Section 7.16
Forest Management

(March 2023)

EMISSION INVENTORY SOURCE CATEGORY

Miscellaneous Processes / Managed Burning and Disposal / Forest Management

EMISSION INVENTORY CODES (CES CODES) AND DESCRIPTION

670-666-0200-0000 (47274) Forest Management

METHODS AND SOURCES

This source category provides emission estimates from prescribed burning performed in natural vegetation types such as forests and woodlands. A prescribed burn is a fire ignited by a planned management action, most often administered by a public land management agency and on a variety of vegetation types including forests, woodlands, shrub lands, marshlands and grasslands. Forest residue pile burning is part of the forest management category, and pile burn emissions are included in this inventory. The emissions reported in this category do not include activity from cropland burning, wildfires, or wildland fire use (WFU) fires because these categories are reported under other emission inventory categories (EIC).

OVERVIEW OF ESTIMATION METHODOLOGY

Forest management prescribed burning emissions are estimated using the First Order Fire Effects Model (FOFEM 6.7, Lutes 2020) and a custom geoprocessing tool (Emission Estimation System, EES) developed for CARB by researchers at UC Berkeley (Clinton et al. 2006, 2003; Scarborough 2014; Scarborough et al. 2001). Coded in the Python programming language, the current EES serves as a pre- and post-processor to FOFEM.[1]

The pre-processor module of the EES performs geoprocessing tasks in a Geographic Information System (GIS). It overlays prescribed burn project perimeters (polygons) from a geodatabase maintained by the California Department of Forestry and Fire Protection (CALFIRE) Fire and Resource Assessment Program (FRAP)(CALFIRE 2022) on to a 30 meter pixel resolution

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[1] FOFEM is a fuel consumption and smoke production model developed by USDA – Forest Service, Rocky Mountain Research Station, Missoula Fire Laboratory. The FOFEM model determines pre-burn fuel loading, fuel mass consumed, and smoke emissions generated per fire acre burned.

raster layer of California vegetation “fuel beds” (Ottmar et al. 2007, LANDFIRE 2019). The pre-processor tabulates the fuel bed types and their corresponding area extent, retrieves fuel loading and fuel moisture values, type of burn (e.g. broadcast, hand pile, machine pile, or jackpot), and creates a batch input file that FOFEM can read. For each fuel bed, FOFEM calculates the mass of fuel consumed in flaming and smoldering phases of combustion and corresponding emissions, based on fuel moisture condition. A post-processor module in EES scales the per unit area fuel bed emissions from FOFEM to total emission based on the area extent of each fuel bed within the fire perimeter, and provides estimates for additional pollutants NH_3, N_2O, and Total Non-Methane Hydrocarbons (TNMHC). This approach was used to calculate emissions for prescribed burns performed on all vegetation types in 2000 – 2021, and will be used for subsequent annual updates.

EMMISSION ESTIMATION METHODOLOGY

Activity Data – Prescribed Burn Project Perimeters. Burn project perimeters and ignition dates are provided by the FRAP geodatabase. The FRAP geodatabase contains prescribed burn project perimeters mapped principally by federal land management agencies, CALFIRE, and cooperating state and local agencies. Updated annually by FRAP, the dataset represents the most comprehensive interagency prescribed burn geodatabase available for California.

Emission Factors and Pollutants. FOFEM calculates emissions for PM_{10}, $PM_{2.5}$, CO, CH_4, CO_2, NO, and SO_2, while the EES post-processor module includes emissions of N_2O, NH_3, and TNMHC. Emission factors for PM_{10}, $PM_{2.5}$, CO_2, CH_4 and CO are functions of combustion efficiency and the flaming and smoldering phases of biomass burning under different fuel moisture conditions (Table A, reproduced from Lutes 2012). The post-processor module in the EES adds emission estimates for NH_3, N_2O and TNMHC using an emission ratio approach (Lobert et al. 1991). The approach is based on the observation that emissions correlate with CO or CO_2 depending on whether the compound evolves primarily in the flaming or smoldering phase of combustion. CARB converts the FOFEM NO output to conventional NO_2 based on molecular weight ratios. CARB TOG and ROG estimates are based on the model’s estimates for CH_4 and TNMHC.

$NOx = NO * NO_2 (MW 46) / NO (MW 30) = NO * 1.533$

$TOG = (CH_4 + TNMHC) * 2$

ROG = TOG * FROG (Reactive Fraction)

For a more detailed explanation of emission factors, consult the references.

