions*

Landfire Existing Vegetation Types (EVT) with highest incidence of wildfire area burned				Available	Total	PM 2.5 Emissions (kg/ha)			
Vegetation type	Structure	US Region	Fuelbed name	Fuel (Mg/ha)	Consumption (Mg/ha)	Total	Flaming	Smoldering	Residual Smoldering
Grassland	Annual graminoid	W	Wheatgrass-cheatgrass grassland	0.3	0.2	2.8	2.5	0.3	0.0
	Annual graminoid/forb	W	Great Basin & Intermountain Introduced Annual and Biennial Forbland	0.5	0.4	5.0	4.5	0.5	0.0
		SE	Southeastern US ruderal grassland	8.7	6.8	81.6	73.5	8.2	0.0
	Perennial graminoid	C, W	Bluebunch wheatgrass-bluegrass grassland	5.6	2.6	31.2	28.1	3.1	0.0
	Grass/steppe	W	Great Basin & Intermountain ruderal shrubland	15.2	14.7	162.5	146.3	16.3	0.0
Shrubland	Deciduous	W	Willow-birch shrubland	28.6	17.8	197.9	152.8	34.8	10.3
	Dwarf deciduous	W	Huckleberry-heather shrubland	14.1	13.4	148.0	133.2	14.8	0.0
		NE	Dwarf bilberry-bog blueberry shrubland	21.8	14.1	156.7	129.3	23.9	3.5
	Mixed	W	Western juniper/sagebrush-bitterbrush shrubland	11.7	10.6	147.0	126.4	20.3	0.3
		C, E	Chinkapin oak-eastern redcedar/bluestem savanna	10.0	5.0	65.4	58.5	6.5	0.4
	Dwarf mixed	W	Gambel oak/sagebrush shrubland	24.3	15.9	220.9	187.6	29.5	3.8
	Evergreen	W	Sagebrush shrubland - exotic species	11.8	11.5	128.1	115.3	12.8	0.0
		SE	Saw palmetto/three-awned grass shrubland	51.4	29.5	354.3	197.3	126.6	30.4
	Dwarf evergreen	W	Low sagebrush shrubland	8.3	8.3	91.6	82.5	9.1	0.0
Deciduous forest	Closed canopy	W	Quaking aspen forest	93.7	47.1	715.6	427.4	192.1	96.1
	Open canopy	E	Northern oak forest	55.8	31.9	471.2	432.2	36.9	2.1
	Open canopy	W	California black oak woodland	82.6	49.6	684.9	591.8	84.1	8.9
	Sparse	C, E	Bur oak savanna	56.3	34.0	502.2	430.8	59.5	11.9
Mixed forest	Closed canopy	W	Black cottonwood-Douglas-fir-quaking aspen forest	136.1	74.5	1163.1	619.0	349.4	194.7
		E	Eastern white pine-northern red oak-red maple forest	94.3	57.5	847.7	655.1	141.0	51.5
	Open canopy	W	Interior Douglas-fir-interior ponderosa pine/gambel oak forest	140.0	75.1	1122.2	727.6	254.1	140.5
	Sparse canopy	W	Oregon white oak-Douglas-fir forest	123.1	70.2	1022.4	726.9	187.5	108.1
		C, E	Eastern redcedar-oak/bluestem savanna	15.2	10.6	138.6	123.1	13.0	2.4
Evergreen forest	Closed tree canopy	W	Grand fir-Douglas-fir forest	294.0	131.9	2110.8	986.8	606.6	517.4
		SE	Loblolly pine forest	118.7	64.6	845.2	616.6	180.6	48.0
	Open tree canopy	SE	Slash pine-longleaf pine/gallberry forest	85.7	57.3	750.6	579.7	142.8	28.2
		W	Interior ponderosa pine-Douglas-fir forest	158.5	85.5	1298.9	784.5	355.8	158.6
	Sparse tree canopy	W	Ponderosa pine savanna	49.9	21.6	261.3	166.8	49.1	45.4
		C, E	Eastern redcedar/big bluestem savanna	13.2	9.7	126.7	114.3	11.3	1.1

*Representative fuels from the Fuel Characteristics Classification System were assigned for each existing vegetation type subclass from the LANDFIRE EVT layer (Figure 1.4) with highest incidence of wildfire in the Northeast (NE), Eastern (E), Southeastern (SE), Central (C) and Western (W) regions. Total $PM_{2.5}$ emissions are further divided into flaming, smoldering and long-term smoldering (residual) combustion phases which correlate to smoke production and duration of wildfires (Susan Prichard, University of Washington and Pete Lahm, U.S. Forest Service).

1.2B Meteorology and Smoke

Weather conditions such as wind, temperature, and humidity contribute to fire behavior and smoke accumulation. Winds bring a fresh supply of oxygen to the fire and push 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, leading to impacts for communities that may be far from where the wildfire is burning (Figure 1.5).

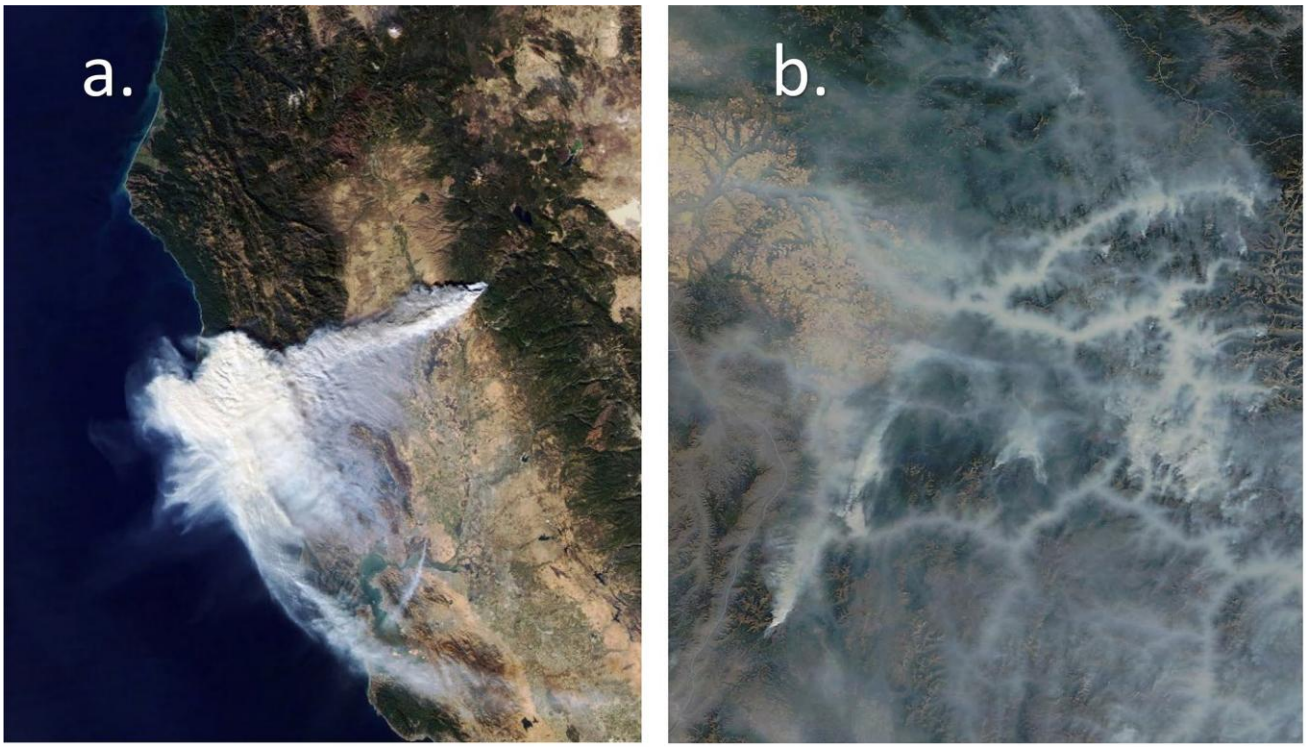


Figure 1.5 Long range transport of wildfire smoke. *Strong winds can cause rapid fire spread and move smoke into communities far from a wildfire. In 2018, smoke from the Camp fire caused weeks of poor air quality in the San Francisco Bay area (a). Light winds and stable atmospheric conditions cause smoke to pool near a wildfire and flow down valleys to nearby communities as seen in central Idaho in 2012 (b) (NASA, MODIS Land Rapid Response Team).*

Very high winds may limit the dispersion of smoke by preventing column development resulting in high smoke concentrations at the ground (Figure 1.6).

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 diluted 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. As the sun sets, 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.

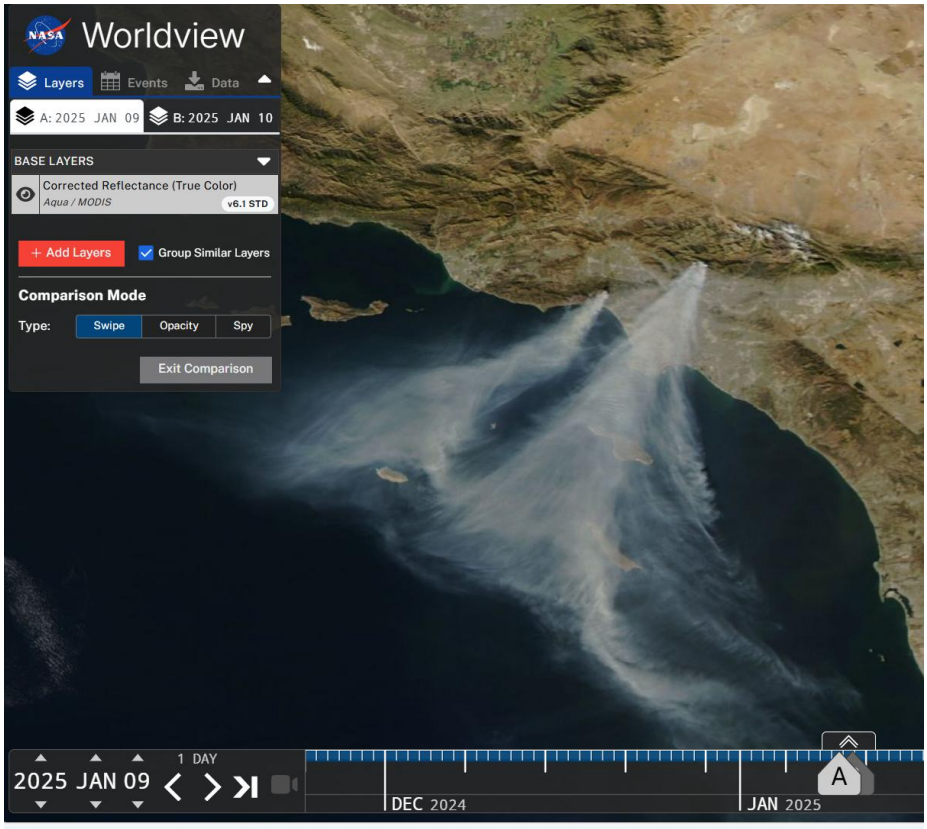


Figure 1.6 Dense smoke from the 2025 Eaton Fire. *Demonstration of a possible dispersion pattern as a result of high winds (NASA Worldview, 2025. https://worldview.earthdata.nasa.gov/).*

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 circulate and help reduce smoke concentrations.

Smoke levels in populated areas can be difficult to predict and will often depend on 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.

1.3 Wildland Fire Management

Most 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 priority is always protecting the safety of the public and firefighters. Some wildfires continue past the initial attack, occur in areas where the risks of attack are high, or are in areas where the likelihood of suppression success is low. Such fires can become large, may have a long duration, and become a significant source of smoke. When these wildfires elude initial attack efforts, exceed local firefighting capabilities, or become large quickly, the landowner or, for federal lands, the agency administrator, can engage external assistance for additional resources to assist their local efforts. On these types of fires, an Incident Management Team (IMT) is usually delegated as the authority to manage the wildfire. The landowner/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 infrastructures will be attacked aggressively. This may include retardant drops from aircraft and the use of 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.

1.3A 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 and coordinate decisions that affect nearby communities including those related to smoke. Every IMT has an incident commander to oversee and control the infrastructure of the team. IMTs work, eat, and sleep in a set 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, stakeholder coordination, and concerns are discussed. These are important opportunities for engagement on smoke issues.

In the initial phases of a large wildfire when an IMT is just arriving or recently arrived, there may be a focus on public safety and even evacuations which may limit the focus on smoke and its effects. For these wildfires where evacuations are the focus, messaging about smoke and those at-risk may get less attention. However, after the initial safety focus there are opportunities to get public smoke messages out whether by the Public Information Officer of the IMT, the Air Resource Advisor (ARA) (see Section 1.3B) or through other cooperating agencies. When planning begins for re-populating evacuated areas, it is important that concerns about remaining smoke and those at higher risk to smoke be addressed. See Chapter 5 for further air quality and clean-up considerations when evacuees return after the wildfire.

1.3B The Interagency Wildland Fire Air Quality Response Program and Air Resource Advisors

The Interagency Wildland Fire Air Quality Response program (IWFAQRP, https://wildlandfiresmoke.net) is an interagency effort led by the U.S. Forest Service (USFS) to directly assess, communicate, and address risks posed by wildland fire smoke to the public as well as fire personnel. This need for predicting smoke impacts associated with wildfires and the role of the IWFAQRP was recognized and authorized by Congress in 2019. The IWFAQRP has several components including tools for enhanced monitoring and modeling of smoke, creating consistent smoke outlook forecasts in a simple format for sharing with the public, and messaging in conjunction with state, local, and Tribal air quality agencies as well as health departments.

Much of this work is done through the deployment of technical specialists called Air Resource Advisors (ARAs) working with either wildfire IMTs or directly with land management agencies. If smoke and air quality issues become a concern, the IMT can order an ARA who understands how smoke moves, how it affects air quality, and what it means for people's health. ARAs come from a variety of backgrounds but have specialized training in the health effects of smoke, and specifically fine particles, air quality monitoring, smoke dispersion modeling, predicting future air quality based on meteorology and fire behavior, and communicating this information to the public in an understandable and consistent way. 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.

An ARA's primary tasks are to help communicate wildland fire smoke impacts to the public, as well as assess potential impacts from smoke on public transportation corridors and smoke impacts on incident personnel. Since dispatched ARAs work directly with IMTs they are in a unique position to gain insight into expected fire growth, smoke emissions, and associated air quality impacts in a way that automated air quality modeling systems cannot. An ARA generally works in the planning section of the IMT and consults closely with experts in fire weather and fire behavior. ARAs are trained to use a variety of

smoke dispersion models in conjunction with air quality monitoring to develop smoke forecasts and information products for the public. ARAs can help local officials understand ongoing air quality concerns, including the difference between wildfire smoke versus ash or debris from burned structures. They have briefed utility crews, public works teams, and other recovery workers on safer times to operate and ways to reduce exposure. By providing clear, local information throughout the response and recovery phases, ARAs help communities, cooperators, and workers stay safe and make confident decisions during and after wildfire smoke events.

1.4 Characteristics of Prescribed Fires

Prescribed fires are a fire management tool that uses planned, controlled fires to reduce fuel loads and achieve the social, economic, and ecological benefits of fires while reducing the potential for catastrophic uncontrolled fires (US EPA, 2021). Prescriptions for fire are based on clearly defined objectives, which might include ecological aspects, such as habitat diversity and endangered species recovery, reductions in the risk to highly valued resources and assets including communities, as well as fuel reduction to reduce the potential of high intensity, high severity fires (US EPA, 2021). Prescriptions also take into account environmental and meteorological conditions, fuels, burn area, and planned approaches for suppression once objectives have been met to reduce potential adverse effects, including effects associated with smoke emissions (US EPA, 2021). The effectiveness of prescribed fires in reducing the potential for severe wildfires is dependent on weather patterns and ecosystem characteristics such as types of fuels, as well as the interactions between them and treatment prescription and implementation (US EPA, 2021).

When implementing prescribed fires, land managers operate under smoke management plans that directly consider potential smoke impacts on surrounding communities and plan to burn when they know the smoke will disperse most quickly (US EPA, 2021). Smoke from a prescribed fire is designed to be of short duration resulting in generally less of an impact on air quality than from a wildfire.

1.4A Prescribed Fire and Smoke Management

On federal and most state lands, prescribed fire is only used after thorough preplanning (e.g., by creating land management plans, environmental assessments, burn plans) and coordination with partners. Such planning is only done by highly trained and experienced professionals and burn plans include consideration of smoke and its potential impacts (NWCG,2022, Standards for Prescribed Fire Planning and Implementation, PMS 484). Prescribed fires are only implemented when the resource benefit as outlined in the burn plan is met and adequate contingencies are in place or confirmed by managers and agency administrators. Go/no-go checklists are used to determine compliance with policies and the prescribed fire plan parameters (US EPA, 2021).

Compared to wildfires, prescribed fire presents a unique opportunity to prepare individuals for smoke, especially residents at increased risk of experiencing health effects in response to smoke exposure. See Chapter 5 to learn about actions public health officials can take to reduce smoke exposure. Federal and many state land managers plan and then time the prescribed burns to minimize smoke impacts to reduce health and safety risks to the public. Use of Basic Smoke Management Practices (NRCS, 2011) is policy for most federal agencies that use prescribed fire as well as for many state land management agencies. Basic Smoke Management Practices are dependent on the resource objectives of the prescribed fire and include evaluation of smoke dispersion conditions, monitoring effects on air quality, record-keeping of the activity, communication with the public, coordination with other nearby burners and consideration of emission reduction techniques. Many states have smoke management programs for state, local, Tribal, and private land managers that aid burner coordination and efforts to minimize impacts of prescribed fire smoke on the public and communities (NWCG, 2019, NWCG Smoke Management Guide for Prescribed Fire, PMS 420-3).

2. Health Effects of Wildfire Smoke

2.1 Introduction

Wildfires pose significant health risks to people in the vicinity of the fire but, from a public health perspective, the smoke emitted affects many more people both near and far from the fire (O'dell et al. 2021). This chapter provides an overview of the current state of the science with respect to the public health implications of wildfire smoke exposure with an emphasis on the health effects attributed to different exposure durations, emerging issues on the relationship between wildfire smoke and health, and identification of those populations at-risk of experiencing wildfire smoke-related health effects or greater wildfire smoke exposure.

As discussed in Chapter 1, smoke, either from a wildfire or prescribed fire[1], is a complex mixture of pollutants including gases and particles. Of that mixture the pollutant of greatest health concern, and most well-studied, is particulate matter, specifically fine particulate matter ($PM_{2.5}$; particles with an aerodynamic diameter less than or equal to 2.5 μm). The overall understanding of the health effects of wildfire smoke is rooted in decades of science on ambient $PM_{2.5}$ exposures (i.e., $PM_{2.5}$ exposures occurring on a typical day, not an extreme event like a wildfire), which has been used to support the setting of National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$, with additional more recent evidence from studies specifically focusing on wildfire smoke (US EPA, 2019, 2022).

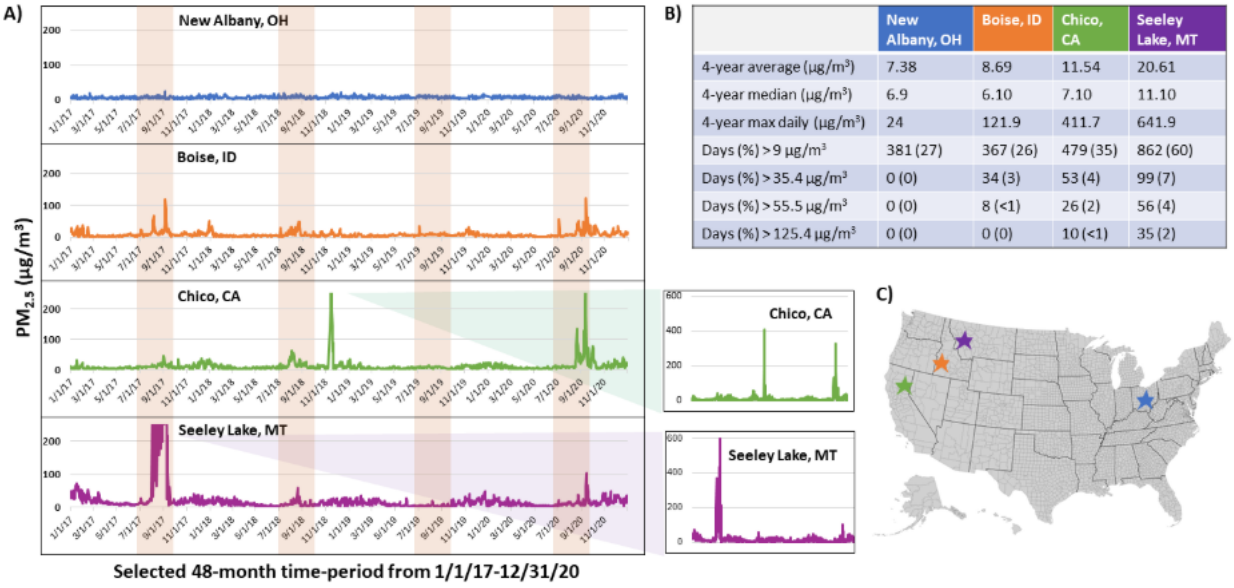
2.2 Exposure Duration

The characterization of the scientific evidence on wildfire smoke exposure and health depends on the length of time someone experiences the exposure, referred to as the exposure duration. Exposure duration is a critical component to consider because it dictates the type of health effects that people may experience. For example, short-term (or daily) $PM_{2.5}$ exposures are representative of exposures that lead to the exacerbation of already-existing disease (e.g., asthma attack) or the triggering of an event (e.g., myocardial infarction, stroke) while long-term (or annual) exposures lead to the development of

[1] As defined in 40 CFR § 50.1 wildfire is "any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions, or a prescribed fire that has developed into a wildfire. A wildfire that predominantly occurs on wildland is a natural event." Prescribed fire, also referred to as planned fires, controlled burns, or prescribed burns, is defined as "any fire intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific land or resource management objectives."

new diseases or more rapid progression of an outcome (e.g., atherosclerosis). To date, much of the focus on wildfire smoke and health has been on short-term exposures lasting one or more days. These types of studies are like those used to examine the health implications of ambient $PM_{2.5}$ exposures as both focus on examining day-to-day changes in pollutant concentrations and corresponding changes in health effects. As a result, the combination of studies examining short-term ambient $PM_{2.5}$ exposure and wildfire smoke exposure collectively form the evidence base on potential health effects people may experience.

In contrast to short-term exposures, when considering longer duration exposures (e.g., repeated and episodic exposures occurring within or across years) the patterns of exposure between ambient $PM_{2.5}$ and wildfire smoke are not comparable. Wildfire smoke is a dynamic exposure that varies in intensity, frequency, and duration across space and time; whereas, long-term (often referred to as annual average) ambient $PM_{2.5}$ exposures are relatively stable (Figure 2.1, Panel A; e.g., New Albany, OH) (Casey et al. 2024; Sacks et al. 2025). As a result, unlike the evidence base for short-term smoke exposure and health which builds on studies of ambient $PM_{2.5}$, studies of long-term ambient $PM_{2.5}$ exposure and health are not directly translatable to understanding the relationship between longer duration smoke exposure and health (Sacks et al. 2025).



	New Albany, OH	Boise, ID	Chico, CA	Seeley Lake, MT
4-year average (µg/m³)	7.38	8.69	11.54	20.61
4-year median (µg/m³)	6.9	6.10	7.10	11.10
4-year max daily (µg/m³)	24	121.9	411.7	641.9
Days (%) > 9 µg/m³	381 (27)	367 (26)	479 (35)	862 (60)
Days (%) > 35.4 µg/m³	0 (0)	34 (3)	53 (4)	99 (7)
Days (%) > 55.5 µg/m³	0 (0)	8 (<1)	26 (2)	56 (4)
Days (%) > 125.4 µg/m³	0 (0)	0 (0)	10 (<1)	35 (2)

Figure 2.1 Comparison of $PM_{2.5}$ concentrations between different locations *(Sacks et al., 2025)*.

The graphs in Figure 2.1A show $PM_{2.5}$ concentrations observed between 2017 and 2020 in four different community settings to demonstrate the dynamism of wildland fire smoke in contrast to more traditional ambient $PM_{2.5}$ exposures from anthropogenic sources such as industrial and automobile emissions. The light orange bars represent a typical wildfire season in the US and the additional graphs for Chico and Seeley Lake are included to present the full peaks in $PM_{2.5}$ concentrations. A summary of exposure

characteristics is shown in Figure 2.1B including the number of days where air quality at regulatory monitors exceeded thresholds that coincide with air quality index (AQI) levels of moderate (> 9.0 $\mu g/m^3$), unhealthy for sensitive groups (35.4 $\mu g /m^3$), unhealthy (55.5 $\mu g /m^3$), and very unhealthy (125.4 $\mu g /m^3$). The three Western US communities referenced in Figure 2.1C commonly experience wildfire smoke exposures that vary in duration, frequency, and intensity, which differs from the relatively constant ambient $PM_{2.5}$ concentrations experienced by those in the representative community of New Albany, OH.

The concept of exposure duration is reflected in the description below on the health effects of wildfire smoke. Delineating the health effects people may experience for different exposure durations is necessary in order to provide clear and consistent messaging on the health risks of wildfire smoke exposure before, during, and after wildfire smoke events.

2.3 From Exposure to Health Effects

The ability of wildfire smoke, and specifically $PM_{2.5}$, to lead to health effects depends on multiple factors including how much is inhaled (i.e., intake), where it deposits in the body (i.e., deposition), how long it stays there (i.e., retention), and where it goes (i.e., translocation). The amount of particles that are deposited and retained in the respiratory tract depends on the $PM_{2.5}$ concentration to which someone is exposed, the exposure duration, and their physical activity levels and breathing pattern (i.e., nose-only or nose-and-mouth).

Once inhaled, $PM_{2.5}$ can initiate biological pathways that can ultimately lead to health effects resulting in an emergency department visit, hospital admission, or even death. These well-documented pathways include inflammation and oxidative stress, effects on the autonomic nervous system which can impact heart function, and the translocation of particles out of the respiratory tract into the blood where they can affect other organs, such as the heart.

Because less is known about the concentrations of other pollutants (e.g., VOCs) in smoke and the exposure durations people experience, the potential health implications of exposure to those pollutants remains unclear. However, as detailed in Chapter 3, reducing exposure to smoke through actions that reduce $PM_{2.5}$ concentrations can help reduce the overall public health impacts.

2.3A Short-Term Smoke Exposures

The underlying basis of the relationship between wildfire smoke and health is rooted in the large and extensive evidence base demonstrating a relationship between numerous health effects, including

respiratory- and cardiovascular-related outcomes and premature mortality, and short-term ambient $PM_{2.5}$ exposures (U.S. EPA, 2019, 2022). A growing body of scientific evidence since 2010 focuses specifically on short-term (i.e., occurring over one or more days) wildfire smoke exposures, which reports evidence of health effects consistent with those observed when examining short-term ambient $PM_{2.5}$ exposures (Liu et al. 2015; Reid et al. 2016; Cascio et al. 2018; U.S. EPA 2021).

