3. Nitrous Oxide

Nitrous oxide (N_2O) is emitted from a variety of natural and anthropogenic sources. It is produced from natural microbiological processes in soil and water, as well as from human-related activities like agriculture, industry, energy, and waste management. As a result of human activity, atmospheric concentrations of nitrous oxide have risen by approximately 13 percent during the last 200 years (IPCC 1996). Nitrous oxide is estimated to be 310 times more effective at trapping heat in the atmosphere than carbon dioxide over a 100-year time period.

This chapter presents emission inventories and projections for developed countries from 1990 through 2010 for the following nitrous oxide source categories:

- Agricultural soils;
- Industrial processes: adipic acid and nitric acid production;
- Fossil fuel combustion: both stationary and mobile sources; and
- Livestock manure management.

Agricultural soils are by far the largest source of emissions, representing nearly two-thirds of N_2O emissions overall, and accounting for the majority of nitrous oxide emissions from nearly every country and region. Industrial processes and mobile sources are also important sources of N_2O.

3.1 Overview

Exhibits 3-1 and 3-2 summarize total nitrous oxide emissions estimates by sector and region for the period 1990 through 2010. More detailed nitrous oxide emissions data for each country are presented in Appendix C.

Aggregate nitrous oxide emissions from developed countries declined from 1990 to 2000, but are expected to begin to increase. Much of the initial decline was due to the economic restructuring taking place in Russia and Eastern Europe, which caused a contraction of the agricultural sectors. In the EU-15, emissions dropped primarily due to the reform of the

Exhibit 3-1: Nitrous Oxide Emissions – By Source ($MMTCO_2$)

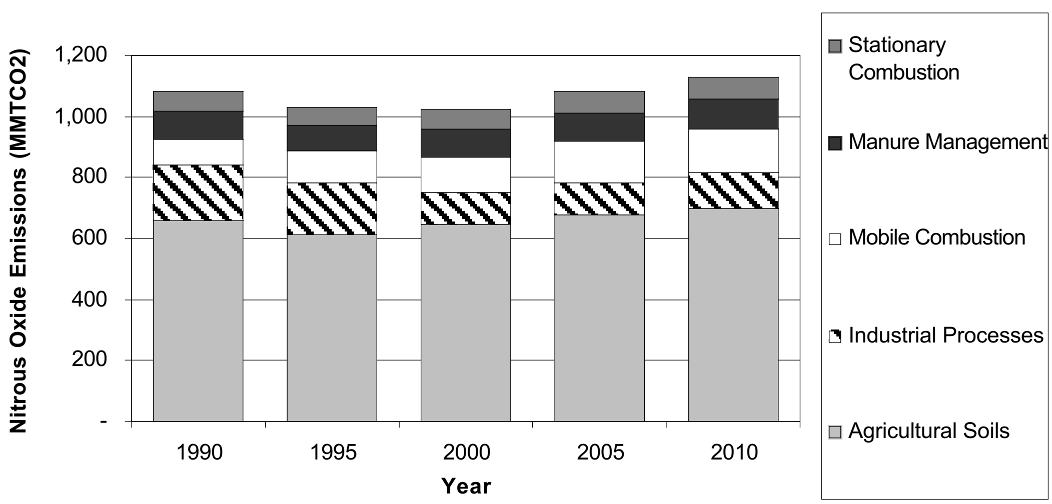


Exhibit 3-2: Total Nitrous Oxide Emissions from Developed Countries ($MMTCO_2$)

Region	1990	1995	2000	2005	2010
EU-15	371	347	307	314	318
Other Western Europe	8	8	8	8	8
Russia	79	51	57	67	74
Eastern Europe	130	89	106	122	136
AUS/NZ	29	31	34	38	39
Japan	16	18	24	28	29
Canada	60	66	64	69	73
U.S.	389	423	424	438	455
Total	1,082	1,033	1,024	1,084	1,131

Common Agricultural Policy (CAP), which shifted from production-based support to direct area-based payments. This policy change increased pressure to optimize agricultural inputs and thus reduced fertilizer use. Therefore emissions from fertilizer use and manufacturing in the EU-15 dropped significantly and are expected to continue that trend through 2010.

