5. Solvent and Other Product Use

Greenhouse gas emissions are produced as a by-product of various solvent and other product uses. In the United States, solvent-related activities were a minor source of U.S. anthropogenic greenhouse gas emissions, accounting for less than 0.1 percent of total emissions on a carbon equivalent basis in 2002 (see Table 5-1).

Table 5-1: N_2O Emissions from Solvent and Other Product Use

Gas/Source	1990	1996	1997	1998	1999	2000	2001	2002
Nitrous Oxide Product Usage								
Tg CO_2 Eq.	4.3	4.5	4.8	4.8	4.8	4.8	4.8	4.8
Gg	13.9	14.4	15.4	15.4	15.4	15.4	15.4	15.4

5.1. Nitrous Oxide Product Usage (IPCC Source Category 3D)

Nitrous oxide is a clear, colorless, oxidizing liquefied gas, with a slightly sweet odor. Nitrous oxide is produced by thermally decomposing ammonium nitrate (NH_4NO_3), a chemical commonly used in fertilizers and explosives. The decomposition creates steam (H_2O) and N_2O by a low pressure, low-temperature (500°F) reaction. Once the steam is condensed out, the N_2O is purified, compressed, dried, and liquefied for storage and distribution. Two manufacturers of N_2O exist in the United States (CGA 2002).

Nitrous oxide is primarily used in carrier gases with oxygen to administer more potent inhalation anesthetics for general anesthesia and as an anesthetic in various dental and veterinary applications. As such, it is used to treat short-term pain, for sedation in minor elective surgeries and as an induction anesthetic. The second main use of N_2O is as a propellant in pressure and aerosol products, the largest application being pressure-packaged whipped cream. Small quantities of N_2O are also used in the following applications:

- Oxidizing agent and etchant used in semiconductor manufacturing;
- Oxidizing agent used, with acetylene, in atomic absorption spectrometry;
- Production of sodium azide, which is used to inflate airbags;
- Fuel oxidant in auto racing; and
- Oxidizing agent in blowtorches used by jewelers and others (Heydorn 1997).

Production of N_2O in 2002 was approximately 17.0 thousand metric tons. Nitrous oxide emissions were 4.8 Tg CO_2 Eq. (15.4 Gg) in 2002 (see Table 5-2). Production of N_2O has stabilized over the past decade because medical markets have found other substitutes for anesthetics, and more medical procedures are being performed on an outpatient basis using local anesthetics that do not require N_2O. The use of N_2O as a propellant for whipped cream has also stabilized due to the increased popularity of cream products packaged in reusable plastic tubs (Heydorn 1997).

Table 5-2: N_2O Emissions from Nitrous Oxide Product Usage

Year	Tg CO_2 Eq.	Gg N_2O
1990	4.3	13.9
1996	4.5	14.4
1997	4.8	15.4
1998	4.8	15.4
1999	4.8	15.4
2000	4.8	15.4
2001	4.8	15.4
2002	4.8	15.4

Methodology

Emissions from N_2O product usage were calculated by first multiplying the total amount of N_2O produced in the United States by the share of the total quantity of N_2O that is used by each sector. This value was then multiplied by the associated emissions rate for each sector. After the emissions were calculated for each sector, they were added together to obtain a total estimate of N_2O product usage emissions. Emissions were determined using the following equation:

> Nitrous Oxide Product Usage Emissions = $\sum_i$ [Total U.S. Production of Nitrous Oxide] × [Share of Total Quantity of N_2O Usage by Sector i] × [Emissions Rate for Sector i], where i = sector.

The share of total quantity of N_2O usage by sector represents the share of national N_2O produced that is used by the specific sector (i.e., anesthesia, food processing, etc.). In 2002, the medical/dental industry used an estimated 86 percent of total N_2O produced, followed by food processing propellants at 6.5 percent. All other categories combined used the remainder of the N_2O produced (Tupman 2002). This sector breakdown has changed only slightly over the past decade. For instance, the small share of N_2O usage in the production of sodium azide has declined significantly during the decade of the 1990s. Due to the lack of information on the specific time period of the phase-out in this market sector, most of the N_2O usage for sodium azide production is assumed to have ceased after 1996, with the majority of its small share of the market assigned to the larger medical/dental consumption sector. Once the N_2O is allocated across these sectors, a usage emissions rate is then applied for each sector to estimate the amount of N_2O emitted.

Only the medical/dental and food propellant sectors are estimated to release emissions into the atmosphere, and therefore these sectors are the only usage sectors with emission rates. For the medical/dental sector, due to the poor solubility of N_2O in blood and other tissues, approximately 97.5 percent of the N_2O is not metabolized during anesthesia and quickly leaves the body in exhaled breath. Therefore, an emission factor of 97.5 percent is used for this sector (Tupman 2002). For N_2O used as a propellant in pressurized and aerosol food products, none of the N_2O is reacted during the process and all of the N_2O is emitted to the atmosphere resulting in an emissions factor of 100 percent for this sector (Heydorn 1997). For the remaining sectors, all of the N_2O is consumed/reacted during the process, and therefore the emissions rate is considered to be zero percent (Tupman 2002).

