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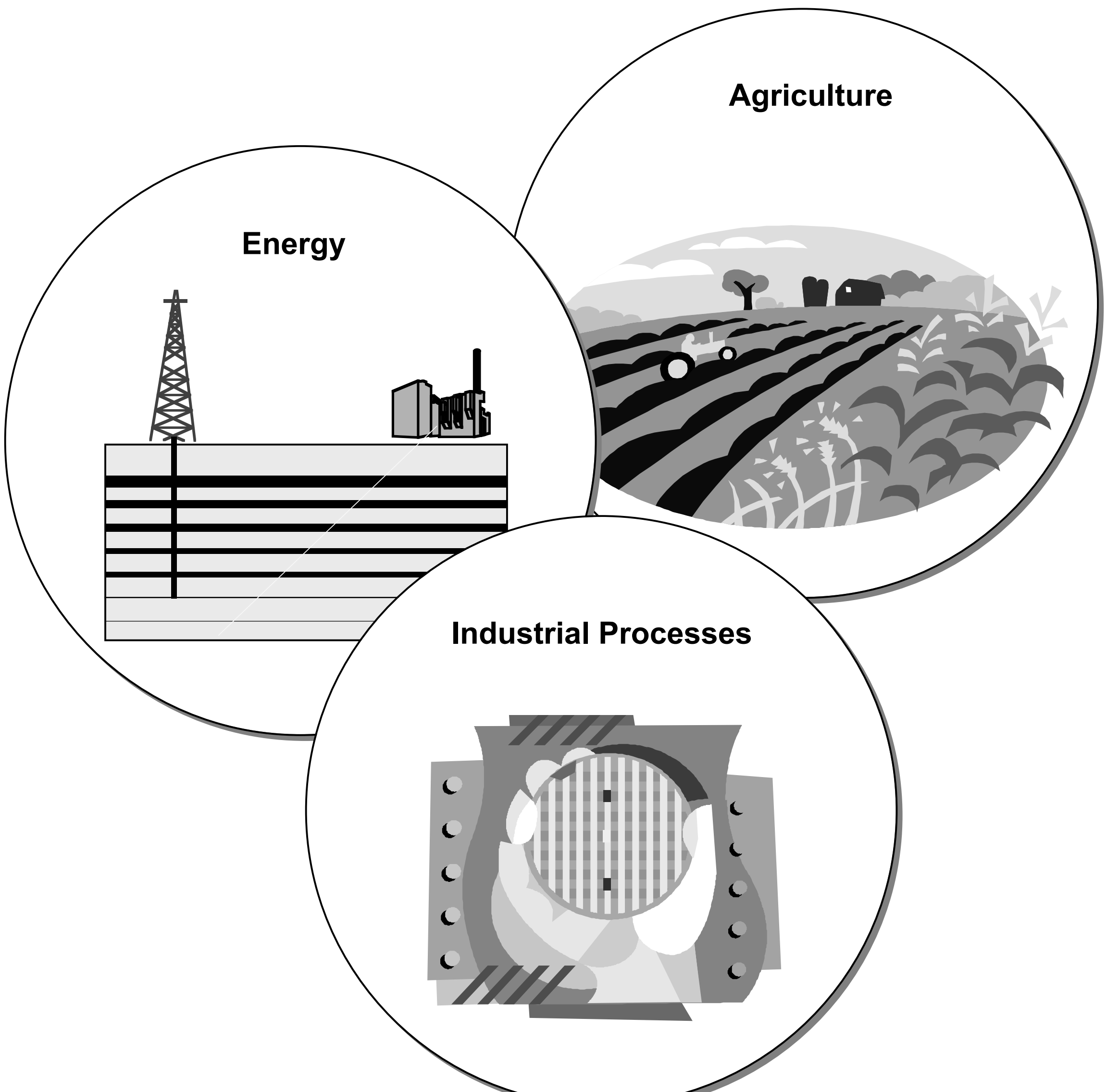
# Non-$CO_2$ Greenhouse Gas Emissions from Developed Countries: 1990-2010



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# For Further Information

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# Acknowledgements

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# 1. Introduction and Aggregate Results

While projections of carbon dioxide ($CO_2$) emissions from energy consumption are widely available, this information has been lacking for the other (non-$CO_2$) greenhouse gases (GHGs). The aim of this report is to fill this gap by presenting emissions and baseline projections of the non-$CO_2$ gases from major anthropogenic sources for all developed countries. This report provides a consistent and comprehensive estimate of non-$CO_2$ greenhouse gases that can be used to understand national contributions to climate change, mitigation opportunities and costs, and progress under the United Nations Framework Convention on Climate Change (UNFCCC).

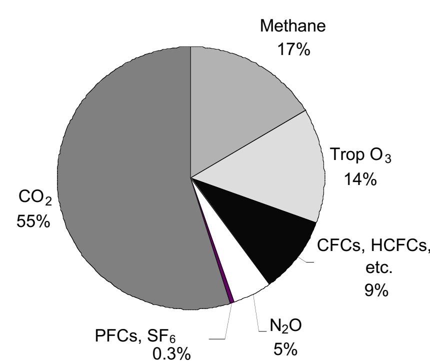
The gases included in this report are the direct greenhouse gases reported by parties to the UNFCCC: methane ($CH_4$), nitrous oxide ($N_2O$), and the high global warming potential (high GWP) gases. Historical estimates are reported for 1990 and 1995, and projections of emissions in the absence of climate measures ("Business As Usual") are provided for 2000, 2005, and 2010. Historical and future trends are shown by region and by gas. The emission estimates presented in this report are derived from publicly available country-submitted estimates, when they are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997). In specific cases, the U.S. Environmental Protection Agency (EPA) has revised the national estimates and calculated estimates where they are unavailable from country-submitted reports. Any revisions are intended to ensure overall consistency in approach, because in some cases the available estimates could not be compared to other data in their original form. These revisions and recalculations do not suggest that the country level data are inaccurate. All changes and modifications to national data have been documented.

## 1.1 Overview of Non-$CO_2$ Greenhouse Gas Emissions

Each non-$CO_2$ greenhouse gas is more effective at trapping heat than $CO_2$. As a result, emissions of these gases contribute significantly to climate change. As shown in Exhibit 1-1, global emissions of methane, nitrous oxide, and all of the high GWP gases (including Montreal Protocol Gases such as CFCs and HFCs, which are not addressed by the UNFCCC) account for approximately 30 percent of the enhanced greenhouse effect since pre-industrial times. In 1990, the non-$CO_2$ greenhouse gas emissions among the developed countries were 3,573 million metric tons of carbon dioxide equivalent ($MMTCO_2$).

