EMISSION FACTOR

DOCUMENTATION FOR AP-42

SECTION 2.5, OPEN BURNING

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1.0 INTRODUCTION

The document "Compilation of Air Pollution Emission Factors" (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new source categories and to update existing emission factors.

This report provides background information to support the emission factors in the open burning of solid waste section of AP-42 (Section 2.4). Specifically, this report provides the basis for adding emission factors for open burning of scrap tires and of inorganic agricultural waste.

The report is divided into the following sections: open burning of scrap tires (Section 2.0), open burning of nonagricultural waste (Section 3.0), open burning of agricultural plastic film (Section 4.0), open burning of organic agricultural waste (Section 5.0), and references (Section 6.0). A copy of the revised AP-42 section is included as Section 7.0. Each section consists of discussions of data sources used to develop the new emission factors, and presentation of the emission factors. The databases containing emissions information from the data sources are presented in Appendices A and B.

2.0 OPEN BURNING OF SCRAP TIRES

Approximately 240 million vehicle tires are scrapped annually. Although viable methods of reclamation exist, less than 25 percent are re-used or re-processed. The remaining scrap tires are discarded in illegal dumps, above ground stockpiles, or landfills.[1] However, it is very costly to cut or shred tires into a condition suitable for landfill disposal. The alternative is to dispose of tires by combusting them. Although open burning of scrap tires is not allowed as a disposal method in many states, it is not uncommon for fires to start at the tire stockpiles.

An analysis performed on the rubber portion of passenger car tires indicated that they are generally comprised of carbon, hydrogen, ash, oxygen, sulfur and nitrogen.[1] Emissions from open burning scrap tires include a variety of organic and inorganic compounds, many of which may pose health risks.

2.1 DATA SOURCES[1]

Qualitative data on the open burning of scrap tires is limited to one recent study funded by the EPA's Air and Energy Engineering Research Laboratory (AEERL). The study identified and quantified the emissions of organic and inorganic compounds from the simulated open burning of tires comprised of rubber only. Steel belted tires were not tested. Emission factors were developed in the report for large "chunks" of tires that are burned, and for smaller slices or "shredded" tires.

Test burns of scrap tires were conducted inside an outbuilding modified for small-scale combustion experiments. Emissions from the tires were transported through a duct to various sampling trains. It was determined that the tests and procedures used to measure the emissions were generally of good quality. However, original raw field data sheets and laboratory data sheets were not provided in the report, nor was the actual time for each test run. For these reasons, a rating of "C" was assigned to most of the emission factors in this reference. An emission factor rating of "D" was assigned to the polycyclic aromatic hydrocarbons (PAH's) emission factors, as AEERL's test report indicates that the volume of each sample was estimated rather than accurately measured.

2.2 EMISSIONS AND EMISSION FACTORS

Emissions from burning scrap tires are dependent on the burn rate of the tire. The AEERL study indicates that a greater potential for emissions exists at lower burn rates, such as when a tire is smoldering, rather than when it is burning out of control. Oxygen transport is the controlling mechanism for sustaining the combustion process, and the gaps between the tire material provides the major avenue of oxygen transport.

Compounds emitted from the open burning of scrap tires include particulate matter, aromatic hydrocarbons, cyclic alkanes, alkenes, dienes, sulfonated compounds, and nitrogenated hydrocarbons. These compounds emitted are grouped into the following categories: organic compounds, PAH's, and particulate metals.

2.2.1 Organic Compounds

Tests for organic emissions from open burning tires were conducted on two successive days. Volatile organic compounds were sampled using a volatile organic sampling train (VOST), and semi-volatile compounds were sampled using a XAD-2 canister. Emission factors (in mg pollutant per kg tire burned) were supplied in the study for tires burned at different rates over the two test days. A weighted average emission factor for each compound was developed using the following equation:

$$\text{Weighted Average} = \frac{EF_1\,(BR_1) + EF_2\,(BR_2) + EF_n\,(BR_n)}{BR_1 + BR_2 + BR_n}$$

Where: $EF_{1,2,...n}$ = Emission factor for each compound for burn rate 1, 2,...n. (mg/kg tire)

$BR_{1,2,...n}$ = Burn rate 1,2,...n (kg tire/hr)

The weighted average emission factors for the measured organic compounds are presented in Table 2-1. Some compounds were measured in both the VOST and XAD-2 samples. For these pollutants the largest values were used as a default value. A database containing emission factors at each burn rate is presented in Appendix A.

2.2.2 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons were sampled over the two consecutive days using a XAD-2 canister. Emission factors in the AEERL report were supplied for both a XAD-2 extract and its accompanying filter. The total emission factor was calculated by adding the filter and extract values for each day. A weighted average over the two days of testing was calculated using the formula presented in Section 2.2.1.

