Table 8
Emissions from burning pools of liquid fuels (mg/kg burned)

Class	Compound	Fuel oil	Crude oil
VOCs	Benzene	1022	251
	Toluene	42	
	Ethylbenzene	10	
	Xylenes	25	
	Nonane	13	
	Ethyltoluenes[a]	22	
	1,2,4-Trimethylbenzene[a]	32	
Carbonyls	Formaldehyde	303	139
	Acetaldehyde	63	32
	Acrolein	39	11
	Acetone[a]	35	20
	Propionaldehyde		
	Crotonaldehyde[a]	6	
	Methylethylketone	13	7
	Benzaldehyde[a]	104	44
	Isovaleraldehyde[a]	17	5
	Valeraldehyde[a]		
	p-Tolualdehyde[a]		13
	Methylisobutylketone	11	
	Hexanal[a]		
	2,5-Dimethylbenzaldehyde[a]	13	
PAHs	Naphthalene	162	44
	Acenaphthylene	99	4
	Acenaphthene	10	
	Fluorene	1	0.5
	1-Methylfluorene	26	0.2
	Phenanthrene	13	6
	Anthracene	15	1
	Fluoranthene	20	4
	Pyrene	2	5
	Benzo[*a*,*b*]fluorine	4	0.3
	Benzo[*a*]anthracene	5	1
	Chrysene	9	1
	Benzo[*b*&*k*]fluoranthene	7	2
	Benzo[*a*]pyrene	5	1
	Indeno[1,2,3-*cd*]pyrene	5	1
	Benzo[*g*,*h*,*i*]perylene		
PCDDs/Fs	TCDD		
	PeCDD		
	HxCDD		
	HpCDD		7.07×10^{-5}
	OCDD		1.34×10^{-4}
	TCDF		2.05×10^{-4}
	PeCDF		
	HxCDF		1.86×10^{-5}
	HpCDF		
	OCDF		
	Total PCDD/F		4.28×10^{-4}

Source. Based on pollutant concentrations from Ref. [69] and PM and CO emission factors from Ref. [25].
[a] Compound of interest not on HAP list.

characterize the PCDD/F emission factor from barrel burning [36,37]. The variation between duplicate runs of the later tests was significantly less than in the original ones. Based on these more recent studies, this source has been moved to the quantitative inventory of dioxin sources in the US [1]. Based on estimated AFs, barrel burning appears to be one of the largest measured sources of PCDD/F in the US now that maximum achievable control technology standards have been implemented for all of the major industrial PCDD/F sources (it must be noted that other non-characterized sources could be as significant as barrel burning, but no data are available). Table 9 lists the emissions for air toxics from open burning of household waste in barrels. To derive the emissions estimates in Table 10, the data for the four experimental conditions [34], were averaged, with non-detects set to zero. When compound-specific analyses were performed (e.g. PAHs, chlorobenzenes, and carbonyls), the data from the compound-specific analysis was used instead of the general screening analysis. PCDD/F and PCB data were taken from Ref. [37], and represent the average of baseline conditions reported in their experiments.

3.3.2. Landfill fires and burning dumps

For many of the same reasons that open burning of household waste in barrels is a major source of PCDDs/Fs, it is speculated that burning dumps and landfill fires might be similarly high emitters of PCDDs/Fs and other air toxics. There are currently very little data available on emissions of air toxics from these types of open burning. There were a few studies published that had data available on air toxics from research in Scandinavia. Ruokojarvi et al. [75] presented data from both intentional and spontaneous fires at municipal landfills in Finland. Ettala et al. [76] discussed occurrences and circumstances of landfill fires, also in Finland; little quantitative data were presented in this study, however. There was a study by Pettersson et al. [77] that reported on emissions of criteria pollutants from both actual and simulated fires in Sweden. Table 10 lists the emissions of air toxics from burning dumps and landfill fires. Note that data were not sufficient to convert the information to emission factor units, so only plume concentrations are reported in Table 10. In light of the lack of emission factors, a qualitative comparison was performed between landfill fires and open burning of household waste in barrels. Comparing the relative emissions of individual PAHs and PCBs to Table 9 (backyard barrel burning), the total PCBs were somewhat higher than individual PAHs in the case of the landfill fires, but an order of magnitude or so less than individual PAHs in the case of the open burning of household waste in barrels, which suggests that different combustion conditions may dominate in a landfill fire than are predominant in a backyard burning situation and that it is not appropriate to extrapolate emissions from that source to this source.