A comprehensive multi-gas mitigation strategy can be less expensive and more effective in mitigating climate change than focusing on only $CO_2$. In 1999, researchers with the Massachusetts Institute of Technology demonstrated that the "inclusion of sinks and abatement opportunities from gases other than $CO_2$ could reduce the [global] cost of meeting the Kyoto Protocol by 60 percent" (Reilly et al., 1999a). Additionally, a recent National Academy of Sciences article by NASA scientists concludes that the climate forcing of direct and indirect non-$CO_2$ greenhouse gases equals that of $CO_2$ and, at this current forcing level, has contributed to at least 0.5 degrees of future temperature increase (PNAS, 2000). The anticipated

**Exhibit 1-1: Contribution of Anthropogenic Emissions of all Greenhouse Gases to the Enhanced Greenhouse Effect Since Industrial Times (measured in Watts/m²)**




Source: IPCC, 1996

future temperature increase is sensitive to atmospheric lifetimes of these gases. For example, methane remains in the atmosphere for approximately 8 to 12 years compared to 50 to 200 years for carbon dioxide (IPCC, 1996). If methane emissions were significantly reduced today, the complete effect on atmospheric concentrations could be seen within a decade, much more quickly than similar reductions in $CO_2$ emissions. Conversely, the longer lived non-$CO_2$ gases such as sulfur hexafluoride ($SF_6$) should be considered as well since any emissions of these gases will continue to affect the atmosphere for at least several hundred years.

## 1.2 Emission Sources

This report focuses exclusively on anthropogenic sources of the non-$CO_2$ direct greenhouse gases not covered by the Montreal Protocol. The emissions are converted to a $CO_2$ equivalent basis using the global warming potentials shown in Exhibit 1-2, as published by the IPCC and recognized by the UN Framework Convention on Climate Change. Exhibit 1-3 lists the source categories discussed in this report. All anthropogenic sources of methane are included, with the major sources considered individually. The major sources of nitrous oxide emissions are presented: agricultural soils, industrial processes, combustion, and manure management. The high GWP sources include substitutes for ozone depleting substances (ODS) and industrial sources of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$). More detailed information on each gas and source can be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 through 1999* (EPA, 2001) and *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997).

**Exhibit 1-2: Global Warming Potentials**

| Gas | GWP |
|---|---|
| Carbon Dioxide ($CO_2$) | 1 |
| Methane | 21 |
| Nitrous Oxide ($N_20$) | 310 |
| HFC-23 | 11,700 |
| HFC-125 | 2,800 |
| HFC-134a | 1,300 |
| HFC-143a | 3,800 |
| HFC-152a | 140 |
| HFC-227ea | 2,900 |
| HFC-236fa | 6,300 |
| HFC-4310mee | 1,300 |
| $CF_4$ | 6,500 |
| $C_2F_6$ | 9,200 |
| $C_4F_{10}$ | 7,000 |
| $C_6F_{14}$ | 7,400 |
| $SF_6$ | 23,900 |

**Exhibit 1-3: Sources Included**

| Gas | Source |
|---|---|
| Methane | Landfills<br>Coal Mining<br>Natural Gas<br>Oil Systems<br>Livestock Manure Management<br>Livestock Enteric Fermentation<br>Wastewater Treatment<br>Other Agriculture:<br>• Rice Cultivation<br>• Agricultural Residue Burning<br>• Prescribed Burning of Savannah<br>Other Non-Agriculture:<br>• Fuel Combustion<br>• Industrial Processes<br>Waste Incineration |
| Nitrous Oxide | Fossil Fuel Combustion<br>Industrial Processes<br>Agricultural Soils<br>Livestock Manure Management |
| High GWP Gases | |
| HFCs, PFCs | Substitute for Ozone-Depleting Substances |
| HFC-23 | HCFC-22 Production |
| PFCs | Aluminum Production |
| $SF_6$ | Magnesium Production<br>Electrical |
| PFCs, $SF_6$ | Semiconductor Manufacturing |

## 1.3 Approach

The analysis provides estimates for 38 developed countries for 1990, 1995, 2000, 2005, and 2010. In addition to the individual country data, EPA presents overall trends by region and by gas. The regional groupings include the 15 countries of the European Union (EU-15), other western European countries, Eastern Europe, and Australia/New Zealand. These

**Exhibit 1-4: Definition of Regional Country Groupings**

**EU-15**: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom

**Other Western**: Iceland, Liechtenstein, Monaco, Norway, Switzerland

**Eastern Europe**: Bulgaria, Croatia, Czech Republic, Estonia Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia, Ukraine

regional country groupings are further defined in Exhibit 1-4.

The emission estimates for methane, nitrous oxide, and the high GWP gases are described in Chapters 2 through 4, respectively. Chapter 5 describes in detail the methodologies used to compile the historical and projected emissions. In general, estimates were developed as follows:

- For all methane sources and the industrial sources of nitrous oxide, the primary sources of data on historical and projected emissions are National Communications and annual inventories submitted by Parties to the UNFCCC.
- For the remaining nitrous oxide sources, for many countries EPA adjusted the estimates because many Second National Communications did not use the *Revised 1996 IPCC Guidelines*. The use of these new methods for agricultural nitrous is important because the methods have improved significantly. For 1990 and 1995 historical inventories, EPA used recent annual inventories submitted to the UNFCCC, if consistent with the IPCC guidelines. The projections for 2000 to 2010 are based upon internationally recognized data sets to compute projections consistent with the *Revised 1996 IPCC Guidelines*.
- Most countries did not include detailed estimates for high GWP emissions and projections in their Second National Communications. Where estimates are available from national sources, they have been used. Otherwise, this analysis developed emission estimates for the high GWP source categories not covered by the Montreal Protocol.

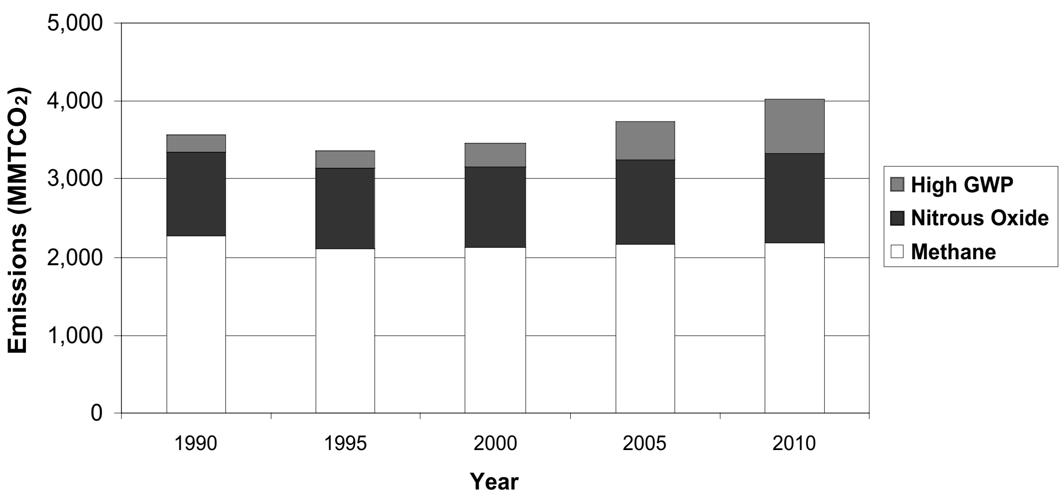
The projections in this report provide a consistent baseline to compare opportunities and costs of mitigation options across countries. In some cases, national projections were adjusted in order to remove the effects of climate policies. This step was necessary to ensure that assessments of the applicability of various mitigation options to particular sources were done on a consistent basis – in this case, one that assumed no climate policies. For this reason, actual emissions over time are likely to be lower than these business as usual (BAU) forecasts because many businesses and governments plan to implement additional actions to reduce emissions.

