California Environmental Protection Agency

Air Resources Board

2015 Edition

California's
Black Carbon Emission Inventory

Technical Support Document

State of California
Air Resources Board
Air Quality Planning and Science Division

April 2016

Disclaimer

This document has been prepared by the staff of the California Air Resources Board. Publication does not signify that the contents reflect the views and policies of the Air Resources Board.

Table Of Contents

INTRODUCTION

Ambient particulate matter (PM) consists of a complex mixture of chemical compounds. Black carbon (BC) is the carbonaceous fraction of PM that absorbs all wavelengths of visible solar radiation and contributes to atmospheric warming. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report estimates that BC is the third most important individual contributor to warming after carbon dioxide and methane (IPCC 2013). This warming effect is a result of BC's high global warming potential (GWP) of 900 over a 100-year time frame, and 3,200 over a 20-year time frame (IPCC 2013).

The carbonaceous content of PM consists of thousands of individual compounds that are broadly classified into categories based on measurement technique and the physical and chemical properties of the compounds. These classes include organic carbon (OC), brown carbon (BrC) and elemental carbon (EC). These categories are only loosely defined, and there is some overlap between the categories. EC measurements are commonly used as a proxy for BC for inventory purposes (Chow, Watson et al. 2010, USEPA 2012). As such, the California BC inventory represents EC, and does not account for the warming effects of brown carbon.

Thermal-optical methods quantify EC and OC using a combination of temperature protocols to evaporate, pyrolyze, and combust the carbon-containing compounds in a PM sample then quantify the evolved carbon gases. Two different thermal protocols are commonly used in national air quality monitoring networks since the 1990s: IMPROVE (Interagency Monitoring of Protected Visual Environments) and NIOSH 5040 (U.S. National Institute for Occupational Safety and Health). While these thermal-optical methods are considered a reference methodology to quantify EC and OC, results of these two methods can show disagreement. If available, speciation profiles used in California's BC inventory were restricted to measurements using the IMPROVE thermal/optical method because it is most commonly used at air quality sites across California.

I. Overview

Senate Bill (SB) 605 (Lara, Chapter 523, Statutes of 2014) directed the California Air Resources Board (ARB) to develop emission inventories for three short-lived climate pollutants: methane, short-lived fluorinated gases, and BC. Methane and short-lived fluorinated gases (F-gases) are inventoried as part of the annual ARB Greenhouse Gas (GHG) emission inventory (ARB 2015a) as required by Assembly Bill (AB) 1803 (Committee on Budget, Chapter 77, Statutes of 2006) and AB 32 (Núñez, Chapter 488, Statutes of 2006). Unlike methane and F-gases, BC is not routinely inventoried by ARB. This BC emission inventory was developed for key years in support of the Short-Lived Climate Pollutant Strategy.

California's BC emission inventory is based on existing $PM_{2.5}$ emission inventories (ARB 2015b, ARB 2015c) combined with speciation profiles that define the fraction of $PM_{2.5}$ that is BC (ARB 2015d) (Equation 1). The methodology and data sources are described in detail below. Both $PM_{2.5}$ emissions and BC speciation profiles are a compilation of many data sources identified as the most accurate and most California-specific data available; however, there is large variability in the scientific understanding of BC speciation from different sources. BC speciation profiles from some sources, such as on-road transportation, utilize many California-specific emission tests and are known with higher accuracy. Speciation profiles from other sources, especially open burning, are compiled from few emission tests that are more generalized and contain much higher uncertainty. The uncertainty in speciation profiles is compounded with the inherent uncertainty in any $PM_{2.5}$ emission inventory when producing a BC inventory.

Equation 1: General BC Emission Calculation

$$E_{BC,i} = F_{BC,i} \bullet E_{PM\,2.5,i}$$

Where,

$E_{BC,\,i}$ = Emissions of BC for a given source i

$F_{BC,\,i}$ = Fraction of $PM_{2.5}$ that is BC for a given source i

$E_{PM2.5,\,i}$ = Emissions of $PM_{2.5}$ for a given source i

II. $PM_{2.5}$ Emission Inventory

A. On-Road Transportation

$PM_{2.5}$ emissions from on-road transportation was derived from the Air Resources Board's 2014 Mobile Source EMission FACtors Model (EMFAC) version 1.0.6 (ARB 2015c). Annual emissions from EMFAC 2014 are provided in tons of $PM_{2.5}$ emitted per typical weekday. Engine-specific annual activity data was used to convert tons $PM_{2.5}$ per typical weekday to tons $PM_{2.5}$ per year (Table 1) (ARB 2014b). Additionally, EMFAC modeled state-wide gasoline and diesel fuel consumption was proportionally scaled to match the 2000, 2012, and 2013 total fuel sales consistent with ARB's Official Greenhouse Gas (GHG) Emission Inventory (ARB 2014b). Fuel sales correction factors are summarized in Table 2.