Table A. FOFEM emission factors in grams/kg of fuel consumed. FOFEM assumes flaming combustion efficiency (FCE) equals 0.97 and smoldering combustion efficiency (SCE) equals 0.67.

Pollutant	Flaming Phase		Smoldering Phase	
	Formula	Multiplier	Formula	Multiplier
$PM_{2.5}$	67.4 – (FCE x 66.8)	2.604	67.4 – (SCE x 66.8)	22.644
CH_4	42.7 – (FCE x 43.2)	0.796	42.7 – (SCE x 43.2)	13.756
CO	961 – (FCE x 984)	6.520	961 – (SCE x 984)	301.720
CO_2	FCE x 1833	1778.01	SCE x 1833	1228.11
PM_{10}	PM2.5 x 1.18	3.07272	PM2.5 x 1.18	26.71992
NO	3.2	3.2	0	0
SO_2	1.0	1.0	1.0	1.0

Fuel Loading and Fuel Consumption. The Fuel Characteristics Classification System (FCCS) raster layer (LANDFIRE 2019) spatially represents fuel beds, with each 30-meter resolution pixel labelled with an FCCS fuel bed identifier. Each fuel bed (vegetation community type) is represented by nine fuel components: duff; litter; 0 - ¼ inch ("1-hour"), ¼ -1 inch ("10-hour"), 1-3 inch ("100-hour"), and 3+ inch ("1000-hour") diameter dead woody fuels; herbaceous; shrub; and canopy fuels. Duff consists of partially decomposed organic material of the forest floor and lies beneath the litter layer. Litter is comprised of fallen twigs, cones, needles, and leaves covering the surface. The hour nomenclature for dead woody fuels represent the time it takes for woody fuels to respond to changes in humidity. Thousand-hour fuels are sub-divided into sound and rotten fractions (percent), with size categories of 3-6 inch, 6-9 inch, 9-20 inch, and greater than 20-inch diameter. FOFEM provides for prescribing the weight distribution among the four size classes of 1000-hour fuels. For 1000-hour fuels CARB staff used FOFEM default settings for sound and rotten fractions and an even weight distribution. The category "Herbaceous" represents grasses and herbaceous vegetation that comprise forest understory and the dominant plant types of other vegetation communities, such as grasslands. Shrubs are woody plants of relatively low height. Two components define tree canopy fuels: canopy branch wood (lateral branches along a tree trunk that lead to the canopy) and canopy foliage (leaves or needles).

A FOFEM look-up table contains fuel loading values for each FCCS fuel bed and corresponding fuel components. Component fuel loadings are defined in units of tons per acre. Combustion efficiency and fuel consumption determine the emissions from burned fuel. Fuel consumption is the mass (tons) of fuel consumed by fire. FOFEM uses the Burnup model (Albini et al. 1997, 1995) to predict consumption of woody fuels. FOFEM uses a decision tree based on inputs for Region, Season and Cover Group to determine which algorithms are used to estimate consumption of grasses/herbaceous vegetation, shrubs, and duff. In general, FOFEM assumes that fire consumes 100% of litter. FOFEM assumes full consumption for grasses and herbaceous vegetation, except in springtime. Tree canopy fuel consumption is a FOFEM input parameter (percent) prescribed by the user. CARB staff applied a default canopy consumption rate of 1% for prescribed burns. In the Burnup model, the spatial arrangement of fuel components also regulates the combustion process. FOFEM therefore defines an input called Fuel Category (Natural, Slash, or Piles), to be prescribed by the user. CARB staff use the Natural fuel category for broadcast burns, and the Piles category for hand pile, machine pile and jackpot burns.

Thousand-Hour Fuel Moisture. Moisture conditions for dead woody fuels and duff are assigned based on reported National Fire Danger Rating System Thousand-Hour (NFDR-TH) fuel moisture values. The NFDR-TH moisture value input to FOFEM affects both fuel consumption and combustion efficiency. The proportions of CO and CO_2 released from fuel consumption define combustion efficiency. Combustion efficiency is related to the portions of consumption that occur in the flaming and smoldering phases of fire. Efficient combustion is associated with dry fuel conditions, with a large portion of fuel consumption occurring in the flaming phase. Conversely, when fuels are moist, the majority of fuel consumption occurs in the less efficient smoldering phase. FOFEM provides an option for setting moisture values for the 10-hour and duff fuel components based on NFDR-TH values.