## 1.4 Summary Estimates

In the "Business as Usual" scenario, emissions in developed countries are projected to be 4,009 million metric tons of $CO_2$ equivalent ($MMTCO_2$) in 2010, an increase in emissions of approximately 12 percent from 1990. Emissions declined from 1990 to 1995 but will increase from 1995 through 2010. As Exhibit 1-5 shows, while methane and nitrous oxide emissions drop slightly in the middle of the period, they are generally expected to recover to the 1990 levels by 2010. High GWP gas emissions, although small in 1990, are projected to triple over the period, as new chemicals are deployed as substitutes for the ozone depleting substances being phased out under the Montreal Protocol.

There are three main driving forces for the non-$CO_2$ GHG trends in the developed countries. First, the economic transitions of several countries during the early 1990s, in particular, resulted in an emissions decline for methane and nitrous oxide. Since 1995, however, emissions have been increasing as the

**Exhibit 1-5: Evolution of Non-CO2 GHG Emissions 1990 through 2010 ($MMTCO_2$)**




economies recover. Secondly, the coal industry is undergoing restructuring in a number of countries, resulting in a sustained decrease in methane emissions. Third, there will continue to be growth in emissions of high GWP gases due to the phase out of Ozone Depleting Substances and strong predicted growth in other industrial applications.

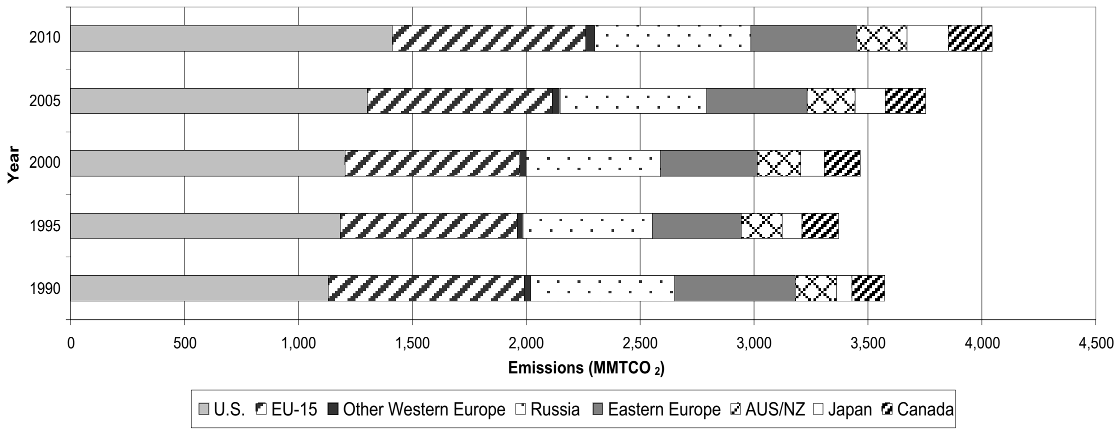
In the early 1990s, Eastern Europe and the countries of the Former Soviet Union began a rapid transformation to market economies that led to an economic downturn in many sectors, particularly agriculture and livestock. According to the most recent projections submitted in National Communications to the UNFCCC, these countries expected their economic recovery to be well underway by 2000, explaining the fall and subsequent rise in projected emissions. Based on actual experience, however, these projections may be overstated. In many cases the economies are not recovering as quickly as expected.

Additional restructuring occurred in the coal sectors of transitioning countries (EITs) as well as in other European countries. Many European countries have closed most of their gassiest underground mines, thereby reducing methane emissions significantly. Unlike the other sectors, emissions are not expected to increase as quickly since many of the mines will remain closed for the foreseeable future due to the removal of subsidies and continuation of unfavorable market conditions.

Despite the impact of major economic and sector restructuring, in the absence of climate mitigation policies, total methane emissions are projected to recover to 1990 levels by 2010. This increase is due to the expected economic recovery in EITs, and high industrial and agricultural growth in other regions. The growth in emissions is lessened somewhat by significant efforts to manage methane emissions in the waste sector. As many developed countries increasingly rely on landfills, they are also improving waste management practices, resulting in a relatively stable emission rate in spite of overall economic and population growth.

As shown in Exhibit 1-5, nitrous oxide emissions decreased only slightly between 1990 and 1995 despite the economic restructuring in several countries. Large agricultural countries with growing economies such as the U.S. and EU-15 offset the emission reductions experienced by others. However, another significant change is occurring as the second largest source of emissions shifts from industrial processes to mobile sources. In 1990, industrial processes accounted for about 15 percent of total emissions. However, these emissions drop

**Exhibit 1-6: Regional Non-$CO_2$ GHG Emissions and Projections 1990 through 2010 ($MMTCO_2$)**




dramatically from 1990 to 2000 and are expected to stay near 2000 levels out to 2010. Total $N_2O$ emissions remain level because of the dramatic increase in mobile source emissions.

Unlike methane and nitrous oxide, emissions of high GWP gases are expected to grow significantly over the period due to the phase out of Ozone Depleting Substances (ODS) under the Montreal Protocol, and strong predicted growth in other applications such as semiconductors. As ODSs are phased out in developed countries, other gases, including HFCs and PFCs, are substituted. The rate of growth is uncertain, however, because the choice of chemicals and potential new technologies or operating procedures could eliminate or decrease the need for these gases. In the BAU case the increase in these sectors offsets an overall reduction in methane. As noted earlier, these projections do not include climate initiatives such as the semiconductor industry's voluntary reduction plan, which is expected to reduce emissions substantially from this sector.

From 1990 to 2010, emissions of non-$CO_2$ greenhouse gases increase in every region except Eastern Europe, as Exhibit 1-6 illustrates. U.S. emissions are projected to increase by 210 $MMTCO_2$ over this period, the largest absolute increase and a percentage increase of over 200 percent**.** EU-15 is next with an increase of 107 $MMTCO_2$. Japan, Russia, and Canada project increases of 74, 32, and 13 $MMTCO_2$, respectively.

## 1.5 Limitations

Although this report includes the latest historical data available, such data are not available for the year 2000. For a given time series, a national inventory is not due to the UNFCCC for almost a year and a half after that year (i.e., 2000 inventories are due in April 2002). As this information becomes available, it will be incorporated in updated publications of this report.

While the latest available information is reflected in these estimates, the projections are sensitive to changes in key assumptions. For example, the emissions rates of new equipment using the ODS substitutes are likely to be much lower than the leakage rates of the older equipment. This newer equipment is only now being phased in, and the long-term emissions characteristics are not yet well known.

Additionally, in some cases the "business as usual" baseline includes incidental greenhouse gas reductions originating from climate related actions or government polices. For consistency, EPA deducted the effects of planned mitigation efforts, using methods based on US technologies. The assumptions may not hold true for all countries to which it was applied. Alternative definitions of "business as usual" activities could lead to different estimates for some sources.