Table 2.1 Health effects and outcomes associated with short-term exposure to wildfire smoke

Health Effects from Short-Term Smoke Exposures (i.e., over a few days)
Eye irritation Respiratory symptoms • Coughing • Increased phlegm • Wheezing • Difficulty breathing Respiratory effects • Bronchitis • Reduced lung function • Asthma exacerbation and aggravation of other lung diseases • Emergency department (ED) visits and hospital admissions Cardiovascular effects • Heart failure • Heart attack • Stroke • Emergency department (ED) visits and hospital admissions Birth outcomes • Premature birth Premature death

The health effects of short-term $PM_{2.5}$ exposure, and subsequently wildfire smoke, can range from relatively minor (e.g., eye and respiratory tract irritation) to more serious health effects (e.g., exacerbation of asthma and heart failure, premature death) (Table 2.1). In addition, there is initial evidence that short-term smoke exposure may lead to preterm birth (Picciotto et al. 2024) and impact brain health (e.g., cognitive function, specifically attention) (Cleland et al. 2022). Fine particles are respiratory irritants, and exposure to high concentrations can lead to persistent coughing, phlegm, wheezing, and difficulty breathing. Exposure to $PM_{2.5}$ may also impair the body's ability to remove inhaled foreign materials, such as viruses and bacteria, from the lungs. For example, some studies have reported an increase in the risk of COVID-19 cases and deaths in response to wildfire smoke exposure

(Zhou et al. 2021; Meo et al. 2021; Schwarz et al. 2022). Although most healthy people will recover quickly from wildfire smoke exposure, some may experience health effects including pulmonary inflammation and transient reductions in lung function (U.S. EPA 2019 – PM ISA).

2.3B Sub-Daily Smoke Exposures

Wildfire smoke is more temporally and spatially variable than ambient $PM_{2.5}$ concentrations, but much of the health effects evidence focuses on daily (i.e., 24-h average) $PM_{2.5}$ exposures, with limited analysis of shorter exposure durations, also referred to as sub-daily (i.e., < 24-h average exposures). The lack of information on sub-daily exposures can partly be attributed to most epidemiologic studies focusing on 24-hour average $PM_{2.5}$ exposures as well as the challenges around obtaining time resolved health data. The few studies conducted to date examining sub-daily smoke exposures provided initial evidence for increases in ambulance discharges for respiratory- and cardiovascular-related outcomes within one hour of exposure (Yao et al. 2020) and reductions in cognitive performance, as measured by attention using a brain-training game, within 3 hours of exposure (Cleland et al. 2022).

2.3C Longer Duration Smoke Exposures and Health

In contrast to ambient (non-wildfire) $PM_{2.5}$ exposures which are rather constant over time, longer duration wildfire smoke exposures (which include persistent/repeated, episodic, and cumulative exposures) vary within and across years. While the combination of scientific information on ambient $PM_{2.5}$ and wildfire smoke provides an extensive database of the health risks of wildfire smoke exposure, uncertainties remain with respect to the relationship between smoke and health for these other exposure durations. To date, few epidemiologic studies have examined longer duration smoke exposures and provide initial evidence for:

- *Persistent or repeated smoke exposures*:[2] initial evidence of effects on mental health and well-being (Eisenman and Galway 2022).
- *Persistent or repeated smoke exposures within/across specific exposure windows*:[3] some evidence that smoke exposure during pregnancy is associated with increased risk of pre-term birth and low birth weight (Heft-Neal et al. 2021; Abdo et al. 2019)

[2] While there is extensive evidence for long-term (i.e., annual) exposures to ambient $PM_{2.5}$ and a range of health effects (U.S. EPA, 2019, 2022), wildfire smoke is a more dynamic exposure that is not as constant as ambient $PM_{2.5}$. As such, these studies that examined longer-duration smoke exposure and health should be viewed with caution as many do not account for the dynamic nature of smoke exposure, with some averaging exposures over time, which assumes that people are exposed to smoke every day. While smoke exposure may be associated with the outcomes examined, studies have not adequately accounted for the frequency, intensity, and duration of smoke exposure in examining the health effects attributed to longer-duration exposures.

[3] Some, but not all, of the studies examining these exposure durations, represent initial studies that employed novel approaches to account for the intensity, frequency, and duration of smoke exposures.

- *Cumulative smoke exposure over multiple years*:[3] initial evidence of increased risk of premature mortality and cancer (Gao et al. 2023; Gao et al. 2024).
- *Average smoke exposure over multiple years*:[2] some evidence of increased risk of mortality (Ma et al. 2024) and incident dementia (Zhang et al. 2023).

Overall, the evidence base for studies examining longer duration smoke exposures is relatively small, but these initial studies indicate that the health effects from wildfire smoke exposure may not be limited to effects in response to short-term exposure. While uncertainties remain in the characterization of these longer duration exposures, it is well established that smoke exposure can lead to health effects. Therefore, it is recommended that whenever smoke concentrations are elevated, all efforts are taken to reduce smoke exposure to protect public health (see Chapters 3 and 5).

2.3D Long-term Health Implications of Smoke Exposure

The public may express concerns about the potential long-term health implications of repeated smoke exposures over a few days and up to a number of weeks from singular wildfire events. Specifically, some member of the public express concerns about whether they are at increased risk of developing health effects in the future, such as chronic health conditions (e.g., heart disease), potential impacts on their children, and whether they are at increased risk of cancer. To date, relatively few studies have examined these types of health effects. However, those studies conducted do provide an initial indication of:

- Reductions in lung function in the years following repeated high smoke exposure over several weeks (Orr et al. 2020).
- Increased risk of influenza infection during the winter season following summer smoke exposure (Landguth et al. 2020).

Health effects in children include increased risk of respiratory infection before 1 year of age when exposed in utero (Lan et al. 2025), increased risk of respiratory effects when exposed during infancy (Berns and Haertel 2024), and impacts on lung development when exposed during adolescence (Black et al. 2017).

2.4 Emerging Issues on Wildfire Smoke and Health

In addition to the general health risks associated with wildfire smoke exposure, additional issues have emerged regarding the wildfire smoke-health relationship. Specifically, recent research has examined exposure to additional wildfire smoke-related pollutants, the combined effect of heat and wildfire smoke on health, and the potential toxicity of wildfire smoke in comparison to other sources of $PM_{2.5}$.

2.4A Exposures to Other Smoke-Related Pollutants

While $PM_{2.5}$ remains a central focus of efforts to protect public health from wildfire smoke, wildfire smoke is a complex mixture of pollutants, some of which are individually associated with health effects. Additionally, as more wildfires enter the wildland-urban interface (WUI) and transition from burning primarily biomass (e.g., trees, plants, shrubs) to human-made structures and materials, additional pollutants may also be of health concern.

Some additional pollutants emitted in wildfire smoke, specifically nitrogen oxides and VOCs as precursors to the formation of ground-level ozone, can impact health. Ozone is formed through complex photochemical processing that requires the presence of sunlight. While increases in ground-level ozone have been observed during smoke events, these tend to occur downwind of the fire, where smoke is less dense and conditions for photochemical processing are favorable. However, there is high variability in ozone precursor concentrations in smoke and atmospheric conditions resulting in substantial variability in reported ozone concentrations around smoke events (U.S. EPA, 2021 – CAIF). Although ozone is less of a health concern during wildfire smoke events, in instances where ozone concentrations are elevated, short-term exposures can lead to a range of respiratory-related effects such as reductions in lung function, inflammation of the airways, chest pain, coughing, wheezing, and shortness of breath – even in healthy people. These health effects can be more serious in people with asthma and other lung diseases, as well as children, older adults, and outdoor workers who experience greater exposures to ozone (U.S. EPA, 2020 – Ozone ISA). There is more limited evidence of an association between short-term ozone exposure and other health outcomes, such as cardiovascular effects and premature mortality (U.S. EPA, 2020 – Ozone ISA).

Carbon monoxide is also present in smoke emitted from wildfires and WUI fires. Typically, short-term exposures to carbon monoxide from wildfire smoke do not pose a significant hazard to the public. However, if $PM_{2.5}$ concentrations approach hazardous (i.e., > 225 $\mu g/m^3$), CO concentrations may be elevated to concentrations of health concern (> 12 ppm; breakpoint for "Unhealthy" AQI category). Near a fire, $PM_{2.5}$ concentrations can be extremely high along with carbon monoxide. In those instances, carbon monoxide can be an immediate health concern for people nearby. 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 at lower concentrations of carbon monoxide than healthy people. Although extended exposures to high carbon monoxide concentrations (i.e., hundreds of ppm) can cause headache, weakness, dizziness, confusion, nausea, disorientation, visual impairment, coma, and death, even in otherwise healthy individuals, the presence and type of effect observed can vary by individual and is dictated by the duration and concentration of the exposure (U.S. EPA, 2010).

Initial research on WUI fire smoke has shown elevated concentrations of metals (e.g., lead) and hazardous air pollutants (HAPs), including volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) (Boaggio et al.; Baliaka et al. 2025; Holder et al. 2023). Analyses of the air quality implications of wildfire smoke have generally observed increases in HAPs, but there were few instances of HAPs exceeding acute or chronic concentrations of health concern (Rice et al. 2023). However, in instances where wildfires have entered the WUI, there are documented increases in some carcinogenic components (Holder et al. 2023). As noted earlier, the ability of pollutants, such as PAHs, to result in health effects depends on the concentration and exposure duration people experience. In general, the risks of cancer or other chronic conditions from short-term wildfire smoke exposures are thought to be relatively low. Short-term elevated exposures (i.e., over days to weeks) to carcinogens found in wildfire smoke are small relative to total lifetime exposures to carcinogens.

2.4B Heat and Smoke

Heat on its own can lead to numerous detrimental health effects (see www.heat.gov). As the frequency of heat events has increased, so has the frequency of days impacted by wildfire smoke (Burke et al. 2023; Childs et al. 2022) resulting in more frequent instances in which they coincide. There is some evidence that the combined effect of wildfire smoke and heat may be greater than each individually, resulting in increased risks of cardiorespiratory emergency department visits, hospital admissions, and premature death (Chen et al. 2024; Heaney et al. 2022; Rahman et al. 2022). However, the frequency of days on which both heat and wildfire smoke occurs (often defined as $PM_{2.5}$ concentrations above a specific threshold) is relatively rare.

2.4C Toxicity of Wildfire Smoke

With the increase in wildfire smoke in recent years, research has examined whether $PM_{2.5}$ from wildfire smoke is more toxic than $PM_{2.5}$ from other sources, such as automobiles and industrial facilities. To assess toxicity, experimental studies examined different combustion phases (i.e., flaming and smoldering) and individual fuel sources. Some animal toxicological studies provide evidence of distinct health responses to smoke generated by individual fuel sources (e.g., pine, eucalyptus) (Kim et al. 2018) as well as combinations of combustion phases and individual fuel sources (Koval et al. 2022). However, it is unclear how these wildfire smoke exposures compare with the human experience, which involves smoke emitted from a combination of fuel sources.

Over the years, epidemiologic studies have extensively examined whether the risk of adverse health effects varies by $PM_{2.5}$ source. The collective body of evidence examining potential differences across $PM_{2.5}$ sources was evaluated in the 2019 Integrated Science Assessment for Particulate Matter (PM ISA) (U.S. EPA, 2019). This assessment concluded that the studies evaluated "confirm and further support the conclusion of the 2009 PM ISA that many $PM_{2.5}$ components and sources are associated with many

health effects and that the evidence does not indicate that any one source or component is consistently more strongly related with health effects than $PM_{2.5}$" (U.S. EPA, 2019). Some recent epidemiologic studies on wildfire smoke have analyzed the risk of health effects attributed to wildfire-$PM_{2.5}$ exposure with those attributed to non-wildfire-$PM_{2.5}$ exposure. These studies reported evidence of a greater risk of respiratory-related hospital admissions in response to wildfire-$PM_{2.5}$ than to non-wildfire $PM_{2.5}$ (Aguilera et al. 2020; Aguilera et al. 2021). However, differences in risk estimates can be attributed to numerous factors (e.g., exposure misclassification, differences in the distribution of $PM_{2.5}$ concentrations and the increment used to calculate the risk estimate, study location, etc.) and do not necessarily indicate a difference in toxicity.

In addition, in recent years, there have been more instances of wildfire entering the WUI and burning human-made materials and structures (e.g., CA) (CalFire, 2025). As noted earlier, the burning of these materials and structures in addition to emitting $PM_{2.5}$, also emits additional pollutants (e.g., metals, VOCs, PAHs), not traditionally found in wildfires that burn primarily biomass (Holder et al. 2023). Examining the health effects associated with WUI fire smoke is challenging because WUI fires are often fast-moving events that can decimate towns and cities in a few hours to days, and in the process destroy available air quality monitors. Even in those instances where air quality monitors remain intact, not all monitors measure $PM_{2.5}$ composition. Those monitors that measure $PM_{2.5}$ composition do not operate daily (i.e., collecting samples every 3rd or 6th day) and do not measure all of the specific chemicals that may be emitted during a WUI fire. Additionally, because of the short-term period of WUI fire events, it's challenging to get air quality monitors in place before the event is over. The combination of the short time-period of WUI fire smoke events and the lack of refined air quality data has made it challenging to study the potential health implications. As a result, analyses conducted to date have focused on understanding the pollutants emitted in smoke during such events, which show that populations may be exposed to elevated concentrations of heavy metals, VOCs, and PAHs in addition to $PM_{2.5}$.

Regardless of the origin of smoke or the toxicity of wildfire-specific $PM_{2.5}$, current public health guidance around wildfire smoke focuses on reducing $PM_{2.5}$ exposure. Reducing $PM_{2.5}$ concentrations will reduce exposure to some additional pollutants found in WUI smoke that are in the $PM_{2.5}$ size fraction (e.g., metals) but less is known about the effectiveness of such interventions in reducing gaseous pollutant exposures.

2.5 At-Risk Populations and Lifestages

Based on epidemiological studies, certain life stages and populations may be at greater risk of experiencing health effects and may experience more severe effects due to wildfire smoke. These groups are referred to as at-risk populations or sensitive groups (used in the AQI).

Evidence indicates that the risk of $PM_{2.5}$-related health effects varies throughout a lifetime. Risk is generally higher during childhood and then middle age through old age, rather than during young adulthood. As people age, they are also more likely to be affected by chronic diseases, such as heart and lung disease, hypertension, and diabetes. Additionally, some people may fall within multiple at-risk populations. These people should be particularly diligent about limiting exposure to wildfire smoke. Therefore, all people, but especially those who are members of at-risk populations should follow recommendations to reduce smoke exposure, which will be discussed in Chapter 3. The following section details those populations and lifestages at-risk of experiencing health effects in response to wildfire smoke exposure (with an emphasis on short-term exposures), why they are at-risk, and in some cases the types of health effects they may experience.

2.5A People with Chronic Diseases

Asthma and other lung diseases

Smoke exposure can trigger severe breathing responses in people with lung diseases.

Effects: Trouble breathing (e.g., coughing, wheezing, chest tightness) and worsening of chronic lung diseases, such as asthma and chronic obstructive pulmonary disease (COPD), that may require a trip to the emergency department or a hospital stay and can be fatal.

Cardiovascular disease

Smoke exposure can trigger severe cardiovascular events in people with underlying cardiovascular diseases and related conditions (e.g., diabetes, obesity).

Effects: May include heart attacks and strokes that require a trip to the emergency department or a hospital stay and can be fatal.

2.5B Lifestages

Children

Children up to 18 years of age are at greater risk of smoke-related health effects, because their lungs are still growing. In addition, compared to adults, they are more likely to be exposed to smoke because they spend more time outdoors. Children also engage in more vigorous activity and inhale more air per pound of body weight than adults, both of which impact the dose of smoke they experience and their risk of a health effect. Compared to adults, children are more likely to have asthma.

Effects: May include trouble breathing (e.g., coughing, wheezing, chest tightness), and reduced lung function. Children with asthma may have worsened asthma symptoms or asthma attacks that can require a trip to the emergency department, or a hospital stay.

Older adults

Adults ages 65 and older are at greater risk because they are more likely to have chronic lung and heart disease. In addition, the body's ability to respond to health challenges generally declines with age.

Effects: May include cardiovascular events (e.g., heart attacks, strokes) and respiratory events (e.g., asthma attacks, COPD events) that require a trip to the emergency department or a hospital stay and can be fatal.

Pregnant women

Changes in the body that occur during pregnancy (e.g., increased breathing rates) may increase sensitivity to smoke exposure. During pregnancy, the fetus may be more sensitive to smoke exposure.

Effects: Some evidence suggests that smoke exposure can lead to gestational diabetes and high blood pressure during pregnancy. Exposure can also lead to low birth weight and preterm birth.

2.5C People with Higher Exposure

Higher smoke exposures could lead to increased risk of respiratory- or cardiovascular-related trips to the emergency department or hospital stays and can be fatal. These groups include:

People from some ethnic and racial minority groups

Ethnic and racial minority groups can experience economic, social, environmental, and other factors that may limit their ability to reduce their exposure to wildfire smoke.

People with lower incomes

People with fewer financial resources often have less access to health care, which can lead to untreated or inadequately treated underlying health conditions (e.g., asthma, diabetes). They may also have higher smoke exposure due to less access to measures to reduce wildfire smoke exposure (e.g., ability to work from home, use air cleaners), living in poor quality housing that can lead to higher indoor smoke concentrations (or being unhoused), or spending more time outside traveling to work.

Outdoor workers

Outdoor workers can be exposed to high concentrations of smoke for extended periods.

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3. Specific Strategies to Reduce Exposure to Wildfire Smoke

Quick Tips to Reduce Exposure to Wildfire Smoke in Homes and Vehicles

🏠 **Stay Indoors**

1. Keep windows and doors closed.
2. Use air conditioning in recirculate mode and limit the use of devices that exhaust air from the home (e.g., range hoods, bathroom fans) to avoid drawing in more particles from outdoors.
3. Avoid indoor activities that generate particles (e.g., cooking, burning candles, vacuuming without a HEPA filter).
4. Air out your home when outdoor air quality improves.

🌀 **Filter Your Indoor Air**

- Use MERV 13 or higher filters if compatible with central HVAC systems and run HVAC fans continuously.
- Use portable air cleaners in rooms where you spend the most time.
- Use DIY air cleaners when portable air cleaners are unavailable or unaffordable.
- Check filters often and change them when dirty.

❄️ **Stay Cool Without Letting Smoke In**

- Use fans and AC on recirculate to cool your home while keeping it sealed.
- If you must open windows for cooling, do so when outdoor air is cooler (often at night). Once indoor air is cool, close windows and use portable air cleaners and HVAC filters to filter the air.
- Use swamp coolers sparingly (unless filtered) during heavy smoke.
- Use single-hose portable ACs sparingly during heavy smoke.

🎈 **Create a Cleaner Air Space**

- Choose a room with few windows and doors.
- Use a portable air cleaner and seal the room.
- Spend as much time as possible in this space during smoke events.

📊 **Monitor Air Quality**

- Check the AirNow Fire and Smoke Map or other sources for local air quality information.
- Use $PM_{2.5}$ sensors to track indoor and outdoor air quality.
- Adjust your activities and ventilation based on real-time data.

⛹️‍♂️ **Reduce Physical Activity**

- Avoid exercising outdoors or in indoor environments with poor air quality.
- Alternatively, consider exercising indoors in an environment with acceptable air quality.

🚗 **Reduce Exposure in Vehicles**

- Keep windows closed and AC on recirculate.
- Upgrade to a HEPA cabin filter if possible.
- Do not use your car as a shelter from smoke.

😷 **Use Respirators When Needed**

- Consider respirators if you must go outside or you have health effects from smoke indoors.
- NIOSH-approved® N95® or P100® respirators offer protection when worn properly.
- Consult a healthcare provider before use if you have heart or lung conditions.
- If respirators are unavailable, one-strap masks or surgical masks may provide some smoke protection.
- Do not use cloth face coverings for smoke protection.

In areas where the public is experiencing a wildfire smoke event, public health and air quality agencies should provide advice on actions that can reduce smoke exposure, especially for those in at-risk groups (see Chapter 2). 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.

The strategies described in this chapter focus on residential buildings. Similar strategies can be implemented in larger public and commercial buildings, including schools, as described in Reduce smoke exposure in public and commercial buildings. Many of these strategies are intended to reduce exposure to PM2.5 as one of the main pollutants in wildfire smoke. Some strategies can also reduce exposure to other pollutants, such as those produced when human-made materials burn (see Chapter 1), but there is generally less evidence regarding the effectiveness of each strategy for pollutants other than PM2.5.

3.1 Stay Indoors

The most common advisory issued during a smoke episode is to stay indoors with doors and windows closed, but the benefit of this strategy varies in different buildings. During wildfire smoke events, indoor $PM_{2.5}$ concentrations tend to be lower than outdoors, but higher compared to non-wildfire periods, even when occupant behaviors reduce infiltration of outdoor air and smoke to the indoor environment (Liang et al., 2021; O'Dell et al., 2023; Shrestha et al., 2019; Walker et al., 2023).

Staying indoors is more effective in some homes than others because infiltration of $PM_{2.5}$ in wildfire smoke is highly variable across homes. In general, indoor PM2.5 concentrations will be around 55-60% of outdoor concentrations during wildfire smoke events when doors and windows are closed, and portable air cleaner (PACs) are not in use. However, this can vary greatly across homes from as low as 30% to as much as 100% (Barn et al., 2008; Xiang et al., 2021). Newer homes and homes with central air conditioning tend to keep out PM2.5 from outdoor sources more effectively than older homes (Liang et al., 2021; Walker et al., 2023; Xiang et al., 2021). Newer homes tend to be "tighter," meaning that they allow less air exchange between the indoor and outdoor air around the home via infiltration of air through gaps and cracks in the building envelope. Air sealing, one aspect of weatherization, can reduce infiltration and may reduce the amount of smoke that enters the home. In any home, if doors and windows are left open, $PM_{2.5}$ concentrations indoors and outdoors will be similar (Shrestha et al., 2019).

In preparation for a smoke event, it is a good idea to have enough food and medication on hand to last several days to minimize driving and trips outdoors. Stored food should require minimal cooking,

especially using high-heat techniques such as frying or broiling, which can produce high concentrations of $PM_{2.5}$ in the kitchen and dining areas (see Section 3.3).

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. They can open windows and doors, run kitchen and bathroom exhaust fans, and/or turn on or open the fresh air intake on the heating, ventilation, and air conditioning (HVAC) system to help remove smoky air and bring in cleaner air during even brief periods of improved outdoor air quality.

When the smoke clears it is also a good idea to clean indoor surfaces, especially horizontal surfaces where ash and smoke particles may have settled out of the air. Use a damp mop or damp dust cloth to minimize re-suspending settled particles. See Chapter 5 for more information about cleaning up ash when returning home after a fire.

3.1A Use Caution During Heat

An important caveat about advising people to stay inside with windows and doors closed is the increased risk of heat stress, especially in homes without air conditioning. See Chapter 2 for a discussion of the health effects of exposure to heat and smoke. Note that some air conditioning units can bring more smoke indoors. See Adjust air conditioners and ventilation systems for more information.

In homes without air conditioning, windows and doors may need to be opened to allow cooling even if smoke enters. Advise the public to open windows for cooling at night when the air is cooler and use fans to exhaust hot air from rooms or draw in cooler air from outdoors. Individuals should not direct the flow of fans toward themselves when the room is hotter than 90°F to avoid dehydration (EPA 2016). Opening windows for cooling may bring in considerable smoke if outdoor air quality is poor; people may want to wear a respirator (see Use Respirators for Wildfire Smoke and Ash) while the windows are open, unless they are sleeping. Once the air indoors is cool, doors and windows can be closed and indoor air filtered using the strategies described later in this chapter. During the day, before it gets hot outside, people should close windows and window coverings such as shades, blinds, and awnings.

For heat events, when the temperature stays elevated at night, or when humidity is high, these measures may not cool the home sufficiently. In these cases, residents may consider purchasing an affordable air conditioning unit, staying with family and friends who have air conditioning and air filtration options in use, spending time in a cleaner air and cooling center (see Provide public cleaner air shelters and cleaner air spaces), or leaving the impacted area.

3.2 Reduce Activity

Reducing physical activity lowers the dose of inhaled air pollutants and reduces health risks during a smoke event. Outdoor exercise and exercise in indoor environments with poor air quality should be limited during smoky periods. Indoor exercise in an environment with acceptable air quality may be a practical alternative during these times.

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.

3.3 Reduce Other Sources of Indoor Air Pollution

Indoor sources of air pollution such as smoking or vaping, spraying aerosol products, cooking, some cleaning activities, burning candles or incense, and using gas or wood-burning stoves and furnaces can all increase indoor pollutant concentrations. Some of these same pollutants are also present in wildfire smoke. Reducing indoor air pollutant emissions during smoke events can decrease indoor PM2.5 concentrations.

Cooking, especially using high-heat techniques such as frying or broiling, can produce high concentrations of PM2.5 in the kitchen and dining areas. Both the process of cooking and some cooking appliances can increase the concentrations of polycyclic aromatic hydrocarbons (PAHs), carbon monoxide, acrolein, and nitrogen oxides, all of which are potentially harmful to health. Small sources such as candles and burning incense can produce surprisingly large quantities of PM2.5 and should not be used during wildfire smoke events. Vacuuming can temporarily stir up dust. To avoid re-suspending particles, do not vacuum during a smoke event, unless using a high-efficiency particulate air (HEPA) filter-equipped vacuum. When cleaning, use a damp mop or damp dust cloth to minimize re-suspending settled particles. See the EPA website for more information about indoor pollutants and sources.

3.4 Adjust Air Conditioners and Ventilation Systems to Keep Smoke Out

Air conditioners can impact smoke exposure indoors in several ways:

1. Air conditioners allow occupants to keep windows and doors closed, even during hot weather.

2. Operating air conditioners can reduce the amount of smoke that comes indoors, depending on the type of device.
3. Upgrading the filters in central air systems reduces PM2.5 from smoke in the indoor air (see Use air filters in central air systems).

Homes with air conditioning generally have lower concentrations of PM2.5 from the outdoors compared to homes that use open windows for cooling. Most air conditioners are designed 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 evaporative (swamp) coolers, can bring in large quantities of unfiltered outdoor air. Portable air conditioners with a single hose, in addition to ventilation devices that exhaust air to the outdoors (e.g., range hoods, bathroom fans), can create a pressure imbalance that brings in unfiltered outdoor air from elsewhere in the house. Below is a brief overview of common types of cooling and ventilation systems and how to adjust them to reduce smoke intrusion.

3.4A Central Air Systems

Most residential central air systems recirculate air within the home and, in most cases, operating them for comfort or air filtration (see Use air filters in central air systems) should not bring significant amounts of smoke into the home. Some central air systems are installed with the air handler and/or some duct work in an unconditioned area such as an attic or crawlspace. Depending on how well the ducts are sealed, operating the system could bring in smoke from the unconditioned space. The impact may be reduced by using a high-efficiency filter in the central air system, though filters may soil more quickly.

For newer central 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 (ERV/HRV) 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.

3.4B Mechanical Ventilation Systems

Mechanical ventilation in new homes is now required by building codes in some jurisdictions. Many newer homes 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 relative to the outside), controlled exhaust ventilation (creating negative pressure in the building, typically through an exhaust fan in a bathroom or central location), or balanced ventilation strategies that typically employ a heat-recovery or energy-recovery ventilator (HRV/ERV).

Ventilation 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. Similar to central air systems with a fresh air intake, this may require closing the outdoor air damper or sealing off outdoor air intakes, setting the system on "recirculate" only, or turning off the ventilation device.

If supply air is not filtered, supply or balanced ventilation systems may bring smoky air inside directly. Supply air filtration may need to be coupled with an efficient filter for recirculating air in the home for greater effectiveness (Singer et al., 2017).