Equation 2: Calculation of Annual $PM_{2.5}$ Emissions from On-Road Sources

$$AE_{PM2.5,i,j} = TWDE_{PM2.5,i,j} \bullet A_{PM2.5,i} \bullet FS_j$$

Where,

$AE_{PM2.5,i,j}$ = Annual Emissions of BC for a given source *i* and fuel *j* [tons / year]

$TWDE_{PM2.5,i,j}$ = Typical Weekday Emissions for a given source *i* and fuel *j* [tons / typical weekday]

$A_{PM2.5,i}$ = Activity factor used to convert typical weekday emissions to annual emissions for a given source *i* (Table 1) [typical weekdays / year]

FS_j = Fuel Sales correction for a given fuel *j* (Table 2)

Table 1. Engine-specific activity data used to convert on-road emissions from tons $PM_{2.5}$ per typical weekday to tons $PM_{2.5}$ per year.

Category	Annual Conversion (days per year)
ALL OTHER BUSES - DIESEL (OBD)	292
HEAVY DUTY DIESEL URBAN BUSES (UB)	327
HEAVY DUTY GAS URBAN BUSES (UB)	327
HEAVY HEAVY DUTY DIESEL TRUCKS (HHDV)	312
HEAVY HEAVY DUTY GAS TRUCKS (HHDV)	312
LIGHT DUTY PASSENGER (LDA)	347
LIGHT DUTY TRUCKS - 1 (LDT1)	347
LIGHT DUTY TRUCKS - 2 (LDT2)	347
LIGHT HEAVY DUTY DIESEL TRUCKS - 1 (LHDV1)	327
LIGHT HEAVY DUTY DIESEL TRUCKS - 2 (LHDV2)	327
LIGHT HEAVY DUTY GAS TRUCKS - 1 (LHDV1)	327
LIGHT HEAVY DUTY GAS TRUCKS - 2 (LHDV2)	327
MEDIUM DUTY TRUCKS (MDV)	347
MEDIUM HEAVY DUTY DIESEL TRUCKS (MHDV)	312
MEDIUM HEAVY DUTY GAS TRUCKS (MHDV)	312
MOTOR HOMES (MH)	327
MOTORCYCLES (MCY)	347
OTHER BUSES - GAS (OBG)	327
OTHER BUSES - MOTOR COACH - DIESEL (OBC)	292
SCHOOL BUSES - DIESEL (SBD)	327
SCHOOL BUSES - GAS (SBG)	327

Table 2. Diesel and gasoline correction factors used to convert EMFAC modeled fuel consumption to reported fuel sales.

Fuel	2000	2012	2013
Gasoline	0.998979494	0.992749279	1.009901491
Diesel	0.994333516	0.955092352	0.988692887

B. Other Sources

Statewide $PM_{2.5}$ emissions for all other sources were obtained from the California Emissions Projection Analysis Model (CEPAM) 2016 Ozone SIP version 1.0, which uses a 2012 base year (ARB 2015b). Emissions represent a compilation of data from a wide variety of data sources, including models, data reported by air districts, and ARB inventory calculation methodology. Data for 2000, 2013, 2020, and 2030 are modeled using sector-specific growth and control assumptions by geographical region, in collaboration with air districts when applicable. Adjustments were made to some CEPAM emission assumptions as described below.

1. Agricultural Burning

Agricultural burning PM emissions for year 2000 were adjusted to match the trend in district-reported data from 2000 to 2012 maintained in the ARB California Emission Inventory Develpment and Reporting System Database (CEIDARS) (ARB 2013). This update more accurately reflects historical agricultural burning PM emissions.

2. Fuel Combustion Projection

The fuel combustion projection was adjusted to match GHG projection methodology and to reflect the expected effects of Cap-and-Trade on future fuel use. The fuel combustion category consists of stationary point source emissions from various sectors such as electricity generation, industrial sector, the service sector, and agricultural processing. Natural gas emissions were set equal to projection assumptions made for the GHG emission forecast, using a 2012 base year (ARB 2016). Due to the stringent local air districts rules that effectively limit new combustion sources to using only natural gas fuels, combustion of non-natural-gas fuels are not expected to grow in the future. Therefore, coal, wood, and bark combustion for electricity and co-generation were set to no growth after 2012.

