

## 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, emissions from Nitrous Oxide (N<sub>2</sub>O) Product Uses, the only source of greenhouse gas emissions from this sector, accounted for less than 0.1 percent of total U.S. anthropogenic greenhouse gas emissions on a CO<sub>2</sub> equivalent basis in 2009 (see Table 5-1). Indirect greenhouse gas emissions also result from solvent and other product use, and are presented in Table 5-5 in gigagrams (Gg).

Table 5-1: N<sub>2</sub>O Emissions from Solvent and Other Product Use (Tg CO<sub>2</sub> Eq. and Gg)

Gas/Source	1990	2000	2005	2006	2007	2008	2009
N <sub>2</sub> O from Product Uses							
Tg CO <sub>2</sub> Eq.	4.4	4.9	4.4	4.4	4.4	4.4	4.4
Gg	14	16	14	14	14	14	14

### 5.1. Nitrous Oxide from Product Uses (IPCC Source Category 3D)

N<sub>2</sub>O is a clear, colorless, oxidizing liquefied gas, with a slightly sweet odor. Two companies operate a total of five N<sub>2</sub>O production facilities in the United States (Airgas 2007; FTC 2001). N<sub>2</sub>O 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<sub>2</sub>O is as a propellant in pressure and aerosol products, the largest application being pressure-packaged whipped cream. Small quantities of N<sub>2</sub>O also are 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<sub>2</sub>O in 2009 was approximately 15 Gg (Table 5-2).

Table 5-2: N<sub>2</sub>O Production (Gg)

Year	Gg
1990	16
2000	17
2005	15
2006	15
2007	15
2008	15
2009	15

N<sub>2</sub>O emissions were 4.4 Tg CO<sub>2</sub> Eq. (14 Gg) in 2009 (Table 5-3). Production of N<sub>2</sub>O stabilized during the 1990s because medical markets had found other substitutes for anesthetics, and more medical procedures were being performed on an outpatient basis using local anesthetics that do not require N<sub>2</sub>O. The use of N<sub>2</sub>O 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 5-3: N<sub>2</sub>O Emissions from N<sub>2</sub>O Product Usage (Tg CO<sub>2</sub> Eq. and Gg)

Year	Tg CO <sub>2</sub> Eq.	Gg
1990	4.4	14

2000	4.9	16
2005	4.4	14
2006	4.4	14
2007	4.4	14
2008	4.4	14
2009	4.4	14

## Methodology

Emissions from N<sub>2</sub>O product usage were calculated by first multiplying the total amount of N<sub>2</sub>O produced in the United States by the share of the total quantity of N<sub>2</sub>O attributed to each end use. This value was then multiplied by the associated emission rate for each end use. After the emissions were calculated for each end use, they were added together to obtain a total estimate of N<sub>2</sub>O product usage emissions. Emissions were determined using the following equation:

$$\text{N}_2\text{O Product Usage Emissions} = \sum_i [\text{Total U.S. Production of N}_2\text{O}] \times [\text{Share of Total Quantity of N}_2\text{O Usage by Sector } i] \times [\text{Emissions Rate for Sector } i]$$

where,

i = Sector.

The share of total quantity of N<sub>2</sub>O usage by end use represents the share of national N<sub>2</sub>O produced that is used by the specific subcategory (i.e., anesthesia, food processing, etc.). In 2009, the medical/dental industry used an estimated 89.5 percent of total N<sub>2</sub>O produced, followed by food processing propellants at 6.5 percent. All other categories combined used the remainder of the N<sub>2</sub>O produced. This subcategory breakdown has changed only slightly over the past decade. For instance, the small share of N<sub>2</sub>O usage in the production of sodium azide has declined significantly during the 1990s. Due to the lack of information on the specific time period of the phase-out in this market subcategory, most of the N<sub>2</sub>O 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 subcategory (Heydorn 1997). The N<sub>2</sub>O was allocated across the following categories: medical applications, food processing propellant, and sodium azide production (pre-1996). A usage emissions rate was then applied for each sector to estimate the amount of N<sub>2</sub>O emitted.