Because they create negative pressure in the building, controlled exhaust ventilation systems can draw smoke inside via infiltration at small openings, joints, cracks, and around closed windows and doors. Whole-house fans and local mechanical ventilation devices, including range hoods, kitchen fans, bathroom fans, and clothes dryers, also create negative pressure inside the building and can draw in smoke. These devices should be turned off or used sparingly during smoke events.

Mechanical ventilation systems used in public and commercial buildings differ and are discussed further in Reduce smoke exposure in public and commercial buildings.

3.4C Swamp Coolers

Some 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 a fan motor, fan, water tray, and pump. 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.

If the evaporative cooler is safely accessible, completely covering the outside air intakes with 4-inch-thick high-efficiency (MERV 13) furnace filters can reduce the amount of smoke brought inside by about 50% for 0.3-0.5 µm particles, the most challenging to remove. Removal efficiencies generally increase with particle size (Singh et al., 2025). The external filters may need to be replaced frequently due to wind or rain damage and should only be deployed temporarily for smoke events. A laboratory study has shown that evaporative coolers without external filters can reduce PM10 up to 50%, and PM2.5 by 10-40% (Paschold et al., 2003), however this can still result in significant amounts of smoke coming inside. If the outside air intakes cannot be covered with filters, evaporative coolers should be used sparingly

during periods of heavy smoke. Regardless of whether filters are installed, other outdoor pollutants such as ozone are not filtered out and indoor concentrations can be nearly equal to outdoor concentrations.

3.4D Ductless Mini-Split Systems

Some homes may have ductless mini-split heat pumps or air conditioning systems. A ductless mini-split system uses an air handling unit mounted inside the home connected to a compressor located outside the home. It will cool effectively in a home that has been sealed up to minimize smoke infiltration and generally will not compromise indoor air quality.

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.

3.4E Window-Mounted 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, some window units can be operated in recirculation mode or fresh air mode. During a high smoke event, the window AC unit should be set to operate in recirculation mode.

3.4F Portable Air Conditioners (PACs)

PACs are typically used to condition the air in a single room of the home. Depending on the make and model, a portable air conditioner will have either a single- or dual-hose configuration.

Single-hose portable air conditioners can result in outdoor smoke being drawn into the home, and they should be used sparingly during periods of heavy smoke. The single-hose configuration expels hot exhaust air to the exterior of the home, but the supply air is taken from the home itself. The net effect is that the room is placed under slight negative pressure, drawing unfiltered air into the home through any leaky points in the building envelope.

Dual hose portable air conditioners can be used without restriction during a smoke event. Dual-hose configurations have two separate airflow paths, so the air pressure inside the room remains balanced. One hose draws supply air from the outside to cool the condenser, then exhausts the warmer air back

out through the second hose. Indoor air comes into the unit, is cooled by the evaporator, and then recirculated within the room.

3.5 Use Air Filters and Air Cleaners

Using high-efficiency HVAC filters, PACs, and do-it-yourself (DIY) air cleaners, alone or in combination, can reduce PM2.5 concentrations in indoor environments. PACs and DIY air cleaners are intended to deliver cleaner air to a single room, while HVAC filters can deliver cleaner air to the whole home. However, two or more well-placed PACs and/or DIY air cleaners can be equally effective, and their cost may still be less than operating a central air system continuously with a high-efficiency filter. The Wildfire Guide fact sheet on Indoor Air Filtration summarizes the information in this section for the general public.

In general, upgrading the HVAC filter is expected to be most effective in tighter (typically newer) homes when the HVAC fan is run continuously and the filter is installed correctly and changed frequently (Alavy and Siegel 2019; Zhang et al., 2020). One study during an extreme wildfire event (PM2.5 > 200 µg/m3 for several days) observed a 45% decrease in PM2.5 concentrations relative to outdoors using a MERV 13 filter with intermittent HVAC operation as needed for air conditioning (Antonopolous et al., 2024). Modeling indicates that even with a typical low-efficiency (MERV 4) filter, running the system continuously may reduce PM2.5 concentrations by about 24% compared to intermittent operation (Fisk and Chan 2017).

Portable air cleaners alone can effectively reduce PM2.5 concentrations, even in homes that do not have central air conditioning and are most effective if windows and doors remain closed and excessive heat is not a concern. During a wildfire smoke event, PACs may reduce indoor PM2.5 concentrations by 50-80%, averaging around 65% (Barn et al 2008, Xiang et al. 2021). Properly constructed DIY air cleaners can perform similarly to commercial air cleaners (Holder et al., 2022; Eykelbosh 2023; May et al., 2021).

PACs can be used in combination with HVAC filter upgrades to maximize the reduction of indoor PM2.5. In one study during an intense smoke event lasting nearly two weeks, using both a PAC and an HVAC system with a MERV 13 filter reduced indoor PM2.5 concentrations by about 80% relative to the outdoors, compared to about 45% using the HVAC system with a MERV 13 filter alone (Antonopolous et al., 2024).

3.5A Choose Air Cleaners and Filters that Do Not Produce Ozone

Use only CARB-certified air cleaners. Ozone is a lung irritant that poses serious health risks for humans and animals. 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. See the List of CARB-Certified Air Cleaning Devices.
For more information about ozone and air cleaners, see:

- EPA: Ozone Generators that are Sold as Air Cleaners
- CARB: Hazardous Ozone-Generating Air Purifiers

A single air cleaning product may use one or more air cleaning technologies. These technologies typically use one or both of the following mechanisms for particle removal:

- Mechanical mechanisms that capture particles in a fibrous and/or fabric filter. For example, HEPA filters and other pleated filters are mechanical filters. Mechanical air cleaners and filters, especially higher-efficiency filters, can effectively remove PM2.5 from smoke and do not produce ozone. Some filters use electrostatically charged fibers to increase their efficiency, which also does not produce ozone.
- Electronic mechanisms that use electric fields to remove particles from the air. This category includes ionizers, electrostatic precipitators, and other electronic air cleaning technologies. Electronic air cleaners have the potential to produce ozone. There is some evidence that these air cleaners can produce other harmful byproducts as well (Collins and Farmer 2021; NASEM 2022). There is limited evidence that electronic air cleaners can effectively remove PM2.5 from smoke in the air and they are not recommended for smoke removal (Zeng et al., 2022a; Zeng et al., 2022b; Stinson et al., 2024; NASEM 2024). Ionizers, in particular, can cause particles to stick to materials (e.g., carpet, walls) near the device which can be resuspended into the indoor air if disturbed.

Other air cleaning technologies, such as photocatalytic oxidation (PCO) technology, hydroxyl generators, and devices with UV light components, are not designed to remove particles from the air. There is limited evidence that these technologies are effective for smoke or odor removal (Stinson et al., 2024.; Zeng et al., 2022; NASEM 2024). (Note that some technologies that can effectively inactivate pathogens, such as ultraviolet germicidal irradiation (UVGI), do not remove smoke.) Similar to electronic air cleaners, they also have the potential to produce ozone or other harmful byproducts (Collins and Farmer 2021; NASEM 2022).

Given that electronic air cleaning technologies are not recommended for smoke removal, **the following sections focus on mechanical air cleaners and filters**.

3.5B Use Air Filters in Air Systems

Choose an Appropriate Filter for the System

Forced air heating and air conditioning systems contain filters that remove some airborne particles with different degrees of efficiency. These filters only work to reduce PM while running

the forced air system for cooling or heating or running the fan only. Most systems are equipped with a flat panel, low-efficiency filter primarily designed to protect the equipment from clogging with large debris like hair and dust. If possible, a pleated medium- or high-efficiency particle filter should be installed in the central heating and/or cooling system. Higher-efficiency filters (e.g., filters rated at MERV 13 or higher, see below) are preferred because they can capture more of the PM2.5 associated with smoke and reduce the amount of outdoor air pollution that gets indoors. However, caution must be taken to ensure that the system is able to handle the increased airflow resistance from a higher-efficiency filter. Consultation with an HVAC technician may be necessary to confirm if or which high-efficiency filters will work with an individual system.

Filter Rating Systems

Furnace and HVAC filters are rated based on how well they remove particles from the air, most often reported as a Minimum Efficiency Reporting Value (MERV) rating based on the average removal efficiency across three particle size ranges (Table 1). For more information, see the EPA webpage What is a MERV rating?.

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.

Table 3.1 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
MERV 1-7	Not tested	Not tested	<20 to ≥50
MERV 8-10	Not tested	20 to ≥50	70 to ≥80
MERV 11-12	20 to ≥35	65 to ≥80	85 to ≥90
MERV 13-16	50 to ≥95	85 to ≥95	90 to ≥95
HEPA	≥99.97		

*Adapted from ANSI/ASHRAE Standard 52.2

Maximize Filter Performance During Smoke Events

Filters should fit snugly in their slot so that air passes through the filter rather than around it. Filters also need to be replaced regularly and more frequently during and after smoke events for optimal performance.

Note that many filters with higher MERV ratings use electrostatically charged fibers to increase their efficiency. Electrostatically charged filters may become less effective quickly during smoke events and it is especially important to change them frequently. See Section 2.4 of the EPA Best Practices Guide for Improving Indoor Air Quality in Commercial/Public Buildings for more information about electrostatic filters.

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 (e.g., fan switch on the thermostat set to "ON" rather than "AUTO") to obtain maximum particle removal by the HVAC filter. Setting the fan to run continuously during a smoke event increases filtration because air will move through the filter continuously instead of only during temperature change. This will temporarily increase energy use and costs. The thermostat fan setting can be reset to "AUTO" after the wildfire smoke clears.

3.6 Use Portable Air Cleaners (PACs)

Choosing to buy a PAC, also called a room air cleaner or air purifier, is a decision that ideally should be made **before** a smoke event occurs, particularly in homes with occupants in at-risk groups (see Chapter 2). During a smoke emergency, it may be hazardous to go outside due to poor air quality or drive due to poor visibility, and PACs may be in short supply.

3.6A Choose a PAC Appropriate for the Size of the Indoor Environment

PACs can help reduce indoor PM2.5 concentrations. Ideally, PACs should be sized to provide a filtered airflow at least four to five times the room volume per hour. Most PACs will state on the package the unit's Clean Air Delivery Rate (CADR). The CADR is a rating that combines particle removal efficiency and airflow to indicate how quickly the device delivers cleaner air to the room.

The Association of Home Appliance Manufacturers (AHAM) maintains a certification program for PACs. The AHAM seal on the PAC's box lists separate CADR numbers for different particle sizes represented by tobacco smoke (the smallest particles tested), pollen, and dust, usually reflecting performance at the highest fan speed. The higher the CADR, the faster PM concentrations will be reduced and the larger the area the PAC can serve.

To determine whether a PAC is powerful enough for the size of the room where it will be used, choose a product with a CADR for tobacco smoke that is at least two-thirds the room's area in square feet (often called the "2/3 rule"). For example, a 10' x 12' room (120 square feet) would require a PAC with a tobacco smoke CADR of at least 80. If the ceiling is higher than 8 feet, a PAC rated for a larger room will be needed. In large rooms, using multiple PACs may be more cost-effective than using a single unit with a high CADR. If the room area is larger than any available product will serve, multiple PACs may be needed to serve that space. Air filtration could be increased by also using an HVAC filter (see Use air filters in central air systems) or DIY air cleaner (see Consider DIY air cleaners when PACs are not available or affordable), if appropriate.

In some cases, people may benefit from a PAC with a higher CADR than is indicated by the "2/3 rule." Whether a higher CADR (or additional PACs) is worth the investment will depend on individual circumstances. A PAC with a higher CADR, or additional PACs, may be particularly beneficial in situations such as:

- **In extremely smoky conditions or for people who are at greater risk of health effects.** A PAC with a higher CADR, or additional PACs, may be needed to reduce PM2.5 indoors to an acceptable level. One recommendation suggests choosing a PAC with a CADR equal to the area of the room in square feet in this situation.
- **In locations impacted by frequent smoke events.** People may find that filters last longer when using a PAC with a higher CADR, or multiple PACs on lower fan speeds, while also providing higher filtration capacity when needed.
- **When noise is a concern.** A PAC with a higher CADR can be run at a lower (quieter) fan speed.

3.6B Other Considerations for Selecting PACs

Some practical considerations are useful for selecting a PAC:

- **Check the noise level of the PAC.** Noise is especially important if it is used in a shared space or sleeping area. Some PACs will have a sleep mode or low fan setting that will be very quiet but will be less effective for cleaning the air. Most manufacturers will provide noise levels for the PAC at various fan settings. Noise levels will be listed in decibels (dB), and anything below 50 dB is considered close to background noise in an average home.
- **Consider PAC size and weight.** If the PAC is to be placed in a small room or must be moved frequently by the user, they may want to consider a PAC with a small footprint that is lightweight.
- **Consider whether the PAC needs to remove odors or gases.** PACs that remove volatile organic compounds (VOCs) and other gases (many of which are odorous) will have filters with activated carbon, or chemisorbents such as impregnated alumina or permanganate. These filters will generally be quite expensive and often have a relatively short lifespan.
- **Consider operating costs.** These include replacing the filters and running the device. How long

a filter will last will vary depending on the concentration of the pollutant that is being filtered (e.g., PM or gaseous pollutants such as VOCs). Some filters can be relatively inexpensive, but filters that remove both particles and gases can be quite expensive. The Energy Star program Room Air Cleaners website provides energy use estimates for certified devices.

3.6C Consider DIY Air Cleaners when PACs are not Available or Affordable

In some cases, before or during a wildfire smoke episode, commercial air cleaners may not be readily available or may be too costly for some people. An effective and less expensive option is a DIY air cleaner.

Building a DIY air cleaner involves attaching one or more furnace filters to a box fan (Figure 3.1). A laboratory assessment of different types of DIY air cleaners has shown that the 4-filter cube design is considerably more cost-effective, long-term, than a single panel design (Holder et al., 2022). In general, designs that use more filters, thicker filters, and a cardboard shroud are more cost-effective. Different designs may have different advantages in terms of initial cost, size, or ease-of-assembly. DIY air cleaners may be noisier than commercial PACs which may discourage their use (Prathibha et al., 2024). DIY air cleaners should be placed and operated similarly to PACs (see Place and operate PACs to maximize removal of $PM_{2.5}$ from smoke).

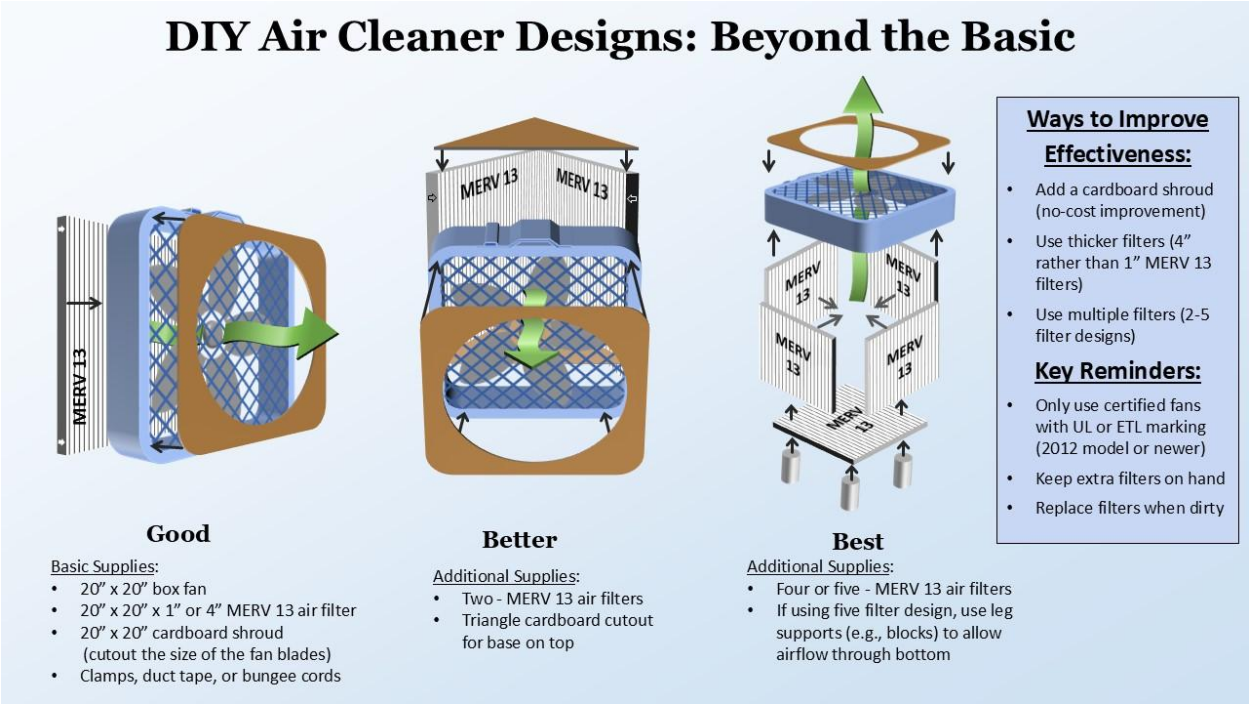

Figure 3.1 DIY air cleaner designs

Many of the concerns about DIY air cleaner safety have been addressed through a safety evaluation (Underwriters Laboratories 2021). When building a DIY air cleaner, it is important to use only newer box fans (built since 2012) with an Underwriters Laboratories (UL) or Intertek (ETL) safety marking because these fans have added safety features.

For more information about DIY air cleaners, including instructions for how to build them, see:

- EPA: Research on DIY Air Cleaners to Reduce Wildfire Smoke Indoors
- EPA: DIY Air Cleaners

3.6D Place and Operate PACs to Maximize Removal of $PM_{2.5}$ from Smoke

PACs will provide the most protection when placed where people spend the most time, such as a bedroom or cleaner air space (see Create a cleaner air room at home). An easily portable device can also be moved between rooms throughout the day. To maximize PAC effectiveness, operate it continuously, or as often as possible. Use the highest fan speed and make sure the air flow to the PAC is not obstructed. Keep outside doors and windows closed to prevent smoky air from entering the room.

Check filters often and replace them when they appear dirty, start to release smoke odors, or when the smoke event is over. They may need to be changed more often than recommended by the manufacturer during a smoke event.

For more information about PACs, see:

- EPA: Air Cleaners and Air Filters in the Home
- CARB: Air Cleaner Information for Consumers
- AHAM Verifide Program

3.7 Humidifiers

Humidifiers are not air cleaners. They will not significantly reduce PM2.5 concentrations during a smoke event, nor will they remove gases. 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 individuals' 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 (see the EPA's Use and Care of Home Humidifiers). The usefulness of humidification during a smoke event has not been studied.

3.8 Create a Cleaner Air Room at Home

Cleaner air rooms are set up to keep concentrations of $PM_{2.5}$ and other air pollutants from smoke as low as possible during wildfire smoke events. Anyone can benefit from spending time in a cleaner air room at home — especially those at higher risk of air pollution-related health effects (see Chapter 2). It is also a good strategy if it is impractical to maintain cleaner air throughout the entire home during a smoke event.

People can take the following steps to create and maintain a cleaner air room at home:

1. **Choose a room.** Pick a room big enough for everyone in your household to be comfortable. An interior room with few windows and doors and/or a bedroom with an attached bathroom is a good choice.
2. **Prevent smoke from entering the room.** Close windows and doors, but do not do anything that makes it hard to leave the room in an emergency.
3. **Stay cool.** Run fans, window air conditioners, or central air conditioning. If your air conditioner has a fresh air option, turn it off or close the intake and run it in recirculation mode (see Adjust air conditioners and ventilation systems to keep smoke out).
4. **Filter the air in the room when there is a smoke event.** You will need to buy a higher efficiency HVAC filter, PAC, and/or make a DIY air cleaner before a smoke event (see Use air filters and air cleaners).
5. **Avoid activities that create air pollutants indoors, such as smoking or vaping, burning candles, using aerosols, and vacuuming, unless you use a vacuum with a HEPA filter.** Avoid cooking with a stove or oven, especially anything that involves high heat or a long cooking time. Use a damp cloth or mop to trap settled dust particles (see Reduce other sources of indoor air pollution).
6. **Spend as much time as you can in the cleaner air room to get the most benefit from it.** When the air quality improves, even temporarily, air out the cleaner air room to freshen the air. Airing out the room helps remove any contaminants from smoke that may have entered the room as well as reducing the concentration of carbon dioxide that may build up from exhaled breath while the room is closed.

Note that some pollutants from smoke may still enter the home even if all these steps are taken, and staying indoors with windows closed may be dangerous in hot weather. People who cannot stay cool at home, lose power, or still have too much smoke entering the home after taking these steps should be advised to seek relief from smoke elsewhere.

For additional information, see:

- Wildfire Guide fact sheet: How to Create a Cleaner Air Room at Home

- EPA: Create a Clean Room to Protect Indoor Air Quality During a Wildfire

3.9 Reduce Smoke Exposure in Public and Commercial Buildings

Like residential buildings, public and commercial buildings offer varying levels of protection from smoke: studies indicate that indoor $PM_{2.5}$ can range between 30-80% of outdoor concentrations during wildfire smoke episodes (May et al. 2021, Pantellic et al. 2019). Many of the same strategies to reduce smoke exposure in residential settings can also be used in principle to reduce exposure in larger public and commercial buildings, including schools.

A key difference in these larger buildings is often in the HVAC system. In many cases, the system will bring in outside air by design to provide adequate ventilation to the building. Multiple systems may serve different parts of the building, adding to the complexity of adjusting the system for smoke. Other strategies, such as using PACs, closing doors and windows, and/or air sealing can essentially be scaled up to the size of the building.

Developing a building-specific smoke ready plan *before* a smoke event is critical to protect building occupants. Due to the complexity of many public and commercial building systems, measures to reduce smoke entry through the HVAC system may need to be tested and supplies purchased before implementation. Roles, responsibilities and lines of communication among responsible individuals (e.g., administrators, facility managers, occupants) should be established in advance of a smoke event for timely implementation of the smoke ready plan. Consider defining decision points for implementing the plan based on air quality similar to Table 5.2 or the decision matrix presented in ASHRAE guidance. It is strongly recommended to document the smoke ready plan in writing, including checklists and photos to aid implementation and return to normal operations, and revise the plan as necessary after each smoke event.

Key elements of a smoke ready plan include:

1. **Ensure building systems are in good working order,** like checking if doors and windows close and seal properly, inspecting HVAC systems and performing repairs as needed. Also, ensure supplies such as high-efficiency air filters are available before a smoke event.

2. **Plan to keep smoke out of the building,** including by closing doors and windows, restricting building entrances (especially loading docks), air sealing (weatherizing) exterior penetrations in the building (e.g., windows, doors, service penetrations), and adjusting mechanical ventilation systems (see next step). If any occupied part of the building does not have air conditioning,

consider how to moderate indoor temperatures in the event that heat and smoke occur at the same time.

3. **Adjust HVAC systems and enhance filtration during a smoke event.** Plan to adjust mechanical ventilation systems to minimize smoke intrusion and enhance filtration to filter out $PM_{2.5}$ from smoke that enters the building. Building managers may need professional assistance in advance to develop, test, and implement these plans.

   When adjusting mechanical ventilation systems, reduce outdoor air intake to a minimum that is protective of human health and equipment while maintaining positive building pressure. This often involves disabling or minimizing the use of economizers (a component of some HVAC systems) when smoke is present. Plan to add supplemental air filtration at the outside air intake when possible. Consider impacts on local exhaust systems such as utility, kitchen, and bathroom exhausts. This step can be particularly complex to implement and should be tested before a smoke event occurs.

   Enhanced filtration measures include installing high-efficiency filters (i.e., MERV 13 or as high as the system can handle) in HVAC systems and/or deploying PACs (commercial or DIY) in spaces not served by an HVAC system or where supplemental filtration is needed. Building managers should determine the highest efficiency filter that can be used in each filter location in advance and stock up accordingly. See Use PACs for information about how to choose and operate PACs. In large spaces, multiple PACs may be needed to achieve a CADR sufficient for the space. Expect to change filters more frequently during smoke events.

4. **Reduce indoor air pollutant sources.** See Reduce other sources of indoor air pollution above. Common sources in public and commercial buildings include cooking, some cleaning activities, and using air fresheners or printers. In schools, activities such as chemistry labs or art projects that require dedicated ventilation due to chemical use may need to be restricted during smoke events.

5. **Monitor indoor air quality** in a few representative spaces throughout the building. Plan how to analyze, use, and communicate about the data collected from air sensors in advance. See Monitor $PM_{2.5}$ in indoor air. In addition to $PM_{2.5}$, some building managers may monitor CO_2 as an indicator of adequate ventilation in public and commercial buildings, especially while measures are in place to reduce outdoor air intake.

6. **Air out the building when air quality improves, and clean indoor surfaces as needed.** When outdoor air quality improves, bring in outdoor air through mechanical ventilation or opening

windows to reduce the concentration of any indoor air pollutants that may have become more concentrated during the smoke event. In addition, cleaning indoor surfaces will reduce potential exposure to pollutants that may have settled during the smoke event.

When the strategies listed here cannot be implemented across the building, plan to designate cleaner air spaces in locations where indoor air quality can be effectively improved during a smoke event. These spaces can be especially helpful for people at greater risk of smoke-related health impacts.

The following resources provide additional guidance for reducing smoke exposure in public and commercial buildings:

- EPA: Best Practices Guide for Improving Indoor Air Quality in Commercial/Public Buildings during Wildland Fire Smoke Events
- ASHRAE Guideline 44: Protecting Building Occupants from Smoke during Wildfire and Prescribed Burn Events and the ASHRAE Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events
- Canadian National Collaborating Centre for Environmental Health: A public health companion for ASHRAE Guideline 44: Protecting building occupants from smoke during wildfire and prescribed burn events
- EPA: Wildfires and Indoor Air Quality in Schools and Commercial Buildings

3.10 Provide Public 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 (for overnight and longer-term relief) or cleaner air spaces (for short-term relief throughout the day).

When opening a cleaner air shelter or cleaner air space, choose locations with adequate filtration, ventilation, and cooling/heating capacity to sufficiently clean and condition the air (see Reduce smoke exposure in public and commercial buildings). Consider locations with backup power if power outages are likely due to the threat of wildfires or other conditions. Ideally, selected locations will be equipped with air sensors to monitor indoor conditions (see Monitor PM2.5 in indoor air) and a smoke ready plan specific to the building will be developed and tested in advance (see Reduce smoke exposure in public and commercial buildings).

Note that cleaner air spaces and shelters are not appropriate for every community or every smoke episode. Many people prefer to maintain their routines when possible or shelter in place at home rather than go to a public cleaner air space or shelter. Driving to and from a public cleaner air space for short-term relief can increase smoke exposure and the stress of evacuating for an extended stay in a cleaner air shelter can potentially result in health consequences. In communities where cleaner air spaces and shelters are underutilized, ensuring that people have access to cleaner air in homes, schools, workplaces, and other essential locations may be a more effective strategy. Conversely, communities with a significant unhoused population with no alternative access to cleaner air may find cleaner air spaces and shelters especially useful.

3.10A Cleaner Air Shelters

Cleaner air shelters are public spaces for people who are displaced by wildfires 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). 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 a smoke episode. Choose locations with features needed to serve as evacuation centers (see, for example, FEMA's Guidance on Planning for Integration of Functional Needs Support Services in General Population Shelters).