The weighted average emission factors are presented in Table 2-2. The database in Appendix A contains emission factors for both the XAD-2 extract and filter for the two days of testing.

2.2.3 Particulate Metals

Airborne particulate metals were sampled across two filters at different burn rates on two successive days. The emission factors were summed for the two filters. A weighted average emission factor over the two days was calculated using the equation presented in Section 2.2.1. The weighted average emission factors for the measured metals are presented in Table 2-3. Appendix A contains the emission factors at each burn rate.

3.0 OPEN BURNING OF NONAGRICULTURAL MATERIAL

New emission factors for open burning of municipal refuse and automobile components were not found. The existing emission factors were reassigned an emission factor rating of "D" because field and laboratory data sheets were not provided.

4.0 OPEN BURNING OF INORGANIC AGRICULTURAL PLASTIC FILM

Agricultural waste that is disposed of by open burning includes plastic film that has been used to control ground moisture and weeds. The plastic film is disposed of by burning the film with field crops or gathering the film into piles and then burning it.

A recent study attempted to quantify emissions from burning plastic film. As a result of this study, emission factors have been developed for various organic compounds.

4.1 DATA SOURCES[2]

A study funded by the U.S. EPA on the burning of agricultural plastic film was conducted to determine the pollutants that may be emitted during this activity. A small utility shed equipped with an air-delivery system was used to simulate pile burning and forced-air incineration of 1 pound of plastic film. Emissions were analyzed for combustion gases, volatile, semi-volatile, and particulate compounds.

The study included test burns of plastic film previously used in fields and unused plastic. Sampling was also conducted for used and unused plastic film burned with a forced air convection system to simulate air-curtain incineration. Volatile organic compounds were measured using a VOST sampling train, and semi-volatile compounds and PAH's were measured with the XAD-2 canister. It was determined that the test procedures were generally of good quality. However, original field data sheets and laboratory data sheets were not provided. For this reason arating of "C" was assigned to the emission factors derived from this reference.

4.2 EMISSIONS AND EMISSION FACTORS

As previously stated, the study identified several volatile, semi-volatile, and particulate compounds that were emitted when burning inorganic agricultural waste. The study only quantified emissions from four volatile compounds (benzene, toluene, ethylbenzene, and 1-hexene) and several PAH's.

4.2.1 Organic Compounds

Samples of 20 liters were collected using the VOST sampling train for each charge of plastic burned (0.454 kg). Emissions of benzene, toluene, ethylbenzene, and 1-hexene are reported in concentration values (mg/m^3). An emission factor in terms of milligrams emitted per kilogram burned was calculated using the following conversion:

$$\frac{\text{Emissions (mg)}}{\text{Plastic charge (kg)}} = \frac{(\text{concentration mg/m}^3)(20\ \text{l})(.001\ \text{m}^3/\text{l})}{(0.454\ \text{kg})}$$

The emission factors for benzene, toluene, ethylbenzene, and 1-hexene from burning used and unused plastic in piles and with a forced air current are presented in Table 4-1. Concentration values reported in the study are presented in Appendix B.

4.2.2 Polycyclic Aromatic Hydrocarbons

The study provided concentration values ($\mu g/m^3$) for several PAH's. These values were converted to mass flowrates using a typical sampling rate (0.1 m^3/min) and the average sampling time (1 hr) used for the XAD-2 canister. Emission factors in terms of mass emitted (µg) per mass burned (0.454 kg) were calculated using the following equation:

$$\frac{\text{Emissions } (\mu\text{g})}{\text{Plastic charge (kg)}} = \frac{(\text{concentration } \mu\text{g/m}^3)(0.1\ \text{m}^3/\text{min})(60\ \text{min})}{0.454\ \text{kg}}$$

The emission factors for the PAH's measured are presented in Table 4-2. Appendix B contains the concentration values reported in the study.

5.0 OPEN BURNING OF ORGANIC AGRICULTURAL WASTE

No new emission factors were located for this source category. However, the existing emission factors were reassigned an emission factor rating of "D" because the original references, and the corresponding field and laboratory data sheets were not found.

6.0 REFERENCES

1. Characterization of Emissions from the Simulated Open Burning of Scrap Tires, Acurex Corporation, Research Triangle Park, October 1989. U. S. Environmental Protection Agency. EPA-600/2-89-054.

2. Linak, W. P., et al., "Chemical and Biological Characterization of Products of Incomplete Combustion from the Simulated Field Burning of Agricultural Plastic" Journal of Air Pollution Control Association. Vol. 39, No. 6, June 1989.