Although much smaller than the agricultural soil emissions, industrial and mobile source emission trends are noteworthy. In 1990, industrial processes were the second largest source, accounting for about 15 percent of total emissions. These emissions dropped dramatically in the last decade, however, they are expected to stay near 2000 levels thereafter. The installation of abatement technologies, shifts in chemical production to developing countries, and decrease in nitric acid demand have all contributed to this decrease in emissions. Emissions from mobile sources, on the other hand, have increased dramatically. This increase comes as a result of a significant increase in the number of vehicles and miles traveled, as well as increased use of NO_x abatement technologies that produce N_2O as a byproduct.

3.2 Agricultural Soils

Nitrous oxide is produced naturally as part of the nitrogen cycle in soils, through the microbial processes of denitrification and nitrification. A number of anthropogenic activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of nitrous oxide emitted. Anthropogenic activities add nitrogen to the soils both directly and indirectly.

Direct nitrogen additions occur through:

- Cropping practices:
  - ❑ Application of fertilizers;
  - ❑ Production of nitrogen-fixing crops (beans, pulses, and alfalfa);
  - ❑ Incorporation of crop residues into the soil; and
  - ❑ Cultivation of high organic content soils (histosols).
- Livestock waste management:
  - ❑ Spreading of livestock wastes on cropland and pasture; and
  - ❑ Direct deposition of wastes by grazing livestock.

Indirect additions occur through two pathways:

- Volatilization and subsequent atmospheric deposition of ammonia and oxides of nitrogen that originate from the application of fertilizers and the production of livestock wastes; and
- Surface runoff and leaching of nitrogen from the same sources.

Total Nitrous Oxide Emissions from Agricultural Soils

Year	$MMTCO_2$	Gg N_2O
1990	656	2,120
1995	614	1,980
2000	645	2,080
2005	675	2,180
2010	701	2,260

As shown in Exhibit 3-3, emissions decreased from 1990 to 1995 but are expected to increase steadily to 2010. Since the application of synthetic fertilizers is typically the largest emission sub-source for agricultural soils, the consumption of fertilizers has a significant effect on the trends.

The short-term decline resulted from agricultural policy changes in the EU-15 and economic restructuring in Eastern Europe and the FSU. The economic transitioning in Eastern Europe and FSU created a downturn in the overall economy. Due to the lowering of income, farmers purchased and used less fertilizer. During the same period, EU-15 countries also reduced their use of fertilizer as a result of the reform of the Common Agricultural Policy (CAP), which reduced market support prices to world prices and offset the impact by direct payments. EU-15 farmers had more incentive to optimize input use, including fertilizer. The reduction in fertilizer use led to a significant decrease in emissions. Only Italy, Canada, and the U.S. showed an increase in emissions from 1990 to 1995. The largest increase was in the U.S., where there was an increase in agricultural acreage and increased fertilizer use.