3.10B Cleaner Air Spaces

Individuals who do not have regular access to cleaner air at home or in other locations should be encouraged to seek out pre-identified cleaner air spaces located in their communities for periods of respite from the smoke throughout the day. Choose locations that have facilities or activities that encourage people to spend several hours there (e.g., workspaces, play areas, entertainment, food and drink) and can provide cleaner air and adequate cooling. Examples of potential sites for cleaner air spaces could include libraries, museums, indoor shopping malls, theaters, indoor sports arenas, and senior centers.

3.10C Measures to Address Airborne Pathogens in Cleaner Air Shelters and Spaces

Because community cleaner air spaces and shelters are meant for large numbers of people, additional precautions may be needed to protect people from exposures to airborne infectious diseases. One of the methods typically utilized to lower airborne pathogens and increase ventilation is to introduce as much outside air as possible to dilute and remove pathogens circulating in the air. However, during a wildfire smoke event, ventilation is kept as low as possible. Measures to enhance filtration such as

utilizing HVAC filters rated MERV 13 or higher and deploying PACs with sufficient CADR for the space can remove airborne pathogens from the air along with PM2.5 from wildfire smoke.

If there are local advisories or concerns for local outbreaks of airborne infectious diseases, additional precautions may be needed before opening a cleaner air space or shelter to the public. These include configuring the space to ensure physical distancing, making face masks (e.g., NIOSH Approved® N95® respirators) available, frequent surface cleaning and disinfecting, installation of upper room UVGI systems, signage regarding cough and sneeze etiquette and handwashing, and providing tissues, hand sanitizer and handwashing facilities. These added precautions are also a good idea even if there are no local infectious disease advisories; modifications of the HVAC system and PACs may not entirely eliminate the potential for airborne transmission of infectious diseases, and some members of the public may be especially vulnerable to these illnesses.

For more information, see:

- CDC: Guidance for General Population Disaster Shelters During the COVID-19 Pandemic
- American Red Cross: Coronavirus: Disaster Shelters When a Hurricane or Wildfire Happens

3.11 Monitor $PM_{2.5}$ in Indoor Air

Air sensors, also called portable, low- or lower-cost air quality sensors, or sometimes "monitors", can provide useful, real-time information about pollutant concentrations outdoors and indoors. During a smoke event, data from air sensors can be used to:

- Advise the public about where to go to avoid smoke exposure and when to go outside.
- Identify buildings with cleaner indoor air.
- Advise building managers when to adjust strategies to reduce smoke exposure indoors.

This section discusses using air sensors to monitor indoor air quality during smoke events with a focus on $PM_{2.5}$ sensors. Air sensors that measure $PM_{2.5}$, one of the main components of wildfire smoke, are well-studied and widely available. Most $PM_{2.5}$ air sensors on the market today do well at capturing the trends in air quality but may not produce accurate concentration estimates. Some air sensors may be able to measure other pollutants including different size fractions of PM (e.g., PM1 or PM10), carbon dioxide, ozone, and nitrogen oxides, but their performance may not be as robust due to technological limitations, interferences from other pollutants or conditions, or difficulty in interpreting the information they present.

Additional resources available on this topic include:

- The Wildfire Guide Fact sheet Using Air Quality Sensors for Smoke summarizes this information for the general public.
- EPA's Best Practices Guide for Improving Indoor Air Quality in Commercial/Public Buildings

During Wildland Fire Smoke Events provides more detailed information on how to use air sensors in commercial/public buildings.
- The EPA webpage Air Sensor Technology and Indoor Air Quality provides general information on using sensors indoors.

For more information on using air sensors to monitor outdoor air quality during a smoke event, see Chapter 4.

3.11A Selecting an Air Sensor

Air sensors come with a variety of features that can be useful for different applications. Clearly defining how sensors and their data will be used and by whom is essential for choosing an appropriate product.

For wildfire smoke, it is important to choose a sensor that detects $PM_{2.5}$. Some sensors detect multiple pollutants, which may be desirable for other applications. Also, consider how the sensor reports data, such as by particle mass or number concentration, or as the AQI.

Figure 3.2 Indoor PurpleAir Sensor. *Photo Credit: Alison Savage, U.S. EPA*

Sensors may display data in various ways. Some sensors:
- Connect to the internet via Wi-Fi or cellular networks and allow you to view or download data from a website or app.
- Store data on a removeable memory card for analysis on a computer.
- Display graphics, colors, or numbers directly on the device.

When selecting a sensor, consider how you wish to use it and how you will provide power. Sensors may be stationary (meant to be deployed to monitor one location) or portable (e.g., wearable, handheld, or mobile). They may plug into a wall outlet, use a small solar panel/battery system, or run off a battery. Other important features to consider include durability, ease-of-use, operation and maintenance requirements, and cost (both initial and ongoing).

Some applications may require higher quality data and more accurate sensors. Information about sensor performance may be available from the sensor manufacturer or a third-party evaluator or can be developed by co-locating sensors and developing a correction equation (see Comparing sensor data to regulatory data). Between 2021 and 2024, EPA developed air sensor performance targets and testing

protocols for criteria air pollutants (see EPA Air Sensor Performance Targets and Testing Protocols). Comparing a sensor's performance to these targets may help consumers choose high quality sensors.

EPA's performance targets and protocols were not explicitly designed for smoke measurement, but EPA researchers made several recommendations for how the protocols could be adapted to better understand performance in smoke. If your application requires higher quality data, especially if you plan to compare sensor data to regulatory data, look for or develop performance data that:

1. **Uses 1-hour averaged data.** Higher time resolution data is often useful in smoke situations.
2. **Evaluates performance under high $PM_{2.5}$ concentration conditions (>500 $\mu g/m^3$).** Concentrations can get quite high during smoke episodes.
3. **Indicates the sensor has a tight precision target.** This allows a correction equation to be applied to a batch of sensors rather than needing a correction equation for each individual sensor.
4. **Reflects relevant particle sources.** Sensor performance can be dependent on particle sources (e.g., what fuel is burned), fire conditions, and humidity so performance should be evaluated in the area where you anticipate using sensors, during multiple fires, and in multiple seasons to capture as much variability as possible.
5. **Uses an appropriate reference monitor.** Federal equivalent method (FEM) monitors may not be sited in locations impacted by smoke. Temporary smoke monitors are portable and can be deployed into smoke impacted areas. They may be used as a reference monitor for sensor performance evaluation provided that the data is first carefully reviewed and quality controlled.
6. **Applies the appropriate correction equation before evaluating performance metrics.** If a correction equation will be applied to the data before public display or use, it should be developed and applied to all data before developing visualizations and calculating the performance metrics in the testing report.

For sensors that will be used indoors, a suitable reference monitor will often be unavailable. Correction equations based on outdoor conditions are sometimes applied to indoor sensor data. This may have limitations (Bi et al., 2021) because the size distribution and composition of $PM_{2.5}$ may change as it moves indoors and mixes with PM from indoor sources. Depending on the application, these limitations may still be preferable to using raw sensor data.

For information on sensor accuracy and related topics, see:

- EPA: Enhanced Air Sensor Guidebook
- EPA: Air Sensor Performance Targets and Testing Protocols
- EPA: Performance of low-cost indoor air pollution monitors
- South Coast Air Quality Management District: Air Quality Sensor Performance Evaluation Center

(AQ-SPEC)

3.11B Placing an Air Sensor

The ideal location for an air sensor depends on the purpose of air monitoring. In public and commercial buildings, including schools, ASHRAE Guideline 44-2024 recommends locating one or more sensors in areas representative of general building use, and one in a planned cleaner air space. In general, when placing sensors indoors:

- Try to place the sensor 3-6 feet off the ground (at breathing height) and in a location that does not restrict airflow to the sensor.
- Avoid placing the sensor near exterior doors, windows, stoves, heating and cooling vents, humidifiers, or showers where changes in temperature and humidity can negatively impact sensor readings.
- Place the sensor near a power source where the sensor data will be accessible (e.g., with Wi-Fi coverage or where the memory card is within reach).
- Place it where it will not be unplugged or damaged.
- Get permission to monitor air quality at the site, if needed.

If using a portable sensor, the user should stand still briefly (e.g., 1-2 minutes) so that readings stabilize. Repeating measurements can also improve confidence in the accuracy of the readings.

For more information about siting sensors, see EPA's Guide to Siting and Installing Air Sensors.

3.11C Checking the Quality of Sensor Data

It is a good practice to check that sensors are performing as expected while they are deployed. Sensor performance can change over time, and sensors can fail in ways that can be difficult to recognize immediately. Comparing readings among nearby sensors (or regulatory monitors for outdoor sensors) can indicate how well sensors are working. They may not report exactly the same values, but they should show similar trends over time.

In addition, routinely review sensor data to help identify these common problems with $PM_{2.5}$ sensors:

- **Suspicious data:** Values that do not change (stuck values), sudden frequent jumps in the data, or sudden very erratic data may indicate a problem.
- **Consistently very low values:** If the sensor reports very low values, you may not be able to tell whether this is accurate or a sensor malfunction. You can do a simple test to see if the sensor is responding, such as safely lighting a match nearby.
- **Large differences in duplicate measurements:** Some sensor products report data from two sensors in the same unit. You can compare the data to make sure they both respond similarly.

- **Declining performance over time:** Sensor readings may become less accurate when sensors have been in operation for a long time, or during high $PM_{2.5}$ concentrations.

If you notice a problem with the data from an air sensor, consult the manufacturer's recommendations for troubleshooting or replacing the device.

3.11D Interpreting Data from Air Sensors

It is important to advise people using sensors that if they are experiencing health effects from smoke, they should take action to reduce exposure regardless of what a sensor is reading.

For many applications, simple approaches to interpreting raw, uncorrected sensor data, including examining trends over time or comparing $PM_{2.5}$ concentrations in different locations, can be informative for real-time decision making.

- **Examining trends in $PM_{2.5}$ concentrations over time** in one location can inform when to implement certain strategies to reduce smoke exposure, such as when to deploy PACs.
- **Comparing $PM_{2.5}$ concentrations in different locations** can inform decisions about where to spend time to reduce smoke exposure, such as when and where to hold an indoor recess at a school.

When using these approaches, it is usually appropriate to compare sensor data from sensors of the same type in different locations or from the same sensor over time to get a general sense of trends in air quality. If this is not possible, or if you are using a sensor that reports data with different units (e.g., can report mass concentration and Air Quality Index (AQI)), it is important to make sure you compare values with the same units. When interpreting indoor sensor data, it can be especially helpful to have suitable outdoor air quality data for comparison to see how outdoor conditions are impacting indoor air quality.

In indoor environments, collecting baseline data is strongly recommended to understand what is typical for the monitored location and to better interpret sensor data during a smoke event. $PM_{2.5}$ concentrations can fluctuate with outdoor concentrations, occupancy levels, occupant activities, HVAC or portable air cleaner operation, or other conditions. Baseline data should cover an appropriate period of time to understand typical concentrations and variations related to routine uses of the space. For example, baseline monitoring in a classroom may include times when the classroom is occupied by students during various types of activities (e.g., seated, moving around, working on art or science projects), occupied by the teacher alone, during cleaning, and unoccupied overnight.

Air sensors can help make decisions to reduce smoke exposure, but they are not intended to replace regulatory monitors. Air sensors have a higher level of uncertainty, and their raw data is often not directly comparable to that from regulatory monitors. Air sensors can also be affected by unrelated interferences such as fog, relative humidity, and temperature. Different makes/models of sensors may respond differently to the same conditions; use the same sensor model when comparing air quality in different locations whenever possible.

3.11E Comparing Sensor Data to Regulatory Data

To compare sensor data to reference values such as the National Ambient Air Quality Standards (NAAQS) or AQI (see Chapter 4), you will need to correct (or calibrate) the sensor data and ensure you use the appropriate time-averaging.

Corrections are most accurate for similar conditions. For instance, a correction equation based on outdoor conditions may not be accurate for indoor conditions where the sizes and sources of particles may be different. Correction equations, including equations specifically for smoke, may be available for some sensors (e.g., corrections employed on the Fire and Smoke Map). Learn more about correcting sensor data in Section 3.6.2 of EPA's Enhanced Air Sensor Guidebook.

Correction equations are typically developed by co-locating, or operating sensors side-by-side (often with regulatory monitors) in the same location for a period of time. Co-location should be repeated periodically because sensor performance typically changes over time as particle sources, emission intensity, or sensor age changes.

- **For sensors that will be used outdoors,** the most common way to correct sensor data is to co-locate air sensors within a few meters of regulatory monitors for a few days to weeks and develop a correction equation. EPA's Collocation Instruction Guide provides more information.
- **For sensors that will be used indoors,** sensors can be placed together to ensure that they perform similarly when measuring the same air. See Appendix 4 of EPA's Best Practices Guide for Improving Indoor Air Quality in Commercial/Public Buildings During Wildland Fire Smoke Events for more information.

Corrected sensor data can be compared to reference values such as the NAAQS or AQI with appropriate time-averaging of the sensor data (most low-cost sensors report readings frequently, such as every 10 minutes, whereas concentrations for $PM_{2.5}$ are usually averaged over 24 hours). These approaches to compare sensor data to reference values are somewhat sophisticated and may be used by larger sensor networks:

- **Correction and the NowCast algorithm:** If you can correct your sensor data so that it is comparable to the local air quality monitoring network, you can use 1-hour averaged data and

apply the NowCast algorithm to calculate the NowCast AQI directly. (EPA uses this approach with sensors in the AirNow Fire and Smoke Map.)

- **Compare peak-to-mean ratio to the 24-hour $PM_{2.5}$ NAAQS:** Use EPA's pilot Sensor Scale with 1-hour sensor data to predict whether 24-hour $PM_{2.5}$ concentrations will be below, near, or above the 24-hour $PM_{2.5}$ NAAQS.

3.12 Reduce Smoke Exposure Inside Vehicles

Individuals can reduce the amount of smoke in their vehicles by keeping the windows closed and, if available, operating the air conditioning in "recirculate" mode. However, in hot weather and in the absence of air conditioning, a car's interior can heat up very quickly 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 $PM_{2.5}$ coming in from outside, but the vehicle owner should not assume that they will get the same level of protection they would get from a dedicated cleaner air room or cleaner air space. Most vehicles can recirculate the inside air, which will help keep $PM_{2.5}$ concentrations lower.

Several aftermarket suppliers have replacement HEPA cabin filters, including some that have activated carbon for odor control, for new and older vehicles. Replacing the automobile's factory filter with a HEPA filter can significantly improve the air quality in the vehicle cabin. Also, it is increasingly common to see manufacturers provide high efficiency filtration in select trim levels of new vehicles. Drivers of vehicles with a high-quality air filtration system should familiarize themselves with the operation of the system and be encouraged to use it, especially during episodes of poor air quality. After a high smoke event or extended smoke event, it is a good idea to replace the cabin filter.

Drivers should check the owner's manual and ensure that the system is set correctly to minimize entry of $PM_{2.5}$ and other pollutants from smoke. However, studies have shown that carbon dioxide concentrations can quickly accumulate to very high levels (possibly exceeding 2,500 parts per million) in newer cars due to occupants' exhaled breath when the outside air intake 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 or with multiple passengers, it may be a good idea to briefly open windows or open the outside air intake occasionally when smoke concentrations are low to avoid the build-up of carbon dioxide. Finally, vehicles should not be used as a shelter from smoke, but rather as a means of transportation to indoor locations with cleaner air.

3.13 Use Respirators for Wildfire Smoke and Ash

Respirators are any respiratory protection device that is designed to provide a breathable atmosphere for the wearer, either by purifying or enhancing a hazardous or inadequate atmosphere or by supplying a breathable atmosphere.

The most common type of air-purifying respirators is filtering facepiece respirators (FFR), for example: N95®, N99®, N100®4. FFRs can be useful for reducing personal inhalation of the fine particles in wildfire smoke or ash. Studies have shown that when correctly put on according to the manufacturer's instructions (including minimizing any gaps between the face and respirator) and used properly, N95® respirators will significantly reduce the wearer's exposure to smoke particles (Brosseau et al. 2010; Coffey et al. 2004; Duling et al. 2007).

Respirators are widely available and offer 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 approved 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 Wildfire Guide fact sheet, Protect Your Lungs from Wildfire Smoke or Ash, has been designed for the public and includes links to other resources. Respirators described in this section would also help to protect the public involved in cleaning up ash. There is additional guidance in Chapter 5 on wildfire ash, and a Wildfire Guide fact sheet for the public on cleaning up ash, Protect Yourself from Ash.

Ideally, respiratory protection would not be used without first ensuring that no medical conditions exist that would make use of respiratory protection a risk and first providing users with "fit tests" to ensure a reliable seal to the face. However, these steps are generally not practical 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 a 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. NIOSH has information on fit testing that can be found at Personal Protective Equipment - Fit Testing and Filtering out Confusion: Frequently Asked Questions about Respiratory Protection, Fit Testing.

[4] N95®, N99®, N100®, R95®, P95®, P100® and NIOSH Approved® are registered certification trademarks of the U.S. Department of Health and Human Services (HHS) in the United States. *N95* and *NIOSH Approved* are registered certification trademarks of the U.S. Department of Health and Human Services (HHS) in the United States and several other countries.

Since fit testing is usually not available to the public, users can assess how well the device fits by performing a user seal check every time they put on the respirator following the instructions on the package. The websites Filtering Facepiece Respirators and How to Wear Your Filtering Facepiece Respirator contain general information on performing a user seal check. If individuals cannot get a good face seal, they should try a different model or size. Note that fit testing, if available, assesses fit better than a user seal check alone (Goko et al., 2023; Cass et al., 2023).

Respiratory protection use in workplace situations is beyond the scope of this section. 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. For more information see the NIOSH Science Blog How to Protect Workers and the Public from Wildfire Smoke.

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 state or federal 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. More information about this topic can be found in OSHA standard Appendix D of 29 CFR 1910.134.

3.13A 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. If one must be outdoors during wildfire smoke events, a tight-fitting, NIOSH-Approved® N95® or P100® respirator should be worn.

People experiencing health effects from a smoky environment indoors may also benefit from using one of these respirators if they cannot move to locations with better air quality or take other steps to clean their indoor air.

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 and they do not have access to cleaner indoor air, these groups should consider going to a temporary location out of the smoky area as they are able.

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 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.

3.13B 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 3.3). Respirators must be approved by NIOSH, and the words "NIOSH" and either "N95" or "P100" will be printed on the facepiece by the manufacturer.

Figure 3.3 Two types of N95® disposable particulate respirators. *Note the presence and placement of the two straps above and below the ears (California Department of Public Health).*

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 NIOSH Science Blog Beards and Respirators: Navigating No Shave November Safely has a graphic showing the types of facial hair that do not interfere with the respirator seal. NIOSH recommends wearing a

respirator only when clean shaven since this provides the highest level of protection (De-Yñigo-Mojado et al., 2021; Stobbe et al., 1988; McGee et al.; 1983; Hyatt et al., 1973). Studies have shown protection decreases as facial hair increases. Based on these studies, a respirator when worn with shorter facial hair may still provide some protection (Skretvedt et al., 1984; Floyd et al., 2018). Care should be taken so that hair, eyeglasses, facial scars, or other objects do not interfere with the seal of the respirator to the face.

The numbers "95" and "100" on a filtering facepiece respirator indicate its efficiency, 95% or 99.97%, respectively, at capturing the hardest to filter particles. 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 rather than filtration efficiency will determine the level of protection. "N" and "P" indicates if the filter material is resistant to degradation in the presence of oil mist; "N" filters are not while "P" filters are. In environments where smoke and/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. These other types of NIOSH Approved® respirators are also appropriate: R95®, P95®, and P99® filtering facepiece respirators, and non-disposable respirators, such as elastomeric half-mask. The non-disposable respirators have a tight-fitting, flexible, re-useable half-mask facepiece and replaceable N95 or P100 particulate filters. When used with an organic vapor cartridge, these respirators can reduce exposure to irritating gases in smoke, such as aldehydes, as well as particulates (filtering facepiece N95® or P100® respirators remove only particles, not gases or vapors.) Non-disposable respirators can make communications more difficult, block downward vision if the cartridges are bulky, and must be properly stored, cleaned, and disinfected between uses. More information about elastomeric respirators can be found at A Guide to Air-Purifying Respirators, What are Air-Purifying Respirators?, and Understanding Your Elastomeric Respirator.

3.13C 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.

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. Elastomeric half-mask respirators do not have metal nose clips.

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

3.13D Children and Respirator Use

Children are especially at-risk from exposure to wildfire smoke because their lungs are still developing, and they breathe more air relative to their body size than adults. See the Wildfire Guide fact sheet Children's Health and Wildfires: A Resource for Families for information on reducing children's exposure.

NIOSH Approved® respirators may not have been tested for broad use in children, and NIOSH does not currently approve respirators for use by children. Most children ages 2 years and older can wear respirators. If children are age 7 or older, NIOSH Approved® respirators and international respirators may be available in smaller sizes that fit them. However, manufacturers design them to be used by adults in workplaces. For children ages 2 to age 7, it is less likely to find an N95® respirator that will fit their face well. To wear a respirator safely, a child should be capable of telling an adult about any problems they have with the mask and should be able to remove it themselves. If they cannot, other smoke-reduction strategies (like cleaner air spaces) should be used. A well-fitting respirator provides the most protection to the wearer. If well-fitting respirators are not available, there are some masks available such as pediatric face masks that meet or exceed ASTM F2100 Level 1 standards for surgical face masks which may provide some protection.

Parents should choose a respirator or mask that the child can wear comfortably over their nose and under the chin, does not impair vision, and fits closely to the face with minimal gaps. Follow the user instructions for the respirator or mask. If a respirator or mask fits poorly or is uncomfortable, a child might take it off or wear it incorrectly (for example, pull it down from their nose). This reduces the intended benefits. More information about respirators and children can be found at CDC's Wildfire Smoke and Children.

3.13E 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 disease 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 respirator can be removed. Adequate hydrating and rest in a cooler area, such as in shade, 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.

3.13F Certain Masks Do Not Provide Protection

The public should be cautioned that masks with one strap such as nuisance dust masks or surgical or procedure masks with two straps that loop around the ears are not respirators (Figure 3.4). They are not designed to seal tightly to the face but may provide some protection from wildfire smoke or ash if respirators are not available. Cloth face coverings, bandanas (damp or dry), handkerchiefs, and tissues held over the mouth and nose should not be relied on for protection.

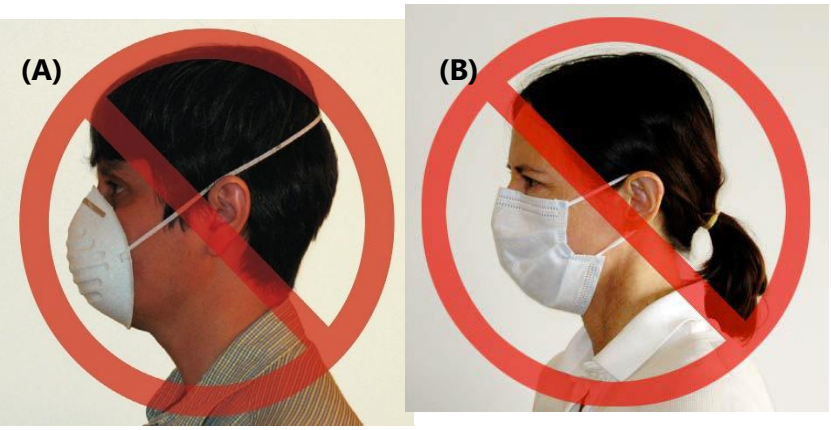

Figure 3.4 (A) One-strap paper mask and (B) Surgical Mask. *(A) A one-strap paper mask is not a respirator and provides little or no protection from smoke particles. (B) A surgical mask is designed to capture infectious particles generated by the wearer, is not a respirator, and provides less protection from smoke particles than a respirator (California Department of Public Health).*

3.13G 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.

Results from a 2020 NIOSH study suggested certain N95 models beyond their manufacturer-designated shelf life will be protective. However, CDC/NIOSH recommends that N95s that have exceeded their manufacturer-designated shelf life should be used only as outlined in the Strategies for Optimizing the Supply of N95® Respirators and Strategies for Conserving the Supply of N95® Filtering Facepiece Respirators.

Respirators certified under international standards such as the People's Republic of China Standard (for example, KN95) will provide greater protection than surgical masks, homemade masks, or improvised

mouth and nose covers, such as bandanas and scarves. Internationally made filtering facepiece respirators meet the requirements specified by the country, which includes manufacturing quality. However, international standards do not require the manufacturer to demonstrate quality. Since international manufacturers design these respirators for populations outside of the United States, they may not seal as well to your face as a NIOSH Approved® respirator.

3.13H Respiratory Protection Resources

The following resources provide additional information on respiratory protection for the public:

- The NIOSH Science Blog, 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.
- The NIOSH website, Find Filtering Facepiece Respirators on the Certified Equipment List, has links to listings by NIOSH approval number of All filtering facepiece respirators (FFRs) and N95® FFRs only.
- The NIOSH Personal Protective Equipment website provides information on all respirator types and their uses.

3.14 Avoid Smoky Periods

Smoke concentrations 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 areas that use these outreach tools. For example, officials in California, Idaho, Oregon, Washington, and Montana currently post forecasts to smoke blogs during fire season. Some wildfires may have their own forecast for smoke in the impacted area which can be found on the Fire and Smoke Map, on the INCIWEB site by named wildfire incidents, and at the Interagency Wildland Fire Air Quality Response Program page. See Chapter 1 for further detail on the Interagency Wildland Fire Air Quality Response Program. Public health officials can recommend the use of current air quality in terms of the AQI values from nearby monitors or sensors to help people identify and avoid the smokiest times of day (see the AirNow Fire and Smoke

Figure 3.5 Portable air quality monitoring station deployed by Lake Almanor during the 2018 Camp Fire. *Photo credit: Charles Pearson, Incident Air Monitoring Section, CARB.*

Map). Visual range-based estimation can be used in places where relative humidity is low if no monitoring is representative of the impacted areas (see Chapter 4).

3.15 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 concentrations 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 concentrations 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 prioritize 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.

3.16 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, some may not have the financial means or physical ability to evacuate, and most people do not want to leave their homes, pets, or livestock. 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 likely to be impacted by smoke, public health officials are encouraged to develop plans to help at-risk groups shelter in place.

In case evacuation becomes necessary, consider whether the community has an existing evacuation plan that can be adapted for smoke. Some communities participate in programs such as the International Fire Chiefs Association's Ready, Set, Go! program that help them prepare for and implement evacuation plans during wildfires. Remember to consider pets and livestock when planning

for evacuation. See Chapter 5 and the Wildfire Guide fact sheets Protect Your Pets from Wildfire Smoke and Protect Your Large Animals and Livestock from Wildfire Smoke.

When 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 emergency management officials 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 section 3.13).

It is important to consider smoke concentrations when allowing those evacuated for fire safety reasons to return to their homes. For example, poor visibility due to smoke may make driving to affected homes hazardous. Medical capability (from available transport to urgent care and hospital capacity) to address smoke-induced medical situations should be assessed if smoke concentrations are predicted to be high. Additionally, the smoke from smoldering natural and human-made materials poses ongoing hazards that should be considered.

Note that considerations for returning home after an evacuation, including hazards related to ash cleanup and smoke remediation, are addressed in Chapter 5.