During the first compliance period of Cap-and-Trade (covering 2013-2014 emissions), an emission cap is placed on the largest GHG-emitting facilities in state, including all petroleum refineries, most oil and gas production facilities, and most electricity and cogeneration facilities. Although year-to-year emission changes cannot be precisely forecasted, emissions from these sectors are generally expected to either remain flat or decrease due to the emission cap. Non-natural-gas fuel combustion by sectors under the first Cap-and-Trade compliance period were set to no growth after 2013 to reflect the emission cap imposed on these sectors. There are other smaller fuel combustion sources that are not directly covered by the Cap-and-Trade regulation, but are combusting fuels provided by fuel suppliers that are brought into Cap-and-Trade during the second compliance period (covering 2015-2017 emissions). These fuel combustion activities were set to no growth starting in 2018. Year 2018 is chosen because it is conservatively assumed that the market will take some time to adjust to the emission cap before emissions start to decline. Table 3 contains a summary of these projection updates in the fuel combustion category.

Table 3. Summary of fuel combustion projection adjustments.

<table>
<tr><th>Sector</th><th>Fuel</th><th>Note</th></tr>
<tr><td rowspan="11">Electricity
Cogeneration</td><td>Coal</td><td rowspan="2">No increase after 2012</td></tr>
<tr><td>Wood/Bark</td></tr>
<tr><td>Diesel #1</td><td rowspan="7">No increase after 2013</td></tr>
<tr><td>Diesel #2</td></tr>
<tr><td>Landfill Gas</td></tr>
<tr><td>Gasoline</td></tr>
<tr><td>LPG</td></tr>
<tr><td>Refinery Gas</td></tr>
<tr><td>Process Gas</td></tr>
<tr><td>Natural Gas</td><td rowspan="2">Match GHG Inventory Projection, 2012 base year</td></tr>
<tr><td>CNG</td></tr>
<tr><td rowspan="8">Oil & Gas Production
Petroleum Refining</td><td>Diesel #1</td><td rowspan="6">No increase after 2013</td></tr>
<tr><td>Diesel #2</td></tr>
<tr><td>Landfill Gas</td></tr>
<tr><td>Gasoline</td></tr>
<tr><td>LPG</td></tr>
<tr><td>Refinery Gas</td></tr>
<tr><td>Natural Gas</td><td rowspan="2">Match GHG Inventory Projection, 2012 base year</td></tr>
<tr><td>CNG</td></tr>
<tr><td rowspan="9">Food Processing
Agricultural Processing
Manufacturing
Industrial
Service
Commercial</td><td>Diesel #1</td><td rowspan="7">No increase after 2018</td></tr>
<tr><td>Diesel #2</td></tr>
<tr><td>Landfill Gas</td></tr>
<tr><td>Gasoline</td></tr>
<tr><td>LPG</td></tr>
<tr><td>Propane</td></tr>
<tr><td>Sewage Gas</td></tr>
<tr><td>Natural Gas</td><td rowspan="2">Match GHG Inventory Projection, 2012 base year</td></tr>
<tr><td>CNG</td></tr>
</table>

III. Speciation Profiles

BC speciation profiles were previously developed and compiled by ARB, with documentation of the individual profiles available (ARB 2015d). Each $PM_{2.5}$ source is mapped to a speciation profile that defines the fraction of PM that is BC. Speciation profiles were developed considering fuel, engine technology, engine year, and pollution after treatment if available. The speciation profiles are primarily derived from California-specific source tests funded by ARB, the scientific literature, or profiles from the USEPA SPECIATE database (USEPA 2014). A summary of the fraction BC in all speciation profiles can be found in Appendix A.

While ARB has compiled a comprehensive database of speciation profiles, there is no scientific consensus on the choice of speciation profile for a given source and this remains a large source of uncertainty in BC inventory development. Many emission sources have few available source tests and those source tests that are available exhibit high variability. BC emission estimates are highly dependent on the choice of speciation profile and more research is necessary to better constrain BC emissions in California.

A. Speciation Profile Adjustments

Adjustments were made to the existing ARB speciation profiles as follows.

1. Profile 163, Incineration of Solid Fuel

The BC fraction from incineration of solid fuel in profile 163 is listed as zero. Incineration sources that emit $PM_{2.5}$ should also emit BC. All instances of speciation profile 163 were substituted with speciation profile 162, incineration of liquid fuels, which lists BC emissions as 50% of $PM_{2.5}$.

