CALIFORNIA
AIR RESOURCES BOARD

Wildfire Emission Estimates for 2022

Introduction

The California Air Resources Board (CARB) annually releases estimates of greenhouse gas (GHG) and particulate matter emissions from wildfires. This document summarizes estimates of statewide wildfire emissions from 2000 to 2022 for carbon dioxide (CO_2), particulate matter that are 10 microns or smaller in size (PM_{10}), and particulate matter that are 2.5 microns or smaller in size ($PM_{2.5}$). Emissions are estimated using the First Order Fire Effects Model (FOFEM) developed by the U.S. Forest Service (USFS) for fires reported in the California Department of Forestry and Fire Protection's (CAL FIRE) wildfire geodatabase using Geographic Information Systems (GIS) data on wildfire perimeters, vegetation fuels, and fuel moisture.

Fire has served natural functions in California's diverse ecosystems for millennia, such as facilitating germination of seeds for certain tree species, replenishing soil nutrients, clearing dead biomass to make room for living trees to grow, and reducing accumulation of fuel that leads to high-intensity wildfires. However, fire also impacts human health and safety and releases GHG emissions and other air pollutants, including those that contribute to ozone formation. In recent years the magnitude and intensity of wildfires have increased across California.

Overview of the 2022 Fire Season

State data reported 305 wildfires totaling approximately 0.3 million acres for 2022, comparable to total acreage reported for 2019. Total wildfire area in 2022 was approximately one-tenth the amount of wildfire area in 2021. As in previous years, a few wildfires comprised most of the year's reported burned area. Over half of the state total burn acreage was dominated by three fires: Mosquito (El Dorado and Placer counties), McKinney (Siskiyou County), and Campbell (Trinity County). The Mosquito Fire was the 77th largest fire event reported by CAL FIRE (76,739 acres), while the McKinney (60,077 acres) and Campbell (30,120 acres) fires were the 107th and 246th largest fires. Fuel loads in forested lands together with dry conditions fostered extensive fuel consumption and emissions.

Emissions Modeling Results

The estimates in this document are derived using the FOFEM developed by the USFS. Fire is a physical process that is highly variable at all spatial and temporal scales, so estimates of wildfire emissions for the entire state will have inherently high uncertainties. Sources of uncertainties include vegetation fuel types, fuel loading, fuel moisture, burned area, modeled fuel consumption in flaming and smoldering phases, and emission factors. CARB staff used GIS data on wildfire perimeters, vegetation fuels, fuel moisture, and FOFEM to account for some of this uncertainty and variation when they estimate emissions from fires reported in an interagency wildfire geodatabase (CAL FIRE 2023).

A wildfire's total emissions represent the contribution from the mosaic of vegetation types and fuels consumed within the fire footprint. Forest and woodland vegetation typically contain greater fuel loads per unit area (typically dead wood and surface fuels) than vegetation types dominated by shrubs, herbaceous plants, or grasses. Large fires extend across a variety of vegetation types. For example, the Mosquito fire extended across 28 different vegetation types, spanning forest, woodland, shrub and grass-dominated areas. However, 73% of the fire area and 77% of the total pre-burn fuel load was dominated by just three vegetation types: Douglas Fir-Sugar Pine-Tanoak Forest (FCCS 7), Jeffrey Pine-Ponderosa Pine-Douglas Fir-California Oak Woodland (FCCS 16) and California Black Oak Woodland (FCCS 14).

While there is year-to-year variation in the amount of land area affected by wildfire, the variation in total annual fire emissions is properly understood as a function of the amounts of fuel consumed. Total estimated fuel consumption (Table 1) in 2022 was less than a tenth of the fuel consumption in 2021. Total emissions of PM_{10}, $PM_{2.5}$ and CO_2 in 2022 were correspondingly smaller in magnitude compared to 2021. The 2019 and 2022 fire seasons experienced similar total acreage burned (Figure 1), while contrasting fuel consumption accounts for their emissions differences (Figures 2, 3, and 4). In 2022, total fuel consumption was approximately twice the magnitude of total fuel consumption in 2019. In turn, emissions of CO_2 and PM_{10} in 2022 were nearly double the magnitude of 2019's emissions.