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4. Communicating Air Quality Conditions During Smoke Events

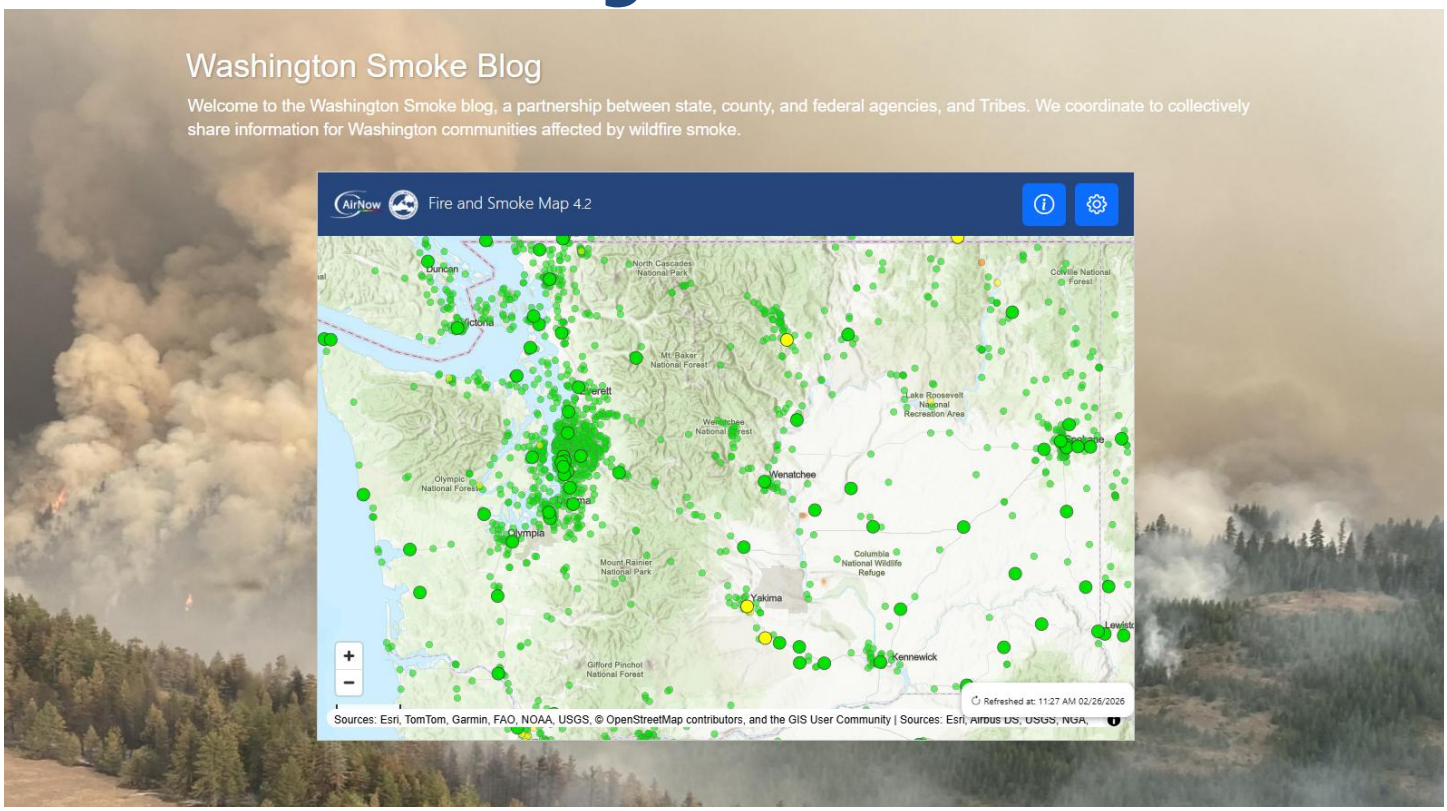

Figure 4.1 Washington State Smoke Blog. *Authored by Federal, State, Regional & County Government Staff (wasmoke.blogspot.com, 2026).*

An important goal of air quality monitoring during a wildland fire (i.e., wildfire or prescribed fire) smoke event is to relay information to the public in a timely manner so people can make decisions about how to protect their health. The unplanned nature of wildfire events means communities should be aware of air quality communication tools before a wildfire. Prescribed fire events are carefully planned and managed, which presents a unique opportunity to inform the public in advance. There are many tools available that provide information about air quality conditions and exposure reduction behaviors. This section discusses the different air quality communication resources and their uses during smoke events.

4.1 Air Quality Index

The U.S. Air Quality Index, or AQI, is a nationally uniform index promulgated by the EPA for reporting and forecasting daily air quality nationwide. It reports information about the most common ambient air pollutants, including those most relevant to wildfire smoke: particulate matter ($PM_{2.5}$ or PM_{10}) and ozone. The AQI for each pollutant draws on the scientific information that supports the health-based National Ambient Air Quality Standard (NAAQS) for that pollutant. The index converts ambient air pollution concentrations (in units of micrograms per cubic meter, $\mu g/m^3$ or parts per billion, ppb) to a number on a scale from 0-301+. The AQI scale is divided into six categories that correspond to different levels of health concern, using the health-based descriptors: Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, and Hazardous. For ease of use, the six categories are color-coded and provide statements about local air quality, which groups of people from healthy to sensitive (or at-risk) may be affected, and steps people can take to reduce their exposure to air pollution.

Table 4.1 U.S. Air Quality Index. *AQI values, categories and colors*

U.S. Air Quality Index		
AQI Value	**AQI Category**	**AQI Color**
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151-200	Unhealthy	Red
201-300	Very Unhealthy	Purple
301+	Hazardous	Maroon

AQI values correspond to the level of the short-term (e.g., daily for PM) NAAQS for a given pollutant. An AQI value of 100 represents a clear demarcation between satisfactory and unhealthy air quality. When AQI values for a pollutant are above 100, air quality is considered unhealthy for certain sensitive (or at-risk) groups of people, then for everyone as AQI values exceed 150. During smoke events, the AQI provides actionable activity and exposure reduction recommendations for at-risk groups and the general public to reduce smoke exposure. There are additional air quality indices provided by other organizations that may be based on different time averages, pollutants and thresholds.

4.1A Current Air Quality (AQI NowCast)

AirNow (discussed more in the following section) provides near real-time air quality information, using the NowCast method, that people can easily use to inform behavior, reduce risk, and protect their health. The AQI for $PM_{2.5}$ and PM_{10} is calculated as a daily (midnight to midnight) 24-hour average. However, to provide hourly air quality conditions, AirNow uses a method called the NowCast which estimates the 24-hour AQI updated for each hour. These hourly estimates are then reported as current air quality. The NowCast method is responsive to rapidly changing air quality, which is frequently observed during wildfires. It calculates a weighted average of the past 12 hours, with greater emphasis on the most recent data when air quality fluctuates. When conditions are stable, the NowCast uses a longer averaging time, approaching 12 hours. The NowCast approach helps ensure that AQI

information on AirNow closely matches what people experience outdoors on a short-term basis. (Figure 4.2).

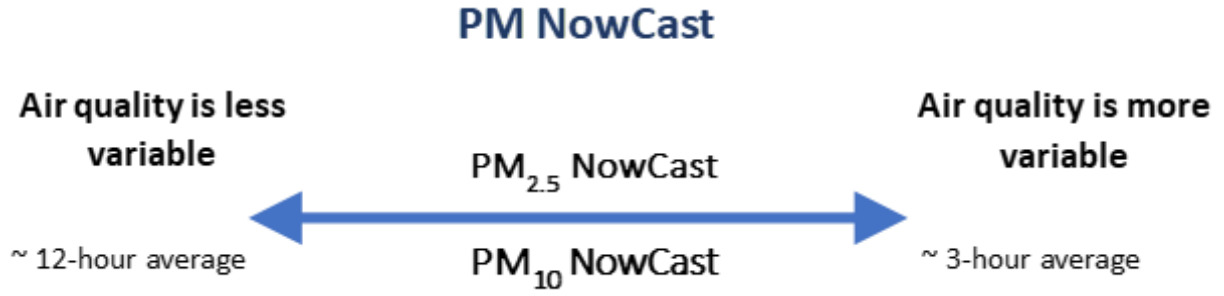

Figure 4.2 PM NowCast algorithm**.** *When air quality is stable, the NowCast algorithm approaches a 12-hour average. When air quality is changing more rapidly, the most recent hours are weighted more (approaching a 3-hour average).*

NOTE: If during a wildfire smoke event, only PM_{10} measurements are available, it can be assumed that the increase in PM_{10} concentrations can primarily be attributed to increases in fine particles ($PM_{2.5}$). This assumption is based on scientific evidence showing that during combustion-related activities, such as wildfires, particles in the $PM_{2.5}$ size range are the primary particles emitted.

4.2 AirNow

The AirNow website is a multiagency website run by EPA that reports air quality using the AQI.

4.2A Fire and Smoke Map

The Fire and Smoke Map (or FASM, https://fire.airnow.gov/) is designed to compile essential information and should be the primary resource for air quality information during smoke events. This interactive map was jointly created by the U.S. Forest Service and EPA. On this map, the public can access information about current wildfire activity and air quality conditions across the country (Figure 4.3). The FASM provides information on levels of fine particle pollution ($PM_{2.5}$) by bringing together information from permanent air quality monitors that report to AirNow, temporary monitors deployed by agencies for smoke events, and air sensors that have demonstrated good comparability with the permanent regulatory monitoring network after quality assurance and bias correction. The map also displays information on fire locations, direct links to current wildfire information (provided by INCIWEB and CalFIRE wildfire information sources), satellite observed smoke plumes, and Smoke Outlooks produced by Air Resource Advisors (ARAs; as discussed in the Interagency Wildland Fire Air Quality Response Program and Air Resource Advisors, see Chapter 1). The air quality data are shown in the color of their current AQI value. Clicking on a monitor or sensor on the map will bring up a new display giving more information, including name and type of measurement device, the $PM_{2.5}$ NowCast AQI

number and category, Smoke Outlooks (if available), cautionary statements, air quality trends, and recent observations. This display can be expanded to find more detailed information. One of the strengths of the FASM is that it provides near real-time, quality-controlled, consistent, and understandable outdoor air quality information. FASM simplifies the filtering task by removing bad sensor data and indoor monitors, which some other platforms may not.

Although the primary purpose of the map is to provide information on smoke and its primary pollutant ($PM_{2.5}$), the map also provides some information about PM_{10} and ozone (O_3), if these pollutants have AQI values greater than $PM_{2.5}$. Currently, these additional pollutants are measured by permanent monitors, as reported on AirNow.

There may be state, local, and Tribal sources of air quality information, including apps, that can help you better understand what is happening in your area. See Appendix B for more information about some of these sources and how they can be used.

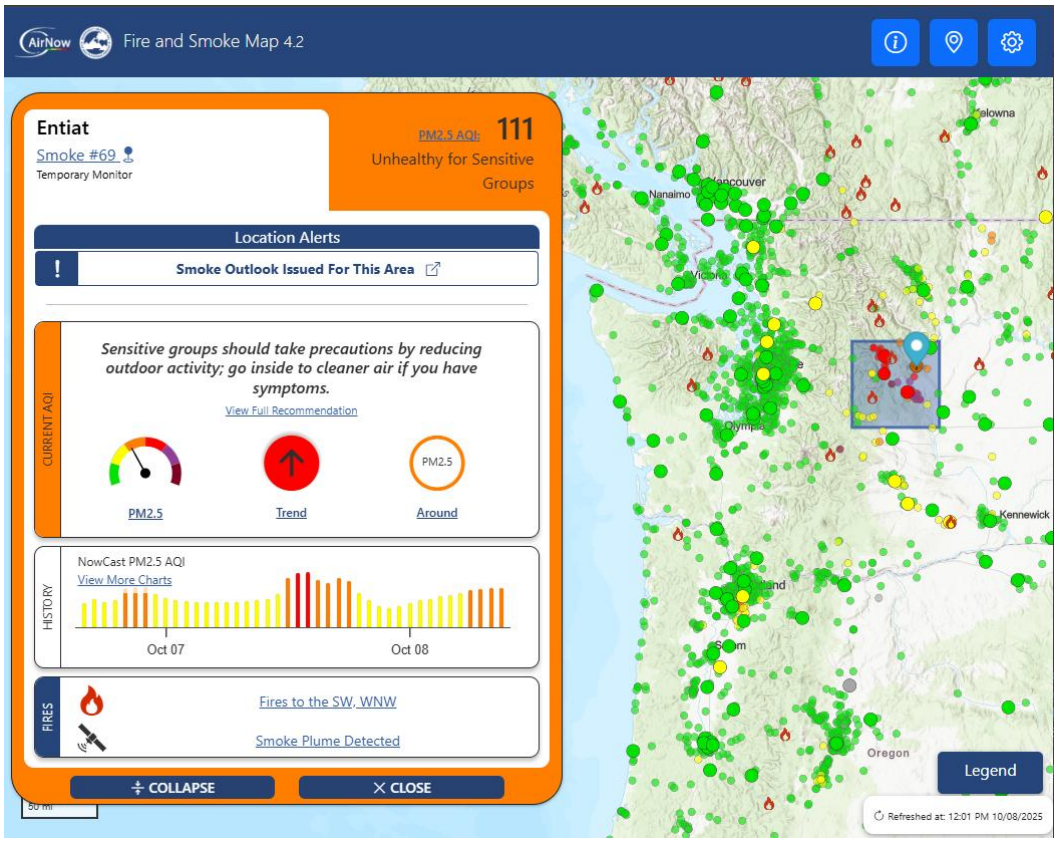

Figure 4.3 Fire and Smoke Map. *Sample of Fire and Smoke Map version 4.2 (October 2025) with expanded air quality pop-up information. The shaded box indicates a Smoke Outlook has been issued for the outlined area. The color-coded circles show the current AQI category based on the data from a permanent monitor (largest circle), temporary monitor (medium circle) or sensor (smallest circle). The expanded air quality pop-up shows the past and trending (forecasted) air quality information.*

4.2B AirNow Program

The AirNow program accepts, stores, and displays data provided by federal, state, local, and Tribal air quality agencies. Agencies submit continuous PM data to AirNow from more than 1,200 $PM_{2.5}$ monitors and 500 PM_{10} monitors, plus temporary monitors, on an hourly basis. Agencies also submit continuous ozone data to AirNow from more than 1,400 monitors. This data is publicly accessible via an interactive map on airnow.gov and through email notifications, widgets, and smart-phone apps (Figure 4.4). Media outlets and web developers can also access the data through AirNow's Application Program Interface (airnowapi.org). For air quality professionals, Appendix B provides additional details on AirNow-Tech, a specialized platform used for data analysis and management. This includes tools such as the Navigator, which assist in evaluating wildland fire-related air quality impacts.

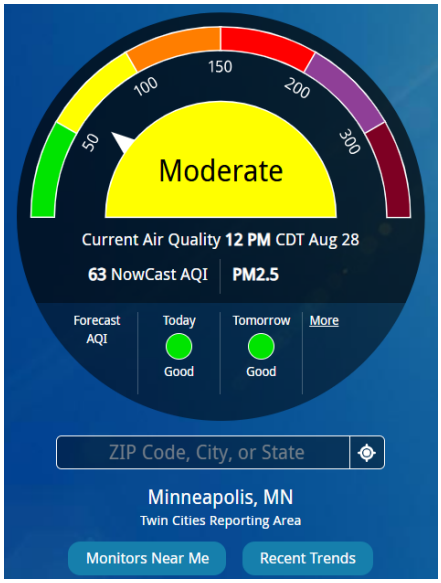

Figure 4.4 AirNow Dial. *AirNow.gov has an AQI Dial that shows the current and forecasted air quality for an entered area (airnow.gov).*

4.2C EnviroFlash

Offered in many areas around the country, EnviroFlash is a system that sends the daily air quality forecast by email to anyone who signs up. Many air agencies also use it to send an email alert during an event such as a fire, including suggested safety measures to take when air quality is unhealthy. Information about EnviroFlash is available at http://www.enviroflash.info.

4.2D Air Quality Flag Program

The Air Quality Flag Program (https://www.airnow.gov/air-quality-flag-program/) is a simple way to visually alert schools and other organizations to the local air quality forecast. Each day, the participating organization raises a flag that corresponds to how clean or polluted the air is. The color of the flag corresponds to the forecasted AQI category for each day. Seeing the flag alerts people about the potential for unhealthy air quality so that they know whether they should check current air quality that day and make any adjustments to reduce their exposure to air pollution.

4.3 Air Resource Advisor Outlooks - Interagency Wildland Fire Air Quality Response Program

When ARAs are deployed by the Interagency Wildland Fire Air Quality Response Program (or IWFAQRP, see discussion of program in Chapter 1) to a large fire, one of their tasks is to develop localized, sub-

daily forecasts that are useful to the public in the area. The primary way that ARA-developed smoke forecasts are communicated to the public are through Smoke Outlooks (Figure 4.5) which can be accessed through the Fire and Smoke Map as well as at https://outlooks.airfire.org/outlook. Smoke Outlooks describe how wildfire smoke concentrations, based on the AQI, vary in specific locations throughout a 24-hour period. The intent is to provide the public with a smoke forecast so that they can plan their days accordingly by avoiding the worst periods and taking advantage of when smoke levels are better. Both the "one-pager" and online versions of the Smoke Outlooks are also provided in Spanish.

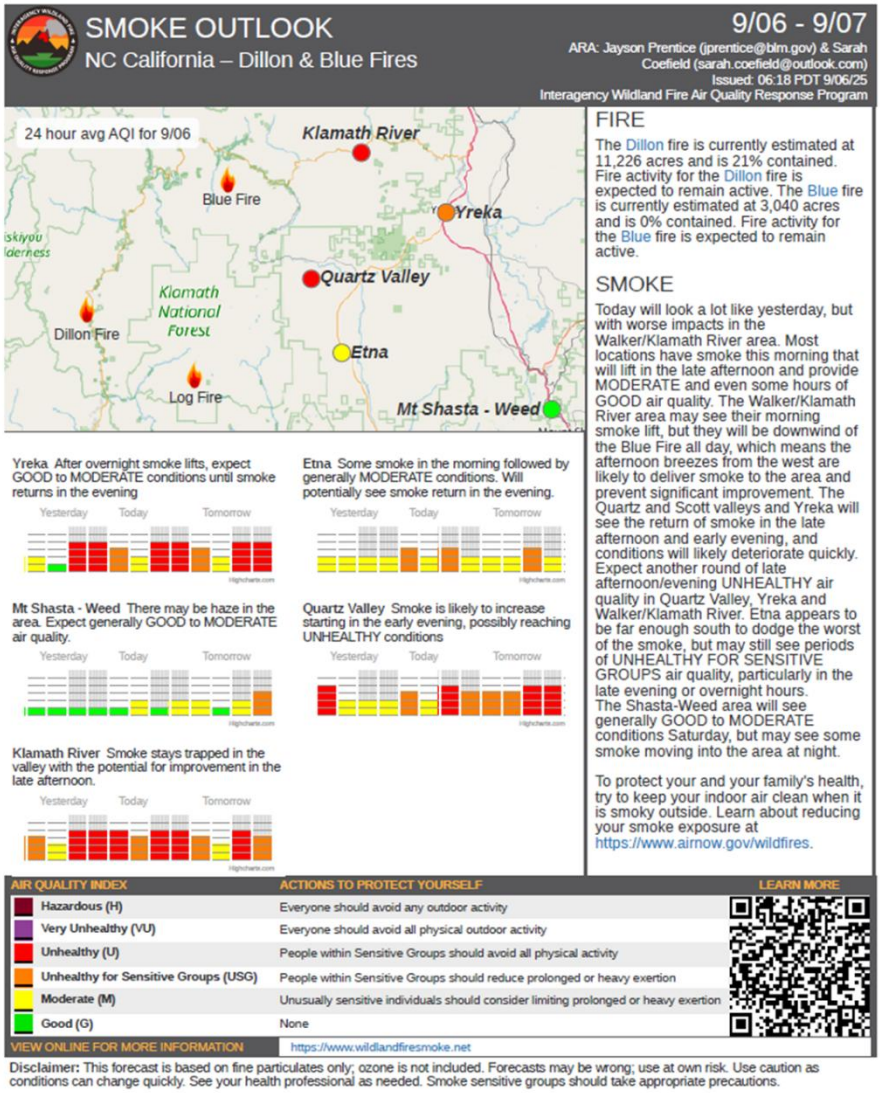

Figure 4.5 Northern California - Dillon and Blue Fires Smoke Outlook. *Example of a "1-pager" smoke outlook produced by an Air Resource Advisor assigned to Dillon and Blue Fires. These Smoke Outlooks are posted in communities near wildfires by the Incident Management Teams. Current Smoke Outlooks are available at https://outlooks.airfire.org/outlook. (Interagency Wildland Fire Air Quality Response Program, 2025)*

ARAs use a national USFS cache of deployable smoke monitors (typically E-SAMPLERS and E-BAMS with real-time telemetry capability) measuring $PM_{2.5}$ and CO, in addition to emerging monitoring technology such as multipollutant sensors and mobile monitors, such as the vehicle add-on mobile monitoring system (VAMMS) developed by EPA. ARAs deploy these instruments during wildland fire incidents to provide ground information to communities closest to the fire. ARA deployments and contact information are available at https://wildlandfiresmoke.net. A collection of IWFAQRP-related tools developed by the U.S. Forest Service Pacific Northwest Research Station's AirFire Team are shown in Appendix B and are available at https://tools.airfire.org.

4.4 Monitoring and Modeling Air Quality

4.4A $PM_{2.5}$ Monitoring Network

EPA and state, local, and Tribal air monitoring programs work together to maintain a robust national network of $PM_{2.5}$ samplers and monitors (Figure 4.6). This network supports multiple monitoring objectives (Appendix D to Part 58, Title 40, section 1.1) including timely public reports and forecasts of air pollution data, input for compliance and review of PM National Ambient Air Quality Standards (NAAQS), and data for air pollution research studies.

Figure 4.6 Air Data Air Quality Monitors Map. *Map of active $PM_{2.5}$ monitoring network as of September 24, 2025 (EPA, https://www.epa.gov/outdoor-air-quality-data/interactive-map-air-quality-monitors).*

There are three main components of the $PM_{2.5}$ monitoring program for ambient (outdoor) air: Federal Reference Methods (FRMs), $PM_{2.5}$ continuous mass monitors, and Chemical Speciation Network (CSN) samplers. The FRMs are primarily used for comparison to the NAAQS but also serve other important purposes such as developing trends and evaluating the performance of $PM_{2.5}$ continuous mass monitors. $PM_{2.5}$ continuous mass monitors are automated methods primarily used to support forecasting and reporting of the AQI but are also used for comparison to the NAAQS when approved as Federal Equivalent Methods (FEMs). FRMs and FEMs are the monitors identified as "permanent" in the Fire and Smoke Map. The CSN and related Interagency Monitoring of Protected Visual Environments (IMPROVE) network are used to provide chemical composition of $PM_{2.5}$, with data available weeks to months after post-sampling laboratory analysis.

For most urban locations, $PM_{2.5}$ monitors (FEMs and FRMs) are sited at the neighborhood scale, where typical ambient fine particle concentrations are reasonably homogeneous throughout an entire urban sub-region. For rural locations, each State is required to maintain background and transport monitoring sites with flexibilities to use non-reference or equivalent methods, such as IMPROVE or continuous $PM_{2.5}$ monitors, to meet this requirement. Background sites are intended to quantify regionally

representative $PM_{2.5}$ located away from populated areas and other significant emission sources. Transport sites are intended to measure fine particulate contributions from upwind source areas that move into populated areas. Each of these site types are typically located in rural areas at the regional scale representing hundreds of kilometers when they are away from cities and local emission sources. Although limited in scope to just two required sites per state outside of urban areas, these sites are a critical component of evaluating large smoke events since they provide additional $PM_{2.5}$ data spatial coverage. Details on $PM_{2.5}$ monitoring requirements can be found in 40 CFR part 58 Appendix D.

4.4B Air Sensors

Air sensors are widely used by the IWFAQRP, air agencies, communities, and individuals for supplemental air monitoring providing observational measurements in more locations. They are often capable of reporting measurements at high temporal resolution (e.g., every minute). While sensors are not permanent monitors, the observations can be incredibly helpful during wildfire smoke events when smoke conditions and $PM_{2.5}$ concentrations can change rapidly in both time and space.
It's important to note that not all air sensors perform similarly. For instance, most $PM_{2.5}$ air sensors on the market today do well at capturing the trends in air quality but may not produce accurate concentration estimates. Sensors for other pollutants (e.g., PM_{10}, CO, VOCs) may not be as robust due to technological limitations, interferences from other pollutants, or difficulty in interpreting the information they present.

Because most $PM_{2.5}$ air sensors can capture trends, communities can compare measurements from sensors of the same type to identify where or when air quality conditions are better or worse. Sensors of the same type can also be used to compare conditions outside and inside of homes (see Chapter 3 for more information about monitoring $PM_{2.5}$ in indoor air). However, some $PM_{2.5}$ sensors can be impacted by temperature and humidity which can make comparison challenging. Caution should be taken to minimize the temperature and humidity differences or consider how the sensor responds to changing environmental conditions or sources of humidity (e.g., humidifiers, showers). Users can interpret the trend information they observe to decide where to spend time or when to exercise, open windows, or run portable air cleaners.

Comparing data from sensors and permanent monitors can be tricky because sensor data is not always accurate. The quality of sensor data can be evaluated by co-locating sensors with permanent or temporary reference monitors or, in other words, operating them side-by-side at the same time and place. Then, sensor and reference monitor data is compared to better understand the relationship and to develop the sensor data cleaning (quality assurance steps) and bias correction methodologies that are needed to increase comparability. It is important to understand that the relationship between sensor and reference monitor data may vary as pollutant concentrations increase. Also, a correction equation developed in one place may not be transferable to another because pollutant sources,

pollutant concentrations, and meteorological conditions (temperature and relative humidity) may be different and impactful.

With robustly developed and tested data cleaning (quality assurance steps) and bias correction methodologies that have been validated through high concentration smoke conditions, sensor data can be adjusted to be more accurate and more comparable to data from other monitors. This allows communities to combine several sources of air quality information to get a more consistent picture of local conditions. In fact, these are the steps that allow sensor data to be displayed and interpreted alongside the permanent and temporary monitors on tools like the AirNow Fire and Smoke Map.
Air sensors are also being used for mobile monitoring either on mobile platforms (e.g., cars, bikes) or as personal wearable devices. There are additional concerns and cautions when collecting and interpreting this information including sampling efficiencies, wind effects, and artifacts from clothing. Without careful scientific controls, data collected through these methods should be considered exploratory and more uncertain.

4.4C Satellite Observations

Earth-observing satellites provide a vast array of important information about fires and their impact on air quality. A key advantage of satellite observations is spatial coverage, which typically provides hemispheric to global views. The spatial coverage, however, often comes at a tradeoff between either spatial-resolution or temporal frequency. Satellite data products range from relatively simple images of the earth to highly technical "retrievals" of fire properties or air quality. The suite of satellite data comes from a constellation of satellite instruments observing electromagnetic radiation in the ultraviolet, visible, infrared and microwave windows, each with strengths and weaknesses, that together provide invaluable earth observations.

Satellite data is extremely valuable for spatial coverage that complements surface-based monitors, sensors and models (see Figures 1.5 and 1.6 in Chapter 1). The spatial coverage of the satellite comes from its unique vantage point from space, but that also creates limitations. For example, to get complete spatial coverage from space, satellite instruments measure at kilometer scales rather than street level-scales. Similarly, the view from space makes it difficult to distinguish when particulate matter is near the surface or in a plume high above the earth's surface. As a result, satellite data is often interpreted with additional data. For example, smoke polygons are shown with monitors and sensor data for interpretation or included in "Data Fusion" models (see 4.4D).