The 1990 through 1992 and 1996 N_2O production data were obtained from SRI Consulting's *Nitrous Oxide, North America* report (Heydorn 1997). These data were provided as a range. For example, in 1996, Heydorn (1997) estimates N_2O production to range between 13.6 and 18.1 thousand metric tons. Tupman (2003) was able to provide a narrower range for 1996 that falls within the production bounds described by Heydorn (1997). These data are considered more industry specific and current. The midpoint of the narrower production range (15.9 to 18.1 thousand metric tons) was used to estimate N_2O emissions for years 1993 through 2002 (Tupman 2003).

The 1996 share of the total quantity of N_2O used by each sector was obtained from SRI Consulting's *Nitrous Oxide, North America* report (Heydorn 1997). The 1990 through 1995 share of total quantity of N_2O used by each sector was kept the same as the 1996 number provided by SRI Consulting. The 1997 through 2002 share of total quantity of N_2O usage by sector was obtained from communication with a N_2O industry expert (Tupman 2003). The emissions rate for the food processing propellant industry was obtained from SRI Consulting's *Nitrous Oxide, North America* report (Heydorn 1997), and confirmed by a N_2O industry expert (Tupman 2002). The emissions rate for all other sectors was obtained from communication with a N_2O industry expert (Tupman 2002). The emissions rate for the medical/dental sector was substantiated by the *Encyclopedia of Chemical Technology* (Othmer 1990).

Table 5-3: N_2O Production (Thousand Metric Tons)

Year	Thousand Metric Tons
1990	16.3
1991	15.9
1992	15.0
1993	17.0
1994	17.0
1995	17.0
1996	17.0

1997	17.0
1998	17.0
1999	17.0
2000	17.0
2001	17.0
2002	17.0

Uncertainty

Since plant-specific N_2O production data is confidential, emissions are based on national production statistics acquired as ranges through reports and interviews with industry experts Heydorn (1997) and Tupman (2002). Based on these ranges, the uncertainty associated with the production estimate that was used to develop industry emissions in 2002 was calculated at 7 percent. Information regarding the industry specific use of N_2O is also confidential. Thus, the predicted share of the total quantities of N_2O used by each sector are somewhat uncertain because they are also based on industry expert opinion. While the level of certainty differs by industry, the market shares only vary within a range of 2 to 3 percentage points. The emissions rate for the medical/dental industry, an estimate also based on industry opinion, carries an uncertainty level of 3 percent. Unquantified areas of uncertainty include the schedule of the market decline of sodium azide production.

An uncertainty analysis, based on the Tier 1 methods found in IPCC's *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, was conducted for all inputs to the N_2O Product Usage sector analysis, including activity data, source category shares of N_2O consumption, and emission factors. The combined uncertainty of this source was calculated to be 7.2 percent.

Table 5-4: Quantitative Uncertainty Estimates for N_2O Emissions from Nitrous Oxide Product Usage (Tg CO_2 Eq. and Percent)

IPCC Source Category	Gas	Year 2002 Emissions (Tg CO_2 Eq.)	Uncertainty (%)	Uncertainty Range Relative to 2002 Emission Estimate (Tg CO_2 Eq.)	
				Lower Bound	Upper Bound
Nitrous Oxide Product Usage	N_2O	4.8	7%	4.4	5.1

Recalculations Discussion

A change was made to the shares of total N_2O usage apportioned to each sector. The emissions previously reported were based on a value, the midpoint of an industry-reported range, as the sectoral share for each sector. These midpoints however, summed across the sectors, resulted in a total appropriation above 100 percent. In order to avoid over-estimation of emissions, these midpoints were normalized so that, while their relative shares remain the same, the total equals 100 percent of total N_2O usage. This change resulted in a 0.5 percent decrease in estimated emissions for years 1997 to 2001 when compared to last year's published estimates.

Planned Improvements

Planned improvements include a continued evaluation of alternative production statistics for cross verification and a reassessment of sector usage to accurately represent the latest trends in the product usage.

5.2. Ambient Air Pollutants from Solvent Use

The use of solvents and other chemical products can result in emissions of various ozone precursors (i.e., ambient air pollutants).[1] Nonmethane volatile organic compounds (NMVOCs), commonly referred to as "hydrocarbons," are the primary gases emitted from most processes employing organic or petroleum based solvents. Surface coatings accounted for just under a majority of NMVOC emissions from solvent use—41 percent in 2002—while "non-industrial"[2] uses accounted for about 38 percent and degreasing applications for 7 percent. Overall, solvent use accounted for approximately 22 percent of total U.S. emissions of NMVOCs in 2002, and has decreased 15 percent since 1990.

