GREENHOUSE GASES: NITROUS OXIDE

Nitrous oxide (N_2O) is a greenhouse gas with an atmospheric lifetime of approximately 120 years. Nitrous oxide is about 310 times more effective in trapping heat in the atmosphere than carbon dioxide (CO_2) over a 100-year period. The primary sources of human-influenced emissions of N_2O are agricultural soil management, animal manure management, sewage treatment, mobile and stationary fuel combustion, adipic acid production, and nitric acid production. Nitrous oxide is also emitted naturally from a wide variety of biological sources.

Greenhouse Gas Properties

Nitrous oxide is a clear, colorless gas, with a slightly sweet odor. Due to its long atmospheric lifetime (approximately 120 years) and heat trapping effects — about 310 times more powerful than CO_2 on a per molecule basis — N_2O is an important greenhouse gas. Nitrous oxide has both natural and human-related sources, and is removed from the atmosphere mainly by photolysis (i.e., breakdown by sunlight) in the stratosphere. In the United States, the main human-related sources of N_2O are agricultural soil management, mobile and stationary combustion of fossil fuel, adipic acid production, and nitric acid production. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water. On a global basis, it is estimated that natural sources account for over 60% of the total N_2O emissions.

Atmospheric Concentrations

Global average atmospheric concentrations of N_2O have increased from about 270 parts per billion by volume (ppbv) in 1750 to 314 ppbv in 1998, which equates to a 16% increase for the period. In the last two decades, atmospheric concentrations of N_2O have continued to increase at a rate of 0.25% per year. There has been significant multi-year variance in the observed growth of N_2O concentrations, and the reasons for these trends are not yet fully understood.

Links to Atmospheric Measurement Data

The US Global Change Research Program provides access points to atmospheric measurement data related to N_2O, as well as studies of national and world N_2O emissions. The Carbon Dioxide Information Analysis Center (CDIAC) also provides access points to atmospheric measurement data related to N_2O. CDIAC's data holdings include records of the concentrations of CO_2 and other radiatively-active gases in the atmosphere and the role of the terrestrial biosphere and the oceans in the life cycles of greenhouse gases.

Where Does Nitrous Oxide Come From?

Nitrous oxide is produced by both natural and human-related sources. Primary human-related sources of N_2O are agricultural soil management, animal manure management, sewage treatment, mobile and stationary combustion of fossil fuel, adipic acid production, and nitric acid production. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests. Nitrous oxide emission levels from a source can vary significantly from one country or region to another, depending on many factors such as industrial and agricultural production characteristics, combustion technologies, waste management practices, and climate. For example, heavy

utilization of synthetic nitrogen fertilizers in crop production typically results in significantly more N_2O emissions from agricultural soils than that occurring from less intensive, low-tillage techniques. Also, the presence or absence of control devices on combustion sources, such as catalytic converters on automobiles, can have a significant effect on the level of N_2O emissions from these types of sources.

Human-Related Sources in the United States

Table 1 shows the level of emissions of N_2O from individual sources for the years 1990, 1995, 2000 and 2005 to 2008.

Table 1 U.S. Nitrous Oxide Emissions by Source ($TgCO_2$ Equivalents)

Source Category	1990	1995	2000	2005	2006	2007	2008
Agricultural Soil Management	203.5	205.9	210.1	215.8	211.2	211.0	215.9
Mobile Combustion	43.9	54.0	53.2	36.9	33.6	30.3	26.1
Nitric Acid Production	18.9	21.0	20.7	17.6	17.2	20.5	19.0
Manure Management	14.4	15.5	16.7	16.6	17.3	17.3	17.1
Stationary Combustion	12.8	13.3	14.5	14.7	14.5	14.6	14.2
Adipic Acid Production	15.8	17.6	5.5	5.0	4.3	3.7	2.0
Wastewater Treatment	3.7	4.0	4.5	4.7	4.8	4.9	4.9
N_2O from Product Uses	4.4	4.6	4.9	4.4	4.4	4.4	4.4
Forest Land Remaining Forest Land	2.7	3.7	12.1	8.4	18.0	16.7	10.1
Composting	0.4	0.8	1.4	1.7	1.8	1.8	1.8
Settlements Remaining Settlements	1.0	1.2	1.1	1.5	1.5	1.6	1.6
Field Burning of Agricultural Residues	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Incineration of Waste	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Wetlands Remaining Wetlands	+	+	+	+	+	+	+
International Bunker Fuels	1.1	0.9	0.9	1.0	1.2	1.2	1.2
Total for U.S.	**322.3**	**342.5**	**345.5**	**328.3**	**329.5**	**327.7**	**318.2**