Table 2.4-1

Emission Factors for Open Burning of Municipal Refuse

Emission Factor Rating: D

Source	Particulate	Sulfur Oxides	Carbon Monoxide	VOC[a]		Nitrogen Oxides
				Methane	Nonmethane	
Municipal Refuse[b]						
kg/Mg	8	0.5	42	6.5	15	3
lb/ton	16	1.0	85	13	30	6
Automobile Components[c]						
kg/Mg	50	Neg.	62	5	16	2
lb/ton	100	Neg.	125	10	32	4

[a]Data indicate that VOC emissions are approximately 25% methane, 8% other saturates, 18% olefins, 42% others (oxygenates, acetylene, aromatics, trace formaldehyde).

[b]References 2 and 7.

[c]Reference 2. Upholstery, belts, hoses, and tires burned together.

Table 2.4-2

Particulate Metals Emission Factors from Open Burning of Tires[a]

Emission Factor Rating: C

Tire Condition	Chunk[b]		Shredded[b]	
Pollutant	mg / kg tire	lb / 1000 tons tire	mg / kg tire	lb / 1000 tons tire
Aluminum	3.07	6.14	2.37	4.73
Antimony	2.94	5.88	2.37	4.73
Arsenic	0.05	0.10	0.20	0.40
Barium	1.46	2.92	1.18	2.35
Calcium	7.15	14.30	4.73	9.47
Chromium	1.97	3.94	1.72	3.43
Copper	0.31	0.62	0.29	0.58
Iron	11.80	23.61	8.00	15.99
Lead	0.34	0.67	0.10	0.20
Magnesium	1.04	2.07	0.75	1.49
Nickel	2.37	4.74	1.08	2.15
Selenium	0.06	0.13	0.20	0.40
Silicon	41.00	82.00	27.52	55.04
Sodium	7.68	15.36	5.82	11.63

Titanium	7.35	14.70	5.92	11.83
Vanadium	7.35	14.70	5.92	11.83
Zinc	44.96	89.92	24.75	49.51

[a]Reference 21.

[b]Values are weighted averages

Table 2.4-3

Polycyclic Aromatic Hydrocarbon Emission Factors From Open Burning Tires[a]

Emission Factor Rating: D

Tire Condition	Chunk[b,c]		Shredded[b,c]	
Pollutant	mg / kg tire	lb / 1000 tons tire	mg / kg tire	lb / 1000 tons tire
Acenaphthene	718.20	1436.40	2385.60	4771.20
Acenaphthylene	570.20	1140.40	568.08	1136.17
Anthracene	265.60	531.20	49.61	99.23
Benzo(A)pyrene	173.80	347.60	115.16	230.32
Benzo(B)fluoranthene	183.10	366.20	89.07	178.14
Benzo(G,H,I)perylene	36.20	72.40	160.84	321.68
Benzo(K)fluoranthene	281.80	563.60	100.24	200.48
Benz(A)anthracene	7.90	15.80	103.71	207.43
Chrysene	48.30	96.60	94.83	189.65
Dibenz(A,H)anthracene	54.50	109.00	0.00	0.00
Fluoranthene	42.30	84.60	463.35	926.69
Fluorene	43.40	86.80	189.49	378.98
Indeno(1,2,3-CD)pyrene	58.60	117.20	86.38	172.76
Naphthalene	0.00	0.0	490.85	981.69
Phenanthrene	28.00	56.00	252.73	505.46
Pyrene	35.20	70.40	153.49	306.98

[a]Reference 21.

[b]0.00 values indicate pollutant was not found.

[c]Values are weighted averages.

Table 2.4-4

Emission Factors for Organic Compounds from Open Burning of Tires[a]

Emission Factor Rating: C

Tire condition	Chunk[b,c]		Shredded[b,c]	
Pollutant	mg / kg tire	lb / 1000 tons tire	mg / kg tire	lb / 1000 tons tire
1,1'biphenyl, methyl	12.71	25.42	0.00	0.00
1h fluorene	191.27	382.54	315.18	630.37
1-methyl naphthalene	299.20	598.39	227.87	455.73
2-methyl naphthalene	321.47	642.93	437.06	874.12
Acenaphthalene	592.70	1185.39	549.32	1098.63
Benzaldehyde	223.34	446.68	322.05	644.10
Benzene	1526.39	3052.79	1929.93	3859.86
Benzodiazine	13.12	26.23	17.43	34.87
Benzofuran	40.62	81.24	0.00	0.00
Benzothiophene	10.31	20.62	914.91	1829.82
Benzo(B)thiophene	50.37	100.74	0.00	0.00
Benzsisothiazole	0.00	0.00	151.66	303.33
Biphenyl	190.08	380.16	329.65	659.29
Butadiene	117.14	234.28	138.97	277.95
Cyanobenzene	203.81	407.62	509.34	1018.68
Cyclopentadiene	67.40	134.80	0.00	0.00