NFDR-TH values vary spatially and temporally. CARB staff use geospatially explicit statewide year- and month-specific NFDR-TH rasters to assign realistic fuel moisture values for each prescribed burn. A series of geoprocessing steps are used to create NFDR-TH moisture rasters from georeferenced weather station data reported by the federal Wildland Fire Assessment System (WFAS 2019) and by the gridMET system (Abatzoglu 2013, gridMET 2022).

Fuel Characterization Classification System (FCCS) map. The FCCS layer is a 30-meter pixel resolution raster developed from LANDSAT imagery and ground-based vegetation surveys and periodically updated by the federal LANDFIRE consortium (LANDFIRE 2019). For California, FCCS maps over 70 fuel bed types representing categories of forests, woodlands, grasslands, shrub lands, wetlands and sparsely vegetated lands. CARB staff classified 44 FCCS fuelbeds as forest or woodland types and 28 FCCS fuelbeds as grassland or shrub land types. Emissions estimated for prescribed burns that occurred on forest/woodland types are reported in the Forest Management category (EIC 670-666-0200-0000). Emissions estimated for prescribed burns that occurred on grassland and shrub land vegetation types are reported in the Range Improvement category (EIC 670-664-0200-0000).

TEMPORAL INFORMATION

In the CALFIRE geodatabase, prescribed burn project perimeters (polygons) represent the final spatial extent of a treated area. Therefore, emission estimates based on the final extent of a treated area represent cumulative emissions rather than momentary emissions. Spatially explicit NFDR-TH fuel moistures are month averages specific to the year of the fire.

ASSUMPTIONS AND LIMITATIONS

- The CALFIRE-FRAP geodatabase contains burn project information submitted by cooperating federal, state and local agencies, therefore accuracy and consistency can vary by location and year. FRAP data is updated annually and represents the most comprehensive geospatially explicit prescribed burn activity dataset available.
- Default FCCS fuel loading values used in FOFEM represent typical conditions. Real-world fuel loads change with time.
- The 1% consumption rate for tree canopies is a default assumption. Prescribed burns are generally designed to treat surface fuels.
- FOFEM assumes 100% of the burn area experiences fire.
- NFDR-TH moisture values for each prescribed burn are based on the year-specific month-average value of a pixel corresponding to the ignition start date and the centroid of the prescribed burn polygon. Real-world fuel moistures vary with fuel component, elevation, slope, aspect, and meteorological conditions (Holden and Jolly 2011).

CHANGES IN METHODOLOGY

Emission estimation methods reflect use of FOFEM version 6.7, LANDFIRE FCCS fuels rasters, year- and month-specific fuel moisture rasters created from GIS data, and the EES processor.

EXAMPLE CALCULATION

Below is an example calculating PM_{10} emissions for the Hogsback Wildland Urban Interface (WUI) and Habitat Improvement Broadcast Burn project performed in Tehama County on July 10, 2008. The pre-processor module of EES overlaid the prescribed burn perimeter (retrieved from the CALFIRE-FRAP geodatabase) on the FCCS vegetation fuel beds raster and tabulated fuel bed types, loadings, and their areas. The prescribed burn area was bounded by two roads and encompassed approximately 2,344 acres, including 1,755 acres of forest/woodland and 540 acres of shrub land/grassland fuel bed types, and 49 acres of water bodies and developed land (Figure 1, Tables 1 and 2). Fuel bed

36 (Live oak-Blue oak woodland) accounted for approximately 44% of the nearly 45,000 tons of total fuel load, and 46% of total PM_{10} emissions (Table 3). Together, forest and woodland fuel bed types accounted for approximately 80% of the burn project's total fuel load and 83% of total PM_{10} emissions.