Forest vegetation types dominated pre-fire fuel loads in 2022, with loads ranging from 0 to 138 tons/acre, averaging 19 tons/acre. The model estimated high rates of fuel consumption, with nearly complete consumption of litter, shrubs, and 1-hr, 10-hr and 100-hr dead fuels, as well as high rates for large-diameter dead fuels. Consumption of large-diameter dead fuels and duff (a forest floor dead organic layer between litter and soil layers) is largely associated with combustion in the smoldering phase. Carbon dioxide (CO_2) emissions are associated with fuel consumption in both the flaming and smoldering phases. Table 1 is a summary of 2022 wildfire area, fuel consumption, and emissions.

Table 1. Summary of 2022 wildfire area, fuel consumption, and emissions.

Wildfire Area (million acres)	Fuel Consumed (million short tons)	PM_{10} (thousand short tons)	$PM_{2.5}$ (thousand short tons)	CO_2 (million metric tons)
0.30	6.5	96	82	8.9

The top twenty wildfires comprised approximately 95% of total area burned. Their estimated emissions are listed in Table 2. Together, the Mosquito, McKinney and Campbell fires contributed 64% of the $PM_{2.5}$ emissions estimated for 2022.

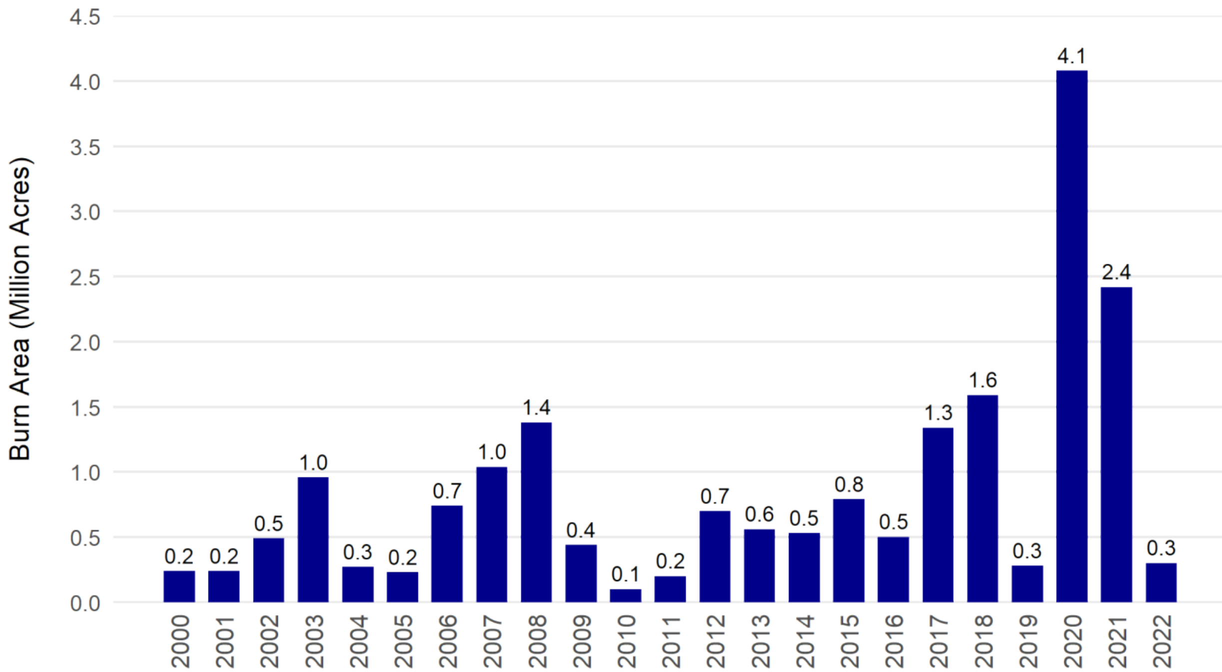
Table 2. Top 20 wildfires of 2022 by area of wildland vegetation burned