3.3.3. Tire fires

Approximately 240 million scrap rubber tires are discarded annually in the US [78,79]. Viable methods for reclamation exist. Some of the attractive options for use of scrap tires include controlled burning, either alone or with another fuel such as coal, in a variety of energy intensive

Table 9
Emissions from barrel burning of household waste (mg/kg material burned)

Class	Compound	Emissions
VOCs (1)	1,3-Butadiene	141.25
	2-Butanone	38.75
	Benzene	979.75
	Chloromethane	163.25
	Ethylbenzene	181.75
	m,*p*-Xylene	21.75
	Methylenechloride	17.00
	o-Xylene	16.25
	Styrene	527.50
	Toluene	372.00
SVOCs (1)	2,4,6-Trichlorophenol	0.19
	2,4-Dichlorophenol[a]	0.24
	2,4-Dimethylphenol[a]	17.58
	2,6-Dichlorophenol[a]	0.04
	2-Chlorophenol[a]	0.95
	2-Methylnaphthalene[a]	8.53
	2-Cresol	24.59
	3- or 4-Cresol	44.18
	Acetophenone	4.69
	Benzylalcohol[a]	4.46
	Bis(2-ethylhexyl) phthalate	23.79
	Di-*n*-butylphthalate	3.45
	Dibenzofuran	3.64
	Isophorone	9.25
	Pentachloro nitrobenzene	0.01
	Phenol	112.66
Chlorobenzenes (1)	1,3-Dichlorobenzene	0.08
	1,4-Dichlorobenzene	0.03
	1,2-Dichlorobenzene[a]	0.16
	1,3,5-Trichlorobenzene[a]	0.01
	1,2,4-Trichlorobenzene	0.10
	1,2,3-Trichlorobenzene[a]	0.11
	1,2,3,5-Tetrachloro benzene[a]	0.03
	1,2,4,5-Tetrachloro benzene[a]	0.02
	1,2,3,4-Tetrachloro benzene[a]	0.08
	1,2,3,4,5-Pentachloro benzene[a]	0.08
	Hexachlorobenzene	0.04
PAHs (1)	Acenaphthene	0.64
	Acenaphthylene	7.34
	Anthracene	1.30
	Benzo[*a*]anthracene	1.51
	Benzo[*a*]pyrene	1.40
	Benzo[*b*]fluoranthene	1.86
	Benzo[*ghi*]perylene	1.30
	Benzo[*k*]fluoranthene	0.67
	Chrysene	1.80
	Dibenzo[*ah*]anthracene	0.27
	Fluoranthene	2.77
	Fluorine	2.99
	Indeno[1,2,3-*cd*]pyrene	1.27
	Naphthalene	11.36
	Phenanthrene	5.33
	Pyrene	3.18
Carbonyls (1)	Acetaldehyde	428.40
	Acetone[a]	253.75
	Acrolein	26.65
	Benzaldehyde	152.03
	Butyraldehyde[a]	1.80
	Crotonaldehyde[a]	33.53
	Formaldehyde	443.65
	Isovaleraldehyde[a]	10.20
	p-Tolualdehyde[a]	5.85
	Propionaldehyde	112.60
PCDDs/Fs and PCBs (2)	Total PCDDs/Fs	5.80×10^{-3}
	TEQ PCDDs/Fs	7.68×10^{-5}
	Total PCBs	1.26×10^{-1}
	TEQ PCBs	1.34×10^{-6}

Source. (1) Ref. [34]. (2) Ref. [37].
[a] Compound of interest not on HAP list.

processes, such as cement kilns and utility boilers [80–82]. Another potentially attractive option is the use of ground tire material as a supplement to asphalt paving materials. The Intermodal Surface Transportation Efficiency Act [83] mandates that up to 20% of all federally funded roads in the US include as much as 20 lb (9 kg) of rubber derived from scrap tires per ton (907 kg) of asphalt by 1997. Lutes et al. [84] measured the air emissions from adding tire rubber to asphalt. In spite of these efforts, less than 25% of the total amount of discarded tires are reused or reprocessed, and the remaining 175 million scrap tires are discarded in landfills, above-ground stockpiles, or illegal dumps. In addition,

Table 10
Emissions from burning dumps and landfill fires (ng/m^3)

Class	Compound	Controlled landfill fire	Uncontrolled landfill fire
PAHs	Acenaphthylene	90	60
	Acenaphthene	50	30
	Fluoranthene	100	50
	Phenanthrene	520	30
	Anthracene	160	85
	Fluorene	120	180
	Pyrene	120	170
	Benzo[*a*]anthracene	60	60
	Chrysene	80	70
	Benzo[*b*&*k*]fluoranthene	50	20
	Benzo[*a*]pyrene	20	15
	Indeno[1,2,3-*cd*]pyrene	10	10
	Dibenz[*a*,*h*]anthracene	10	10
	Benzo[*g*,*h*,*i*]perylene	10	10
	Total PAHs	1480	810
	Total PCBs	15.5	590

Source. Ref. [75].