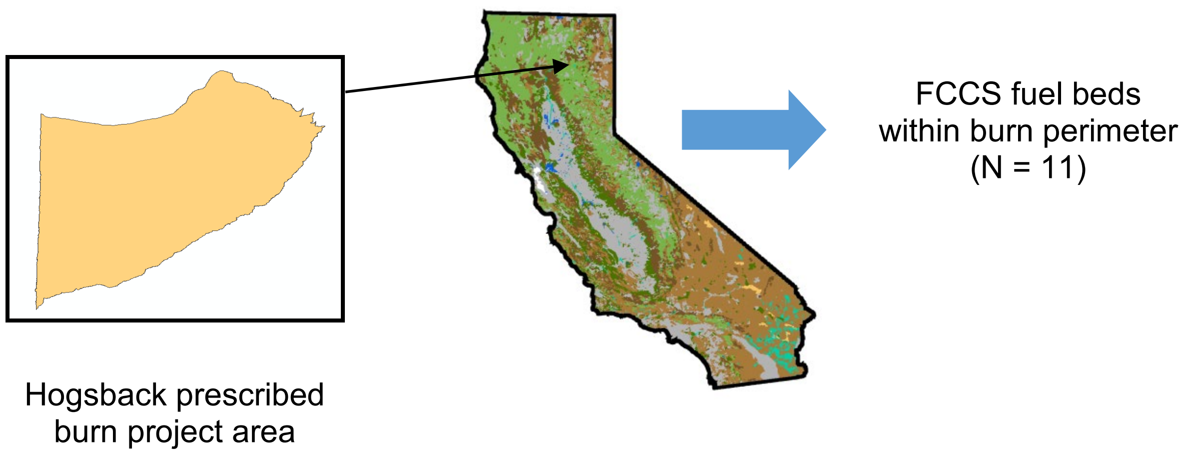

Figure 1. Schematic diagram of FCCS vegetation fuels tabulation.

Table 1. FCCS vegetation types (fuel beds) located within the Hogsback prescribed burn.

Forest and woodland fuel bed types	
FCCS ID	FCCS fuel bed name
5	Douglas fir-White fir forest
14	California Black oak woodland
15	Jeffrey pine-Red fir-White fir-Greenleaf manzanita-Snowbrush forest
16	Jeffery pine-Ponderosa pine-Douglas fir-Black oak Forest
36	Live oak-Blue oak woodland
Shrub land and grassland fuel bed types	
FCCS ID	FCCS fuel bed name
41	Idaho fescue-Bluebunch Wheatgrass grassland
44	Scrub oak chaparral shrub land
46	Chamise chaparral shrub land
57	Wheatgrass-Cheatgrass grassland
60	Sagebrush shrub land
311	Saltbush shrub land

Table 2. FOFEM inputs. Hogsback prescribed burn fuel loading and other parameters. Fuel beds 5 through 36 represent forest/woodland types.

FCCS fuel bed ID		5	14	15	16	36	41	44	46	57	60	311
Area (acres)		89.4	222.4	18.1	55.7	1,369.0	2.4	121.1	394.4	3.8	17.7	0.1
Fuel Component		Load (tons/acre)										
1-hr	0 - ¼"	0.5	0.25	0.08	0.3	0.5	0	0.5	0.5	0	0	0.1
10-hr	¼ - 1"	1.6	0.5	0.7	1.4	0.5	0	0.25	1	0	0	0.2
100-hr	1 - 3"	3.3	0.9	0.23	1.8	1	0	0.25	1	0	0	0
1000-hr	3-6" Sound	2.15	0.625	0.875	0.4	0.5	0	0	0	0	0	0
	6-9" Sound	2.15	0.625	0.875	0.4	0.5	0	0	0	0	0	0
	9-20"Sound	8.9	0	5	2.5	1	0	0	0	0	0	0
	>20" Sound	3.4	0	6	0	0.2	0	0	0	0	0	0
	3-6" Rotten	0.4	0	0.25	0.35	0.1	0	0	0	0	0	0
	6-9" Rotten	0.4	0	0.25	0.35	0.1	0	0	0	0	0	0
	9-20"Rotten	1.6	0	2	2.5	0.2	0	0	0	0	0	0
	>20" Rotten	0.6	0	2	0	0.2	0	0	0	0	0	0
	Litter	4.98	1.87	2.49	2.65	0.54	0.18	4.65	0.3	0.03	0.11	0.05
	Duff	13.17	2.64	55.48	11.44	4.3	0	0.6	3.12	0	0	0
	Herbaceous	0.21	0.1	0.05	0.2	0.4	0.65	0	0	0.11	0.2	0.1
	Shrub	2.98	0.29	6.41	1.93	3.22	0	9.82	12.23	0	0.97	1.07
Canopy	Foliage	16.78	15.71	11.51	6.7	0.97	0	0	0	0	0	0
	Branchwood	4.19	3.93	2.88	1.68	0.24	0	0	0	0	0	0

Region	Pacific West
Season	Summer
Fuel Category	Natural
Crown consumption	1%

Cover Group	FCCS ID
Ponderosa	16
Grass Group	41, 57
Sagebrush	60
Shrub Group	44, 46, 311

Fuel moisture	Percent
NFDR-TH	6
10-hr	6
Duff	20

Table 3. Model output. Hogsback prescribed burn fuel consumption and PM_{10} emissions. Forest and woodland fuel bed types.