	Fire Name	Area (acres)*	CO_2 (million metric tons)	PM_{10} (thousand short tons)	$PM_{2.5}$ (thousand short tons)
1	Mosquito	74,920	2.0	2.0	17
2	Mckinney	55,995	1.6	1.6	14
3	Campbell	29,743	1.5	1.5	17
4	Fairview	27,320	0.6	0.6	2
5	Oak	18,622	0.5	0.5	3
6	Mountain	13,058	0.5	0.5	7
7	Ammon	11,302	0.5	0.5	6
8	Red	7,937	0.3	0.4	5
9	Yeti	7,496	0.1	0.3	3
10	Barnes	5,575	0.1	0.1	2
11	Route	5,056	0.2	0.1	<1
12	Washburn	4,810	0.2	0.2	2
13	Electra	4,323	0.1	<1	<1
14	Border 32	4,166	0.1	0.1	<1
15	Mill	3,315	<1	0.1	<1
16	Airport	3,142	<1	<1	<1
17	Rodgers	2,547	<1	0.1	1
18	Thunder	2,398	<1	<1	<1
19	Summit	1,255	<1	0.1	1
20	Radford	1,009	<1	<1	<1

*Emission estimates are associated with wildland vegetation and do not include developed areas, croplands, or water bodies, which are not included in the vegetation fuel data layer available to CARB.

Figures 1 to 4 present annual wildfire acreages and emissions of CO_2, PM_{10}, and $PM_{2.5}$ for 2000 to 2022.[1]

Figure 1. Acreage of Burned Wildland Vegetation Area*



* These acreages do not include areas where wildland vegetation data for model inputs are not available, e.g., developed areas and croplands.

[1] The wildfire emissions in Figures 1 to 4 include all fire events in the CAL FIRE database (CAL FIRE 2023), including those with the "resource benefit (WFU)" tag. WFU refers to fires that are managed to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in fire management plans.