Finally, data gaps existed in emissions data for several countries. To fill the gaps, EPA used methods ranging from interpolation to growth patterns based on analogous countries. The appendices detail all adjustments for each country and source.

## 1.6 Organization of This Report

The remainder of this report expands upon these results in four main sections. Emission inventories and projections by country and region are presented in Chapter 2 for methane, Chapter 3 for nitrous oxide, and in Chapter 4 for high GWP gases. Within each of these chapters, the discussion covers all key sources that contribute to emissions. Chapter 5 presents the methodology used to gather the most recent emissions inventory and projection data, and the data sources and methods used to adjust the available data where necessary in order to make the overall estimates internally consistent and comparable. Documentation of individual data points is provided in the appendices.

# 2. Methane

Methane ($CH_4$) is the second largest contributor to global warming among anthropogenic greenhouse gases, after carbon dioxide. It is estimated to be 21 times more effective at trapping heat in the atmosphere than carbon dioxide over a 100-year time period (IPCC, 1996). Over the last 200 years atmospheric methane concentrations have doubled and continue to rise (IPCC, 1997, Dlugokencky, et al., 1998). Methane is emitted from both natural and anthropogenic sources, with the major anthropogenic sources including waste, energy, and agricultural sectors. The anthropogenic sources combined to account for 70 percent of global methane emissions in 1990 (IPCC, 1995).

This chapter presents methane emissions from developed countries for 1990 through 2010 for the following anthropogenic sources:

- Natural gas and oil systems;
- Livestock enteric fermentation;
- Landfilling of solid waste;
- Coal mining activities;
- Livestock manure management;
- Wastewater treatment; and
- Minor sources such as rice, fossil fuel combustion, and agricultural residue burning.

## 2.1 Overview

As shown in Exhibit 2-1, natural gas and oil, enteric fermentation, and landfilling are consistently the largest sources. In 2000, these three sources account for over 75 percent of the total methane emissions reported for developed countries. The natural gas and oil industry is the largest anthropogenic source of methane emissions. The contribution from this

**Exhibit 2-1: Methane Emissions – By Source ($MMTCO_2$)**

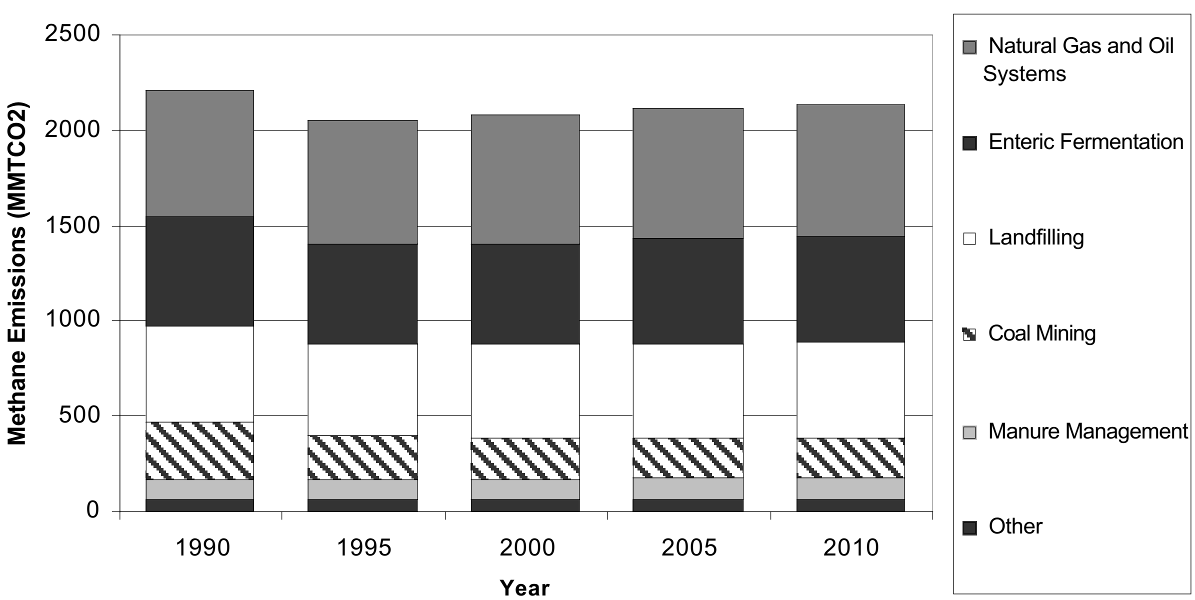


**Exhibit 2-2: Total Methane Emissions from Developed Countries ($MMTCO_2$)**

| Region | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| **EU-15** | 430 | 375 | 379 | 373 | 367 |
| **Other Western Europe** | 12 | 12 | 13 | 13 | 11 |
| **Russia** | 537 | 497 | 517 | 542 | 559 |
| **Eastern Europe** | 391 | 301 | 311 | 314 | 313 |
| **AUS/NZ** | 147 | 144 | 152 | 162 | 171 |
| **Japan** | 32 | 31 | 34 | 33 | 33 |
| **Canada** | 73 | 86 | 82 | 84 | 87 |
| **U.S.** | 645 | 651 | 642 | 646 | 651 |
| **Total** | 2,267 | 2,097 | 2,130 | 2,165 | 2,191 |

source increases in absolute terms over the period by more than 30 $MMTCO_2$, as many developed countries shift away from coal consumption in favor of natural gas.

As shown in Exhibit 2-2, overall methane emissions from developed countries are likely to decline by approximately 3 percent from 1990 to 2010. The trend is largely the result of the transition of the Former Soviet Union (FSU) and Eastern Europe to market economies, reduction of coal production in key countries due to changes in economic policies, and the modernization of oil and gas facilities. In the EU-15 and Eastern Europe, major coal producing nations anticipate a shift away from coal consumption in favor of natural gas and other fuels, leading to lower coal production and associated methane emissions. At the same time, the EU-15 countries are modernizing and upgrading their gas and oil facilities, so that increased gas production and consumption will result in only modest increases in fugitive emissions from gas facilities.

The only two regions experiencing significant growth are Australia/New Zealand and Canada. Australia and New Zealand are experiencing growth in methane emissions from nearly all sources. In Canada, emissions growth occurs in the agricultural sector.

Livestock enteric fermentation accounts for 24 percent of methane emissions in 2000. Its contribution reflects the relatively large livestock industries in the United States and the EU-15. The primary driver for the large drop in emissions from 1990 to 1995 was the rapid economic restructuring taking place in the former Soviet Union and Eastern Europe. In the transition to market economies, these countries drastically reduced the size of their livestock herds, which led to a decrease in the associated methane emissions. Economic projections indicate that livestock populations and methane emissions will grow in the future.

The third largest source is landfilling of solid waste. Currently, most developed countries dispose of the majority of their waste in landfills, which tend to promote methane generation. Significant efforts are underway in most countries to improve waste management practices, resulting in a relatively stable emission level in spite of overall economic and population growth.

