CALIFORNIA AIR RESOURCES BOARD

Wildfire Emission Estimates for 2021

Introduction

Fire has served a natural function 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 greenhouse gas (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. To help contextualize GHG and particulate emissions from wildfires, the California Air Resources Board (CARB) annually releases estimates of fire emissions. This document summarizes statewide wildfire emissions from 2000 to 2021.

Emissions are estimated for fires reported in the California Department of Forestry and Fire Protection's (CAL FIRE) wildfire geodatabase using Geographic Information Systems (GIS) based data on wildfire perimeters, vegetation fuels, and fuel moisture. These estimates are derived using the First Order Fire Effects Model (FOFEM) developed by the U.S. Forest Service (USFS). As with any emission modeling of biochemical processes, wildfire emission estimates have 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. This report summarizes estimated emissions of 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 ($PM_{2.5}$).

Overview of the 2021 Fire Season

State data reported 372 wildfires totaling approximately 2.5 million acres for 2021. As in previous active years, a few large-area wildfires comprised most of the year's reported burned area. Approximately 3% of the wildfires comprised 90% of the total wildfire area reported for 2021. Over half of the state total burn acreage was dominated by three fires: Dixie, Monument, and Caldor. The Dixie Fire was the second largest fire event in California history (963,405 acres), after the August Complex of 2020. High fuel loads associated with forested lands and the high number of forested acres burned together with dry conditions fostered extensive fuel consumption and large magnitude emissions.

Emissions Modeling Results

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 types 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.

While there is year-to-year variation in the amount of land area affected by wildfire, the variation in total annual fire emissions is more a function of the amount of fuel consumed which may or may not directly follow acres burned. Fires burning in lands with lower fuel loads will emit fewer emissions. Estimated pre-fire fuel loading for 2021 totaled 99.2 million tons, approximately 24% less than in 2020. Total estimated fuel consumption (Table 1) was correspondingly less (approximately 18%) than in 2020. Particle emissions (PM_{10} and $PM_{2.5}$) are largely a product of fuel consumption in the smoldering phase of combustion. The quantity of fuel consumed in the smoldering phase in 2021 (44.9 million tons) was approximately 7% less than in 2020 (48.4 million tons), with the result that 2021's PM_{10} emissions are approximately 10% lower than in 2020. Forest vegetation types dominated fuel loads in 2021, with loads ranging from 4 to over 100 tons/acre, averaging over 40 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 2021 wildfire area, fuel consumption, and emissions.

Table 1. Summary of 2020 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)
2.5	66.7	1,268	1,075	85.2

The top twenty largest wildfires comprised approximately 98% of total area burned and total emissions. Their estimated emissions are listed in Table 2. The Dixie Fire contributed over 40% of the wildfire emissions estimated for 2021.