Figure 2. Estimates of Wildfire CO_2 Emissions

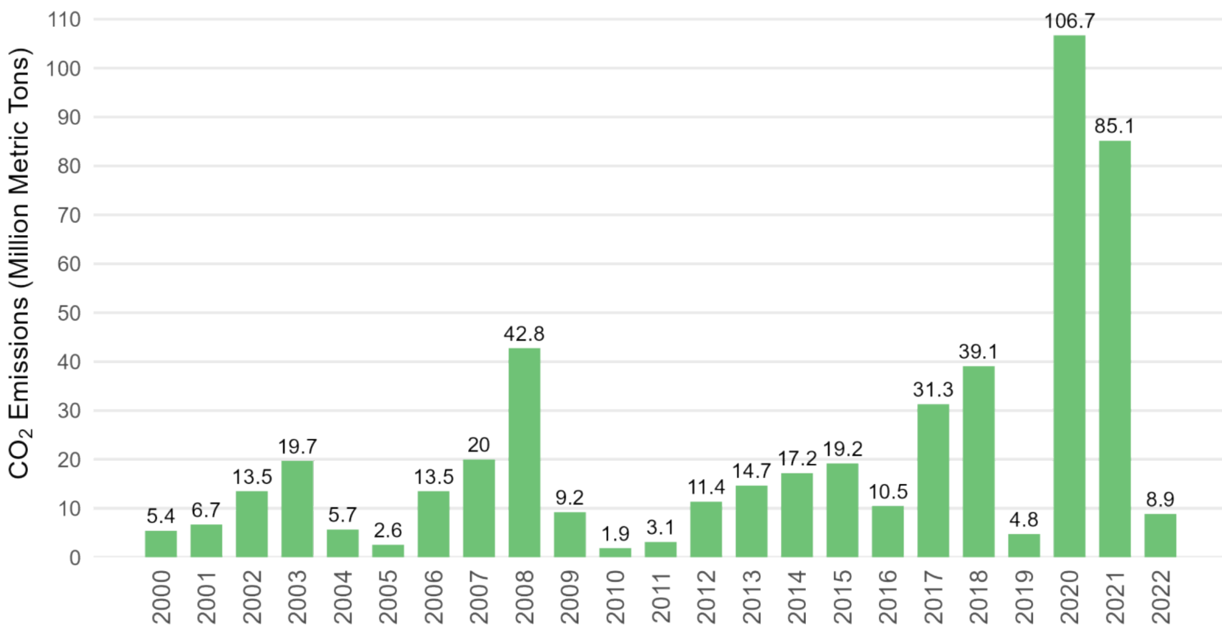


Figure 3. Estimates of Wildfire PM_{10} Emissions

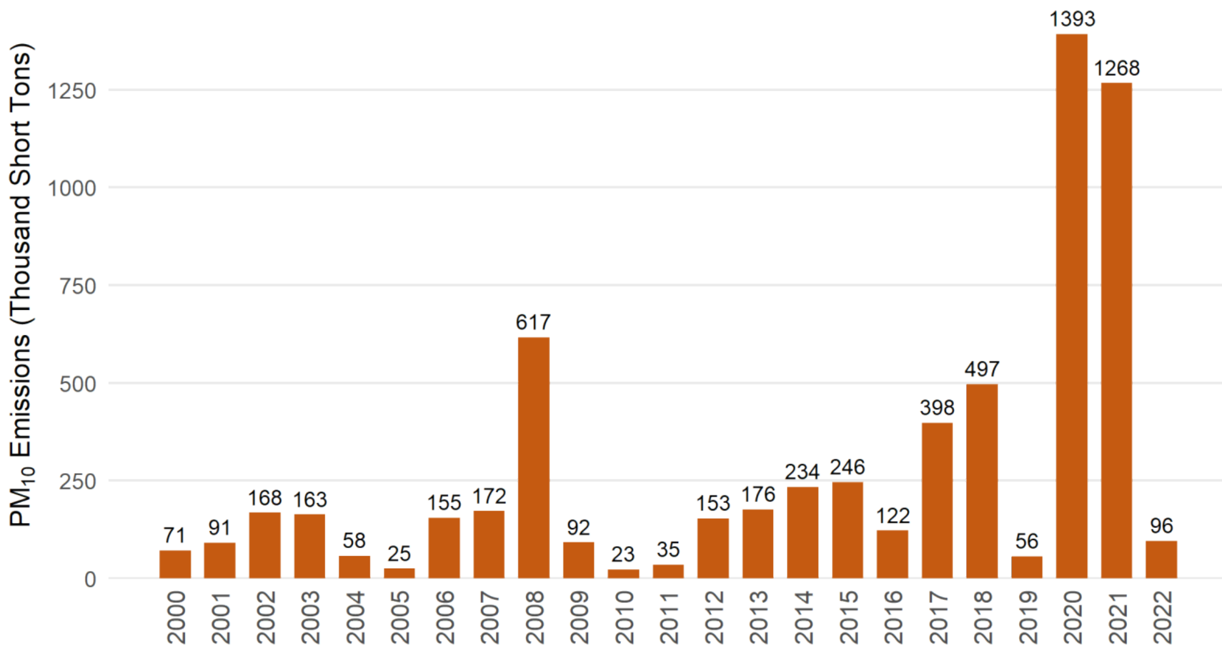
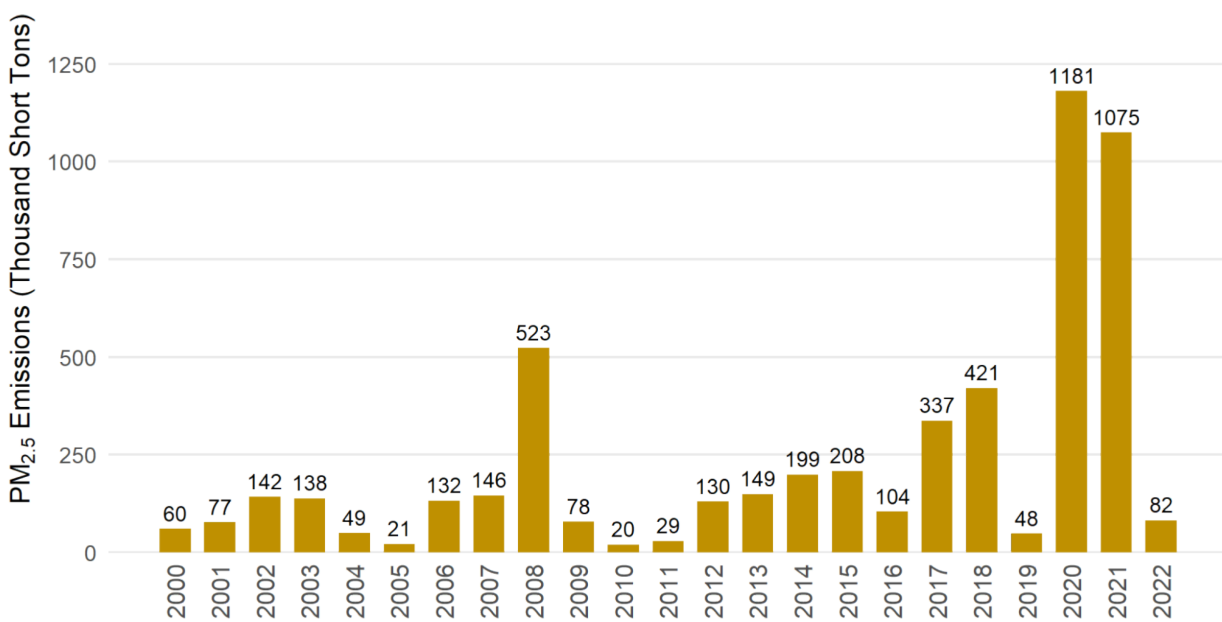