## 2.2 Natural Gas and Oil Systems

Methane is the principal component (95 percent) of natural gas and is emitted from natural gas production, transmission and distribution, and processing operations. Natural gas is often found in conjunction with oil, thus oil production and processing can also emit methane in significant quantities. In both oil and gas systems, methane is emitted by leaking equipment and deliberate venting throughout the systems, including in production fields, processing facilities, transmission lines, storage facilities, and gas distribution lines.

**Total Methane Emissions from Natural Gas and Oil Systems**

| Year | $MMTCO_2$ | Gg $CH_4$ |
|---|---|---|
| 1990 | 663 | 31,600 |
| 1995 | 648 | 30,900 |
| 2000 | 678 | 32,300 |
| 2005 | 684 | 32,600 |
| 2010 | 696 | 33,100 |

As shown in Exhibit 2-3, overall methane emissions are projected to increase almost 6 percent. Russia and U.S. are the largest oil and gas producing and consuming countries, and contribute the bulk of the emissions. Russia alone contributes roughly half of developed country emissions from this source and Russian emissions are projected to increase most significantly (53 $MMTCO_2$). In addition, emissions from Australia are expected to almost double the 1990 level by 2010 and the U.S. will experience a modest increase of 9 $MMTCO_2$. The effect of these increases will be moderated by a decrease in emissions in Eastern Europe of 34 $MMTCO_2$.

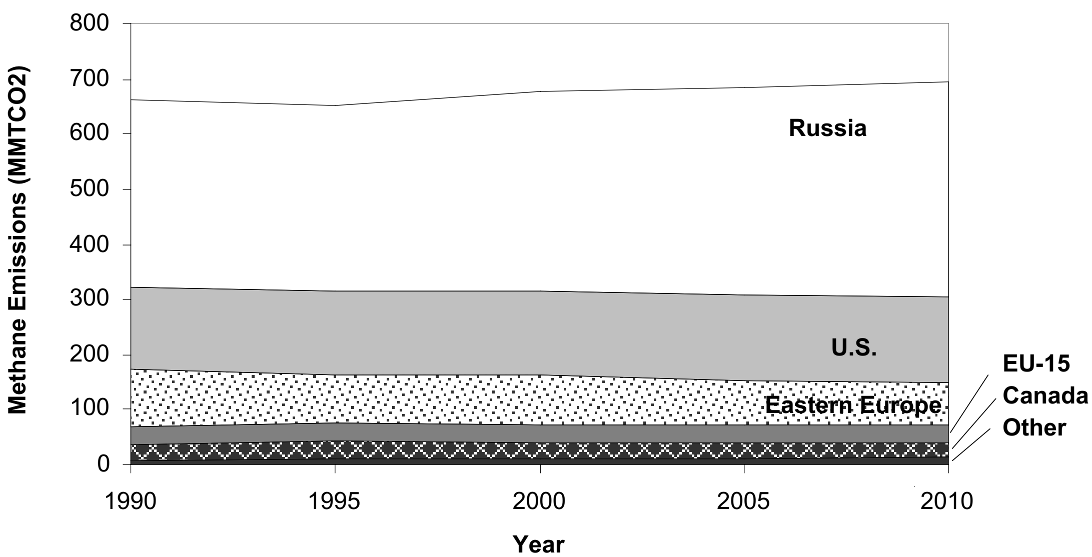
Although demand for gas may be growing in certain regions, for a variety of technical, economic and environmental reasons, emissions are unlikely to increase at the rate of production. Leakage and venting do not necessarily increase linearly with throughput, and newer equipment tends to leak less than older equipment.

Future methane emission levels may be lower than projected here due to some important trends in the sector. First, in many countries, concern is increasing about the contribution of oil and gas facilities to deteriorating local air quality, particularly emissions of non-methane volatile organic compounds. Measures designed to mitigate these emissions, such as efforts to reduce leaks and venting, have the ancillary benefit of reducing methane emissions. Second, economic restructuring in the FSU and Eastern Europe may lead to a modernization of gas and oil facilities. For example, Germany anticipates a reduction in emissions from the former East German system through upgrades and improved maintenance. Russia also plans to focus on opportunities to reduce emissions from its oil and gas system as part of modernization activities.

## 2.3 Livestock Enteric Fermentation

Methane is emitted as part of the normal digestive process of livestock, particularly in ruminant animals (i.e., cattle, buffalo, sheep, and goats). The size of the livestock populations and the management practices in use, particularly feed intake, drive emissions. Thus, demand for livestock products (primarily milk and meat) and efficiency improvements will be the primary drivers of enteric fermentation emissions in the future.

**Exhibit 2-3: Methane Emissions from Natural Gas and Oil Systems 1990 through 2010 ($MMTCO_2$)**



| Total Methane Emissions from Livestock Enteric Fermentation | | |
|---|---|---|
| Year | $MMTCO_2$ | Gg $CH_4$ |
| 1990 | 576 | 27,500 |
| 1995 | 525 | 25,000 |
| 2000 | 527 | 25,100 |
| 2005 | 547 | 26,100 |
| 2010 | 552 | 26,300 |

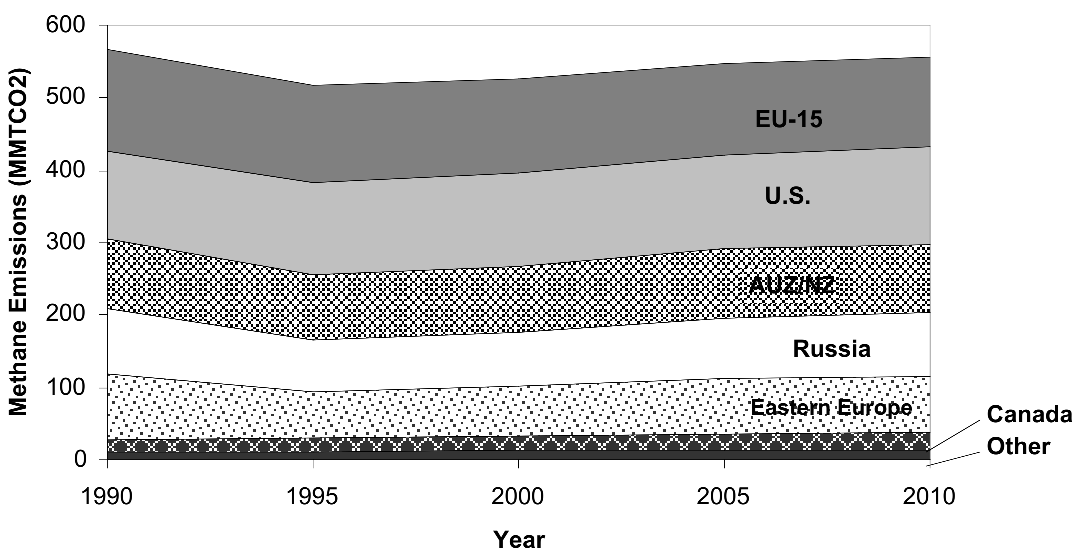
In developed countries, methane emissions from enteric fermentation are expected to be about 4 percent lower in 2010 than in 1990. Emissions dropped by over 9 percent between 1990 and 1995, and are expected to increase slowly after 1995. The decline between 1990 and 1995 was attributable to declines in livestock populations in Europe and Russia. In the EU-15, where approximately two-thirds of all cows are dairy cows, the cattle population is falling by around 2 percent per year due to milk quotas and increasing yields per animal. The number of beef cows (as well as sheep and goats) is stable and emissions are not expected to increase in the EU-15 after 2000. During the 1990s, the farm industries in Eastern European countries and Russia reduced their livestock production as part of their transition to market economies. Production in these countries is expected to increase between 2000 and 2010, leading to corresponding emission increases.