FCCS fuel bed ID		5	14	15	16	36
Fuel component		tons				
Litter	Post-fire	0	0	0	0	0
	Consumed	445.2	415.9	45.2	147.5	739.2
1-hr	Post-fire	0	0	0	0	0
	Consumed	44.7	55.6	1.5	16.7	684.5
10-hr	Post-fire	0	0	0	0	0
	Consumed	143.0	111.2	12.7	77.9	684.5
100-hr	Post-fire	0	71.2	0	0	301.2
	Consumed	295.0	129.0	4.2	100.2	1,067.8
1000-hr Sound	Post-fire	869.8	222.4	81.8	121.9	2,477.8
	Consumed	614.2	55.6	149.5	61.8	533.9
1000-hr Rotten	Post-fire	90.3	0	9.4	75.1	588.7
	Consumed	177.9	0	72.2	103.0	232.7
Duff	Post-fire	292.3	146.8	249.8	158.1	1,464.8
	Consumed	885.0	440.4	756.6	478.6	4,421.7
Herbaceous	Post-fire	0	0	0	0	0
	Consumed	18.8	22.2	0.9	11.1	547.6
Shrubs	Post-fire	106.4	26.7	46.4	42.9	1,766.0
	Consumed	160.0	37.8	69.8	64.6	2,642.1
Canopy Foliage	Post-fire	1,484.9	3,458.4	206.6	369.0	1,314.2
	Consumed	15.2	35.6	2.2	3.9	13.7
Canopy branchwood	Post-fire	372.8	869.6	52.1	92.9	328.5
	Consumed	1.8	4.4	0.2	0.6	0
Emissions		tons				
PM_{10}	Flaming	2.7	1.8	0.4	1.0	14.4
	Smoldering	51.6	19.6	26.6	20.0	185.5
	Total	54.3	21.4	27.0	21.0	199.9

Table 3 continued. Hogsback prescribed burn fuel consumption and PM_{10} emissions. Shrub land and grassland fuel bed types.

FCCS fuel bed ID		41	44	46	57	60	311
Fuel component		tons					
Litter	Post-fire	0	0	0	0	0	0
	Consumed	0.4	563.2	118.3	0.1	1.9	<0.05
1-hr	Post-fire	0	0	0	0	0	0
	Consumed	0	60.6	197.2	0	0	<0.05
10-hr	Post-fire	0	1.2	0	0	0	<0.05
	Consumed	0	29.1	394.4	0	0	<0.05
100-hr	Post-fire	0	18.2	126.2	0	0	0
	Consumed	0	12.1	268.2	0	0	0
1000-hr Sound	Post-fire	0	0	0	0	0	0
	Consumed	0	0	0	0	0	0
1000-hr Rotten	Post-fire	0	0	0	0	0	0
	Consumed	0	0	0	0	0	0
Duff	Post-fire	0	18.2	303.7	0	0	0
	Consumed	0	54.5	926.9	0	0	0
Herbaceous	Post-fire	0	0	0	0	0	0
	Consumed	1.6	0	0	0.4	3.5	<0.05
Shrubs	Post-fire	0	237.4	966.3	0	8.7	<0.05
	Consumed	0	952.0	3857.3	0	8.7	0.1
Canopy Foliage	Post-fire	0	0	0	0	0	0
	Consumed	0	0	0	0	0	0
Canopy branchwood	Post-fire	0	0	0	0	0	0
	Consumed	0	0	0	0	0	0
Emissions		Tons					
PM_{10}	Flaming	<0.05	4.8	12.4	<0.05	<0.05	<0.05
	Smoldering	<0.05	2.6	46.3	<0.05	0.1	<0.05
	Total	<0.05	7.4	58.8	<0.05	0.1	<0.05

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