Figure 4. Estimates of Wildfire $PM_{2.5}$ Emissions



Data Sources and Methods

Emissions are estimated using GIS format data on fire perimeters (FRAP 2023), alarm and containment dates, natural vegetation fuel type (fuel component size class), fuel loads (tons/acre), fuel moistures, and burn severity. The geospatial data are used to develop inputs to a wildland fire emission model (FOFEM version 6.7) (FOFEM 2023). Modeled emissions in flaming and smoldering phases (lbs/acre) by fuel type are integrated over the areas of each vegetation fuel type associated with each wildfire. Flaming and smoldering emissions are summed for reporting and include every fire reported and mapped for the calendar year.

The magnitudes of emissions are proportional to the amount of fuel consumed, and various pollutants are generated in the flaming and smoldering phases of combustion. Fuel moisture influences the proportions of fuel consumed in flaming versus smoldering phases. Forest and woodland vegetation types contain greater fuel loads than vegetation types dominated by shrubs, herbaceous plants, or grasses. Large fires often extend across a variety of vegetation types. Vegetation fuel maps based on the Fuel Characteristic Classification System (FCCS) are developed for specific years by the LANDFIRE.GOV consortium (Ottmar 2007, FCCS 2022). For all other years, CARB staff use FCCS-based vegetation fuel maps developed by researchers at the University of California at Berkeley (UCB 2019). Fuel loads for FCCS vegetation types are defined in FOFEM. Fuel moistures (Abatsoglu 2013, gridMET 2022) are obtained from the Climate Engine consortium (CE 2023). Pollutant emissions associated with fuel consumption in the smoldering phase include PM_{10} and $PM_{2.5}$. Emissions associated with the flaming phase include CO_2.

Uncertainty

Uncertainties associated with mapped vegetation fuel types, fuel loading (tons/acre by fuel size category) (Collins et al. 2016, McKenzie et al. 2007, Riccardi et al. 2007, Sikkink and Keane 2008), fuel moisture, burned area, modeled fuel consumption in flaming and smoldering phases, and emission factors (EFs, mass of pollutant species per unit mass fuel consumed) contribute to large uncertainties in emission estimates reported by CARB. EFs are derived from chemical analysis of air samples during biomass burn events. Derived EFs vary with fuel type, fuel component size class, texture, arrangement, moisture content, combustion conditions (wildfire vs. prescribed burn, flaming vs smoldering, wind speed), and methods (laboratory versus field studies). For some pollutants, EF uncertainty approaches a factor of two (Urbanski 2014, Prichard et al. 2020). Fuel loading is an especially large source of uncertainty: across vegetation types and entire landscapes, fuel loading can vary by up to an order of magnitude. A 2011 study (Urbanski et al. 2011) estimated wildfire emissions across the western U.S. for 2003 through 2008 using a geospatially and temporally explicit fire emission model utilizing remotely sensed vegetation fuel, wildfire activity, and weather data. The study found that uncertainties were approximately a factor of two at spatial (kilometers) and temporal scales (daily) relevant to air quality modeling. The CARB wildfire emission estimates are developed using sources and methods that are independent from those used for the statewide Natural and Working Lands (NWL) inventory of ecosystem carbon stocks and stock-change.

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