As shown in Exhibit 2-4, emission levels in the remaining countries are expected to be relatively flat, following changes in livestock populations. In the U.S. and Canada, cattle populations will grow in response to increased demand for milk and meat products. The effect on emissions will be offset somewhat by increased production efficiencies. The stable emission levels in Japan, Australia, and other western European countries reflect predictions of stable or decreased populations of cattle.

## 2.4 Landfilling of Solid Waste

Methane is produced and emitted from the anaerobic decomposition of organic material in landfills. The major drivers of emissions are the amount of organic material deposited in landfills, the extent of anaerobic decomposition, and the level of landfill methane collection and combustion (e.g., energy use or flaring). Because organic material deep within landfills takes many years to decompose completely, past landfill disposal practices greatly influence present day emissions.

**Exhibit 2-4: Methane Emissions from Livestock Enteric Fermentation 1990 through 2010 ($MMTCO_2$)**



| Total Methane Emissions from Landfilling of Solid Waste | | |
|---|---|---|
| Year | $MMTCO_2$ | Gg $CH_4$ |
| 1990 | 501 | 23,900 |
| 1995 | 481 | 22,900 |
| 2000 | 490 | 23,300 |
| 2005 | 492 | 23,400 |
| 2010 | 496 | 23,600 |

Solid waste disposal is the third largest anthropogenic source of methane in developed countries and accounts for nearly one quarter of their anthropogenic methane emissions. The small decline in emissions from 1990 to 1995 in the EU-15 and U.S. is due to collection and flaring or use of landfill methane. As shown in Exhibit 2-5, although emissions are projected to grow in developed countries between 1995 and 2010, they are not expected to exceed 1990 levels. In many countries, landfill methane emissions are not expected to grow despite continued or even increased landfilling of waste, because of non-climate change related regulations.

The only region that expects an increase in emissions from this source is Eastern Europe, where solid waste will be diverted increasingly to managed landfills as a means of improving overall waste management. Methane emissions are expected to increase at a steady rate from 1995 to 2010.

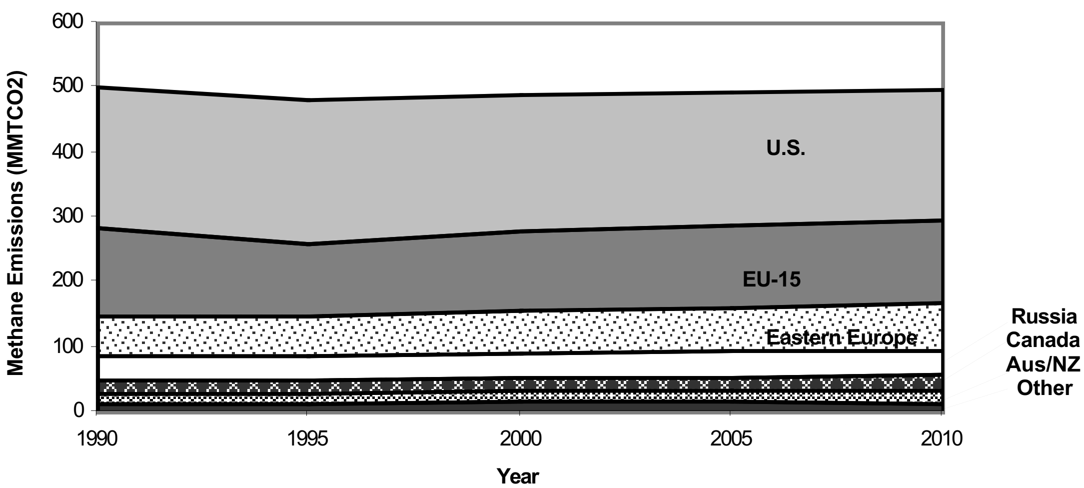
## 2.5 Coal Mining Activities

The methane emitted during coal mining and post-mining activities is a function of the amount of methane contained in the coal and the type of mining. In general, deeper, higher ranked coals contain more methane, and longwall mining releases more methane than other types of underground mining.

Methane is emitted from underground mining either through the mine's ventilation system or degasification system. Prior to mining, a portion of the methane in and around the coal seam can be recovered and used for energy, so that methane emissions during mining can be reduced. In most countries, a small number of the gassiest underground mines usually account for a large percentage of overall methane emitted.

| Total Methane Emissions from Coal Mining Activities | | |
|---|---|---|
| Year | $MMTCO_2$ | Gg $CH_4$ |
| 1990 | 303 | 14,400 |
| 1995 | 229 | 11,000 |
| 2000 | 216 | 10,300 |
| 2005 | 217 | 10,300 |
| 2010 | 216 | 10,300 |

**Exhibit 2-5: Methane Emissions Landfilling of Solid Waste 1990 through 2010 ($MMTCO_2$)**



As shown in Exhibit 2-6, overall emissions declined significantly during the last decade and are expected to remain near 2000 levels out to 2010. Restructuring of the energy industries in Europe and FSU resulted in a decline in coal production, particularly at gassier mines. In Russia and other Eastern European coal producing countries, many of the gassiest underground mines have closed. Since the integration of East and West Germany, total German coal production has also dropped, due to the government's gradual removal of subsidies.

Emissions from coal mining activities are expected to decrease in the U.S. through 2010 because production is shifting from underground coal mines to surface mines. Additionally, coal mines in the U.S. are increasingly recovering methane from degasification systems.