2. Profiles 200 and 220, Solvent Evaporation and Coating Material Evaporation

Profiles 200 and 220 correspond to solvent evaporation or coating material evaporation and listed BC emissions as 50% of $PM_{2.5}$. Non-combustion, evaporative sources should not emit BC. The fraction of BC emitted from these sources was set to 0% in the California BC inventory.

3. Profiles 222 and 223, Paint Application

Profile 222, oil based paint application, and profile 223, water based paint application listed BC emissions as 50% of $PM_{2.5}$. Paint application is a non-combustion source and should not emit BC. The fraction of BC emitted from these sources was set to 0% in the California BC inventory.

4. Profile 424, Fireplaces and Woodstoves

Combustion conditions in residential wood combustion are more highly variable than in controlled combustion, such as motor vehicle engines. BC emission fractions depend on many factors that will change from household to household including burning apparatus, fuel type, fuel moisture, burn rate, burn temperature, and oxygen availability. The limited literature of emissions from California-specific fuel was reviewed, and indicated the percent of BC from residential fireplaces and woodstoves may be slightly lower than the listed ARB speciation profile. The percent BC was adjusted from 17.4% to 12.5%

(Houck, Chow et al. 1989, Schauer, Kleeman et al. 2001, Fine, Cass et al. 2004a, Fine, Cass et al. 2004b, Mazoleni, Zielinska et al. 2007). Though fireplaces and woodstoves likely emit different fractions of BC, there is insufficient literature on California-specific fuels to define separate speciation profiles.

5. Profile 120, Gaseous Material Combustion

Profile 120, gaseous material combustion, lists 50 percent of $PM_{2.5}$ as BC. This profile is often applied to stationary fuel combustion of natural gas, and is inconsistent with other natural gas burning profiles in the inventory. For example, speciation for residential natural gas heaters assumes 5.3 percent of $PM_{2.5}$ is BC, a factor of ten lower than for stationary natural gas combustion.

Updated speciation profiles were identified for key sources (England, Watson et al. 2007). Three speciation profiles were identified for major sources in this category, and these are used in place of Profile 120 for the respective equipment type:

- 1120 – gas-fired boilers and steam generators, 13 percent BC;
- 1121 – gas-fired process heaters, 6.3 percent BC;
- 1122 – I.C. Cycle/Cogeneration with air pollution control device, 2.5 percent BC.

IV. Wildfire Black Carbon

Wildfires constitute the largest single source of BC emissions in the 2013 California BC emission inventory, but emission estimates are also the most uncertain. As with other sources, wildfire black carbon represents elemental carbon, and therefore does not account for the warming from brown carbon.

A. $PM_{2.5}$ Emissions from Wildfire

Annual $PM_{2.5}$ emissions are calculated using geospatial fire activity and vegetation fuels data in combination with the First Order Fire Effects Model (FOFEM), which was developed for use by the fire science and air quality communities (Lutes 2013). The model accounts for vegetation fuel size class distributions, configuration, moisture content, fuel consumption and emissions associated with flaming and smoldering phases.

A series of processing steps performed in Geospatial Information System (GIS) were used to develop vegetation fuel loading and fuel moisture inputs to the model. Georeferenced fire “footprints” (polygons) were retrieved from an interagency wild and prescribed fire geodatabase (FRAP 2012). Data include location, final extent of the fire perimeter (burn area), timing, and other attributes associated with wild and prescribed fires. In prescribed burn cases where vegetation fuels were piled, polygons corresponded to the areas from which fuels were gathered. The geodatabase classifies wildfires according to management objective: suppression or non-suppression (wildfire use for resource benefit).

To develop fuel loading inputs for the model, fire footprints were spatially overlaid on the Fuel Characteristics Classification System (FCCS), a vegetation fuels raster dataset (Ottmar, Sandberg et al. 2007, McKenzie 2012). The FCCS dataset maps fuel loadings in tons per acre by fuel component size classes for categories of forest, woodland, and other vegetation communities ("fuel beds") at a 30 meter resolution. Fire footprints were used to retrieve fuel loading information at the location of each fire event. Fire footprints were also spatially overlaid on year- and month-specific fuel moisture raster datasets (WFAS 2015) to retrieve fuel moisture conditions associated with the location and time of the burn. $PM_{2.5}$ emissions from each fire in a given year are summed to provide the total annual $PM_{2.5}$ emissions.

Wildfire emissions are episodic and vary substantially from year-to-year. The California BC inventory uses the 10-year average $PM_{2.5}$ emissions from 2001 to 2011 to avoid year-to-year variation in wildfire emissions.