Source: U.S. Emissions Inventory 2010: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008.

The principal human-related sources of N_2O are described below.

Agricultural soil management. Nitrous oxide is produced naturally in soils through the microbial processes of denitrification and nitrification. These natural emissions of N_2O can be increased by a variety of agricultural practices and activities, including the use of synthetic and organic fertilizers, production of nitrogen-fixing crops, cultivation of high organic content soils, and the application of livestock manure to croplands and pasture. All of these practices directly add additional nitrogen to soils, which can then be converted to N_2O. Indirect additions of

nitrogen to soils can also result in N_2O emissions. Indirect additions include those processes by which applied fertilizer or manure nitrogen volatilizes into ammonia and oxides of nitrogen and then is ultimately re-deposited onto the soil in the form of particulate ammonium, nitric acid, and oxides of nitrogen. Surface run-off and leaching of applied nitrogen into ground water and surface waters can also result in indirect additions of nitrogen to the soil.

Mobile and stationary sources of fossil fuel combustion. Nitrous oxide is a product of the reaction that occurs between nitrogen and oxygen during fossil fuel combustion. The volume emitted varies with the fuel type, technology, or pollution control device used, as well as maintenance and operating practices. For example, catalytic converters can promote the formation of N_2O, although the latest technical modifications to converters are addressing this problem.

Nitric acid production. Nitric acid is an inorganic compound used primarily as a feedstock for synthetic commercial fertilizer. It is also a major component in the production of adipic acid and explosives. Virtually all of the nitric acid produced in the United States is manufactured by the catalytic oxidation of ammonia in which N_2O is formed as a by-product and is released from reactor vents into the atmosphere.

Livestock manure management. Nitrous oxide is produced as part of the nitrogen cycle through the nitrification and denitrification of the organic nitrogen in livestock manure and urine. The production of N_2O from livestock manure depends on the composition of the manure and urine, the type of bacteria involved in the process, and the amount of oxygen and liquid in the manure system. Nitrous oxide emissions are most likely to occur in dry manure handling systems that have aerobic (in the presence of oxygen) conditions, but that also contain pockets of anaerobic (in the absence of oxygen) conditions due to saturation. It should be noted that emissions from livestock manure and urine deposited on pasture, range, or paddock lands, as well as emissions from manure and urine that is spread onto fields, are accounted for under the source category of "Agricultural Soil Management."

Human sewage. Domestic human sewage is usually mixed with other household wastewater, which includes shower drains, sink drains, washing machine effluent, etc. and transported by a collection system to either an on-site (e.g., a septic system) or centralized wastewater treatment plant. Nitrous oxide (N_2O) may be generated during both nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate via nitrification, an aerobic (in the presence of oxygen) process converting ammonia-nitrogen into nitrate (NO_3). Denitrification occurs under anaerobic conditions (in the absence of oxygen), and involves the biological conversion of nitrate into dinitrogen gas (N_2). Nitrous oxide can be an intermediate product of both these processes.

Adipic acid production. Although only responsible for about 1 percent of the total nitrous oxide emissions in the U.S., adipic acid production is an important category from an individual plant perspective and because of the efforts that have been made to reduce emissions from those plants. N_2O is generated as a by-product during the production of adipic acid which is used in the production of nylon and as a flavor enhancer for some foods. This white crystalline solid is used in the manufacture of synthetic fibers, coatings, plastics, urethane foams, elastomers, and synthetic lubricants.