4.4D Air Quality Models and Data Fusion

Modeling tools, including chemical transport models, statistical models, and data fusion products, estimate air quality in places between existing monitoring locations or at some point in the future.

Chemical transport and statistical models use information such as meteorology and fire conditions to calculate and predict the location and concentration of pollutants downwind of a fire. This information can be extremely valuable to communities that do not have nearby measurements. These models can also be used to predict or forecast what might happen in the future and are one of the only tools available to help communities prepare their response in advance. The USFS BlueSky modeling framework (discussed further in Appendix B) links independent models for fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion to calculate pollution emissions, plume trajectories and profiles, and downwind smoke concentrations. There are additional wildfire chemical transport and smoke dispersion models available from NOAA, NASA, and the Navy. Due to the complexity of modeling wildfires, an ensemble prediction, i.e., the average of all available predictions, is more robust than individual model predictions.

Data fusion products blend near-current observational data (e.g., permanent monitors, sensors, satellite observations) with chemical transport models to estimate air quality conditions at a specific time and place. The ground-based observational data helps to adjust the models to conditions on the ground which could increase the accuracy of near real-time air quality estimates at locations where monitoring data does not exist. Various data fusion products may use different subsets of inputs or give their inputs different importance or uncertainty, leading to differences in the product output. A good example of data fusion is EPA's AirFuse product (Figure 4.7) available in AirNow-Tech that integrates NOAA's forecast and near real-time AirNow measurements and sensor data. AirFuse is being piloted on AirNowTech.org for potential public release.

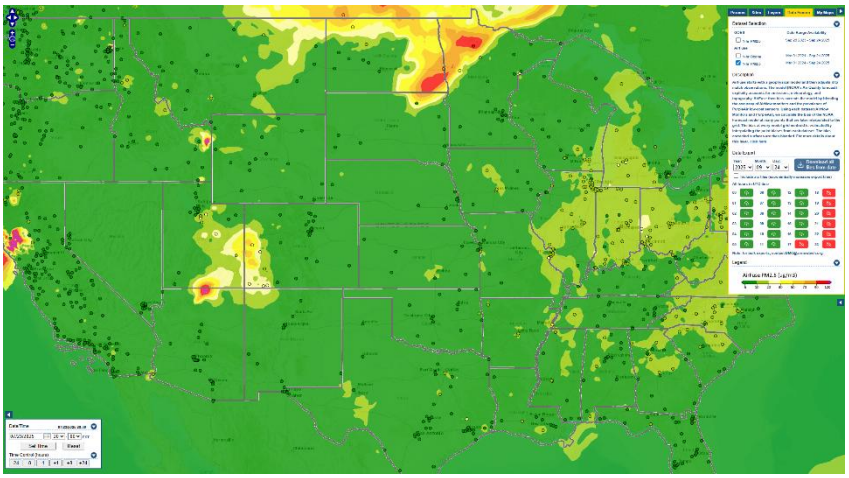

Figure 4.7 AirFuse data fusion hourly $PM_{2.5}$ product from AirNowTech.org on July 23, 2025 showing impacts from the France Canyon Fire on the Arizona/Utah border and Canadian wildfires. *Both areas had few monitor observations, but AirFuse estimates fill in the gaps (EPA, https://www.airnowtech.org/).*

Just like weather forecasts, air quality models and data fusion products can be uncertain and can change over time as new information is collected. Models and data fusion products can help to determine the general location and timing of smoke. However, some features, such as complex terrain, changes in the wind, and nighttime inversion layers are extremely complex and difficult to capture in a model. Further, these models rely on simplistic assumptions to forecast fire behavior that do not account for changing weather and fire management activities. A model's accuracy depends on the

resolution and accuracy of the meteorological and emissions inputs. A data fusion product's accuracy can depend on the spatial and temporal resolution of the model it uses and the set of observations it incorporates. Different models and data fusion products could lead to different predictions of the severity and spatial extent of fire impacts on local air quality. Because of this complexity, it is best to include trained experts to help interpret this information.

4.5 Using Visual Range to Assess Smoke Levels in the Interior Western United States

Many communities do not have access to continuous PM monitoring and may need other ways to evaluate local air quality. Visual range (i.e., how far away objects can be seen), like other instantaneous monitoring approaches, can inform and help the public respond to smoky conditions. This is true even in areas that have continuous monitors, because smoke concentrations can vary widely within a couple of miles and can change rapidly.

4.5A Basic Approach

Table 4.2 Visual Range Guide. *When there is no access to current air quality information, communities may need to use what they can see (visual range). This table notes the distance you can see during a smoke episode and the associated protective actions that can be taken.*

Visual Range Guide for Smoke Exposure and Recommended Actions.		
Distance	**Healthy Adults**	**Older Adults, Pregnant Women, Children and People with Lung or Heart Disease**
> 10 miles	- Watch for changing conditions. - Make outdoor activities shorter and less intense based on personal sensitivity[1].	
5-10 miles	Minimize outdoor activity by making it shorter and less intense.	Minimize or avoid outdoor activity. Consider going indoors to cleaner air, especially if you have symptoms.
< 5 miles	Minimize or avoid outdoor activity. Consider going indoors to cleaner air.	Stay indoors in cleaner air or go to a location with better air quality.
[1] Sensitivity to smoke can vary greatly from person to person and individuals can become more sensitive to smoke after extended periods of exposure. Individuals should pay attention to the advice of a medical professional or local health officials and adjust activity accordingly to their particular tolerance or sensitivity.		

To determine visual range, one must:

- Use this method only during daylight hours, avoiding sunrise and sunset.
- Use this method only if relative humidity is less than 65%.
- Focus on the darkest object, such as something black.
- Determine the limit of visual range by looking for targets at known distances (miles). The visible range is the point at which even high-contrast objects (e.g., a dark forested mountain viewed against the sky at noon) totally disappear.
- Use Table 4.2 to identify actions to take to reduce exposure, after determining visual range in miles.

Often, it is difficult to assess "the point at which even high-contrast objects (e.g., a dark forested mountain viewed against the sky at noon) totally disappear." Instead, it may be more useful to use known landmarks at a given distance away to assess possible visual ranges. For example, target A is 2 miles away and visible, but target B, which is 4 miles away, is not visible. Therefore, the visual range is somewhere between 2 miles and 4 miles. Use Table 4.2 to identify the range of actions to reduce smoke exposure.

4.5B Western United States

An important caveat is that the above visual range categories only apply in dry air conditions typically found in the interior west and inland of coastal areas. The combination of water and particulate matter in the atmosphere dramatically reduces visibility; therefore, this method of estimation should not be used when relative humidity is greater than 65%.

4.5C Eastern United States and Higher Humidity Locations

This approach cannot be used in humid areas (above 65%), which are more common in the Eastern United States. When there is an absence of local air quality data, individuals should rely on other sensory cues (e.g., smell of smoke) in estimating smoke conditions (e.g., mild, moderate, heavy) and the kinds of protective actions that might be necessary to address personal response to the smoke.

4.5D Other Considerations

This method of estimating a visual range also contains much uncertainty (as discussed in Malm and Schichtel, 2013), further strengthening the need to use personal judgment when assessing smoke conditions. Smoke concentrations vary substantially from minute to minute. By comparison, continuous monitoring devices average their measurements over 1, 3, or even 24 hours, so what is seen at a particular moment may not be representative of the average reported at a nearby monitor. More uncertainty stems from sighting on non-black bodies (e.g., green forested landmarks, snow-covered peaks), difficulty at judging when an object is just barely visible, variations in the atmosphere and

thickness of the smoke across the line of sight, and assuming the atmosphere remains constant after using an instantaneous "look" to assess conditions. A common issue with this method arises when the concentration along the visual path is inconsistent. For instance, if there is minimal smoke at the surface but a dense layer of smoke higher up, and the reference point is above the smoke layer, the viewer ends up looking through the smoke. In such situations, this method becomes invalid. This method is also not effective in early morning or twilight hours when the sun is low on the horizon.
No matter how far one can see, it is always prudent to take measures such as those presented in Chapter 3 of this guide to protect oneself if smoke exposure is a concern.

4.6 Understanding Conflicting Air Quality Information

Individuals may receive air quality information from a variety of sources including television, online news, websites, apps, phone notifications, newspapers, and more. Although it can be helpful to have this information at your fingertips, especially during an emergency, it can be incredibly confusing and frustrating to receive conflicting information.
Conflicts often arise because there are differences in the underlying data sources, methods used, time frame represented, temporal or spatial variations, data refresh rate or lag, presentation of the information, or terminology used. For more information about specific sources of information see Appendix B.

- **Underlying data** refers to the subset of measurements (e.g., permanent monitors, sensors, satellite observations) or other data inputs (e.g., meteorology, models) used in developing the information presented. Each data input has its own data accuracy, uncertainty, and limitations. For instance, satellite observations can show the large-scale movement of a smoke plume and could be used to estimate PM concentrations, but this data may be more uncertain than other measurements because the satellite cannot tell if the smoke is at ground-level or suspended higher in the atmosphere. Additionally, satellites cannot see smoke impacts through cloudy skies or at night.
- **Methods** can include measurements, interpolation between measurements, chemical transport models, statistical models, or a combination of models and measurements in data fusion products. There can be differences between similar methods due to the algorithms used. For instance, not all chemical transport models include the same chemical processes. Various data fusion products may use different subsets of inputs or give their inputs different importance or uncertainty, leading to differences in the product output.
- **Time frame** refers to the period of time the data is meant to reflect. For instance, data may reflect past, current, or future conditions. Most often, measurements reflect near-current conditions describing the recent past or present. EPA's AQI (24-hour average) or NowCast AQI (approximately 3-12 hour averages dependent on variability) are averages of past conditions. Air quality indices provided by other organizations may be based on different time averages (and

maybe different pollutants and thresholds). Forecasts, often based on models, describe the probable future. Just like weather forecasts, there can be differences between what is expected to occur and what actually occurs.

- **Temporal variations** in concentration result from rapid changes in weather, meteorology, and fire/smoke conditions. Rapid concentration changes may be difficult to measure and air quality reports may appear inaccurate due to data reporting delays, data averaging, or due to the way data is presented. For instance, many sensors can report data at high time resolution (e.g., every minute) while most permanent monitors report data less frequently (e.g., every hour). Therefore, sensors may reflect changes more quickly and with more variation than may be observed in the hourly averaged permanent monitor data that is updated at the end of an hour.
- **Spatial variations** over short distances may result from proximity to the pollution source, terrain and elevation, and buildings, trees, and other vegetation. This may be especially true near fires where smoke plumes can rapidly change with changing fire conditions and weather. Data from tools like sensors, which respond rapidly to changing conditions, may accurately reflect these variations. Other tools may try to predict the location of a plume and errors in that estimate may make predictions of spatial variation inaccurate.
- **Data refresh or lag** can contribute to information being out of date and reflecting past conditions by the time it reaches the user. Air quality conditions can change rapidly but it can take time for an air quality measurement or estimate to be made and reported. It can take time, especially for some satellite observations, for a measurement to be transmitted and processed into useable data. If a measurement is made but not updated on a public facing website for several minutes or even several hours, it may no longer reflect current conditions.
- **Presentation** of air quality information can vary based on goals and audience. For instance, to quickly convey information to public audiences, conditions may be communicated with colors (e.g., AQI), include action messages, and will focus on the primary pollutant of interest. However, organizations may use different colors to convey similar information which may cause confusion. Information meant for more technical audiences could provide additional information including concentration data for several pollutants at high time resolution. It is possible that all presentations reflect similar information, but confusion arises when direct comparison is difficult.
- **Terminology**, or the words used to convey air quality information, can cause confusion. For instance, many apps, organizations, and countries have an AQI-like index with similar colors, but they may have different thresholds and may use color gradients instead of discrete colors. Terms like "air quality alert" often don't have a universal meaning. Terms are often defined by the organization who made them, and they can be consulted for definitions and details.

When evaluating conflicting information, there are a number of questions that can be asked to try to deduce what might be causing the conflict. Such questions include:

- What is the source of the data being presented?
- Is the information presented reflective of past, current, or predicted conditions?
- What pollutants/methods/data sources were used?

- What uncertainties are associated with these methods or outputs?
- Is the information truly a conflict or just a different presentation of the information?

Learning how to consider and weigh the information presented can be challenging and can take practice. We recommend following these three rules:

- **Lean on expertise.** Your primary source of information should be air quality professionals. Air Resource Advisors (ARAs) are technical specialists that have been trained and have access to tools to help with developing their air quality forecasts. Local air monitoring agencies have decades of experience in local air quality measurement and forecasting along with localized knowledge of sources, geography, and meteorological patterns that may influence local air quality trends. Special tools like the AirNow Fire and Smoke Map capitalize on technical expertise to provide a consistent picture of air quality backed by science and measurements.
- **Weigh measurements and observations.** Even the best forecasts can be wrong from time to time. Ground measurements provide a better picture of what is happening in near-real time. Temporal and spatial variations may mean that nearby measurements may not reflect the actual conditions where you are. Smelling smoke and decreased visual range observations often indicate smoke in the vicinity and a need to act before measurement data is available. Hazy skies may not necessarily mean dangerous conditions on the ground as smoke may be entrained and trapped aloft so consider multiple measurements, observations, and indicators when determining how to respond.
- **Be cautious.** When uncertain, consider taking the most health protective actions.

5. Recommendations for Public Health Actions

This chapter provides specific guidance to public health officials on actions to protect and advise the public during a wildfire smoke event, preparations to make before fires occur, and recommendations for cleaning up ash after a fire. Because there are many factors to consider during a wildfire smoke event, these recommendations should be adapted for each specific situation.

5.1 Prepare for Smoke Events

Preparation is key to an effective response to wildfire smoke events. Wildfires can start and spread rapidly, and a smoke event may impact a community in a matter of hours. It is critical that public health officials have communication plans and response frameworks in place to prepare for, respond to, and recover from a smoke event. These plans should include building strong partnerships with air quality agencies, land management agencies, healthcare providers, community groups and other partners before a crisis begins. Communities should be prepared and empowered to provide their residents with evidence-based, locally relevant information during smoke events and recommended actions to reduce public health impacts from smoke. A range of preparedness activities may be appropriate, depending on the forecasted wildfire risk, the frequency and severity of smoke impacts, the nature of the fire event (wildfire or prescribed fire), underlying risk factors of local populations, and other attributes of the community. A smoke ready community will assess these risks in advance, plan for appropriate responses, and take action during a smoke event. Resources to support communities and the public in becoming smoke ready can be found at epa.gov/wildfires.

Recommended organizing steps for public health officials before a smoke event

Before wildfire smoke arrives, public health officials should consider taking some or all the following steps, especially if they are in an area at higher risk of smoke events:

1. Assess fire and smoke risks and identify at-risk populations.
    a) Review the wildfire risk level in monthly outlooks on the National Interagency Fire Center (NIFC) website and, especially if fire risk is high, communicate risk to the public (see Assess Fire and Smoke Risk section below).
    b) Identify community members most at-risk for health effects from smoke, including children, older adults, people with heart and lung disease, pregnant women (see Chapter 2), and groups that experience greater exposures, such as outdoor workers and outdoor activity participants. Identify locations where at-risk groups may be concentrated or gathered, such as schools or nursing homes, and locations where people may experience greater exposure, such as outdoor venues. (See Chapter 1)

2) Identify and form partnerships with community leaders and stakeholders such as air quality agencies, local health care providers, the media, and others. Use existing networks when possible. (See section 5.3 and Figure 5.1 below.)
    a) In addition to forming local partnerships, when feasible, connect, communicate, and plan with neighboring communities and create partnerships to share resources and information.
    b) Maintain partnerships and keep key partner contact information updated over time.
3) Prepare a communication plan (see section 5.4 below and information about communicating air quality in Chapter 4).
    a) Include a plan for quick dissemination of information to the public. Make sure it includes strategies to reach members of at-risk populations.
    b) Develop a messaging template that can be completed and distributed quickly during an event, as well as preparedness messaging that can be used throughout the year and when smoke risk increases.
    c) Develop messages about mental health and available mental health services, since the stress of coping with smoke can cause mental health symptoms (Humphreys et al., 2022, Eisenman & Galway, 2022).
    d) Inform the public about steps to prepare for wildfire smoke – use the Prepare for Smoke fact sheet.
4) Facilitate education and outreach to increase awareness and preparation for smoke events in your community.
    a) Consider holding community demonstrations and workshops about ways to reduce smoke exposure in homes and public/commercial buildings (see Chapter 3).
    b) Participate in community wildfire preparedness planning meetings to ensure smoke preparedness is included.
    c) Consider working with schools and community groups to provide education about smoke health effects and ways to reduce exposure.
5) Consider how to implement actions in your community to reduce smoke exposure (see below and Table 5.2 for examples). Assess which resources people in your community are most likely to need and would be willing and able to use to reduce their exposures.
    a) Assess ventilation and filtration systems (see Chapter 3) in places where at-risk populations gather (e.g., schools, preschools, daycares, senior centers, and nursing homes) and investigate approaches to improving indoor air quality (IAQ) in those buildings, if necessary. Provide guidance for improving indoor air quality to building operators (see Chapter 3).
    b) Consider approaches to supplying indoor air quality sensors to places where at-risk populations gather so they can understand how smoke is impacting their spaces and make changes as needed (see Chapter 3).
    c) Have a supply of NIOSH Approved® particulate respirators, like N95® respirators, to disseminate to the public.
    d) Consider approaches to supplying portable air cleaners (PACs), do-it-yourself (DIY) air cleaners (see Chapter 3), and/or air conditioners to places where at-risk populations gather or to help individuals shelter in place.

e) Identify locations that could serve as cleaner and cooler air spaces or shelters (see Chapter 3). In general, a cleaner air space is a publicly accessible building, such as a shopping mall, library or community center, that provides filtered air and cooling during regular operating hours. A cleaner air shelter is a designated location for sheltering individuals for overnight and longer-term relief. Cleaner air shelters require more resources and may not be appropriate for every community.

f) If you or other groups in your community set up cleaner air spaces or shelters, consider possible barriers for people using them (i.e., unwillingness to leave behind possessions, inability to bring pets, distrust in authorities, etc.) and how to overcome those barriers, accommodate concerns, or seek alternate means of reducing exposure. This may include providing equipment (e.g., PACs, air conditioners, etc.) that will help individuals shelter in place.

6) Work with air quality agencies to assess local air quality monitoring networks and identify gaps in the network's coverage (especially in rural areas); assess sensor networks; and identify temporary air monitoring options and potential locations to fill in gaps (See Chapter 4).

After smoke events, the effectiveness of the response should be assessed to identify areas for improvement. A discussion with partners and preparation of a "lessons learned" plan or after-action report will help the partnership continue to grow and improve. More information on tools and resources for being smoke ready can be found at https://www.epa.gov/wildfires/smoke-ready-communities.

5.2 Assess Wildfire and Smoke Risk

The National Interagency Fire Center (NIFC) develops the National Significant Wildland Fire Potential Outlooks (https://www.predictiveservices. nifc.gov/outlooks/outlooks) that give an idea of the predicted severity of fire risk in the coming months. These assessments indicate which areas of the country are more likely to see significant fire activity. They are designed to inform decision makers for proactive wildland fire management and can also be used to gauge likelihood of smoke events. Current month, next month, and seasonal outlooks are available. However, long-range predictions are uncertain; even if the NIFC predicts normal or below normal fire activity in your region, fires can still occur. You may also be downwind of an area that is expected to have heightened fire activity and may experience smoke without being in a fire risk area or near the fire source. Local knowledge and data from past smoke events can also be used to understand the likelihood of smoke impacts in the current year.

5.3 Build Strong Partnerships

Relationships among health departments, air quality agencies, land management agencies, community groups and other partners should be in place before smoke is in the air. To reduce potential public confusion, partner agencies responding to a wildfire smoke episode need to begin working together

right away to inform the public of smoke and health risks using consistent messages. A pre-existing partnership enables a rapid response to a smoke episode and allows everyone to quickly access and share vital information. Furthermore, established relationships across these agencies are beneficial for risk communication during prescribed fire events. Prescribed fire events offer a continued and regular opportunity to establish these essential relationships that will also be needed during wildfire events. All agencies working on fire and smoke response should coordinate closely during incidents to ensure consistent communication and to leverage resources for developing and delivering information to the public. This can be achieved through steps such as cross-linking websites and clearly directing public and media inquiries to the appropriate agency and subject matter experts. For example, some agencies may have the best experts for media interviews while another may have easy access to language translation services. Many states have daily or periodic wildfire smoke coordination calls that can provide opportunities to establish this coordination, including with Interagency Wildland Fire Air Quality Response Program Air Resource Advisors (ARAs) assigned to large wildfires (for more on ARAs, see section 5.3B below and Chapter 1). ARAs assigned to fires in adjacent states should be added to these coordination calls when smoke from those fires is impacting or has the potential to impact your location. Building a team that capitalizes on agency and individual strengths while breaking down boundaries is the most effective way to quickly serve the public during a smoke event.

5.3A Coordinate with Prescribed Fire Officials

Compared to wildfires, prescribed fire presents a unique opportunity to prepare individuals for smoke, especially residents at increased risk of experiencing health effects in response to smoke exposure (Sacks et al. 2023). (See Chapter 2 for more information about health effects from smoke exposure.) Prescribed fires are planned events conducted by both land managers and private landowners. Land managers operate under smoke management plans that directly consider potential smoke impacts on surrounding communities. Prescribed fires conducted by private landowners may be guided through smoke management programs managed by state agencies to limit smoke impacts. As a result, prescribed fires are typically scheduled when conditions are best for the smoke to quickly disperse (U.S. EPA, 2021). For more information on prescribed fires, see Chapter 1.

Just like with wildfires, regular coordination between public health officials, air quality agencies and prescribed fire officials can help inform and prepare communities for smoke from prescribed fires. Often, interactions between prescribed fire land managers and public health agencies may be minimal, which can result in limited communication and public awareness of when prescribed fires will occur and what actions can be taken to reduce smoke exposure. Some coordination is starting to address this communication gap. For example, prescribed fire information from the NIFC is included on the AirNow Fire and Smoke Map, though be aware many prescribed fires across the country are not entered in NIFC. Local, state or Tribal smoke management program websites are the best cumulative sources for prescribed fire activity information. Federal land managers use their public information channels, unit

websites, and radio announcements to provide information about fire activity. If prescribed fires occur in your area, prescribed fire officials should be included in your coordination and communication plans.

5.3B Establish a Wildfire Smoke Team

Responding to the needs of the public in case of a serious or prolonged wildfire smoke event will be far more effective if relevant state, local, Tribal, and federal agencies and organizations are engaged and working together as a team. While some states have ad hoc wildfire smoke response teams that already form during wildfire smoke response efforts, other states or areas may need to find and engage with partners. Some states, Tribes, and counties have prepared formal emergency smoke response plans that outline local points of contact, responsibilities of state and local agencies and other cooperators, and instructions for acquiring additional needed resources such as air monitors or NIOSH Approved® N95® respirators. In some states, when wildfire smoke impacts are serious or prolonged, these agencies, ARAs assigned to the wildfires, and other local cooperators hold daily, weekly, or as-needed conference calls to share information and coordinate air quality messaging and public outreach efforts. Public health agencies are essential members of these teams as they have valuable community engagement networks and public health systems. Key partners in a public response effort may include:

- **Local and state public health agencies** – State and local health agencies are experts at communicating health risks and protective actions in simple language the public can understand and are well-linked to organizations, such as schools, assisted living facilities, hospitals, and clinics, that serve at-risk groups. Public health agencies also often have language translation expertise so important health messages can reach non-English speakers.
- **Local and state air agencies** – State and local air agencies are experts at accessing and summarizing local air monitoring data and can often forecast conditions that will affect smoke movement and accumulation. State air agencies often coordinate with the National Weather Service to have air pollution advisories issued when needed.
- **Local, state and federal land management agencies** – Typically, land management agencies have the lead in wildfire suppression and response. They will have information on fire suppression planning and, depending on the fire size and complexity, may provide expected smoke outlooks.
- **Tribes** – Many Tribal communities run their own air quality programs and public health agencies and have local information about supplemental air monitors and effective outreach to their communities. EPA regional offices assist with Tribal air programs. Federal agencies can provide information to Tribes if a fire is on, or smoke is affecting Tribal lands. Federal agencies have a trust responsibility to Tribes and have established contacts to help deliver information on wildfire smoke and health.
- **Incident management teams –** Incident management teams assigned to large wildfires are experts at connecting with local communities and frequently host public meetings about the fire(s). These meetings can be an excellent forum for ARAs and public health agencies to deliver messages about smoke and public health actions. Public meetings or cooperator meetings held

by incident management teams (see Chapter 1) are also places to discuss how smoke and public health concerns and messaging can be coordinated. Depending on a fire's potential duration and the smoke's impact on public health, this can include opportunities to discuss the need for an ARA if one is not present.

- **Interagency Wildland Fire Air Quality Response Program (IWFAQRP)** - Any IWFAQRP ARAs working in the area are likely to be assigned to a wildfire incident management team. ARAs are valuable sources of information for the public health community and can help spread public health messages through ongoing communications, including daily Smoke Outlooks for the area. ARA efforts are improved through consultation and coordination with state and local public health entities. To see if an ARA is working in an area, check their website: www.wildlandfiresmoke.net. Additionally, the IWFAQRP may have portable air quality monitors and sensors that can be deployed to smoky areas that are not well represented by existing state monitoring networks. The IWFAQRP website (www.wildlandfiresmoke.net) provides tools to summarize monitoring data from state air monitoring networks and from temporary monitors deployed to wildfires. For more information about the IWFAQRP, see Chapter 1.
- **Local emergency management and response officials** – Emergency management and response officials are typically the key coordinating officials in incidents. They may be able to assist with sharing the most recent incident information with the community and may be part of the Incident Management Team.
- **EPA regional offices** – Regional EPA offices have expertise in air quality and health information and can coordinate across states and regions to reach a broad audience and share information. They also work with state, local, Tribal, and federal partners to collaborate on regional issues.
- **School systems** – School administrators are frequently eager for advice on how to best protect their students from smoke. Schools can be valuable channels for reaching not only children but entire families, particularly in regions where children may be more literate in English than older family members. In addition, schools can sometimes serve as cleaner air spaces and temporary shelters for evacuees.
- **Faith-based and community-based organizations** – Faith-based and community-based organizations can help disseminate awareness messages, may have ties to at-risk populations, and can potentially serve as partners for cleaner air centers and sheltering evacuated residents.
- **Local business and real estate associations** – Business and real estate organizations may be interested partners and able to disseminate information to local businesses and community members.
- **Local health professionals -** Physicians and other health care providers, including veterinarians, often have a high degree of credibility with the public. Having strong working relationships with local health providers who are knowledgeable about the health effects of smoke can be very useful in getting health and exposure reduction information out to the public through the media.
- **News media** – The lay public relies heavily on local news media for health and safety information during adverse environmental events. Building a relationship with broadcast (radio

and television) news organizations, particularly weather forecasters, can facilitate the timely sharing of accurate smoke information.