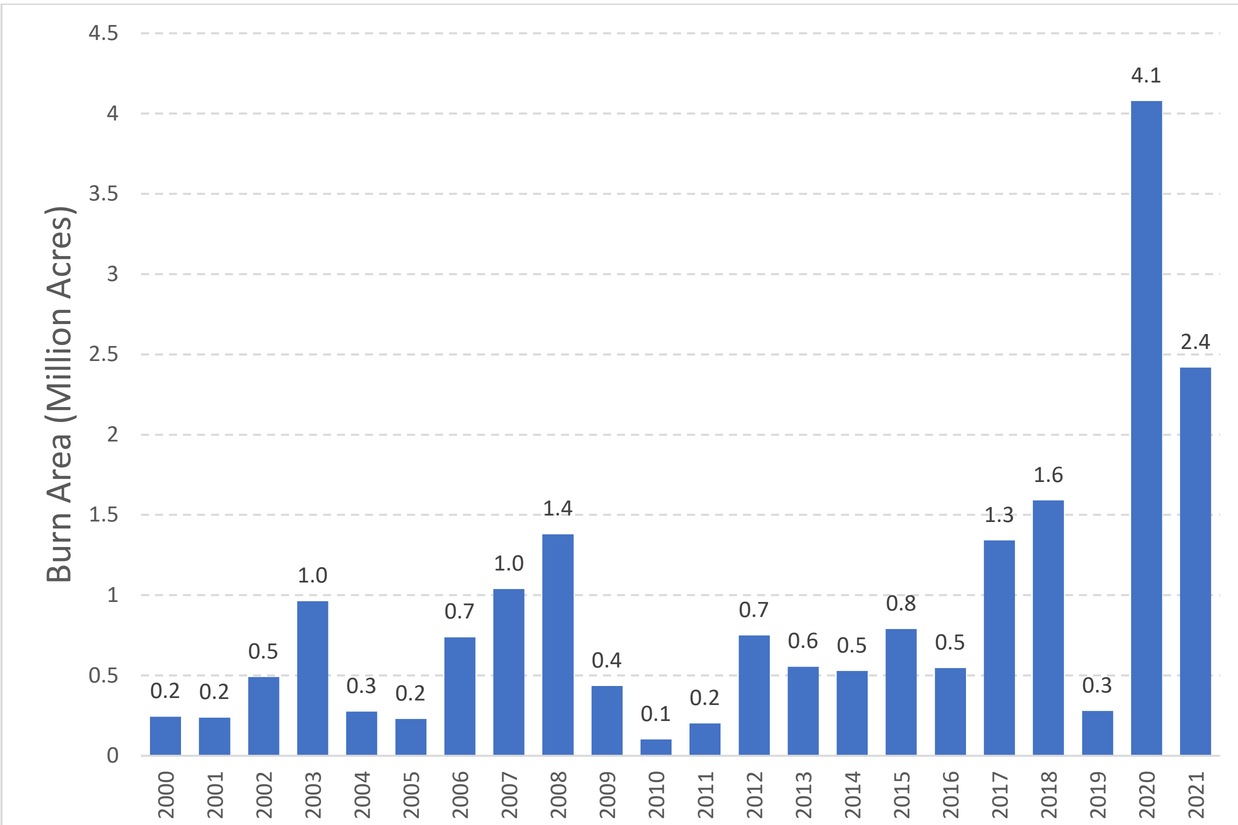
Table 2. Top 20 wildfires of 2021

Fire Name	Area (acres)[1]	CO_2 (million metric tons)	PM_{10} (thousand short tons)	$PM_{2.5}$ (thousand short tons)
Dixie	934,564	37.4	575	487
Monument	220,888	4.7	61	51
Caldor	215,733	9.9	147	124
River Complex	195,464	8.3	129	109
Antelope	135,404	3.8	52	44
McFarland	120,140	3.6	55	47
Windy	96,816	3.2	51	43
Sugar	96,776	3.6	55	47
McCash	94,248	2.4	32	27
KNP Complex	86,095	3.0	40	34
Tamarack	49,607	1.5	24	20
French	26,227	0.9	13	11
Lava	22,336	0.6	8	7
Alisal	16,332	0.2	1	1
Salt	12,487	0.3	4	3
Tennant	10,324	0.2	2	2
River	9,623	0.2	2	1
Walkers	8,464	0.1	2	2
Fawn	8,413	0.2	3	3
Southern	5,188	<0.1	0.1	0.1

[1] Emission estimates are associated with wildland vegetation and do not include developed areas, croplands, or water bodies.

Figures 1 to 4 present annual wildfire acreages and emissions of CO_2, PM_{10}, and $PM_{2.5}$ for 2000 to 2021. Compared to CARB's fire emission report released in 2021, the figures below have been updated to include contributions from infrequent Wildland Fire Use (WFU) fires, a special category of wildfire that refers to naturally ignited wildfires that are intentionally allowed to burn without much, if any, suppression efforts.[1] Therefore, the numbers for 2000-2020 may have slight differences between the 2021 release and the 2022 release.

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] USFS defines WFU as: "Management of naturally ignited wildland fires to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in Fire Management Plans." (USFS 2022).