Natural Sources - Global Emissions

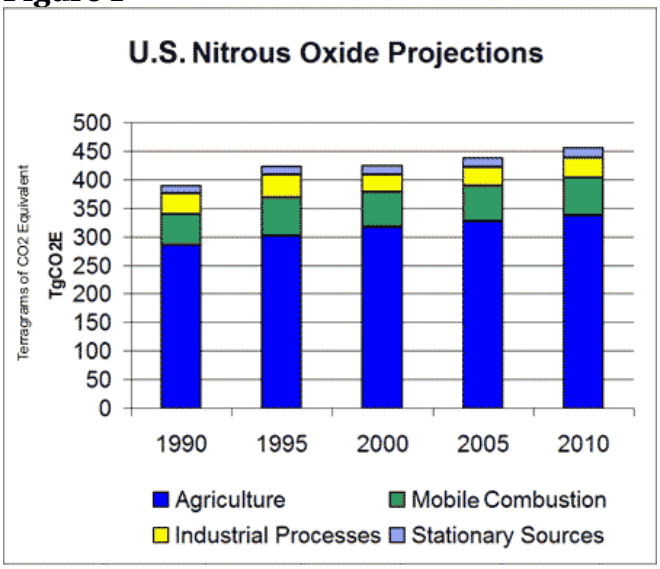
Natural emissions of N_2O primarily result from bacterial breakdown of nitrogen in soils and in the earth's oceans. Globally, soils covered by natural vegetation are estimated to produce 6.6 Tg of N_2O annually and oceans are thought to add around 5.4 Tg of N_2O annually to the atmosphere. Together, these two sources account for over 90 percent of the natural sources. Nitrous oxide is also produced in smaller quantities from chemical reactions in the atmosphere. In some ocean areas, large areas of surface water can become oxygen depleted, allowing active denitrification in open water. Large amounts of oceanic nitrous oxide can also arise from denitrification in marine sediments, particularly in nutrient rich areas such as those of estuaries.

It is important in studies of N_2O emissions to account for the various interactions between natural processes and human influences in the nitrogen cycle, since human impacts can significantly enhance the natural processes that lead to N_2O formation. For example, the nitrogen nutrient loading in water bodies due to fertilization and run-off to streams can enhance N_2O emissions from these natural sources. Human-related ammonia emissions have also been shown to cause N_2O emissions in the atmosphere through ammonia oxidation.

Projections and Mitigation Costs

EPA has developed emissions, projections and conducted economic analyses of the costs of reducing emissions of nitrous oxide (N_2O). Figure 1 shows the historical and projected emissions of N_2O in the U.S. from human-related sources, with a specific breakdown for the two largest N_2O sources, agricultural activities and mobile source combustion.

Figure 1



Source: US Emissions Inventory 2002: Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990 - 2000; Climate Action Report (2002)

At this time there are no formal EPA voluntary programs to promote N_2O reductions in specific industries. However, the historical and projected emissions shown in Figure 1 account for activities that some industries have undertaken independently to address N_2O emissions.

Future Emission Projections and Mitigation Costs

To date, EPA has conducted economic analyses on two N_2O sources: adipic and nitric acid production. EPA issued a report in 2001 that discusses N_2O emissions from adipic and nitric acid production and the technological options for reducing these emissions:

- U.S. Adipic Acid and Nitric Acid N_2O Emissions 1990-2020: Inventories, Projections and Opportunities for Reductions, December 2001 (PDF) (15 pp, 52K). This paper presents the historic and projected emissions of N_2O in the U.S. from adipic acid and nitric acid production. The paper also presents the options for further reducing N_2O from these sources and costs associated with each option.

EPA is currently in the process of estimating emission projections and costs of reducing N_2O emissions from agricultural soils.

References

- IPCC 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)].
- Methane and Nitrous Oxide Emissions From Natural Sources (PDF) (194 pp, 1.9MB, About PDF), April 2010.

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