Figure 5.1 Community stakeholders to engage in smoke ready planning. *Building partnerships with community stakeholders is key to preparation for and response to wildfire smoke events (Fire Adapted Communities, https://fireadaptednetwork.org/resource/smoke-ready-resources/).*

5.3C Educate Health Professionals

Wildfire smoke presents significant public health challenges, affecting communities and health care systems alike. Health care professionals (e.g., physicians, nurses, asthma educators, veterinarians) can play an important role in raising awareness of the public health risks of wildfire smoke and ways to reduce exposure. However, because health impacts of wildfire smoke are not typically covered in medical curriculum, many health care professionals are unfamiliar with the health effects of smoke and ways to limit smoke exposure. In addition, mental health professionals may not be aware that the stress of coping with smoke can cause mental health symptoms. It is therefore important to educate and build relationships with health care professionals before a smoke event. This enables consistent messaging about wildland fire smoke and health risks. As trusted messengers, health care providers can reduce potential public confusion and reinforce the importance of preventative measures to reduce smoke exposure.

The following resources provide professional development and educational training across health professions on the impact of wildfire smoke on healthcare:

- EPA offers an online web course for physicians, nurses and health educators: Wildfire Smoke and Your Patients' Health.
- The Western States Pediatric Environmental Health Specialty Unit (PEHSU) offers free continuing education for health professionals: A Story of Health: Sofia's Story (Wildfire Health Impacts).
- The Western States PEHSU also offers helpful infographics about smoke and children's health.
- The American Veterinary Medical Association has a website about Wildfire Smoke and Animals.
- The Climate Psychiatry Alliance provides a wildfire smoke toolkit with advice for limiting smoke's impacts on mental health: Wildfire Smoke Toolkit

5.4 Recommended Public Actions and Protective Measures

When air quality deteriorates, public health officials should provide the public with health advisories and recommendations for reducing exposure. The following section outline considerations for at-risk groups and scenarios, including prolonged smoke events and combined smoke and heat events. The tables at the end of the section draw from these topics and provide recommended health advisories and public health actions based on air quality index (AQI) values (for more on the AQI, see Chapter 4). For detailed information about communication planning, see Section 5.6, Public Communication.

5.4A Smoke and Heat

Wildfire smoke and heat events are becoming more frequent and are lasting longer. Heat and smoke can both be dangerous. Recent scientific evidence suggests that exposure to both smoke and heat at the same time may be much worse for health than exposure to either of them alone. Public health officials should consider providing shelter from heat when developing plans for providing shelter from smoke. In addition, when a heat event is forecast, the public should be advised on actions to take, especially members for those without air conditioning. Some of these actions differ from those recommended during a smoke event. See the fact sheet Protect Yourself from Smoke and Heat.

5.4B Protecting Children

Children are especially at-risk from exposure to smoke because their lungs are still growing, they spend more time being active outdoors, and a greater proportion of children have asthma, relative to adults (see Chapter 2). Because of this, all children should be considered part of a sensitive group for purposes of evaluating the AQI. Minimizing smoke exposure is key to protecting children during smoke events. The EPA fact sheet Air Quality Activity Guidance for Schools: Particulate Matter provides guidance about when and how schools can modify outdoor and indoor physical activity based on the AQI. If a smoke event is forecasted, local officials should prepare to implement the guidance, including assessing the availability of indoor spaces with good indoor air quality for children to be active (see Chapter 3). Newer

buildings with a central air handling system with filters designed to remove fine particles may be more protective than older buildings or those that rely on open windows for cooling.

As air quality worsens or is projected to worsen, additional protective measures may become necessary. These measures could include allowing children to spend time in indoor school spaces that can provide clean air, stay home, or even consider closing schools entirely. Several location- and event-specific factors should be considered in making these decisions. Some of these factors include the forecasted duration of the smoke event, the relative indoor air quality of the homes and schools in the area, and the ability to transport children safely. In some locations, indoor air quality in schools may be better than in local housing and schools may provide more air conditioning, making school closure less beneficial from a public health perspective. Also, being at school may mean children's activity levels can be better monitored. The capacity to maintain acceptable indoor air quality in schools should be assessed before the start of the fire season to assist in planning and decision-making.
Be sure to consider measures to minimize smoke exposure in specific settings outside of school, including childcare/daycare facilities, before- and after-school programs, athletic events, summer sports programs, and camps.

5.4C Protecting Outdoor Workers

Many workers have jobs that require them to work outdoors, which puts them at greater risk of being exposed to wildfire smoke. In addition to workers who are directly involved with wildland fire management and suppression, there are workers engaged in supporting fire response (e.g., utility workers) or cleanup efforts (e.g., demolition crews), and many others who continue to do their usual non-fire related outdoor jobs (e.g., agricultural workers, landscapers, park personnel) during an incident. Due to their greater likelihood of exposure, outdoor workers may be at-risk for adverse health effects from smoke or ash exposure, particularly if they are in an additional at-risk group (described in Chapter 2). However, some recommendations made to the public on how to reduce their exposure to wildfire smoke hazards may not be relevant or practical for outdoor workers who must continue to work. In addition, their employers may not have anticipated these hazards and may be ill-equipped to implement adequate protections. To better address these issues, employers and employees should prepare for and implement procedures to protect outdoor workers.

Although healthy adult workers may not be significantly affected by short-term exposure to smoke while working outdoors, the risk of adverse health effects is dependent on air pollution concentrations, type(s) of material burned, duration of exposure, level of physical activity, age of the worker, individual susceptibility (e.g., preexisting heart or lung disease), as well as other factors (see Chapter 2). While health responses to exposures will vary (see Chapter 2), wildfire smoke exposure has been shown to result in substantial work loss and cost due to sickness among workers (Meng et al, 2024).

At present, only California, Oregon, and Washington have occupational standards specifically for wildfire smoke; however, employers everywhere can take steps to protect workers from the negative health impacts of unhealthy air quality. Some of the same recommendations listed in this document for the general public can apply when working outdoors in a smoky environment.

Options for limiting workers' smoke exposure include

- postponing or shortening time spent outdoors,
- performing only high priority tasks,
- relocating workers or rescheduling work tasks to smoke-free or less smoky areas or times of the day,
- reducing outdoor workers' physical activity and exertion levels,
- encouraging and ensuring workers take frequent breaks inside cleaner air spaces such as enclosed structures or vehicles with recirculating air,
- and encouraging and using PACs (see Chapter 3) in indoor working areas to reduce overall smoke exposure.

In some cases, NIOSH Approved® particulate respirators, like an N95® respirator, should be considered to protect workers who cannot implement the exposure reduction recommendations listed above when performing outdoor work (see Chapter 3 for more information about respirators). Workers involved in post-fire cleanup activities should be protected from exposure to ash and all other hazards (see Section 5.7, Returning After the Fire) by using a range of control methods (e.g., dust suppression, personal protective equipment).

If an employer requires employees to use respiratory protection to limit smoke exposure in an occupational setting, they must do so as part of a comprehensive respiratory protection program as required under the Occupational Safety and Health Administration's (OSHA) Respiratory Protection standard (29 CFR 1910.134). When respirators are used on a voluntary basis in an occupational setting, employers should follow the OSHA requirements for the voluntary use of respirators. An OSHA-compliant respirator program names a qualified person responsible for administering the program and describes procedures for respirator selection, medical evaluation for safe respirator use, fit testing for tight-fitting respirators, training on topics such as how to use and maintain respirators and program evaluation.

Planning and preparing to implement these recommendations effectively in the workplace are critical. This is especially true in areas where exposure to wildfire fire smoke is common, and workers are required to perform their work outdoors, even when air quality is considered unhealthy, very unhealthy, or hazardous. Working together, employers and employees can take steps to reduce their exposure to wildland fire smoke.

5.4D Protecting other At-risk Groups

Protecting members of other at-risk groups, such as older adults, people with heart or lung disease, pregnant women, and people of lower socioeconomic status (SES) from smoke exposure, is also a high priority for public health officials. Maintaining good indoor air quality is especially important in locations where these groups may often spend time, such as senior centers, hospitals, doctors' offices, or residential facilities for older adults.

To protect some at-risk groups, such as people of lower SES who may live in homes without air conditioning or in locations where the use of air conditioning may not be common, identify publicly accessible buildings that can serve as both cleaner and cooler air spaces and provide respite from smoke and heat during their normal operations, or consider setting up cleaner air shelters (see Chapter 3). People of lower SES may experience social vulnerability due to socioeconomic and demographic factors (e.g., household composition and disability, minority status and language, housing and transportation) that affect the community resilience (Flanagan et al., 2011). In disasters such as wildfires, the socially vulnerable are more likely to be adversely affected and slower and less likely to recover.

In general, individuals in at-risk groups should be advised to avoid or limit outdoor physical activities once air quality is characterized as "Unhealthy for Sensitive Groups" (orange on the AQI), move physical activities indoors to cleaner air when air quality is categorized as "Unhealthy" (red on the AQI) and to remain indoors with windows closed if air quality is categorized as "Very Unhealthy" (purple on the AQI) (see Table 5.1). Families and individuals should consider taking steps to clean their indoor air and avoid adding particles to the air (see Chapter 3). Note that staying indoors with windows closed may be dangerous in hot weather. People who are at-risk of smoke-related health effects and are in homes that are too warm (for example, they do not have air conditioning and must open windows to cool down), should seek shelter from smoke elsewhere. See the fact sheet Protect Yourself from Smoke and Heat.

5.4E Protecting Pets and Livestock

Wildfire smoke also affects the health of pets and livestock. As with humans, short exposure to high levels of smoke may irritate animals' eyes and respiratory tracts. Animals with heart or lung disease and older, pregnant, and very young animals are especially at-risk and should be closely watched during periods of poor air quality. Check the AQI regularly to guide management strategies, inform health-protective behaviors, and to know when it is safe to turn out animals.

Figure 5.2 Wildfire smoke affects animals' health. *When possible, keep pets indoors in cleaner air. Photo credit: Sarah Coefield, U.S. EPA*

Strategies to reduce animals' exposure to smoke are like those for humans: reduce the time spent in smoky areas. If animals are indoors, take care to keep indoor air clean, provide plenty of water, and limit outdoor physical activities that will increase the amount of smoke breathed into their lungs. For large animals and livestock, limit physical activities that require effort. For example, do not run cattle through shoots or ride horses. Provide plenty of water and reduce dust exposure (e.g., wet dirt roadways, use misters in holding areas, minimize driving/tractor activity around animals). If pets or livestock are coughing, having difficulty breathing, or have other signs of ill health, the owner should contact a veterinarian. Continue to monitor animals after a smoke event for delayed health impacts. See the Protect Your Pets from Wildfire Smoke and Protect Your Large Animals and Livestock from Wildfire Smoke fact sheets.

Evidence in humans indicates that the effects of exposure to smoke and heat together are much worse than to smoke alone. This is also likely true for pets and livestock. Animals that are at greater risk from smoke, including younger and older animals and those with chronic medical conditions, are also more likely to be at-risk from heat. In addition to the protective behaviors discussed for smoke exposure, keep pets indoors in cleaner, cooler air and provide plenty of water. For large animals and livestock, provide plenty of water and shade.

Messaging to the community before fire season should advise owners of pets and livestock to have a plan for managing their animals during both smoke events and combined smoke and heat events. If a wildfire moves into the area, they should have an evacuation plan for their animals. Recommend that owners of large animals and livestock open gates and cut fences if they cannot evacuate their animals. Local officials should consider where pets and livestock could be housed if evacuation becomes necessary. For example, in some areas, local shelters will house pets in carriers, and it is not uncommon for temporary livestock shelters to be set up in local fairgrounds or parking lots. Animals that are older or have a medical condition that increases their sensitivity to smoke may require sheltering facilities that can provide cleaner, cooler air or adequate medical attention. Animal accommodations are frequently established in collaboration with local animal control, humane societies, or other animal rescue groups. For more information, check the American Veterinary Medical Association (AVMA) website.

5.4F Prolonged Smoke Events

The longer a smoke event continues, the more likely people will experience adverse health effects. Thus, exposure reduction measures recommended for short-term exposures to smoke become even more important to take with prolonged exposures. For smoke events that last more than a few days or recur throughout fire season, public health officials should consider all options for communicating the importance of reducing smoke exposure. Messages should include actions individuals can take to reduce smoke exposure and should highlight the benefits of creating cleaner air spaces in homes,

schools, and workplaces. Prolonged smoke events may require consideration of additional measures to protect the public, especially people in at-risk groups.

Public health officials should consider partnering with external businesses, agencies, and nonprofits to provide public spaces with cleaner air for daytime use. These cleaner air spaces could include senior centers, libraries, and shopping malls. Providing cleaner air spaces during the day can provide an alternative for people unable to reduce smoke levels in their homes, or who are unwilling or unable to evacuate to a designated cleaner air shelter or out of the area to reduce their smoke exposure.

Before advertising or advocating for cleaner air spaces, public health officials should confirm that the locations have adequate filtration, ventilation, and cooling/heating capacity to sufficiently condition indoor air based on the expected occupancy.

Cleaner air spaces should also have institutional controls to limit smoke infiltration, such as limited door and window use. For more information on improving air quality in non-residential buildings and identifying cleaner air shelters and spaces, see Chapter 3.

As smoke events continue, stress associated with increasing health concerns, loss of control over daily activities, reduction in physical activity, and isolation resulting from remaining at home indoors can cause mental health symptoms to arise. During a prolonged smoke event or repeated smoke events, consider partnering with businesses, agencies, or nonprofits to make cleaner air spaces available where people can socialize and/or exercise. Be aware of mental health issues in your jurisdiction and consider creating messages about mental health and available mental health services.

5.5 AQI, Cautionary Messages, and Recommended Actions to Protect Public Health

The following AQI-based tables can help guide public health officials' actions and recommendations to the public during smoke events. When interpreting the tables, keep in mind that the AQI is based on 24-hour average concentrations, the same as the National Ambient Air Quality Standards. The hourly AQI for $PM_{2.5}$ reported on AirNow and the Fire and Smoke Map is an hourly estimate of the 24-hour AQI based on the NowCast, which has been shown to track hourly $PM_{2.5}$ concentrations well (for more on the NowCast, see Chapter 4). Concurrent publication of both the AQI values and the ambient $PM_{2.5}$ concentrations (in $\mu g/m^3$) to describe air quality may lead to confusion among members of the public. To avoid confusion when issuing cautionary statements or implementing exposure reduction measures, it may be preferable to publish only the AQI values. For both tables, if only PM_{10} measurements are

available during smoky conditions, it can be assumed that the PM_{10} is composed primarily of fine particles ($PM_{2.5}$), and therefore the AQI and associated cautionary statements, advisories and exposure reduction recommendations for $PM_{2.5}$ may be used. It may occasionally happen that ozone is the pollutant with the higher AQI value, especially when smoke levels are low. If both ozone and $PM_{2.5}$ are above an AQI value of 100, follow the recommendations for $PM_{2.5}$, since they are more precautionary. If the AQI value is above 100 for ozone, but not for $PM_{2.5}$, consider following the recommendations for ozone. The Fire and Smoke Map and AirNow will indicate if the elevated AQI is due to ozone rather than $PM_{2.5}$.

Figure 5.3 Use the AQI to make recommendations about outdoor activities. *For example, this may include canceling, postponing, or moving sporting events to places with cleaner air. Photo Credit: Istock.com/iacona*

Table 5.1 provides a general list of health effects and cautionary statements about behavior changes for the public and at-risk groups that can be used in public advisories. The advisories are based on the particulate matter AQI, as well as on experience and evidence from previous smoke events. Public health officials should emphasize the importance of going indoors to cleaner air, and to cleaner and cooler air when it is both hot and smoky outdoors. If people are sensitive to smoke and cannot clean or cool their indoor air, they should consider spending time with friends or family who have air conditioning and air filtration options in use, at a publicly accessible cleaner air space, at community-operated cleaner air shelters, or if possible, leaving the area. For advice on how schools can protect children and staff, see the EPA fact sheet "Air Quality Activity Guidance for Schools: Particulate Matter."

Table 5.2 provides guidance to public health officials on measures to protect public health across AQI categories. This information is intended to help health officials, the media, and the general public make decisions about appropriate strategies to mitigate exposure to smoke. Public health officials may want to recommend some, or all, of the actions associated with these categories, based on an assessment of the local situation. Some factors that should also be considered include:

- **Predicted fluctuations in $PM_{2.5}$ levels.** If $PM_{2.5}$ peaks are predicted to occur relatively infrequently and be interspersed with longer periods of good air quality, people may be advised to schedule outdoor activities during periods of better air quality. If multiple daily $PM_{2.5}$ peaks are superimposed on elevated $PM_{2.5}$ levels, more sustained efforts to reduce exposure will be necessary. ARA Smoke Outlooks (see Chapter 4) and some state/Tribal/local air quality agency

smoke blogs provide information about how smoke concentrations are expected to vary throughout the day.

- **Predicted duration of high $PM_{2.5}$ levels**. The longer $PM_{2.5}$ levels are high, the more important it is to reduce exposure. If air quality is predicted to be in the "Unhealthy for Sensitive Groups" range or worse for multiple days to weeks, public health officials should follow recommendations from the "Prolonged exposures" section above and recommend individuals take additional precautions beyond those indicated by the 24-hour AQI or NowCast AQI.
- **Potential indirect effects.** Smoke can reduce visibility on the roads making driving hazardous. This may justify delaying or canceling events that would require travel to attend.

Table 5.1 Health effects and cautionary messages for at-risk populations for each AQI category

Health Effects: Smoke exposure can lead to health effects ranging from less severe (e.g., eye irritation, coughing, headaches) to more serious (e.g., exacerbation of heart and lung diseases, such as asthma and heart failure, premature mortality). As the AQI increases, more people are likely to experience health effects, first for people in sensitive groups (see Notes for Using This Table, below) and then for everyone as the smoke worsens.	
AQI Category (AQI Values)	**Cautionary Statements**
Good (0-50)	None
Moderate (51-100)	**Unusually sensitive people:** Consider making outdoor physical activities shorter and less intense. Go inside to cleaner air if you have symptoms such as coughing or shortness of breath.
Unhealthy for Sensitive Groups (101-150)	**Sensitive groups:** Make outdoor activities shorter and less intense. It is OK to be active outdoors but take more breaks. Go inside to cleaner air if you have symptoms such as coughing or shortness of breath. **People with lung disease:** Follow the plan for your disease (e.g., asthma action plan) and keep quick relief medicine handy. **People with heart disease:** Contact your health care provider if you experience symptoms such as palpitations, shortness of breath, or unusual fatigue, as these may indicate a serious problem.
Unhealthy (151-200)	**Sensitive groups:** Consider rescheduling or moving all physical activities inside to cleaner air. Go inside to cleaner air if you have symptoms. **People with lung disease:** Follow the plan for your disease (e.g., asthma action plan) and keep quick-relief medicine handy.

	People with heart disease: Contact your health care provider if you experience symptoms such as palpitations, shortness of breath, or unusual fatigue, as these may indicate a serious problem. **Everyone else:** Keep outdoor physical activities shorter and less intense. Go inside to cleaner air if you have symptoms.
Very Unhealthy (201-300)	**Sensitive groups:** Avoid all physical activity outdoors. Reschedule to a time when air quality is better or move activities indoors to cleaner air. **People with lung disease:** Follow the plan for your disease (e.g., asthma action plan) and keep quick-relief medicine handy. **People with heart disease:** Contact your health care provider if you experience symptoms such as palpitations, shortness of breath, or unusual fatigue, as these may indicate a serious problem. **Everyone else:** Limit outdoor physical activity. Go indoors to cleaner air if you have symptoms.
Hazardous (301+)	**Sensitive groups:** Stay indoors in cleaner air and keep activity levels light. **People with lung disease:** Follow the plan for your disease (e.g., asthma action plan) and keep quick-relief medicine handy. **People with heart disease:** Symptoms such as palpitations, shortness of breath, or unusual fatigue may indicate a serious problem. If you have any of these, contact your health care provider. **Everyone:** Avoid all physical activity outdoors. If indoor air quality is poor, keep activity levels light.
Notes for Using This Table: • Sensitive groups include people with heart or lung disease; older adults; children, including teenagers; and pregnant women. In addition, people from some ethnic and racial minority groups, people with lower incomes, and outdoor workers may experience higher smoke exposure that can worsen underlying health conditions. • More caution is warranted during prolonged smoke events. • When smoke is present, follow tips for keeping particle levels low indoors. See Chapter	

3 and Wildfire Guide fact sheets for advice on reducing indoor particle levels.

- If air conditioning is unavailable, staying indoors with the windows closed may be dangerous in hot weather. If you are hot, go someplace with air conditioning or check with your local government to find out if cleaner air and cooling centers are available in your community.

Table 5.2 Actions for public health officials to take and recommend to their communities

AQI Category (AQI Values)	Recommended Actions for Consideration
Good (0-50)	Before smoke season arrives, follow the recommendations in this chapter to help your community become smoke ready. Distribute the School Activity Guidelines (Air Quality Activity Guidance for Schools: Particulate Matter) to local schools and encourage them to prepare to implement the guidelines (for example, stock up on HVAC filters and perform any necessary HVAC maintenance). If a smoke event is forecasted, implement your communication plan.
Moderate (51-100)	Implement your communication plan. Advise the public about health effects, symptoms, and ways to reduce exposure. Consider implementation of recommendations from the School Activity Guidelines.
Unhealthy for Sensitive Groups (101-150)	If the smoke event is projected to be prolonged, contact previously vetted cleaner and cooler air spaces or shelters and notify the public when they are accessible. Consider implementation of the School Activity Guidelines.
Unhealthy (151-200)	Consider canceling outdoor events (e.g., concerts and competitive sports), based on public health and travel safety considerations. Consider ways to reduce exposures in both indoor and outdoor work environments. Implement the School Activity Guidelines.
Very Unhealthy (201-300)	Cancel outdoor events involving physical activity (e.g., competitive sports). Consider canceling outdoor events that do not involve much physical activity (e.g. outdoor markets). Consider air quality in indoor workplaces (see Chapter 3) and take measures to protect workers as needed. Consider curtailment of outdoor work activities unless workers have a fully implemented respiratory protection plan in place and

	clean air respite breaks. Implement the School Activity Guidelines. Taking indoor air quality in local schools into account, consider closing some or all schools or substituting online learning.
Hazardous (301+)	Cancel outdoor events (e.g., concerts and competitive sports). Consider air quality in indoor workplaces and take measures to protect workers as needed (see Chapter 3). Consider curtailment of outdoor work activities unless workers have a fully implemented respiratory protection plan in place and clean air respite breaks. Implement the School Activity Guidelines. Taking indoor air quality in local schools into account, consider closing some or all schools or substituting online learning.
Notes For Using This Table: • More caution is warranted during prolonged smoke events. • For additional school, daycare, and camp considerations, see Section 5.4B on Protecting Children, above.	

5.6 Public Communication

During a smoke event, messaging should focus on protective actions such as staying indoors, reducing outdoor activity levels, filtering indoor air, and using respiratory protection. Wildfire Guide fact sheets such as "Prepare for Smoke," "Reduce Your Smoke Exposure," and "Indoor Air Filtration," contain the information you will need to include in such an effort. Be sure to incorporate the protective messages in Table 5.2 into your outreach efforts. Plain language messages, such as "limit outdoor activities" or "stay indoors" will be most effective and can include links to the fact sheets or information like the locations and hours of local cleaner air spaces or shelters. See Box 1 and Figure 5.4 for examples of simple, plain language messaging.

Box 1: Example of Plain Language Short Recommendations

When smoke is in the air, take actions to protect your health.

1. Check your air quality and local conditions on the Fire and Smoke Map.
2. Reduce outdoor activity levels – Reduce Your Smoke Exposure
3. Keep indoor air as clean as possible – Indoor Air Filtration
4. Consider wearing a NIOSH Approved® N95® respirator if you need to be outside – Protect Your Lungs from Wildfire Smoke or Ash
5. People at greater risk of health effects, including people with asthma, COPD, or heart disease, pregnant women, children, and older adults should take these exposure reduction actions and monitor their symptoms. – At-Risk Groups of People
6. Pay attention to signs of stress – Coping with the Stress of Wildfire Smoke
7. Have a plan for your pets or large animals – Protect Your Pets from Wildfire Smoke and Protect Your Large Animals and Livestock from Wildfire Smoke

Figure 5.4 Example smoke ready social media messaging**.** *This social media graphic was developed by the Northwest Air Quality Communicators group as part of their annual Smoke Ready messaging campaign (https://www.orcaa.org/smoke-ready-week-day-1-stay-informed/).*

It is important to try to reach people by many channels – both to get the message through background noise and to reach as many people as possible. Do an inventory of all potentially useful communication channels in your area. Include social media sites, businesses that could disseminate your messages, and other entities who could be helpful and approach them outside of the crisis period. You may include posters, door hangers, fliers, news releases, social media posts, websites, blogs, radio and television

public service announcements (PSAs), and engaging with community events (e.g., at schools, childcare programs and programs that serve older adults). Note that smoke and messaging frequently cross state and international boundaries, so coordination needs to be developed beyond typical jurisdictions. Work with trusted local information sources to enhance public outreach before, during, and after a smoke event. Local weather forecasters can be particularly effective partners given their regularly scheduled television and radio reporting and generally high credibility with their audiences. Cultivate a relationship with them before and outside any crisis period and ensure they have contact information to use when there is a smoke event. Local healthcare providers, particularly those working with patients at higher risk of adverse health effects from smoke exposure, such as those with asthma and other respiratory conditions, are also an important intermediary to work with both before and during a smoke event. Veterinarians can help owners make plans for their animals.

During an event, you may have to address misinformation, particularly over social media. Develop a process for doing this in an objective, clear, and definitive manner. Having pre-approved "talking points" that answer common questions is one way to do this. In addition, directly address any rumors or misinformation whenever speaking to the media, and inform the public where to obtain accurate information from your agency.

When no smoke events are occurring or anticipated, share preparedness and smoke ready messages from reputable sources such as CDC, EPA, and local public health and emergency services. You can also create messages based on the Wildfire Guide fact sheets.

Create a template or logo with simple graphics that can be easily shared and used across multiple editing platforms or simply and clearly photocopied to unify your communication efforts. Use this same "look" across all your smoke communications so that, when the public sees it, they will recognize it and know your organization is the source of the information.

5.7 Returning After the Fire

> Note: This section presents general considerations for dealing with ash and chemicals. It is not intended to replace advice or assessments from professionals or agencies directly involved in cleanup activities.

Even after the worst of the fire and smoke is over, individuals who return after the fire should be aware of health and safety hazards. Public health officials should work closely with officials from affected counties to warn residents of health and safety concerns during cleanup and to provide information on best practices for homeowners returning after a fire. This may include creating a list of reputable cleanup or debris removal businesses.

Exposure to lingering smoke and ash can cause significant health effects in both healthy individuals and those in at-risk groups. People may experience symptoms including respiratory irritation, heat-related illness, and emotional stress after a fire. Physical stress from cleanup activities, exposure to toxic chemicals, damaged power lines, and equipment such as portable generators can cause injuries during cleanup.

Ash from burned structures in the wildland-urban interface (WUI) may contain traces of hazardous substances such as metals (including arsenic, lead, copper, nickel and chromium); asbestos from older buildings; caustic materials; and other chemicals (Plumlee et al. 2007, Villarruel et al. 2024). It is therefore advisable to be cautious and avoid exposure to the ash. In addition, the burned material itself may pose a hazard. For example, products that contain lithium-ion batteries, like electric vehicles, wheelchairs, power tools, game controllers, and other everyday items, can re-ignite, explode, or emit toxic gases if exposed to wildfire.