Figure 2. Estimates of Wildfire CO_2 Emissions

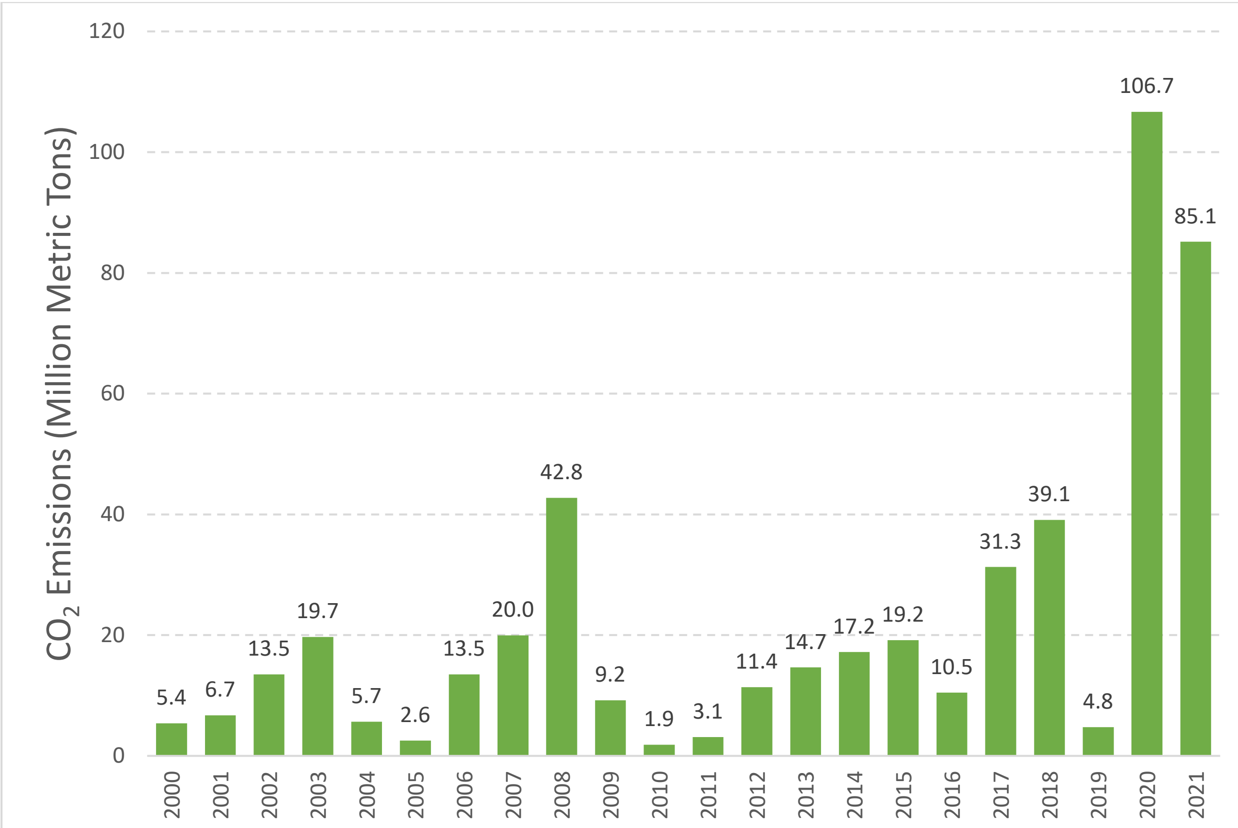


Figure 3. Estimates of Wildfire PM_{10} Emissions

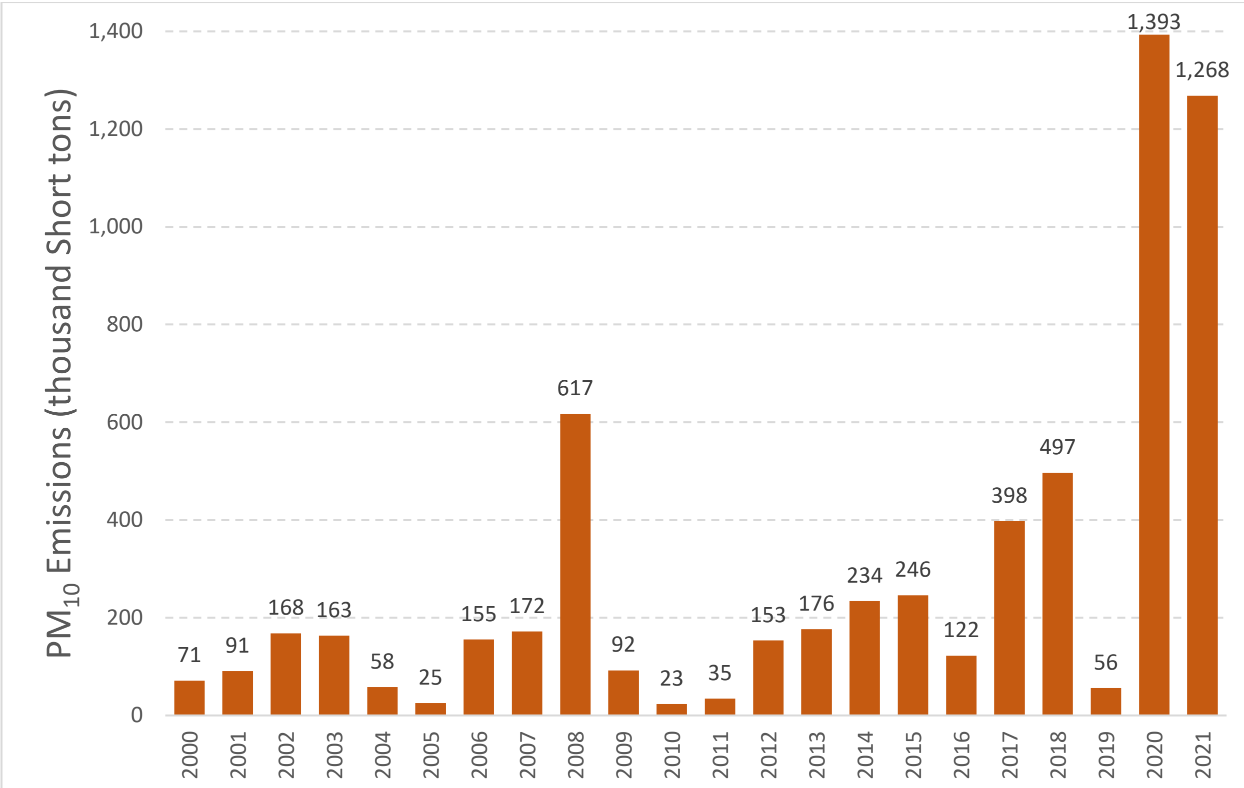
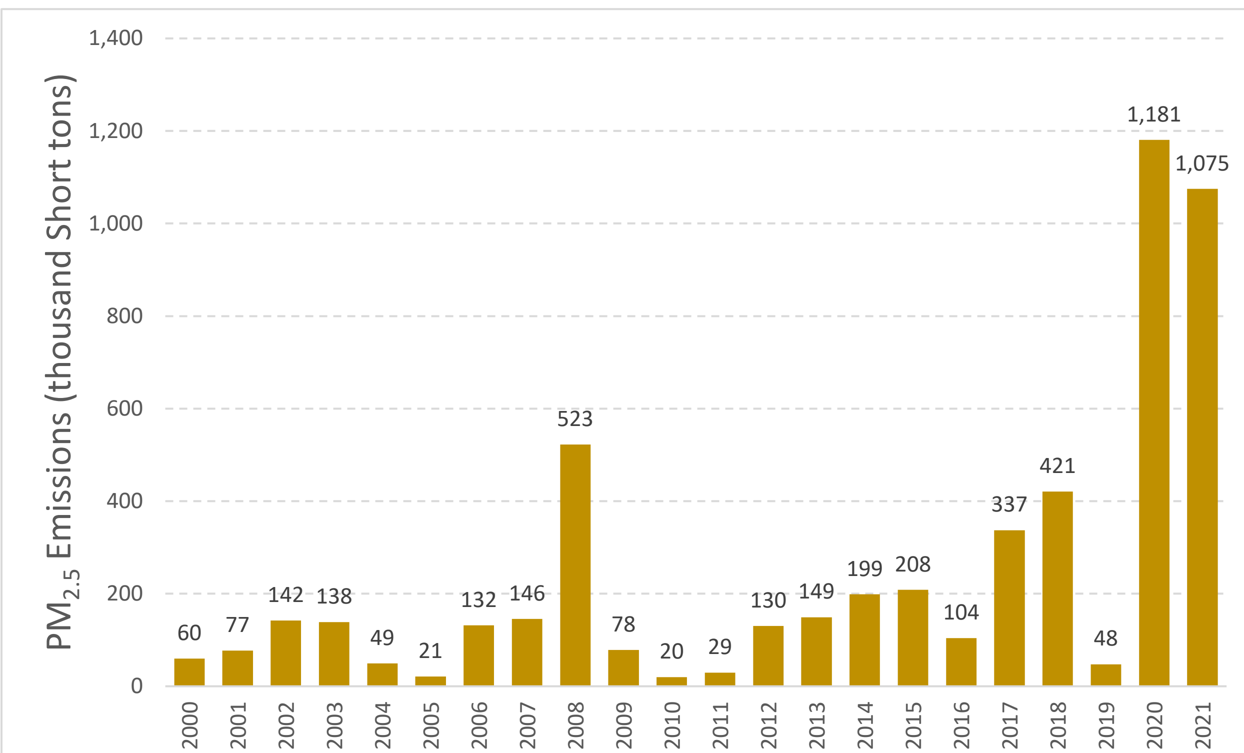


Figure 4. Estimates of Wildfire $PM_{2.5}$ Emissions



Data Sources and Methods

Emissions are estimated using GIS format data on fire perimeters (FRAP 2022), 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 2022). 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 2022). Pollutant emissions associated with fuel consumption in the smoldering phase include PM_{10}, $PM_{2.5}$, CO, CH_4 and total non-methane hydrocarbons (TNMHC). Emissions associated with the flaming phase include NOx, CO_2, and N_2O.

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 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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