B. Speciation of Wildfire Emissions

The wildfire model provides $PM_{2.5}$ emissions but does not provide an estimate of BC emissions. Identifying speciation profiles for wildfire $PM_{2.5}$ emissions is especially complicated due to the variation in parameters that affect BC emissions (fuel, moisture, flaming stage etc.). Additionally, source tests of BC emissions from wildfire are limited and difficult to measure. The available emissions estimates for open burning often use fuels that are not present in California and report high variability in results. Reported emission factors for open burning vary over two orders of magnitude, from 0.8% to 80% BC (Mazoleni, Zielinska et al. 2007, USEPA 2014).

Wildfire BC emissions are calculated using a speciation profile for brush and timber (20%) or grass fires (19%) (Appendix A). There is insufficient scientific understanding to identify more detailed speciation profiles.

The methodology to calculate emissions from wildfire in California's BC inventory necessarily utilizes data and assumptions with high uncertainty. Therefore, wildfire emission estimates should be considered an order of magnitude estimate of BC emissions in a typical year; the actual magnitude of emissions depends on a number of coarse assumptions. Much future research is needed to improve current and future wildfire BC emission estimates.

C. Comparison to Other Wildfire Black Carbon Inventories

1. Air Resources Board 2010 California Black Carbon Inventory

An estimate of California's 2010 BC emissions was presented in the first update to the ARB scoping plan (ARB 2014a). 2013 BC emissions are similar to the 2010 BC inventory with the exception of wildfire. Wildfire BC emissions were reported at approximately 19,000 tons per year in 2010, while 2013 emissions are approximately 30,000 tons per year. This result is not due to a change in wildfire activity, but is a consequence of methodology change. The 2010 wildfire speciation profile used 11% BC while the 2013 profile assumes 20% BC, causing a near doubling of BC emissions with little change to the underlying $PM_{2.5}$ emissions. The 20% speciation profile was assigned to wildfire emissions in CEPAM. Extensive review of the existing wildfire and open burning speciation profiles showed no consensus among different studies, but the median value was near 20%; therefore, the existing speciation assignment was retained. This change in emissions from wildfire between the two inventories is unrelated to trends wildfire emissions over time, as both inventories used similar ten year average $PM_{2.5}$ emissions. This methodology change illustrates the profound impact of speciation profile choice on BC emissions inventories.

2. US EPA 2005 National Black Carbon Inventory

The ARB wildfire speciation profile estimates 19% of $PM_{2.5}$ emissions are BC for grassland fires and 20% of $PM_{2.5}$ emissions are BC from timber and brush fires. By comparison USEPA estimates 9% of $PM_{2.5}$ emissions from wildfire are BC (USEPA 2012, Table 4-2). The USEPA composite profile is based on two sources (USEPA 2014): 1) four samples of Pinyon-Juniper range fire collected near Dinosaur, CO (3.2% EC) (Watson, Blumenthal et al. 1996) and 2) 21 samples from burning pine fence treated with creosote, Mesquite, Tamarisk, Huisache and Grass in Texas (15.8% BC). Review of the literature showed no clear consensus within the range of reported BC emission factors, which span two orders of magnitude. On average, fuels present in California exhibited a higher fraction of BC emissions (Turn, Jenkins et al. 1997, Fine, Cass et al. 2004a, Chen, Moosmüller et al. 2007, Mazoleni, Zielinska et al. 2007, McMeeking, Kreidenweis et al. 2009, Chen, Verburg et al. 2010, Hosseini, Urbanski et al. 2013) in agreement with ARB speciation profiles reporting a higher BC fraction. This result may also be an artifact of sampling and analysis methodology in different regions.