Tire condition	Chunk[b,c]		Shredded[b,c]	
Pollutant	mg / kg tire	lb / 1000 tons tire	mg / kg tire	lb / 1000 tons tire
1,1'biphenyl, methyl	12.71	25.42	0.00	0.00
Dihydroindene	9.82	19.64	30.77	61.53
Dimethyl benzene	323.58	647.16	940.91	1881.83
Dimethyl hexadiene	6.22	12.44	73.08	146.15
Dimethyl naphthalene	35.28	70.55	155.28	310.57
Dimethyldihydro indene	5.02	10.04	27.60	55.20
Ethenyl, dimethyl benzene	11.50	23.01	196.34	392.68
Ethenyl, methyl benzene	12.48	24.95	21.99	43.98
Ethenyl benzene	539.72	1079.44	593.15	1186.31
Ethenyl cyclohexene	4.85	9.70	89.11	178.22
Ethenylmethyl benzene	103.13	206.26	234.59	469.19
Ethyenylmethly benzene	0.00	0.00	42.04	84.07
Ethyl, methyl benzene	79.29	158.58	223.79	447.58
Ethyl benzene	138.94	277.87	335.12	670.24
Ethynyl, methyl benzene	459.31	918.62	345.25	690.50
Ethynyl benzene	259.82	519.64	193.49	386.98
Heptadiene	6.40	12.79	42.12	84.24
Hexahydro azepinone	64.35	128.69	764.03	1528.05

Tire condition	Chunk[b,c]		Shredded[b,c]	
Pollutant	mg / kg tire	lb / 1000 tons tire	mg / kg tire	lb / 1000 tons tire
1,1'biphenyl, methyl	12.71	25.42	0.00	0.00
Indene	472.74	945.48	346.23	692.47
Isocyano benzene	283.78	567.55	281.13	562.25
Isocyano naphthalene	10.75	21.51	0.00	0.00
Limonene	48.11	96.22	2309.57	4619.14
Methyl, ethenyl benzene	21.15	42.30	67.05	134.10
Methyl, methylethenyl benzene	35.57	71.13	393.78	787.56
Methyl, methylethyl benzene	109.69	219.39	1385.03	2770.07
Methyl benzaldehyde	0.00	0.00	75.49	150.98
Methyl benzene	1129.80	2259.60	1395.04	2790.08
Methyl cyclohexene	3.91	7.83	33.44	66.88
Methyl hexadiene	15.59	31.18	102.20	204.40
Methyl indene	50.04	100.07	286.68	573.36
Methyl,methylethyl benzene	11.76	23.52	114.33	228.66
Methyl naphthalene	144.78	289.56	122.68	245.37
Methyl,propyl benzene	0.00	0.00	30.14	60.28
Methyl thiophene	4.39	8.78	10.52	21.03
Methylene indene	30.37	60.75	58.91	117.82

Tire condition	Chunk[b,c]		Shredded[b,c]	
Pollutant	mg / kg tire	lb / 1000 tons tire	mg / kg tire	lb / 1000 tons tire
1,1'biphenyl, methyl	12.71	25.42	0.00	0.00
Methylethyl benzene	41.40	82.79	224.23	448.46
Phenol	337.71	675.41	704.90	1409.80
Propenyl, methyl benzene	0.00	0.00	456.59	913.18
Propenyl naphthalene	26.80	53.59	0.00	0.00
Propyl benzene	19.43	38.87	215.13	430.26
Styrene	618.77	1237.53	649.92	1299.84
Tetramethyl benzene	0.00	0.00	121.72	243.44
Thiophene	17.51	35.02	31.11	62.22
Trichlorofluoromethane	138.10	276.20	0.00	0.00
Trimethyl benzene	195.59	391.18	334.80	669.59
Trimethyl naphthalene	0.00	0.00	316.26	632.52

[a]Reference 21.

[b]0.00 values indicate the pollutant was not found.

[c]Values are weight averages.

