ANNEX H

Methodology for Estimating CO_2 Emissions from Municipal Solid Waste Combustion

Emissions of CO_2 from MSW combustion include CO_2 generated by the combustion of plastics, synthetic rubber and synthetic fibers in MSW, and combustion of synthetic rubber and carbon black in tires. Combustion of MSW also results in emissions of N_2O. The methodology for calculating emissions from each of these waste combustion sources is described in this Annex.

CO_2 from Plastics Combustion

In the report, *Characterization of Municipal Solid Waste in the United States* (EPA 2000c), the flows of plastics in the U.S. waste stream are reported for seven resin categories. The 1998 quantity generated, recovered, and discarded for each resin is shown in Table H-1. The EPA report does not provide estimates for individual materials landfilled and combusted, although it does provide such an estimate for the waste stream as a whole. To estimate the quantity of plastics landfilled and combusted, total discards were apportioned based on the proportions of landfilling and combustion for the entire U.S. waste stream in 1998 (76 percent and 24 percent, respectively). Emissions for 1990 through 1997 were calculated using the same approach. Figures for 1999 and 2000 are calculated using 1998 resin ratios and forecasted from 1998 figures for generation and recovery using a 2.85 percent annual growth rate for plastics generation and a 5.4 percent growth rate for the plastics recovery rate, based on reported trends (EPA 2000c).

Table H-1: 1998 Plastics in the Municipal Solid Waste Stream by Resin (Gg)

Waste Pathway	PET	HDPE	PVC	LDPE/ LLDPE	PP	PS	Other	Total
Generation	2,023	4,500	1,243	4,844	2,576	1,969	3,139	**20,294**
Recovery	354	399	0	127	154	18	45	**1,098**
Discard	1,669	4,101	1,243	4,717	2,422	1,950	3,094	**19,196**
Landfill	1,269	3,116	945	3,585	1,841	1,482	2,351	**14,589**
Combustion	401	984	298	1,132	581	468	742	**4,607**
Recovery*	17%	9%	0%	3%	6%	1%	1%	**5%**
Discard*	83%	91%	100%	97%	94%	99%	99%	**95%**
Landfill*	63%	69%	76%	74%	71%	75%	75%	**72%**
Combustion*	20%	22%	24%	23%	23%	24%	24%	**23%**

*As a percent of waste generation.

Note: Totals may not sum due to independent rounding. Abbreviations: PET (polyethylene terephthalate), HDPE (high density polyethylene), PVC (polyvinyl chloride), LDPE/LLDPE (linear low density polyethylene), PP (polypropylene), PS (polystyrene).

Fossil fuel-based CO_2 emissions for 1998 were calculated as the product of plastic combusted, carbon content, and fraction oxidized (see Table H-2). The carbon content of each of the six types of plastics is listed, with the value for "other plastics" assumed equal to the weighted average of the six categories. The fraction oxidized was assumed to be 98 percent.

Table H-2: 1998 Plastics Combusted (Gg), Carbon Content (%), and Carbon Combusted (Gg)

Factor	PET	HDPE	PVC	LDPE/ LLDPE	PP	PS	Other	Total
Quantity Combusted	401	984	298	1,132	581	468	742	**4,607**
Carbon Content of Resin	63%	86%	38%	86%	86%	92%	66%[a]	**-**
Carbon in Resin Combusted	250	844	115	970	498	432	489	**3,598**
Emissions (Tg CO_2 Eq.)[b]	0.9	3.0	0.4	3.5	1.8	1.6	1.8	**12.9**

[a] Weighted average of other plastics produced in 1998 production.

[b] Assumes a fraction oxidized of 98 percent.