APPENDIX A

I. Speciation Profiles

ID	Name	Fraction EC
200	EVAPORATION	0
220	COATING MATERIAL EVAPORATION	0
222	PAINT APPLICATION-OIL BASED	0
223	PAINT APPLICATION-WATER BASED	0
325	GRAIN DRYING	0
353	STEEL ABRASIVE BLASTING	0.0005
416	WINDBLOWN DUST-UNPAVED RD/AREA	0.001051
470	UNPAVD RD DUST -1997 AND AFTER	0.001164
90007	EPA AVG: PRIMARY METAL PRODCN	0.00341
417	AGRICULTURAL TILLING DUST	0.003545
418	WINDBLOWN DUST - AGRIC. LANDS	0.003545
420	CONSTRUCTION DUST	0.006178
421	LANDFILL DUST	0.006178
471	PAVED RD DUST -1997 AND AFTER	0.007718
90016	EPA AVG: INDUSTRIAL MANUFAC.	0.00894
345	CALCINATION OF GYPSUM	0.01
1191	MARINE VESSELS-HFO (2.5PCT S)	0.013
90013	EPA AVG: MINERAL PRODUCTS	0.01467
393	PAVED ROAD DUST	0.015845
90002	EPA AVG: CHEMICAL MANUFACTURNG	0.01825
1122	I.C. cycle / cogeneration with APCD	0.025
473	BRAKE WEAR	0.0261
90015	EPA AVG: PULP AND PAPER INDUST	0.02634
331	PETROLEUM REFINING	0.04
116	STAT. I.C. ENGINE-DIESEL	0.04
99999	Unknown Combustion	0.04
6204	2020 SB-IDLE	0.044758
501	COMMRCL CHARBROLNG (IMPROVE)	0.048143
423	LIVESTOCK OPERATIONS DUST	0.051557
4251	MARINE VESSELS - MGO (0.1 PCT S)	0.052
122	Residential Fuel Combustion Natural Gas	0.052895
111	FUEL COMBUSTION-RESIDUAL	0.06
4252	MARINE VESSELS - MGO (0.3 PCT S)	0.061
502	COOKING (IMPROVE)	0.062888
1121	Gas fired process heaters	0.063
125	PETROLEUM HEATERS-GAS	0.07
343	CEMENT PRODUCTION	0.08
351	STEEL HEAT TREATNG-SALT QUENCH	0.08
6205	2020 SB-TRANSIENT	0.084031
6304	2030 SB-IDLE	0.103073

6206	2020 TB-IDLE	0.109062
6203	2020 HDDT-TRANSIENT	0.11825
348	GLASS MELTING FURNACE	0.12
6305	2030 SB-TRANSIENT	0.123115
424	FIREPLACES AND WOODSTOVES	0.125
6207	2020 TB-TRANSIENT	0.128378
1120	Gas fired boilers and steam generators	0.13
358	ALUMINUM FOUNDRY	0.13
342	ASPHALTIC CONCRETE BATCH PLANT	0.14
131	COAL/COKE COMBUSTION	0.14
4002	GAS. VEHCL W/0 CATLTC CONVRTR	0.140601
4002	GAS. VEHCL W/0 CATLTC CONVRTR	0.140601
6303	2030 HDDT-TRANSIENT	0.148098
6301	2030 HDDT-IDLE	0.149962
114	STAT. I.C. ENGINE-DIST/DIESEL	0.15
112	FUEL COMBUSTION-DISTILLATE	0.15
151	ORCHARD HEATERS	0.15
161	INCINERATION-LIQUID FUEL	0.15
110	LIQUID MATERIAL COMBUSTION	0.15
141	AIRCRAFT-JET FUEL	0.15
6201	2020 HDDT-IDLE	0.150604
6302	2030 HDDT-CRUISE	0.152531
6307	2030 TB-TRANSIENT	0.152531
6306	2030 TB-IDLE	0.152531
440	WEED ABATEMENT BURNING	0.161796
430	AGRIC. BURNING - FIELD CROPS	0.161796
6202	2020 HDDT-CRUISE	0.181326
461	OPEN BURNING	0.193183
462	WASTE BURNING	0.193183
441	RANGE IMPROVEMENT BURNING	0.193183
123	STAT. I.C.ENGINE-GAS	0.2
115	STAT. I.C. ENGINE-GASOLINE	0.2
356	ELECTRIC ARC FURNACE	0.2
354	STEEL OPEN HEARTH FURNACE	0.2
113	UTILITY BOILERS-RESIDUAL	0.2
464	TIMBER AND BRUSH FIRES	0.202594
463	FOREST MANAGEMENT BURNING	0.202594
1412	Aircraft-Jet Fuel (130-550 ppm S)	0.208941
472	TIRE WEAR	0.22
6141	2014 HDDT-IDLE	0.221005
450	ORCHARD PRUNINGS BURNING	0.22457
341	ASPHALT ROOFING MANUFACTURE	0.24
327	COFFEE ROASTING	0.24
6144	2014 SB-IDLE	0.244691
4001	GAS. VEHICLE W/ CATLTC CONVRTR	0.251753
4001	GAS. VEHICLE W/ CATLTC CONVRTR	0.251753
6131	2013 HDDT-IDLE	0.253884
425	DIESEL VEHICLE EXHAUST	0.264363