## 2.6 Livestock Manure Management

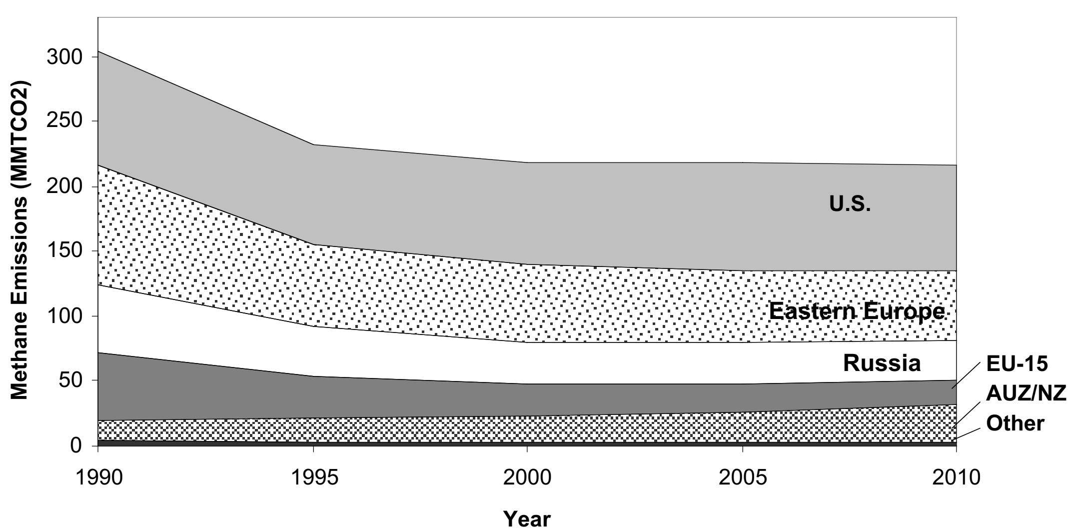
Methane is a by-product of the anaerobic decomposition of livestock manure. Anaerobic conditions usually occur at large confined animal management facilities that manage and store manure as a liquid or slurry. Lagoons, pits, and tanks at large dairy and swine farms are the major source of emissions. Along with the type of manure management, the amount and composition of manure produced and temperature also influence emissions.

**Total Methane Emissions from Livestock Manure Management**

| Year | $MMTCO_2$ | Gg $CH_4$ |
|---|---|---|
| 1990 | 102 | 4,840 |
| 1995 | 98 | 4,680 |
| 2000 | 103 | 4,930 |
| 2005 | 107 | 5,080 |
| 2010 | 109 | 5,210 |

Methane emissions from manure management will grow by 5 percent between 1990 and 2010 due to the growth in animal populations necessary to meet expected demand for milk and meat, and the increased use of liquid manure management systems. These two factors are principally responsible for the increases in the U.S. and Canada from 1995 onward. Russia and many Eastern European countries are reducing their livestock production in the short-term as part of their economic transition. However, as shown in Exhibit 2-7, livestock production and thus emissions are expected to begin a slow increase after 2000. The slight decline in methane emissions anticipated by the EU-15 is primarily due to the

**Exhibit 2-6: Methane Emissions from Coal Mining Activities 1990 through 2010 ($MMTCO_2$)**



projected decrease in livestock populations, particularly in the number of dairy cows where populations are controlled to comply with market ceilings. The animal population growth rates will be relatively flat or minimal in Australia, other Western Europe countries, and Japan.

## 2.7 Wastewater Treatment

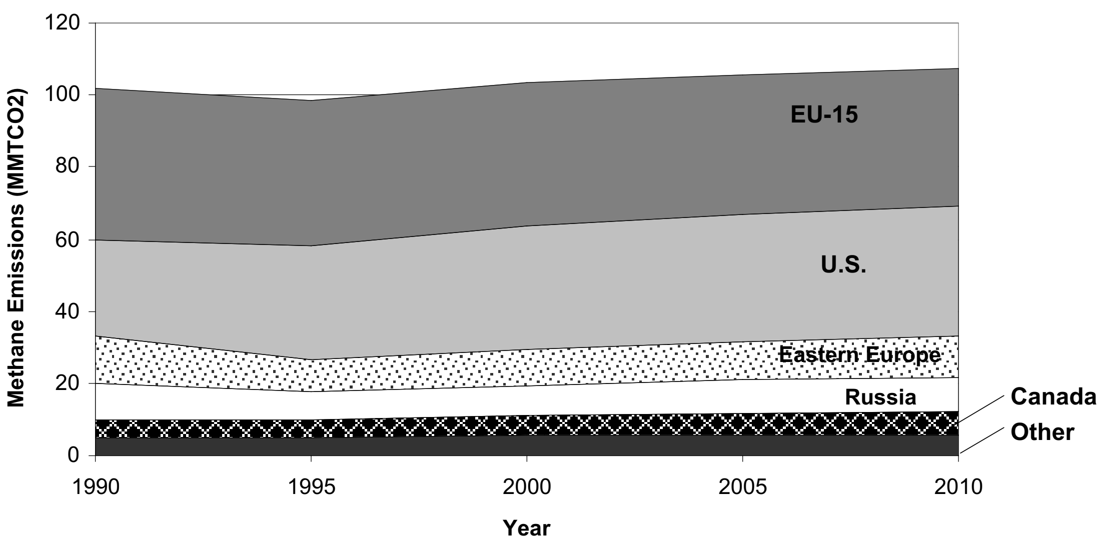
Methane is emitted both incidentally and deliberately during the handling and treatment of municipal and industrial wastewater. The organic material in the wastewater produces methane when it decomposes anaerobically. The amount of organic material produced and the extent to which it is broken down anaerobically drive the emissions. Most developed countries rely on centralized aerobic wastewater treatment to handle their municipal wastewater, so that methane emissions are small and incidental. Industrial wastewater can also be treated anaerobically, with significant methane being emitted.

**Total Methane Emissions from Wastewater**

| Year | $MMTCO_2$ | Gg $CH_4$ |
|---|---|---|
| 1990 | 37 | 1,770 |
| 1995 | 36 | 1,720 |
| 2000 | 36 | 1,740 |
| 2005 | 38 | 1,770 |
| 2010 | 38 | 1,800 |

Proper wastewater handling and treatment is vital to protect surface water, groundwater, and public health. Most developed countries have had an extensive infrastructure to handle urban wastewater for some time, so the main trend in municipal wastewater emissions is associated with changes in population. Exhibit 2-8 projects a slow and steady increase in emissions from 2000 through 2010, in response to these population changes. Heightened attention to the problems of industrial wastewater may lead to a change in treatment practices. If anaerobic treatment is used without methane recovery, net emissions could increase substantially. Additionally, the potential exists for emissions to be higher than estimated because this study excludes the effects of wastewater discharged into lakes and rivers.

**Exhibit 2-7: Methane Emissions from Livestock Manure Management 1990 through 2010 ($MMTCO_2$)**



The small decrease in emissions in Eastern Europe between 1990 and 1995 is due to lower industrial wastewater contributions to the system and increases in the amount of wastewater treated by advanced wastewater treatment systems that include aerobic processes and bio-gas capture. Growth in emissions after 2000 primarily reflects expected increases in industrial productivity and population growth in the Eastern Europe.

Although there is a general lack of data for this source, most experts believe that emissions are relatively small compared to other sources. Therefore, the effect of this uncertainty on total methane emissions is likely to be small.