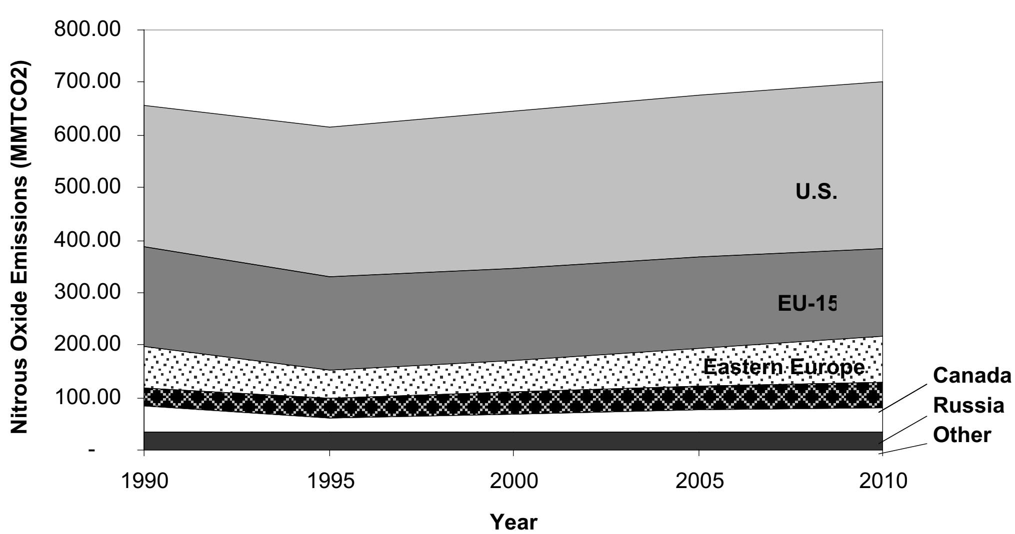
The trend through 2010 has two counteracting drivers: continued economic transitioning in Russia, Ukraine, and Eastern Europe, and continued agricultural restructuring in the EU-15. As the economies of Russia and Eastern Europe improve, N_2O emissions from soils will also increase. This increase will come as a consequence of more fertilizer use and increased livestock production. On the other hand, emissions from many EU-15 countries are decreasing, and in the rest of the EU-15 they are increasing at a lower rate than production. The decreases in fertilizer use as a result of the reform of the CAP is expected to continue. The lower emission rates per unit of production lowers overall emissions despite expected increases in production.

3.3 Industrial Processes

Nitrous oxide is emitted during the production of both adipic and nitric acid.

Adipic acid (hexane-1, 6-dioxic acid) is a white crystalline solid used as a feedstock in the manufacture of synthetic fibers, coatings, plastics, urethane foams, elastomers, and synthetic lubricants. Commercially, it is the most important of the aliphatic dicarboxylic acids, which are used to manufacture polyesters. In the U.S., for example, 90 percent of all adipic acid is used in the production of nylon 6,6 (SRI, 1998). Adipic acid is produced through a two-stage process with nitrous oxide generated in the second stage. By treating nitrogen oxides (NO_x) and other regulated pollutants in the

Exhibit 3-3: Nitrous Oxide Emissions from Agricultural Soils 1990 through 2010 ($MMTCO_2$)



waste gas stream, N_2O emissions can be reduced. Studies confirm that these abatement technologies can reduce N_2O emissions by up to 99 percent, depending on plant specifications (Riemer et al., 1999).

Nitric acid (HNO_3) is an inorganic compound used primarily to make synthetic commercial fertilizer. It is also a major component in the production of adipic acid and explosives. During the catalytic oxidation of ammonia, nitrous oxide is formed as a by-product and released from reactor vents into the atmosphere. While the waste gas stream may be cleaned of other pollutants such as nitrogen dioxide, there are currently no control measures aimed at eliminating nitrous oxide.