Only the medical/dental and food propellant subcategories were estimated to release emissions into the atmosphere, and therefore these subcategories were the only usage subcategories with emission rates. For the medical/dental subcategory, due to the poor solubility of N<sub>2</sub>O in blood and other tissues, none of the N<sub>2</sub>O is assumed to be metabolized during anesthesia and quickly leaves the body in exhaled breath. Therefore, an emission factor of 100 percent was used for this subcategory (IPCC 2006). For N<sub>2</sub>O used as a propellant in pressurized and aerosol food products, none of the N<sub>2</sub>O is reacted during the process and all of the N<sub>2</sub>O is emitted to the atmosphere, resulting in an emission factor of 100 percent for this subcategory (IPCC 2006). For the remaining subcategories, all of the N<sub>2</sub>O is consumed/reacted during the process, and therefore the emission rate was considered to be zero percent (Tupman 2002).

The 1990 through 1992 N<sub>2</sub>O production data were obtained from SRI Consulting's Nitrous Oxide, North America report (Heydorn 1997). N<sub>2</sub>O production data for 1993 through 1995 were not available. Production data for 1996 was specified as a range in two data sources (Heydorn 1997, Tupman 2002). In particular, for 1996, Heydorn (1997) estimates N<sub>2</sub>O production to range between 13.6 and 18.1 thousand metric tons. Tupman (2003) provided a narrower range (15.9 to 18.1 thousand metric tons) for 1996 that falls within the production bounds described by Heydorn (1997). Tupman (2003) data are considered more industry-specific and current. Therefore, the midpoint of the narrower production range was used to estimate N<sub>2</sub>O emissions for years 1993 through 2001 (Tupman 2003). The 2002 and 2003 N<sub>2</sub>O production data were obtained from the Compressed Gas Association Nitrous Oxide Fact Sheet and Nitrous Oxide Abuse Hotline (CGA 2002, 2003). These data were also provided as a range. For example, in 2003, CGA (2003) estimates N<sub>2</sub>O production to range between 13.6 and 15.9 thousand metric tons. Due to unavailable data, production estimates for years 2004 through 2009 were held at the 2003 value.

The 1996 share of the total quantity of N<sub>2</sub>O used by each subcategory was obtained from SRI Consulting's Nitrous

Oxide, North America report (Heydorn 1997). The 1990 through 1995 share of total quantity of N<sub>2</sub>O used by each subcategory was kept the same as the 1996 number provided by SRI Consulting. The 1997 through 2001 share of total quantity of N<sub>2</sub>O usage by sector was obtained from communication with a N<sub>2</sub>O industry expert (Tupman 2002). The 2002 and 2003 share of total quantity of N<sub>2</sub>O usage by sector was obtained from CGA (2002, 2003). Due to unavailable data, the share of total quantity of N<sub>2</sub>O usage data for years 2004 through 2009 was assumed to equal the 2003 value. 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<sub>2</sub>O industry expert (Tupman 2002). The emissions rate for all other subcategories was obtained from communication with a N<sub>2</sub>O industry expert (Tupman 2002). The emissions rate for the medical/dental subcategory was obtained from the 2006 IPCC Guidelines.

## Uncertainty and Time-Series Consistency

The overall uncertainty associated with the 2009 N<sub>2</sub>O emission estimate from N<sub>2</sub>O product usage was calculated using the IPCC Guidelines for National Greenhouse Gas Inventories (2006) Tier 2 methodology. Uncertainty associated with the parameters used to estimate N<sub>2</sub>O emissions include production data, total market share of each end use, and the emission factors applied to each end use, respectively.

The results of this Tier 2 quantitative uncertainty analysis are summarized in Table 5-4. N<sub>2</sub>O emissions from N<sub>2</sub>O product usage were estimated to be between 4.1 and 4.7 Tg CO<sub>2</sub> Eq. at the 95 percent confidence level (or in 19 out of 20 Monte Carlo Stochastic Simulations). This indicates a range of approximately 8 percent below to 8 percent above the 2009 emissions estimate of 4.4 Tg CO<sub>2</sub> Eq.