CO_2 from Combustion of Synthetic Rubber and Carbon Black in Tires

Emissions from tire combustion require two pieces of information: the amount of tires combusted and the carbon content of the tires. The *Scrap Tire Use/Disposal Study 1998/1999 Update* (STMC 1999) reports that 114 million of the 270 million scrap tires generated in 1998 (approximately 42 percent of generation) were used for fuel purposes. Using STMC estimates of average tire composition and weight, the weight of synthetic rubber and carbon black in scrap tires was determined. Synthetic rubber in tires was estimated to be 90 percent carbon by weight, based on the weighted average carbon contents of the major elastomers used in new tire consumption (see Table H-3).[1] Carbon black is 100 percent carbon. Multiplying the proportion of scrap tires combusted by the total carbon content of the synthetic rubber and carbon black portion of scrap tires yielded CO_2 emissions, as shown in Table H-4. Note that the disposal rate of rubber in tires (0.4 Tg/yr) is smaller than the consumption rate for tires based on summing the elastomers listed in Table H-3 (1.3 Tg/yr); this is due to the fact that much of the rubber is lost through tire wear during the product's lifetime and due to the lag time between consumption and disposal of tires. Tire production and fuel use for 1999 and 2000 were extrapolated from trend data for 1994 through 1998.

Table H-3: Elastomers Consumed in 1998 (Gg)

Elastomer	Consumed	Carbon Content	Carbon Equivalent
Styrene butadiene rubber solid	**908**	**91%**	**828**
For Tires	743	91%	677
For Other Products*	165	91%	151
Polybutadiene	**561**	**89%**	**499**
For Tires	404	89%	359
For Other Products	157	89%	140
Ethylene Propylene	**320**	**86%**	**274**
For Tires	10	86%	8
For Other Products	310	86%	266
Polychloroprene	**69**	**59%**	**40**
For Tires	0	59%	0
For Other Products	69	59%	40
Nitrile butadiene rubber solid	**87**	**77%**	**67**
For Tires	1	77%	1
For Other Products	86	77%	67
Polyisoprene	**78**	**88%**	**69**
For Tires	65	88%	57
For Other Products	13	88%	12
Others	**369**	**88%**	**324**
For Tires	63	88%	56
For Other Products	306	88%	268
Total	**2,392**	**-**	**2,101**

*Used to calculate carbon content of non-tire rubber products in municipal solid waste.
- Not applicable

Table H-4: Scrap Tire Constituents and CO_2 Emissions from Scrap Tire Combustion in 1998

Material	Weight of Material (Tg)	Carbon Content	Percent Combusted	Emissions (Tg CO_2 Eq.)*
Synthetic Rubber	0.4	90%	42%	1.1
Carbon Black	0.5	100%	42%	1.7
Total	**0.8**	**-**	**-**	**2.9**

* Assumes a fraction oxidized of 98 percent.
- Not applicable

[1] The carbon content of tires (1,158,000 Tg) divided by for the mass of tires (1,285,000 Tg) equals 90 percent.

CO_2 from Combustion of Synthetic Rubber in Municipal Solid Waste

Similar to the methodology for scrap tires, CO_2 emissions from synthetic rubber in MSW were estimated by multiplying the amount of rubber combusted by an average rubber carbon content. The amount of rubber in the MSW stream was estimated from data provided in the *Characterization of Municipal Solid Waste in the United States* (EPA 2000c). The report divides rubber found in MSW into three product categories: other durables (not including tires), non-durables (which includes clothing and footwear and other non-durables), and containers and packaging. Since there was negligible recovery for these product types, all the waste generated can be considered discarded. Similar to the plastics method, discards were apportioned based on the proportions of landfilling and combustion for the entire U.S. waste stream (76 percent and 24 percent, respectively). The report aggregates rubber and leather in the MSW stream; an assumed synthetic rubber content was assigned to each product type, as shown in Table H-5.[2] A carbon content of 85 percent was assigned to synthetic rubber for all product types, according to the weighted average carbon content of rubber consumed for non-tire uses (see Table H-4). For 1999 and 2000, waste generation values were not available so an average annual rate of increase in generation of synthetic rubber in MSW of 1.85 percent (based on statistics in EPA 2000c) was used to project generation in these years.