Total Nitrous Oxide Emissions from Industrial Processes

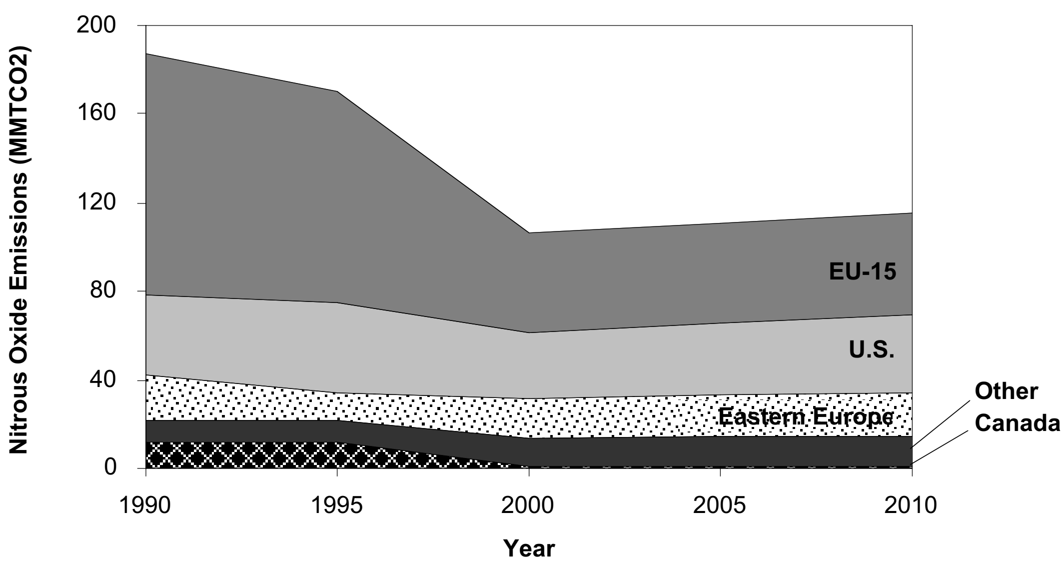
Year	$MMTCO_2$	Gg N_2O
1990	188	606
1995	170	548
2000	106	342
2005	111	358
2010	115	372

Total nitrous oxide emissions from industrial sources dropped substantially from 1990 to 2000 and are expected to remain stable through 2010, as illustrated in Exhibit 3-4.

For adipic acid, process changes and a shift in production to developing countries offset the increase in global demand. Global demand for adipic acid was 4.0 billion pounds in 1995 and was projected to be 4.8 billion pounds in 2000 (SRI, 1998). Much of this increase comes from the growing nylon 6,6 resin end-use market rather than the more mature nylon 6,6 fibers end-use market. Capacity expansions to meet this projected demand occurred in the Far East, instead of in Western Europe and North America. Additionally, industry in the U.S., EU-15, and Canada made efforts to reduce nitrous oxide emissions from the adipic acid production process in the late 1990s. As shown in Exhibit 3-4, Canada expects to reduce emissions significantly by 2000 through the phase-in of abatement technology by the sole adipic acid producer. Similarly, in the U.S., emissions dropped substantially between 1996 and 1998 due to the installation of abatement technology in two of the four plants.

Fertilizer demand, and thus nitric acid use, is expected to decline in Western Europe but increase in Eastern Europe, Ukraine, and Russia. The decline in Western Europe is due to concerns about the level of nitrates in the water supply. Since nitric acid involves

Exhibit 3-4: Nitrous Oxide Emissions from Industrial Processes 1990 through 2010 ($MMTCO_2$)



little global trade (SRI, 1998), it is expected that nitric acid production in this region will decline as well, leading to a decline in nitrous oxide emissions from this source in the EU-15. As demand for fertilizer increases in Russia, Ukraine, and Eastern Europe after 2000, so will N_2O emissions, counteracting the trend in Western Europe.

3.4 Fossil Fuel Combustion

Nitrous oxide is a product of the reaction that occurs between nitrogen and oxygen during combustion of fossil fuels and biomass. Both mobile and stationary sources emit nitrous oxide, and the volume emitted varies according to the type of fuel, combustion technology, and pollution control device used, as well as maintenance and operating practices.

3.4.1 Stationary Combustion

Stationary combustion encompasses all fossil fuel combustion activities except transportation (i.e., mobile combustion). These activities primarily include combustion of fossil fuels and commercially-traded biomass fuels used in large power plants and boilers. Total emissions from stationary combustion are small in comparison to other sources, amounting to only 7 percent of N_2O emissions from developed countries.