Although NMVOCs are not considered direct greenhouse gases, their role as precursors to the formation of ozone—which is a greenhouse gas—results in their inclusion in a greenhouse gas inventory. Emissions from solvent use have been reported separately by the United States to be consistent with the inventory reporting guidelines recommended by the IPCC. These guidelines identify solvent use as one of the major source categories for which countries should report emissions. In the United States, emissions from solvents are primarily the result of solvent evaporation, whereby the lighter hydrocarbon molecules in the solvents escape into the atmosphere. The evaporation process varies depending on different solvent uses and solvent types. The major categories of solvent uses include: degreasing, graphic arts, surface coating, other industrial uses of solvents (i.e., electronics, etc.), dry cleaning, and non-industrial uses (i.e., uses of paint thinner, etc.). Because some of these industrial applications also employ thermal incineration as a control technology, combustion by-products (CO and NO_x) are also reported with this source category.

Total emissions of nitrogen oxides (NO_x), nonmethane volatile organic compounds (NMVOCs), and carbon monoxide (CO) from 1990 to 2002 are reported in Table 5-5.

Table 5-5: Emissions of NO_x, CO, and NMVOC from Solvent Use (Gg)

Activity	1990		1996	1997	1998	1999	2000	2001	2002
NO_x	**1**		**3**	**3**	**3**	**3**	**3**	**3**	**3**
Degreasing	+		+	+	+	+	+	+	+
Graphic Arts	+		1	1	1	+	+	+	+
Dry Cleaning	+		+	+	+	+	+	+	+
Surface Coating	1		2	2	2	3	3	3	3
Other Industrial Processes[a]	+		+	+	+	+	+	+	+
Non-Industrial Processes[b]	+		+	+	+	+	+	+	+
Other	NA		+	+	+	+	+	+	+
CO	**4**		**1**	**1**	**1**	**46**	**45**	**44**	**44**
Degreasing	+		+	+	+	+	+	+	+
Graphic Arts	+		+	+	+	+	+	+	+
Dry Cleaning	+		+	+	+	+	+	+	+
Surface Coating	+		1	1	1	46	45	44	44
Other Industrial Processes[a]	4		+	+	+	+	+	+	+
Non-Industrial Processes[b]	+		+	+	+	+	+	+	+
Other	NA		+	+	+	+	+	+	+
NMVOCs	**5,217**		**4,969**	**5,100**	**4,671**	**4,533**	**4,422**	**4,584**	**4,420**
Degreasing	675		546	566	337	360	318	334	322
Graphic Arts	249		261	266	272	222	224	230	222

[1] Solvent usage in the United States also results in the emission of small amounts of hydrofluorocarbons (HFCs) and hydrofluoroethers (HFEs), which are included under Substitution of Ozone Depleting Substances in the Industrial Processes chapter.

[2] "Non-industrial" uses include cutback asphalt, pesticide application adhesives, consumer solvents, and other miscellaneous applications.

Dry Cleaning	195		140	148	151	265	268	274	264
Surface Coating	2,289		2,155	2,228	1,989	1,851	1,782	1,878	1,811
Other Industrial Processes[a]	85		96	100	101	94	99	104	101
Non-Industrial Processes[b]	1,724		1,768	1,790	1,818	1,701	1,690	1,721	1,659
Other	+		3	3	3	40	41	43	41

[a] Includes rubber and plastics manufacturing, and other miscellaneous applications.
[b] Includes cutback asphalt, pesticide application adhesives, consumer solvents, and other miscellaneous applications.
Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.5 Gg.

Methodology

Emissions were calculated by aggregating solvent use data based on information relating to solvent uses from different applications such as degreasing, graphic arts, etc. Emission factors for each consumption category were then applied to the data to estimate emissions. For example, emissions from surface coatings were mostly due to solvent evaporation as the coatings solidify. By applying the appropriate solvent-specific emission factors to the amount of solvents used for surface coatings, an estimate of emissions was obtained. Emissions of CO and NO_x result primarily from thermal and catalytic incineration of solvent laden gas streams from painting booths, printing operations, and oven exhaust.

These emission estimates were obtained from preliminary data (EPA 2003), which, in its final iteration, will be published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site. Emissions were calculated either for individual categories or for many categories combined, using basic activity data (e.g., the amount of solvent purchased) as an indicator of emissions. National activity data were collected for individual applications from various agencies.

Activity data were used in conjunction with emission factors, which together relate the quantity of emissions to the activity. Emission factors are generally available from the EPA's *Compilation of Air Pollutant Emission Factors, AP-42* (EPA 1997). The EPA currently derives the overall emission control efficiency of a source category from a variety of information sources, including published reports, the 1985 National Acid Precipitation and Assessment Program emissions inventory, and other EPA data bases.

Uncertainty

Uncertainties in these estimates are partly due to the accuracy of the emission factors used and the reliability of correlations between activity data and actual emissions.