Burning techniques not significant[e]										
Asparagus[f]	20	40	75	150	10	20	33	66	3.4	1.5
Barley	11	22	78	157	2.2	4.5	7.5	15	3.8	1.7
Corn	7	14	54	108	2	4	6	12	9.4	4.2
Cotton	4	8	88	176	0.7	1.4	2.5	5	3.8	1.7
Grasses	8	16	50	101	2.2	4.5	7.5	15		
Pineapple[g]	4	8	56	112	1	2	3	6		
Rice[h]	4	9	41	83	1.2	2.4	4	8	6.7	3.0
Safflower	9	18	72	144	3	6	10	20	2.9	1.3
Sorghum	9	18	38	77	1	2	3.5	7	6.5	2.9
Sugar cane[i]	2.3-3.5	6-8.4	30-41	60-81	0.6-2	1.2-3.8	2-6	4-12	8-46	3-17
Headfire Burning[j]										
Alfalfa	23	45	53	106	4.2	8.5	14	28	1.8	0.8
Bean (red)	22	43	93	186	5.5	11	18	36	5.6	2.5
Hay (wild)	16	32	70	139	2.5	5	8.5	17	2.2	1.0
Oats	22	44	68	137	4	7.8	13	26	3.6	1.6
Pea	16	31	74	147	4.5	9	15	29	5.6	2.5
Wheat	11	22	64	128	2	4	6.5	13	4.3	1.9

Backfire Burning[k]										
Alfalfa	14	29	60	119	4.5	9	14	29	1.8	0.8
Bean (red)	7	14	72	148	3	6	10	19	5.6	2.5
Hay (wild)	8	17	75	150	2	4	6.5	13	2.2	1.0
Oats	11	21	68	136	2	4	7	14	3.6	1.6
Wheat	6	13	54	108	1.3	2.6	4.5	9	4.3	1.9
Vine Crops	3	5	26	51	0.8	1.7	3	5	5.6	2.5
Weeds										
Unspecified	8	15	42	85	1.5	3	4.5	9	7.2	3.2
Russian thistle										
(tumble	11	22	154	309	0.2	0.5	0.8	1.5	0.2	0.1
weed)	3	5	17	34	3.2	6.5	10	21		
Tales (wild										
reeds)										

Orchard Crops[d,l,m]										
Unspecified	3	6	26	52	1.2	2.5	4	8	3.6	1.6
Almond	3	6	23	46	1	2	3	6	3.6	1.6
Apple	2	4	21	42	0.5	1	1.5	3	5.2	2.3
Apricot	3	6	24	49	1	2	3	6	4	1.8
Avocado	10	21	58	116	3.8	7.5	12	25	3.4	1.5
Cherry	4	8	22	44	1.2	2.5	4	8	2.2	1.0
Citrus (orange, lemon)	3	6	40	81	1.5	3	5	9	2.2	1.0
Date palm	5	10	28	56	0.8	1.7	3	5	2.2	1.0
Fig	4	7	28	57	1.2	2.5	4	8	4.9	2.2
Nectarine	2	4	16	33	0.5	1	1.5	3	4.5	2.0
Olive	6	12	57	114	2	4	7	14	2.7	1.2
Peach	3	6	21	42	0.6	1.2	2	4	5.6	2.5
Pear	4	9	28	57	1	2	3.5	7	5.8	2.6
Prune	2	3	24	47	1	2	3	6	2.7	1.2
Walnut	3	6	24	47	1	2	3	6	2.7	1.2

Forest Residues[n]										
Unspecified	8	17	70	140	2.8	5.7	9	19	157	70
Hemlock,										
Douglas	2	4	45	90	0.6	1.2	2	4		
fir,	6	12	98	195	1.7	3.3	5.5	11		
cedar[p]										
Ponderosa pine[q]										

a Expressed as weight of pollutant emitted/weight of refuse material burned.

b Reference 12. Particulate matter from most agricultural refuse burning has been found to be in the submicrometer size range.

c Data indicate that VOC emissions average 22% methane, 7.5% other saturates, 17% olefins, 15% acetylene, 38.5% unidentified. Unidentified VOC are expected to include aldehydes, ketones, aromatics, cycloparaffins.

d References 12 - 13 for emission factors, Reference 14 for fuel loading factors.

e For these refuse materials, no significant difference exists between emissions from headfiring and backfiring.

f Factors represent emissions under typical high moisture conditions. If ferns are dried to <15% moisture, particulate emissions will be reduced by 30%, CO emissions 23%, VOC emissions 74%.

g Reference 11. When pineapple is allowed to dry to <20% moisture, as it usually is, firing technique is not important. When headfired at 20% moisture, particulate emissions will increase to 11.5 kg/Mg (23 lb/ton) and VOC will increase to 6.5 kg/Mg (13 lb/ton).

h Factors are for dry (15% moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emissions will increase to 14.5 kg/Mg (29 lb/ton), CO emissions to 80.5 kg/Mg (181 lb/ton), and VOC emissions to 11.5 kg/Mg (23 lb/ton).