Emission estimates have been developed for the electric utilities sector and the manufacturing and construction industry sector. The electric power sector emits more than twice as much nitrous oxide on average as the manufacturing and construction industries combined. The commercial and residential sectors are also sources of nitrous oxide emissions but they are not analyzed in this report because emissions are believed to be much smaller.[1]

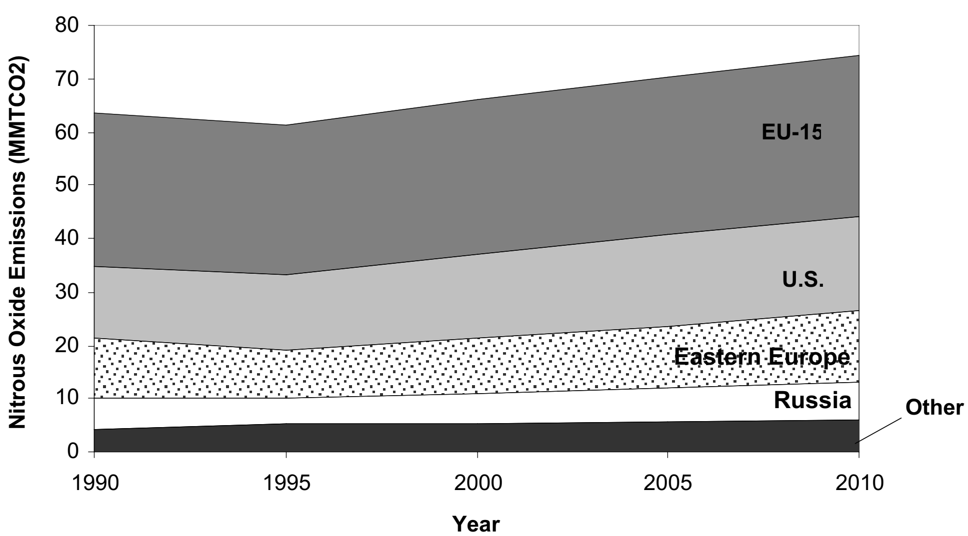
Total Nitrous Oxide Emissions from Stationary Sources

Year	$MMTCO_2$	Gg N_2O
1990	64	205
1995	61	198
2000	66	213
2005	70	227
2010	74	240

Fuel consumption and fuel type are the primary drivers of nitrous oxide emissions from stationary combustion, thus emissions from this source are largely dependent on energy demand and energy use trends.

From 1990 to 1995 the two driving forces behind the decrease in emissions, shown in Exhibit 3-5, were the

Exhibit 3-5: Nitrous Oxide Emissions from Stationary Sources 1990 through 2010 ($MMTCO_2$)



decline in energy consumption in Russia and Eastern Europe along with a shift in Western Europe from coal to natural gas. Emissions are expected to grow after 1995 because of increased energy demand. As the economies of Eastern Europe and Russia recover after 2000, energy demand is expected to rise. High emitting coal boilers and furnaces will continue to be the primary source of emissions in these regions as long as coal remains a major source of energy.

Emissions from the EU-15 are also expected to increase with energy consumption. Emissions per unit of energy will decrease, however, because of a shift from coal to natural gas, and the increased use of fluidized bed systems in coal-fired plants, which reduce nitrous oxide emissions.