425	DIESEL VEHICLE EXHAUST	0.264363
6121	2012 HDDT-IDLE	0.28027
133	WOOD WASTE COMBUSTION	0.3
137	UNPLANNED STRUCTURAL FIRES	0.3
324	FEED AND GRAIN OPERATIONS	0.3
349	FIBERGLASS FORMING LINE	0.3
132	STAT. I.C. ENGINE-SOLID FUEL	0.3
312	CHEMICAL FERTILIZER-UREA	0.33
6051	2005 HDDT-IDLE	0.338653
6134	2013 SB-IDLE	0.348397
6145	2014 SB-TRANSIENT	0.348628
6124	2012 SB-IDLE	0.37698
6142	2014 HDDT-CRUISE	0.382452
361	WOOD OPERATION-SANDING	0.41
362	WOOD OPERATION-RESAWING	0.42
6054	2005 SB-IDLE	0.431139
6126	2012 TB-IDLE	0.438845
6136	2013 TB-IDLE	0.446273
6143	2014 HDDT-TRANSIENT	0.446748
6146	2014 TB-IDLE	0.448685
6056	2005 TB-IDLE	0.46811
162	INCINERATION-GASEOUS FUEL	0.5
120	GASEOUS MATERIAL COMBUSTION	0.5
6052	2005 HDDT-CRUISE	0.500442
6147	2014 TB-TRANSIENT	0.503985
6133	2013 HDDT-TRANSIENT	0.517156
6132	2013 HDDT-CRUISE	0.520725
6299	2029 OFFROAD DIESEL VEHL EXST	0.533626
6135	2013 SB-TRANSIENT	0.547222
6137	2013 TB-TRANSIENT	0.55143
6122	2012 HDDT-CRUISE	0.555102
6123	2012 HDDT-TRANSIENT	0.563353
6127	2012 TB-TRANSIENT	0.602227
6125	2012 SB-TRANSIENT	0.608384
6209	2020 OFFROAD DIESEL VEHL EXST	0.610165
6057	2005 TB-TRANSIENT	0.634998
6139	2013 OFFROAD DIESEL VEHL EXST	0.63797
6129	2012 OFFROAD DIESEL VEHL EXST	0.640113
6053	2005 HDDT-TRANSIENT	0.640871
6099	2009 OFFROAD DIESEL VEHL EXST	0.646699
6055	2005 SB-TRANSIENT	0.653895

REFERENCES

ARB (2013). California Emission Inventory Develpment and Reporting System Database (CEIDARS). ARB Staff queried CEIDARS for total organic gases (TOG) emissions, and then speciated the results, http://www.arb.ca.gov/ei/general.htm.

ARB. (2014a). "First update to the climate change scoping plan building on the framework pursuant to AB32: California's global warming solutions act 2006.", from http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf.

ARB. (2014b). "GHG Emission Inventory Technical Support Document 2000-2012." from http://www.arb.ca.gov/cc/inventory/doc/methods_00-12/ghg_inventory_00-12_technical_support_document.pdf.

ARB. (2015a). "California's Greenhouse Gas Emission Inventory - 2015 Edition. Available at: www.arb.ca.gov/cc/inventory/data/data.htm."

ARB (2015b). "California Emissions Projection Analysis Model (CEPAM). 2016 Ozone SIP V1.0, base year 2012.".

ARB. (2015c). "Mobile Source Inventory, EMission FACtors (EMFAC) model 2014.", from http://www.arb.ca.gov/msei/msei.htm.

ARB. (2015d). "References: Consolidated List for Speciation Profiles.", from http://www.arb.ca.gov/ei/speciate/refspec.htm.

ARB (2016). "Methodology for Projecting California's Greenhouse Gas Emissions, Technical Support Document. 2015 Edition. Available at: http://www.arb.ca.gov/cc/inventory/slcp/slcp.htm."

Chen, L. W. A., H. Moosmüller, W. P. Arnott, J. C. Chow, J. G. Watson, R. A. Susott, R. E. Babbitt, C. E. Wold, E. N. Lincoln and W. M. Hao (2007). "Emissions from laboratory combustion of wildland fuels: Emission factors and source profiles." Environ Sci Technol **41**(12): 4317-4325.

Chen, L. W. A., P. Verburg, A. Shackelford, D. Zhu, R. Susfalk, J. C. Chow and J. G. Watson (2010). "Moisture effects on carbon and nitrogen emission from burning of wildland biomass." Atmospheric Chemistry and Physics **10**(14): 6617-6625.

Chow, J. C., J. G. Watson, D. H. Lowenthal, L.-W. A. Chen and N. Motallebi (2010). "Black and Organic Carbon Emission Inventories: Review and Application to California." Journal of the Air & Waste Management Association **60**(4): 497-507.