Table 5-4: Tier 2 Quantitative Uncertainty Estimates for N<sub>2</sub>O Emissions from N<sub>2</sub>O Product Usage (Tg CO<sub>2</sub> Eq. and Percent)

Source	Gas	2009 Emission Estimate (Tg CO <sub>2</sub> Eq.)	Uncertainty Range Relative to Emission Estimate <sup>a</sup>			
			(Tg CO <sub>2</sub> Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
N <sub>2</sub> O Product Usage	N <sub>2</sub> O	4.4	4.1	4.7	-8%	+8%

<sup>a</sup> Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Note that this uncertainty range (±8 percent) has increased by 12 percent compared to the uncertainty range in last year's Inventory (±2 percent), due to a correction to the uncertainty input parameters. Furthermore, methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2009. Details on the emission trends through time-series are described in more detail in the Methodology section, above.

## Planned Improvements

Planned improvements include a continued evaluation of alternative production statistics for cross verification, a reassessment of N<sub>2</sub>O product use subcategories to accurately represent trends, investigation of production and use cycles, and the potential need to incorporate a time lag between production and ultimate product use and resulting release of N<sub>2</sub>O. Additionally, planned improvements include considering imports and exports of N<sub>2</sub>O for product uses.

### 5.2. Indirect Greenhouse Gas Emissions from Solvent Use

The use of solvents and other chemical products can result in emissions of various ozone precursors (i.e., indirect greenhouse gases).<sup>138</sup> Non-CH<sub>4</sub> volatile organic compounds (NMVOCs), commonly referred to as "hydrocarbons," are the primary gases emitted from most processes employing organic or petroleum based solvents. As some of industrial applications also employ thermal incineration as a control technology, combustion by-products, such as carbon monoxide (CO) and nitrogen oxides (NO<sub>x</sub>), are also reported with this source category. In the United States,

<sup>138</sup> 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.

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.).

Total emissions of NO<sub>x</sub>, NMVOCs, and CO from 1990 to 2009 are reported in Table 5-5.

Table 5-5: Emissions of NO<sub>x</sub>, CO, and NMVOC from Solvent Use (Gg)

Activity	1990	2000	2005	2006	2007	2008	2009
<b>NO<sub>x</sub></b>	<b>1</b>	<b>3</b>	<b>3</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>3</b>
Surface Coating	1	3	3	4	4	4	3
Graphic Arts	+	+	+	+	+	+	+
Degreasing	+	+	+	+	+	+	+
Dry Cleaning	+	+	+	+	+	+	+
Other Industrial Processes <sup>a</sup>	+	+	+	+	+	+	+
Non-Industrial Processes <sup>b</sup>	+	+	+	+	+	+	+
Other	NA	+	+	+	+	+	+
<b>CO</b>	<b>5</b>	<b>45</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>
Surface Coating	+	45	2	2	2	2	2
Other Industrial Processes <sup>a</sup>	4	+	+	+	+	+	+
Dry Cleaning	+	+	+	+	+	+	+
Degreasing	+	+	+	+	+	+	+
Graphic Arts	+	+	+	+	+	+	+
Non-Industrial Processes <sup>b</sup>	+	+	+	+	+	+	+
Other	NA	+	+	+	+	+	+
<b>NMVOCs</b>	<b>5,216</b>	<b>4,384</b>	<b>3,851</b>	<b>3,846</b>	<b>3,839</b>	<b>3,834</b>	<b>2,583</b>
Surface Coating	2,289	1,766	1,578	1,575	1,573	1,571	1,058
Non-Industrial Processes <sup>b</sup>	1,724	1,676	1,446	1,444	1,441	1,439	970
Degreasing	675	316	280	280	280	279	188
Dry Cleaning	195	265	230	230	229	229	154
Graphic Arts	249	222	194	193	193	193	130
Other Industrial Processes <sup>a</sup>	85	98	88	88	87	87	59
Other	+	40	36	36	36	36	24

<sup>a</sup> Includes rubber and plastics manufacturing, and other miscellaneous applications.

<sup>b</sup> 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<sub>x</sub> 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 2010, EPA 2009), and disaggregated based on 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 databases.

## Uncertainty and Time-Series Consistency

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.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2009. Details on the emission trends through time are described in more detail in the Methodology section, above.