i Reference 20. See Section 8.12 for discussion of sugar cane burning. The following fuel loading factors are to be used in the corresponding states: Louisiana, 8 - 13.6 Mg/hectare (3 - 5 ton/acre); Florida, 11 - 19 Mg/hectare (4 - 7 ton/acre); Hawaii, 30 - 48 Mg/hectare (11 - 17 ton/acre). For other areas, values generally increase with length of growing season. Use larger end of the emission factor range for lower loading factors.

j See text for definition of headfiring.

k See text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally to limit emissions, called into-the-wind striplighting, which is lighting fields in strips into the wind at 100 - 200 meter (300 - 600 feet) intervals.

l Orchard prunings are usually burned in piles. There are no significant differences in emissions between burning a "cold pile" and using a roll-on technique, where prunings are bulldozed onto the embers of a preceding fire.

m If orchard removal is the purpose of a burn, 66 Mg/hectare (30 ton/acre) of waste will be produced.

n Reference 10. NO_x emissions estimated at 2 kg/Mg (4 lb/ton).

o Reference 15.

p Reference 16.

TABLE 2.4-5. EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS

EMISSION FACTOR RATING: D

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c] Methane		VOC[c] Nonmethane		Fuel Loading Factors (waste production)	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Field Crops[d]										
Unspecified	11	21	58	117	2.7	5.4	9	18	4.5	2

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c] Methane		VOC[c] Nonmethane		Fuel Loading Factors (waste production)	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Burning techniques not significant[e]										
Asparagus[f]	20	40	75	150	10	20	33	66	3.4	1.5
Barley	11	22	78	157	2.2	4.5	7.5	15	3.8	1.7
Corn	7	14	54	108	2	4	6	12	9.4	4.2
Cotton	4	8	88	176	0.7	1.4	2.5	5	3.8	1.7
Grasses	8	16	50	101	2.2	4.5	7.5	15		
Pineapple[g]	4	8	56	112	1	2	3	6		
Rice[h]	4	9	41	83	1.2	2.4	4	8	6.7	3.0
Safflower	9	18	72	144	3	6	10	20	2.9	1.3
Sorghum	9	18	38	77	1	2	3.5	7	6.5	2.9
Sugar cane[i]	2.3-3.5	6-8.4	30-41	60-81	0.6-2	1.2-3.8	2-6	4-12	8-46	3-17

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c] Methane		VOC[c] Nonmethane		Fuel Loading Factors (waste production)	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Headfire Burning[j]										
Alfalfa	23	45	53	106	4.2	8.5	14	28	1.8	0.8
Bean (red)	22	43	93	186	5.5	11	18	36	5.6	2.5
Hay (wild)	16	32	70	139	2.5	5	8.5	17	2.2	1.0
Oats	22	44	68	137	4	7.8	13	26	3.6	1.6
Pea	16	31	74	147	4.5	9	15	29	5.6	2.5
Wheat	11	22	64	128	2	4	6.5	13	4.3	1.9
Backfire Burning[k]										
Alfalfa	14	29	60	119	4.5	9	14	29	1.8	0.8
Bean (red)	7	14	72	148	3	6	10	19	5.6	2.5
Hay (wild)	8	17	75	150	2	4	6.5	13	2.2	1.0
Oats	11	21	68	136	2	4	7	14	3.6	1.6
Wheat	6	13	54	108	1.3	2.6	4.5	9	4.3	1.9
Vine Crops	3	5	26	51	0.8	1.7	3	5	5.6	2.5

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c] Methane		VOC[c] Nonmethane		Fuel Loading Factors (waste production)	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Weeds										
Unspecified	8	15	42	85	1.5	3	4.5	9	7.2	3.2
Russian thistle										
(tumbleweed)	11	22	154	309	0.2	0.5	0.8	1.5	0.2	0.1
Tales (wild reeds)	3	5	17	34	3.2	6.5	10	21		
Orchard Crops[d,l,m]										
Unspecified	3	6	26	52	1.2	2.5	4	8	3.6	1.6
Almond	3	6	23	46	1	2	3	6	3.6	1.6
Apple	2	4	21	42	0.5	1	1.5	3	5.2	2.3
Apricot	3	6	24	49	1	2	3	6	4	1.8
Avocado	10	21	58	116	3.8	7.5	12	25	3.4	1.5
Cherry	4	8	22	44	1.2	2.5	4	8	2.2	1.0
Citrus (orange, lemon)										
Date palm	3	6	40	81	1.5	3	5	9	2.2	1.0
Fig	5	10	28	56	0.8	1.7	3	5	2.2	1.0
Nectarine	4	7	28	57	1.2	2.5	4	8	4.9	2.2
	2	4	16	33	0.5	1	1.5	3	4.5	2.0