England, G. C., J. G. Watson, J. C. Chow, B. Zielinska, M. C. O. Chang, K. R. Loos and G. M. Hidy (2007). "Dilution-based emissions sampling from stationary sources: part 2 - gas-fired combustors compared with other fuel-fired systems." Journal of Air & Waste Management Association **57**: 79-93.

Fine, P. M., G. R. Cass and B. R. T. Simoneit (2004a). "Chemical characterization of fine particle emissions from the fireplace combustion

of wood types grown in the midwestern and western united states." Environmental Engineering Science **21**(3): 387-409.
Fine, P. M., G. R. Cass and B. R. T. Simoneit (2004b). "Chemical characterization of fine particle emissions from the wood stove combustion of prevalent united states tree species." Environmental Engineering Science **21**(6): 705-721.
FRAP (2012). "Fire and Resource Assessment Program, California Department of Forestry and Fire Protection. Fire perimeters: Fire11_1.gdb http://frap.cdf.ca.gov/data/frapgisdata-subset, accessed Nov 13, 2012."
Hosseini, S., S. P. Urbanski, P. Dixit, L. Qi, I. R. Burling, R. J. Yokelson, T. J. Johnson, M. Shrivastava, H. S. Jung, D. R. Weise, J. W. Miller and D. R. Cocker (2013). "Laboratory characterization of PM emissions from combustion of wildland biomass fuels." Journal of Geophysical Research: Atmospheres **118**(17): 9914-9929.
Houck, J. E., J. C. Chow, J. G. Watson, C. A. Simons, L. C. Pritchett, J. M. Goulet and C. A. Frazier (1989). Determination of particle size distribution and chemical composition of particulate matter from selected sources in California. I. OMNI Environmental Services.
IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. C. U. Press. Cambridge, United Kingdom and New York, NY, USA.
Lutes, D. (2013). FOFEM User Guide. R. M. R. S. Missoula Fire Laboratory, USDA Forest Service. Available at https://www.frames.gov/rcs/15000/15530.html
Mazoleni, L. R., B. Zielinska and H. Moosmüller (2007). "Emissions of levoglucosan, methoxy phenols, and organic acids from prescribed burns, laboratory combustion of wildland fuels, and residential wood combustion." Environ Sci Technol **41**(7): 2115-2122.
McKenzie, D. (2012). "FCCS Fuelbeds Across the Conterminous United States and Alaska at 30-m Resolution. Fire and Environmental Applications Research Team, Pacific Northwest Research Station, USDA Forest Service. Portland, OR. Available at http://www.fs.fed.us/pnw/fera/fccs/maps.shtml."
McMeeking, G. R., S. M. Kreidenweis, S. Baker, C. M. Carrico, J. C. Chow, J. L. Collett, W. M. Hao, A. S. Holden, T. W. Kirchstetter, W. C. Malm, H. Moosmüller, A. P. Sullivan and C. E. Wold (2009). "Emissions of trace gases and aerosols during the open combustion of biomass in the laboratory." Journal of Geophysical Research **114**(D19).
Ottmar, R., D. Sandberg, C. Riccardi and S. Prichard (2007). "An overview of the Fuel Characteristic Classification System - quantifying, classifying, and creating fuelbeds for resource planning." Canadian Journal of Forest Research **37**(12): 2383-2393.
Schauer, J. J., M. J. Kleeman, G. R. Cass and B. R. T. Simoneit (2001). "Measurement of emissions from air pollution sources. 3. C1-C29 organic

compounds from fireplace combustion of wood." Environ Sci Technol **35**(9): 1716-1728.
Turn, S. Q., B. M. Jenkins, J. C. Chow, L. C. Pritchett, D. Campbell, T. Cahill and S. A. Whalen (1997). "Elemental characterization of particulate matter emitted from biomass burning: Wind tunnel derived source profiles for herbaceous and wood fuels." Journal of Geophysical Research **102**(D3): 3683.
USEPA (2012). Report to Congress on Black Carbon.
USEPA. (2014). "SPECIATE Version 4.4." from http://www.epa.gov/ttnchie1/software/speciate/.
Watson, J. G., D. Blumenthal, J. C. Chow, C. Cahill, W. Richards, D. Dietrich, R. Morris, J. E. Houck, R. J. Dickson and S. Anderson (1996). Mt. Zirkel Wilderness Area Reasonable Attribution Study of Visibility Impariment. Volume II: Results of Data Analysis and Modeling. Prepated for the Technical Steering Committee c/o Colorado Department of Public Health and Environment Air Pollution Control Division, Denver, CO.
WFAS (2015). "Wildland Fire Assessment System: Dead fuel moistures. http://www.wfas.net/."