Table H-5: Rubber and Leather in Municipal Solid Waste in 1998

Product Type	Generation (Gg)	Synthetic Rubber (%)	Carbon Content (%)	Emissions (Tg CO_2 Eq.)*
Durables (not Tires)	**2,141**	**100%**	**85%**	**1.6**
Non-Durables	**744**	**100%**	**85%**	**0.2**
Clothing and Footwear	526	25%	85%	0.1
Other Non-Durables	218	75%	85%	0.1
Containers and Packaging	**18**	**100%**	**85%**	**+**
Total	**2,903**	**-**	**-**	**1.8**

* Assumes a fraction oxidized of 98 percent.
+ Less than 0.05 Tg CO_2 Eq.
- Not applicable

CO_2 from Combustion of Synthetic Fibers

Carbon dioxide emissions from synthetic fibers were estimated as the product of the amount of synthetic fiber discarded annually and the average carbon content of synthetic fiber. Fiber in the MSW stream was estimated from data provided in the *Characterization of Municipal Solid Waste in the United States* (EPA 2000c) for textiles. The amount of synthetic fiber in MSW was estimated by subtracting (a) the amount recovered from (b) the waste generated (see Table H-6). As with the other materials in the MSW stream, discards were apportioned based on the proportions of landfilling and combustion for the entire U.S. waste stream (76 percent and 24 percent, respectively). It was assumed that approximately 55 percent of the fiber was synthetic in origin, based on information received from the Fiber Economics Bureau (DeZan 2000). An average carbon content of 70 percent was assigned to synthetic fiber using the production-weighted average of the carbon contents of the four major fiber types (polyester, nylon, olefin, and acrylic) produced in 1998 (see Table H-7). The equation relating CO_2 emissions to the amount of textiles combusted is shown below. Since 1999 and 2000 values were not provided in the *Characterization* report, generation and recovery rates were forecast by applying their respective average annual growth rates for 1990 through 1998 to the 1998 values.

CO_2 Emissions from the Combustion of Synthetic Fibers = Annual Textile Combustion (Gg) ×

(Percent of Total Fiber that is Synthetic) × (Average Carbon Content of Synthetic Fiber) ×

(44g CO_2/12 g C)

[2] As a biogenic material, the combustion of leather is assumed to have no net carbon dioxide emissions.

Table H-6: Textiles in MSW (Gg)

Year	Generation	Recovery	Discards	Combustion
1990	2,884	328	2,557	614
1991	3,064	341	2,723	654
1992	3,225	354	2,901	696
1993	3,458	368	3,090	742
1994	3,674	382	3,291	790
1995	3,674	447	3,227	774
1996	3,832	472	3,361	807
1997	4,090	526	3,564	855
1998	4,269	551	3,781	892
1999*	4,372	566	3,805	913
2000*	4,490	584	3,906	937

*Projected using 1998 data and the 1997 to 2000 Average Annual Growth Rate for Generation (EPA 2000c).

Table H-7: Synthetic Fiber Production in 1998

Fiber	Production (Tg)	Carbon Content	Carbon Equivalent (Tg CO_2 Eq.)
Polyester	1.8	63%	4.1
Nylon	1.3	64%	3.0
Olefin	1.3	86%	4.1
Acrylic	0.2	68%	0.5
Total	**4.6**	**-**	**11.7**

- Not applicable

N_2O from Municipal Solid Waste Combustion

Estimates of N_2O emissions from MSW combustion in the United States are based on the methodology outlined in the EPA's Compilation of Air Pollutant Emission Factors (EPA 1997). According to this methodology, emissions of N_2O from MSW combustion are the product of the mass of MSW combusted, an emission factor of N_2O emitted per unit mass of waste combusted, and an N_2O emissions control removal efficiency. For MSW combustion in the United States, an emission factor of 30 g N_2O/metric ton MSW and an estimated emissions control removal efficiency of zero percent were used. No information was available on the mass of waste combusted in 2000. It was assumed for the purposes of this calculation that the mass of waste combusted in 2000 was the same as estimated for 1999.