3.4.2 Mobile Combustion

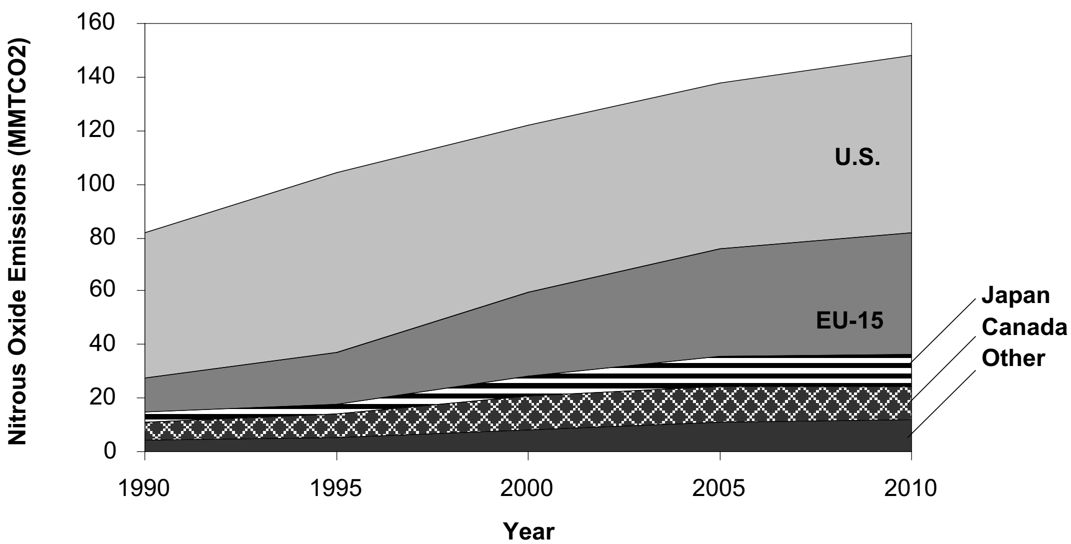
Mobile combustion sources such as automobiles and airplanes emit nitrous oxide. As with stationary sources, nitrous oxide emissions are closely related to air-fuel mixtures and combustion temperature, as well as pollution control equipment on transportation vehicles. The total distance traveled is an important factor in the emissions from all mobile sources. Road transport accounts for the majority of mobile source fuel consumption, and hence the majority of mobile nitrous oxide emissions.

Total Nitrous Oxide Emissions from Mobile Sources

Year	$MMTCO_2$	Gg N_2O
1990	82	263
1995	104	336
2000	122	393
2005	137	443
2010	148	478

The sharp increase in N_2O emissions from mobile sources seen in Exhibit 3-6 is due to two factors. First, an increasing share of the automotive fleet are equipped with emission reduction catalysts. Certain types of catalyst technologies, while achieving substantial reductions in Volatile Organic Compounds (VOCs), Carbon Monoxide (CO), and Nitrogen Oxides (NO_x), may actually result in higher nitrous oxide emissions. In the U.S. and Canada, the automobile industry is planning to phase-in new emission control technologies that produce lower N_2O emissions. The penetration of these new control technologies is expected to occur somewhat later and at a slower rate in the EU-15. Second, a substantial increase in distance traveled and fuel consumption has occurred since 1990 due to strong economic

Exhibit 3-6: Nitrous Oxide Emissions from Mobile Sources 1990 through 2010 ($MMTCO_2$)



growth and low fuel prices during the 1990s and this trend is likely to continue in the future. In the future some of this increased activity will possibly be offset by increasing energy efficiency of passenger cars.

3.5 Manure Management

As with nitrogen in soil, nitrogen in livestock manure undergoes nitrification and denitrification. The nitrous oxide emission rate depends on the system used for waste management. Emissions that occur during storage and handling of manure (i.e., before the manure is added to soils) are included in this source category; emissions associated with the land application of manure are included in the agricultural soils category.

Total Nitrous Oxide Emissions from Livestock Manure Management

Year	$MMTCO_2$	Gg N_2O
1990	94	302
1995	83	268
2000	86	277
2005	91	294
2010	94	302

As shown in Exhibit 3-7, emissions in Russia and Europe decreased between 1990 and 1995. In Russia and Eastern Europe the decrease was due to the economic decline leading to less demand for livestock products. The decline in demand resulted in a decrease in livestock populations and thus lower emissions. As the economies recover, livestock demand will increase. In the EU-15, US, Western Europe, and Australia, governments are reducing production supports. As a result, production is decreasing, leading to less manure and lower emissions. However, in many of these countries, the production decrease is offset by a change in manure management practices. As local environmental quality concerns grow, governments require more sophisticated management systems for manure, which tend to produce more nitrous oxide.

3.6 Explanatory Notes

1. U.S. emissions inventory and projections from this source include commercial and residential sector emissions.

Exhibit 3-7: Nitrous Oxide Emissions from Manure Management 1990 through 2010 ($MMTCO_2$)