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c] Methane		VOC[c] Nonmethane		Fuel Loading Factors (waste production)	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Olive	6	12	57	114	2	4	7	14	2.7	1.2
Peach	3	6	21	42	0.6	1.2	2	4	5.6	2.5
Pear	4	9	28	57	1	2	3.5	7	5.8	2.6
Prune	2	3	24	47	1	2	3	6	2.7	1.2
Walnut	3	6	24	47	1	2	3	6	2.7	1.2
Forest Residues[n]										
Unspecified	8	17	70	140	2.8	5.7	9	19	157	70
Hemlock, Douglas fir, cedar[p]	2	4	45	90	0.6	1.2	2	4		
Ponderosa pine[q]	6	12	98	195	1.7	3.3	5.5	11		

[a] Expressed as weight of pollutant emitted/weight of refuse material burned.

[b] Reference 12. Particulate matter from most agricultural refuse burning has been found to be in the submicrometer size range.

[c] Data indicate that VOC emissions average 22% methane, 7.5% other saturates, 17% olefins, 15% acetylene, 38.5% unidentified. Unidentified VOC are expected to include aldehydes, ketones, aromatics, cycloparaffins.

[d] References 12 - 13 for emission factors, Reference 14 for fuel loading factors.

[e] For these refuse materials, no significant difference exists between emissions from headfiring and backfiring.

[f] Factors represent emissions under typical high moisture conditions. If ferns are dried to <15% moisture, particulate emissions will be reduced by 30%, CO emissions 23%, VOC emissions 74%.

[g] Reference 11. When pineapple is allowed to dry to <20% moisture, as it usually is, firing technique is not important. When headfired at 20% moisture, particulate emissions will increase to 11.5 kg/Mg (23 lb/ton) and VOC will increase to 6.5 kg/Mg (13 lb/ton).

[h] Factors are for dry (15% moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emissions will increase to 14.5 kg/Mg (29 lb/ton), CO emissions to 80.5 kg/Mg (181 lb/ton), and VOC emissions to 11.5 kg/Mg (23 lb/ton).

[i] Reference 20. See Section 8.12 for discussion of sugar cane burning. The following fuel loading factors are to be used in the corresponding states: Louisiana, 8 - 13.6 Mg/hectare (3 - 5 ton/acre); Florida, 11 - 19 Mg/hectare (4 - 7 ton/acre); Hawaii, 30 - 48 Mg/hectare (11 - 17 ton/acre). For other areas, values generally increase with length of growing season. Use larger end of the emission factor range for lower loading factors.

[j] See text for definition of headfiring.

[k] See text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally to limit emissions, called into-the-wind striplighting, which is lighting fields in strips into the wind at 100 - 200 meter (300 - 600 feet) intervals.

[l] Orchard prunings are usually burned in piles. There are no significant differences in emissions between burning a "cold pile" and using a roll-on technique, where prunings are bulldozed onto the embers of a preceding fire.

[m] If orchard removal is the purpose of a burn, 66 Mg/hectare (30 ton/acre) of waste will be produced.

[n] Reference 10. NO_x emissions estimated at 2 kg/Mg (4 lb/ton).

[o] Reference 15.

[p] Reference 16.

TABLE 2.4-6. EMISSION FACTORS FOR LEAF BURNING[a]

EMISSION FACTOR RATING: D

Leaf Species	Particulate[b]		Carbon Monoxide		VOC[c]			
					Methane		NMOC	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton

Black Ash	18	36	63.5	127	5.5	11	13.5	27
Modesto Ash	16	32	81.5	163	5	10	12	24
White Ash	21.5	43	57	113	6.5	13	16	32
Catalpa	8.5	17	44.5	89	2.5	5	6.5	13
Horse Chesnut	27	54	73.5	147	8	17	20	40
Cottonwood	19	38	45	90	6	12	14	28
American Elm	13	26	59.5	119	4	8	9.5	19
Eucalyptus	18	36	45	90	5.5	11	13.5	27
Sweet Gum	16.5	33	70	140	5	10	12.5	25
Black Locust	35	70	65	130	11	22	26	52
Magnolia	6.5	13	27.5	55	2	4	5	10
Silver Maple	33	66	51	102	110	20	24.5	49
American Sycamore	7.5	15	57.5	115	2.5	5	5.5	11
California Sycamore	5	10	52	104	1.5	3	3.5	7
Tulip	10	20	38.5	77	3	6	7.5	15
Red Oak	46	92	68.5	137	14	28	34	69
Sugar Maple	26.5	53	54	108	8	16	20	40
Unspecified	19	38	56	112	6	12	14	28

[a] References 18 - 19. Factors are an aritmetic average of results obtained by burning high and low moisture content conical piles, ignited either at the top or around the periphery of the bottom. The windrow arrangement was only tested on Modesto Ash, Catalpa, American Elm, Sweet Gum, Silver Maple and Tulip Poplar, and results are included in the averages for these species.