Before beginning cleanup work, it is important to ensure structures are safe to enter, assess the level of cleanup needed, and develop a plan for who will perform the cleanup and how. Professional assistance should be considered if there is structural damage or hazardous materials are present, the HVAC system is impacted, or the scale of cleanup is more than the affected individual can manage on their own. Additionally, smoke often accumulates at the highest level of a home or building. People with attics should consider working with a professional to assess potential impacts to insulation and other materials. FEMA's Homeowner's Guide to Risk Reduction and Remediation of Residential Smoke Damage provides guidance on remediating smoke damage in homes, including tips for selecting a contractor and documenting damage for insurance purposes. People returning to their homes for cleanup activities should consider the following:

- If the presence of asbestos, lead, carbon monoxide or other hazardous material is suspected, do not disturb the area. Dust masks or filtering facepiece respirators do not protect against asbestos or gases such as carbon monoxide.
- Avoid handling burned items that may contain hazardous chemicals, such as cleaning products, paint, and solvent containers.
- Do not touch fire-damaged products with lithium-ion batteries. They should be considered extremely dangerous, even if they look intact. If devices emit popping or hissing noises or are actively smoking or on fire, do not attempt to extinguish or smother the battery. Leave the area immediately, move upwind at least the length of a football field (330 feet) and call 911.
- Do not start, move, tow or charge a fire-damaged electric/hybrid vehicle or use or start a fire-damaged residential energy storage or house battery until it has been assessed and deemed safe by a hazardous material professional.

- Do not enter enclosed spaces with lithium-ion battery products; gases and vapors from damaged lithium-ion batteries can build up in enclosed spaces (such as a garage, shed, basement, or closet) and may produce an explosive environment.
- Avoid ash from wooden decks, fences, and retaining walls pressure treated with chromated copper arsenate (CCA) as it may contain lethal amounts of arsenic.
- Avoid stirring up or sifting through ash if possible; ash deposited on surfaces can become inhaled if it becomes airborne during cleanup. For example, avoid using leaf blowers or dry sweeping. Instead, mist hard surfaces with water before sweeping or mopping.
- Clean all carpets and soft goods such as couches, mattresses, pillows, pet beds and plush toys using a high-efficiency particulate air (HEPA) filtered vacuum, if available.
- Wash homegrown fruits and vegetables.
- Dispose of ash in the regular trash. If hazardous waste, including asbestos, is suspected to be in the ash, contact local hazardous waste authorities regarding appropriate disposal.

Children, pregnant women, older adults, and people with heart or lung diseases, such as asthma, should not participate in ash cleanup efforts. Individuals performing cleanup work should wear protective clothing and equipment, such as a well-fitting NIOSH Approved® N95 ® respirator, leather gloves, safety glasses or goggles, long pants, a long-sleeved shirt, and shoes with rugged soles.
Individuals temporarily relocating to a new residence during the cleanup of their home should be advised against transporting any ash-covered or smoke-exposed items in their vehicle or to their temporary residence, to reduce exposure. Affected individuals should wash their hands and change into clean clothing and shoes before entering their vehicles. If it is necessary to transport any items contaminated by ash, they should be placed into a plastic bag while wearing gloves and seal the bag completely before placing it in a vehicle.

Smoke and ash residue can impact air quality in affected structures. Depending on the severity of smoke intrusion into the building and the duration of exposure, some people may notice visible deposits of smoke and ash residue and/or a lingering odor when they return to their homes, schools, or workplaces. Removing smoke odor is difficult, but there are ways to diminish it, beginning with cleaning and thoroughly airing the structure (Laguerre and Gall, 2024, Li et al., 2023).

Every surface of the space exposed to smoke or ash may require cleaning, depending on the extent of the impact. The amount of damage can be assessed with a walk-through of the affected structure checking for visual evidence of smoke and ash residue (e.g., using a white cloth or wipe to check for deposits on surfaces) and smelling for smoke odor. People should be advised to consider seeking professional cleaning or discarding items that are difficult to clean. WUI fires that burn human-made materials can emit chemicals that can be detrimental to health. Chemicals in smoke can deposit on outdoor surfaces and infiltrate into homes. In these cases, consider recommending that household

materials such as carpets and upholstery be discarded, especially if there is direct evidence of hazardous contaminants depositing on indoor or outdoor spaces.

Cleaning includes wiping down the walls, floors, windows, baseboards, doors, frames, cabinets, furniture, and other surfaces. Cleaning using dry methods, wet methods or a combination of both may be appropriate, depending on the surface. Follow manufacturer's instructions when available. Dry methods, such as vacuuming and using sticky rollers or "soot" or "chem" sponges, generally work well for thick deposits of ash and porous materials. Dry sweeping and dusting are not recommended. When vacuuming, a HEPA vacuum is preferred, if available. If a HEPA vacuum is unavailable, features that make a vacuum more suitable for ash cleanup include true HEPA filters on the exhaust and a sealed system that ensures air passes through the filter. A typical household vacuum or a shop vacuum will send some of the collected dust or ash out into the air. If using these, consider wearing a respirator and using techniques to remove ash and pollutants from the air such as increased ventilation or indoor air filtration. Wet cleaning methods, such as damp wiping or mopping, often work well for light deposits and non-porous materials. A dilute solution of water and soap is usually sufficient for wet cleaning. Some people may choose to use additional cleaning products; however, note that some cleaners may also impact indoor air quality. Those who choose to use additional cleaning products should read the labels carefully and follow all instructions. Curtains, rugs, furniture covers, bedding, and anything that can be safely washed in a washing machine can be cleaned in this manner. Carpets will also require cleaning. This can be done professionally or by using a carpet cleaner.

Advise the public to discard food and medicine that has signs of soot or smoke discoloration or damage and remove spoiled food from the home to minimize odor problems that could mask smoke odors. Unopened cans or jars of food that were not subjected to severe heat can be wiped or washed with soap and water. In cases where ductwork has smoke residue and is a source of odors, consult with a local smoke remediation company or HVAC contractor to determine available cleaning options. See the EPA guide Should you Have the Air Ducts in Your Home Cleaned?.

If conditions permit, windows and doors can be opened, and fans can be placed in rooms to circulate the air. A PAC can be used to remove lingering fine particles (see Chapter 3 for information about selecting and using PACs).

Note that while mechanical air filters remove fine particles in the air, they do not remove the gaseous chemicals that cause odors associated with wildfire smoke. These chemicals must be removed by using a PAC with an activated charcoal filter or a filter composed of alumina coated with potassium permanganate. Most portable air cleaner filters for gaseous compounds become saturated quickly and lose effectiveness in smoky environments. They will need to be replaced frequently. PACs with more

robust odor removal are available but are frequently expensive. This is why thoroughly cleaning the home interior to remove sources of off-gassing volatile organic compounds (VOCs) is so important.

In general, avoid using products that add chemicals to the indoor environment to remove or neutralize smoke odors. The use of an ozone generator to remediate smoke odor is not recommended because ozone can create as many problems as it is intended to fix. Many of the chemicals that are broken up by ozone can produce byproducts that are also dangerous to health. Furthermore, ozone does not remove ash and other particles from the air and indoor surfaces. If an ozone generator is used to remove smoke odors, it should be used only by a remediation professional. The space where the ozone generator is used must be unoccupied during use and for a designated period after use to ensure that no one is exposed to ozone. Some companies claim to use "hydroxyl" generators or other oxidizing technologies such as photocatalytic oxidation (PCO) or chlorine dioxide for remediation. These technologies are highly reactive and can also create chemical byproducts. They should be used with the same caution as ozone generators.

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Appendix A

Available fact sheets as of 2026

Recognizing the need for credible information to disseminate to the public, authors and collaborators of this Guide have developed fact sheets on topics of high interest. To find them see the Wildfire Guide Fact Sheet page or click on a link below to go to a particular fact sheet.

- **Prepare for Smoke**
- **Reduce Your Smoke Exposure**
- **Wildfire Smoke and Health**
- **At-Risk Groups of People**
- **Children's Health and Wildfires: A Resource for Families**
- **Protect Your Lungs from Wildfire Smoke or Ash**
- **How to Create a Cleaner Air Room at Home**
- **Indoor Air Filtration**
- **Protect Yourself from Smoke and Heat**
- **Protect Yourself from Ash**
- **Using Air Quality Sensors for Smoke**
- **Coping with the Stress of Wildfire Smoke**
- **Protect Your Pets from Wildfire Smoke**
- **Protect Your Large Animals and Livestock from Wildfire Smoke**

Appendix B

Note: This Appendix was finalized in February 2026. For the latest information, please visit the U.S. Interagency Wildland Fire Air Quality Response Program's website at https://wildlandfiresmoke.net/wildfire-smoke-guide.

B.1 Introduction

When wildfires occur, smoke can impact a wide range of distances, depending on the amount of fire emissions, how high they are lofted into the atmosphere, and the particular meteorological conditions and transport winds.

When dealing with wildfire smoke, it is important to consider not only current air quality conditions, such as:

- Where is current air quality being impacted?
- What have the trends and patterns been over the past several days?

but also, to assess fire information:

- Where are the fires and how big are they?
- How much are they expected to grow?

as well as smoke transport downwind:

- Where are smoke plumes being observed?
- Where do smoke models say smoke will go over the next few days?
- Are there diurnal patterns for the smoke impacts?

There are a number of tools and systems available on the web to access information on all of these topics, but successfully utilizing this information requires an understanding of what these tools are showing as well as the limitations of each type of information source.

This Appendix gives general considerations when accessing and trying to understand the above questions. These considerations are particularly important as the information available may be incomplete and/or contradictory across different systems.

B.2 When Looking at Air Quality Conditions

B.2A Considerations

Considerations when looking at air quality conditions depend on whether the goal is to determine the current prevailing conditions or to extrapolate recent observed patterns into a prediction for the future, whether the data being used is remotely sensed (e.g. by satellites) or based on ground observations, and what kind of devices are being used to collect the data.

Satellite and data fusion products: Satellite based representations of air quality generally show total air column or tropospheric conditions rather than ground concentrations, or ground concentrations are extrapolated based on statistical relationships. Data fusion products incorporate both satellite and ground-based data to create smooth fields of air quality concentrations at the surface. Such products are inherently more accurate close to ground observation locations, in areas away from strong sources of smoke, and in areas with more open terrain.

Ground observations using monitors and sensors: Ground-based observations of air quality generally fall into 3 types: (1) established permanent monitoring sites, where siting, maintenance, and quality control are handled by established agencies and owners; (2) rapidly deployed temporary monitoring equipment put out by agencies such as the federal U.S. Interagency Wildland Fire Air Quality Response Program (see Chapter 1) and state agencies like the California Air Resources Board; and (3) lower cost air quality sensors that may either be owned and deployed by agencies and skilled community groups, but also may be owned and operated by private citizens with unknown training. Each source type has tradeoffs as listed in Table B1.

Table B1. Air quality monitoring — sensor types compared
A comparison of four monitoring approaches across accuracy, maintenance, coverage, time resolution, and reporting latency.

Permanent monitors	
Accuracy	Highest
Maintenance	Regular; agency-run QC
Coverage	Sparse — population centers only
Time resolution	Hourly average
Reporting lag	~30 min

Temporary monitors	
Accuracy	High
Maintenance	Procedures established; QC via aggregator
Coverage	Low — impacted / unmonitored communities
Time resolution	Hourly average
Reporting lag	1–2 hours

Agency or community sensors	
Accuracy	Generally good
Maintenance	Unknown; QC via aggregator
Coverage	Area-specific; many sensors per zone
Time resolution	Hourly or sub-hourly (e.g. 10-min)
Reporting lag	Minutes (wifi)

Privately operated sensors	
Accuracy	Variable
Maintenance	Highly variable; siting matters
Coverage	Many — denser in high-impact areas
Time resolution	Device-dependent
Reporting lag	Minutes (wifi)

Using air quality time series to extrapolate future patterns: Looking at patterns over time of observed air quality conditions can provide valuable insights into the dynamics affecting smoke concentrations in an area. For example, diurnal patterns showing the worst time of day and best time of day are often relatively stable over several days under a consistent weather pattern and fire growth. Trends showing increasing or decreasing impacts of smoke as well as increasing or decreasing areas of impact can also be useful. However, to utilize these patterns, additional knowledge is needed. To utilize diurnal trends, knowledge of whether the meteorological patterns are continuing to follow the past several days is needed; if there is a frontal passage moving through that will typically disrupt diurnal patterns. To utilize trends both an understanding of the stability of the meteorological patterns as well as an understanding of how fire growth has progressed and what fire growth is expected to happen moving forward is needed. Trends in air quality conditions are often directly related to trends in fire growth, as fire emissions are, to a substantial extent, directly related to fire growth.

B.2B Air Quality Tools and Resources

The following section details available monitoring tools, how to use them, and what to keep in mind. See https://wildlandfiresmoke.net/wildfire-smoke-guide for an updated and expanded list:

AirNow Fire and Smoke Map · Collected Air Quality and Fire Information

https://fire.airnow.gov/ | U.S. Federal Government (Environmental Protection Agency and Forest Service)

An official map aggregating air quality and fire information maintained by the EPA and U.S. Forest Service. The map contains air quality information from ground-based monitors and sensors including permanent monitors, temporary monitors, and agency, community, and privately owned air quality sensors. Primarily focuses on fine scale particulate matter ($PM_{2.5}$). Includes sensor data from PurpleAir, Clarity, SensOR and SensWA. Quality control applied including removal of indoor, stuck, or outlier devices. Hourly trends for specific monitors or sensors help to understand the diurnal smoke impact patterns. The displayed sensor values are calibrated to address the range of wildfire smoke impacts. Also provides access to collected fire incident and satellite fire detection information, satellite smoke plume extents, and fire incident issued Smoke Outlooks.

State and Local Air Quality Agency Maps · Air Quality Maps

https://www.airnow.gov/partners/state-and-local-partners/ | State and Local Governments

State and local air quality agencies often have maps that contain agency deployed sensors and may contain local data fusion layers. Names of agencies vary by state. A good starting point is the list of AirNow State and Local Partners listed above.

• CONSIDERATIONS

Sites maintained by these agencies range from extremely sophisticated (e.g. South Coast Air Quality Management District) to simple. Mobile applications have also been developed for this purpose (California Air Resources Board's Smoke Spotter) and state managed smoke blogs can also provide further information.

PurpleAir · Air Quality Sensors

purpleair.com | *Private Network*

PurpleAir sensors are the most prevalent air quality measurements in the United States, measuring fine particulate matter (PM2.5). Devices require external power and a Wi-Fi connection, and are deployed by both government agencies and private owners nationwide. Correlations and corrections have been developed by matching PurpleAir readings with co-located regulatory monitors, enabling the real-time data stream to be adjusted to be compatible with permanent monitoring networks.

• CONSIDERATIONS

The PurpleAir website offers multiple ways to view sensor data, not all of which apply the correction factors needed to align readings with permanent monitors. Several time averages are also available; short-term averages are generally not representative of concentrations that affect human health.

• NOTES

PurpleAir data is incorporated into the AirNow Fire and Smoke Map. The PurpleAir map will only match the AirNow Fire and Smoke Map if the correct combination of averaging time and correction equation is selected. PurpleAir also applies different filtering and quality-control detection than the AirNow Fire and Smoke Map.

Clarity · Air Quality Sensors

https://map.clarity.io | *Private Network*

Clarity air quality sensors are designed to operate in both urban and more rural settings, like agricultural areas. Clarity devices measure fine scale particulates ($PM_{2.5}$). Clarity sensors can use solar power and cellular data connections. Clarity is used by several agencies and groups across the U.S. Correlations and corrections have been developed by matching PurpleAir readings with collocated monitors in order to quality control and adjust the real-time PurpleAir data into a data stream compatible with permanent monitors.

• CONSIDERATIONS

In locations without power, Clarity sensors may reduce their measurement frequency to save power. Such reductions (potentially down to one measurement every few minutes) can impact the hourly average's representativeness. Clarity $PM_{2.5}$ data is generally available hourly.

• NOTES

Clarity sensor data is included in the AirNow Fire and Smoke Map.

B.3 When Accessing Fire Information

B.3A Considerations

Considerations when accessing fire information include how a recent fire of interest started, how the fire information is being gathered, what the inherent or system-specific delays on that information are likely to be, and what kinds of biases may be inherent to the specific types of information being gathered for display. Generally, fire information falls into 3 types, each with its own characteristics: (1) information from observations and reports by the incident command team (IMT) working the fire (see Chapter 1); (2) information from automated satellite systems that can detect fire hotspots; and (3) information on planned activities by the management team, such as a planned burnout of unburned fuels.

Progression of fire information sources: It's often difficult to obtain information about brand new or emerging wildfires and good information from ground reports may take a day or two (or longer) to become available. Until then, the best way to get ground observations about a new wildfire may come as news reports or social media posts as well as automated satellite based remote sensing. Once a wildfire grows to the point that local fire response agencies can no longer manage it, an Incident Management Team will be ordered which will then start feeding information into state and/or national incident response databases.

Source type and timing: Information from an IMT and planned activities are generally input by humans and therefore can have greater value due to the data sources' ability to integrate and assimilate information into a coherent narrative. However, the timing of such information usually lags more automated fire tracking from satellites. Reports from IMTs may be up to multiple posts daily to delayed by up to a few days. Reports from IMTs may also include adjusted fire perimeters from ground observations and from aircraft operations. Automated fire hotspot detection is generally available within 1-3 hours of the observation.

Fire growth: Satellite hotspots are indicative but not an accurate measure of the amount of fire growth of a fire. Issues with assessing fire growth from hotspots include the pixel size of the imagery of the satellite system which range from approx. 375m to several kilometers. Satellites typically cannot reliably record whether the fire has consumed all of part of a pixel creating uncertainty in their fire growth estimates. Additionally, the ability of a satellite to observe the fire can be compromised by heavy clouds and/or smoke which sometimes means that satellites will observe no growth (no hotspots detected) during particularly smoky fire growth days.

B.3B Sources Available on the Web

See https://wildlandfiresmoke.net/wildfire-smoke-guide for an updated and expanded list.

InciWeb · Official Incident Information

https://inciweb.wildfire.gov | *U.S. Federal Government*

Official source of public information regarding all federal response wildfire incidents nationally. Also contains a limited number of planned prescribed fires.

- **CONSIDERATIONS**

  Information is inputted by humans and is likely to be somewhat delayed (hours to days) and may contain (usually minor) typos/errors. Inciweb is a federal system and fires not on federal land or not requiring federal incident teams may not be represented (notably true for California, see CAL FIRE).

- **NOTES**

  Active Inciweb and CAL FIRE incidents are shown on the AirNow Fire and Smoke Map. Clicking on the incident will provide a direct link to the Inciweb or CAL FIRE incident page.

CAL FIRE · Official Incident Information

https://www.fire.ca.gov/incidents | *State Agency Site*

Official source of public information regarding all 10+ acre fires in California where the response is being handled by the California Department of Forestry and Fire Protection (CAL FIRE).

- **CONSIDERATIONS**

  Contains more prescribed burn information than INCIWEB, and data in CAL FIRE system is more highly automated than INCIWEB making reporting faster.

- **NOTES**

  Active CAL FIRE incidents are shown on the AirNow Fire and Smoke Map. Clicking on the incident will provide a direct link to the CAL FIRE incident page.

FIRM · Satellite Detections

https://www.earthdata.nasa.gov/data/tools/firms | *U.S. Federal Government (NASA)*

The Fire Information for Resource Management System (FIRMS) collects satellite fire detections across satellite platforms. Primarily a source of near real-time information. For a longer-term archive use the NASA WorldView system. A tutorial of NASA tools for air quality is available here: https://haqast.org/data-and-tools/

• CONSIDERATIONS

Note that different satellite platforms operate at different resolutions and on different timings and fires will likely be detected by multiple platforms, each providing a somewhat different picture of the fire depending on the conditions that pertained at the time of observation and how the fire size interacts with the satellite system's pixel size.

• NOTES

Current satellite fire detections (after quality control) are shown on the AirNow Fire and Smoke Map showing an overall picture. Detects are shown as an aggregate when zoomed out, but individual detects are clickable when zoomed in to obtain more information. FIRMS provides more detailed information for when that is needed.

Watch Duty · Aggregated Information App

https://watchduty.org (downloadable mobile app) | *Non-profit*

Collects many fire-based information systems from different governmental agencies as well as remote sensing. Primarily oriented to urgent safety issues (e.g. fire location, fire growth and evacuation information) for the U.S. Contains alerts and identifies officially designated areas of concern (e.g. for evacuation). Information on the app is changing with new sources being added.

• CONSIDERATIONS

Contains a mix of different types of data so considerations discussed above apply.

B.4 When Viewing Smoke Plume Extents

B.4A Considerations

Considerations when viewing a smoke plume extent include how the smoke plume extent was determined and therefore what it represents, the timing of when the smoke plume extent was created, and the relationship of the smoke plume extent with smoke concentrations on the ground.

Smoke plume extents are generally derived from satellite observations, from a smoke dispersion model, or from a data fusion product that combines the two. Smoke plume extents are rarely determined from actual observations of ground level air quality as air quality measurements are generally too sparse to generate detailed maps. In some urban areas it is possible to use measurements due to the large number of air quality sensors in the area allowing the creation of detailed progression maps of smoke plumes through the community.

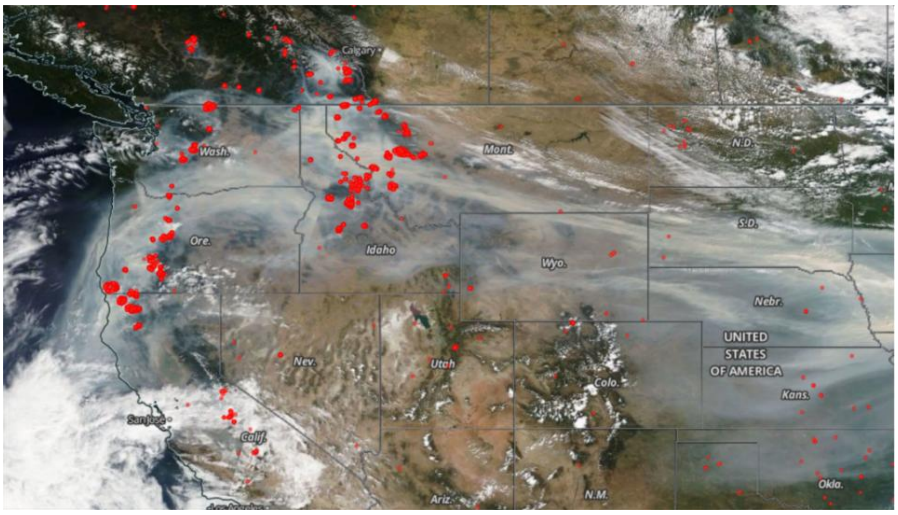

Figure B1. Smoke from many large fires creating haze across the western and central United States. *Red dots are satellite fire hot spot detections (NASA WORLDVIEW, September 4, 2017). To learn more, see the NASA Worldview Tutorial by the NASA Health and Air Quality Applied Sciences Team (HAQAST) at https://haqast.org/nasa-tools.*

Smoke plume extents as determined from satellites are created by automated algorithms based on various kinds of satellite imagery, by combinations of automated systems and human quality control checking, and, where necessary, human-drawn smoke plumes. A constellation of satellites operates in different Earth orbits, providing different combinations of temporal and spatial coverage. Global observations come from polar orbiting satellites, meaning measurements are collected on 14 pole-to-pole orbits with a field of view of Earth below that shifts ~2600 km each orbit. Depending on the instrument, measurements directly beneath the satellite might be as fine as 30m or more commonly coarser (500m-5000m). The coarser measurements – combined with multiple side-by-side measures – allows for global coverage once per day whereas the finer resolution instruments typically require multiple days or multiple satellites to achieve full coverage. In geostationary orbit, a satellite orbits the Earth at the same rate as Earth rotates, so that the focal area on the ground is consistent. At the focal area (e.g., the continental United States, northern Mexico and Southern Canada), the instrument can rapidly repeat measurements at high spatial resolution. The

combination of similar instruments in polar- and geostationary-satellites provides global coverage with higher frequency in focal areas and enables cross-platform verification where the two overlap in time and view.

Smoke plumes determined by satellites usually represent total air column smoke rather than ground level smoke as satellites generally are most capable of detecting the overall opaqueness of the surface-to-space air column they are looking through. This can create a good picture of how smoke in one area is connected to the source in another area, because the plume is being tracked no matter what elevation in the atmosphere it travels. It is most easily thought of as tracking where, if you look up, will the sky be orange or hazy as some elevation above you? However, this total air column smoke plume is logically disconnected from what is generally of most concern which is what the smoke concentrations are at the ground. Even "heavy" total air column smoke plumes – representing significant opaqueness of the total air column as detected by the satellite – may not reach the ground or affect air quality to communities. "Heavy" satellite plumes can often be coupled with "GOOD" air quality levels as measured on the ground. Think of an orange sky above but no smell or effects from smoke at the surface.

Other considerations for satellite derived smoke plumes include clouds and timing. High clouds can obscure satellite detects of smoke plumes. Clouds are distinguishable from smoke plumes by color (clouds are brighter white) and character and both human and automated systems generally are fairly good at making the distinction. Satellites can only detect smoke plumes during the day as they require reflected light. This means that satellite smoke plumes are not available at night and depending on when the overpasses and/or analyses are scheduled, may not be available until mid-morning. Fog can be another confounding factor which may be marked as smoke on these displays.

Smoke plume extents as determined by smoke models or by data fusion products generally try to capture ground level smoke extents. However, some of these products also produce a total air column smoke plume extent to compare to the satellite smoke plumes as discussed above. Therefore, when viewing smoke model or data fusion smoke plumes it is important to check what variable is being shown. Smoke model and data fusion smoke plumes generally are produced on regularly timed intervals.

Satellite observations range from detailed color images that are intuitively valuable to quantitative estimates. Satellites measure light from a variety of sources and different colors. Active satellite instruments measure light that they emit and are less common than passive instruments. Passive satellite instruments measure reflected solar radiation, human lights, or other thermal energy. Anything that relies on direct solar radiation is limited to making measurements during daylight hours. Images of the earth during daylight hours can be reconstructed from measured light of different colors, and are useful for seeing fires, smoke, and plume transport. Analysis of these images is typically qualitative and requires interpretation. For example, the NOAA Hazard Mapping System smoke polygons are hand drawn based on these images. Satellites can also measure specific colors (spectral bands) which can be used to identify the power emitted from fires or burned areas. Fire power and burned areas are

important datasets to estimating air quality emissions from fires. Aerosol optical depth is another measure, which uses reflected solar radiation to measure particulate matter in the atmosphere.

B.4B Sources Available on the Web

See https://wildlandfiresmoke.net/wildfire-smoke-guide for an updated and expanded list:

Hazard Mapping System · Satellite Smoke Plumes and Fire Detections

https://www.ospo.noaa.gov/products/land/hms.html | *U.S. Federal Government (NOAA)*

Official product showing combined, quality controlled, and algorithmic and human analyses of multiple satellite systems. One product shows combined satellite fire detects and another shows the extent of smoke plumes.

• CONSIDERATIONS

Quality control processes are designed to remove false detections. Algorithmic and human analyses can add in detections based on smoke plume behavior. Smoke plume extents include algorithmic and human drawn smoke extents based on multiple types of satellite imagery. However, above considerations on the observability of smoke plumes and fire detections from satellites at night and in periods of cloud or smoke coverage apply.

• NOTES

NOAA HMS smoke plumes are available as a layer on the AirNow Fire and Smoke Map. The time of the smoke plume analysis shown is displayed in the Settings menu. NOAA HMS satellite fire detections include the same satellite detection systems used on the AirNow Fire and Smoke Map.