[b] The majority of particulate is submicron in size.

[c] Tests indicate that VOC emissions average 29% methane, 11% other saturates, 33% olefins, 27% other (arjomatics, acetylene, oxygenates).

Table 2.4-7

Emission Factors for Organic Compounds From Burning Plastic Film[a]

Emission Factor Rating: C

Pollutant	Units	Condition of plastic			
		Unused Plastic		Used Plastic	
		Pile[b]	Forced air[c]	Pile[b]	Forced air[c]
Benzene	(mg/kg plastic)	0.0478	0.0288	0.0123	0.0244
	(lb/1000 tons plastic)	0.0955	0.0575	0.0247	0.0488
Toluene	(mg/kg plastic)	0.0046	0.0081	0.0033	0.0124
	(lb/1000 tons plastic)	0.0092	0.0161	0.0066	0.0248
Ethyl benzene	(mg/kg plastic)	0.0006	0.0029	0.0012	0.0056
	(lb/1000 tons plastic)	0.0011	0.0058	0.0025	0.0111
1-Hexene	(mg/kg plastic)	0.0010	0.0148	0.0043	0.0220
	(lb/1000 tons plastic)	0.0020	0.0296	0.0086	0.0440

[a]Reference 22

[b]Emission factors are for plastic gathered in a pile and burned.

[c]Emission factors are for plastic burned in a pile with a forced air current.

Table 2.4-8

Polycyclic Aromatic Hydrocarbon Emission Factors from Open Burning of Agricultural Plastic Film[a]

Emission Factor Rating: C

Pollutant	Units	Condition of Plastic			
		Unused plastic		Used plastic	
		Pile[b]	Forced air[c]	Pile[b]	Forced Air[c,d]
Anthracene	(ug/kg plastic film)	7.14	0.66	1.32	0.40
	(lb/1000 tons plastic film)	0.0143	0.0013	0.0026	0.0008
Benzo(A)pyrene	(ug/kg plastic film)	41.76	1.45	7.53	0.00
	(lb/1000 tons plastic film)	0.0835	0.0029	0.0151	0.0000
Benzo(B)fluoranthene	(ug/kg plastic film)	34.63	1.59	9.25	0.93
	(lb/1000 tons plastic film)	0.0693	0.0032	0.0185	0.0019
Benzo(e)pyrene	(ug/kg plastic film)	32.38	1.45	9.65	0.00
	(lb/1000 tons plastic film)	0.0648	0.0029	0.0193	0.0000
Benzo(G,H,I)perylene	(ug/kg plastic film)	49.43	2.11	14.93	0.00
	(lb/1000 tons plastic film)	0.0989	0.0042	0.0299	0.0000
Benzo(K)fluoranthene	(ug/kg plastic film)	13.74	0.66	2.51	0.00
	(lb/1000 tons plastic film)	0.0275	0.0013	0.0050	0.0000
Benz(A)anthracene	(ug/kg plastic film)	52.73	2.91	14.41	1.19
	(lb/1000 tons plastic film)	0.1055	0.0058	0.0288	0.0024
Chrysene	(ug/kg plastic film)	54.98	3.70	17.18	1.19
	(lb/1000 tons plastic film)	0.1100	0.0074	0.0344	0.0024

Pollutant	Units	Condition of Plastic			
		Unused plastic		Used plastic	
		Pile[b]	Forced air[c]	Pile[b]	Forced Air[c,d]
Fluoranthene	(ug/kg plastic film)	313.08	53.39	107.05	39.12
	(lb/1000 tons plastic film)	0.6262	0.1068	0.2141	0.0782
Indeno(1,2,3-CD)pyrene	(ug/kg plastic film)	40.04	2.78	10.70	0.00
	(lb/1000 tons plastic film)	0.0801	0.0056	0.0214	0.0000
Phenanthrene	(ug/kg plastic film)	60.40	12.56	24.05	8.72
	(lb/1000 tons plastic film)	0.1208	0.0251	0.0481	0.0174
Pyrene	(ug/kg plastic film)	203.26	18.24	58.81	5.95
	(lb/1000 tons plastic film)	0.4065	0.0365	0.1176	0.0119
Retene	(ug/kg plastic film)	32.38	2.91	18.77	3.04
	(lb/1000 tons plastic film)	0.0648	0.0058	0.0375	0.0061

[a]Reference 22.

[b]Emission factors are for plastic gathered in a pile and burned.

[c]Emission factors are for plastic burned in a pile with a forced air current.

[d]0.00 values indicate pollutant was not found.