## 2.8 Other Sources

Methane is emitted from other agricultural and non-agricultural sources including:

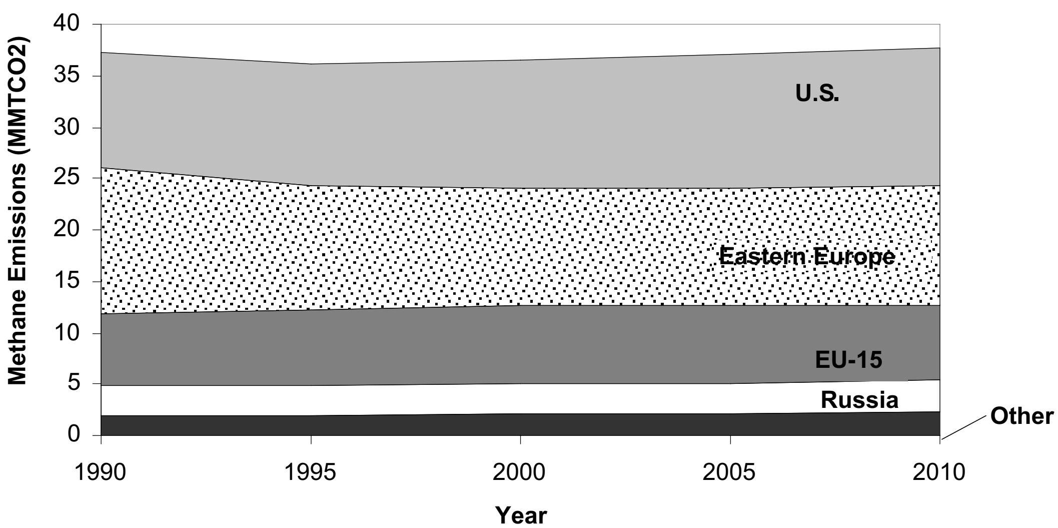
- Rice cultivation: Methane emissions result from the anaerobic decomposition of organic material in flooded rice fields;
- Agricultural residue burning and savannah burning: Methane emissions from burning activities result from incomplete combustion;
- Land conversion: Methane emissions result when burning is used to clear land;
- Fossil fuel combustion from stationary and mobile sources;[1]
- Biomass fuel combustion;
- Waste incineration; and
- Miscellaneous industrial processes.

The smaller agricultural sources are insignificant in many developed countries, which may account for the omissions of these sources in some countries' National Communications. Although rice cultivation is a major source of methane emissions globally, it is not considered a major source in this report because Japan is the only developed country with significant emissions from this source.

**Total Methane Emissions from Other Agricultural Sources**

| Year | $MMTCO_2$ | Gg $CH_4$ |
|---|---|---|
| 1990 | 29 | 1,390 |
| 1995 | 30 | 1,420 |
| 2000 | 31 | 1,470 |
| 2005 | 30 | 1,430 |
| 2010 | 30 | 1,440 |

**Exhibit 2-8: Methane Emissions from Wastewater Treatment 1990 through 2010 ($MMTCO_2$)**



| Total Methane Emissions from Other Non-Agricultural Sources | | |
|---|---|---|
| Year | $MMTCO_2$ | Gg $CH_4$ |
| 1990 | 55 | 2,630 |
| 1995 | 51 | 2,410 |
| 2000 | 50 | 2,370 |
| 2005 | 51 | 2,440 |
| 2010 | 54 | 2,560 |

For other agricultural sources, emissions from developed countries are projected to remain stable through 2010. The lack of reporting on these sources does not allow for accurate analysis of the trends in either category. For other non-agricultural sources, emissions drop 8 percent between 1990 and 1995, but return to 1990 levels by 2010.

## 2.9 Explanatory Notes

1. The amount of methane emitted from fuel combustion is driven by the amount of fuel combusted and the combustion technology used.

# 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 ($MMTCO_2$)**

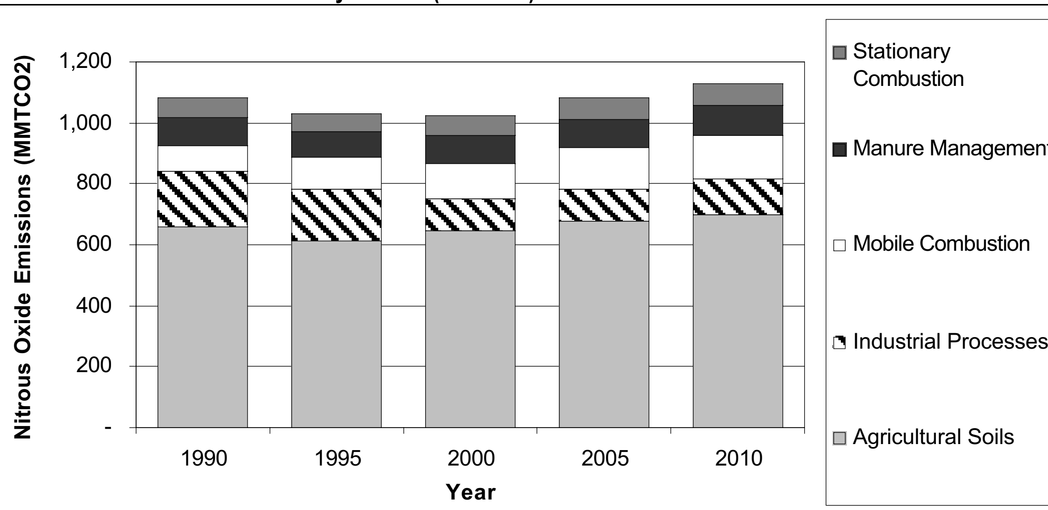


**Exhibit 3-2: Total Nitrous Oxide Emissions from Developed Countries (MMTCO$_2$)**

| 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.

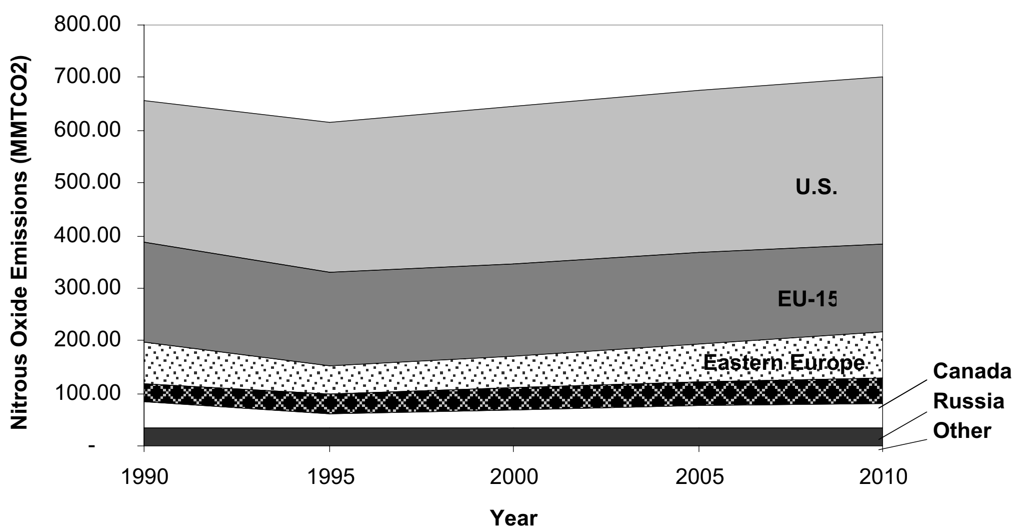
The trend through 2010 has two counteracting drivers: continued economic transitioning in Russia, Ukraine, and Eastern Europe, and continued agricultural restructuring in the EU-15. As the economies of Russia and Eastern Europe improve, $N_2O$ emissions from soils will also increase. This increase will 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**

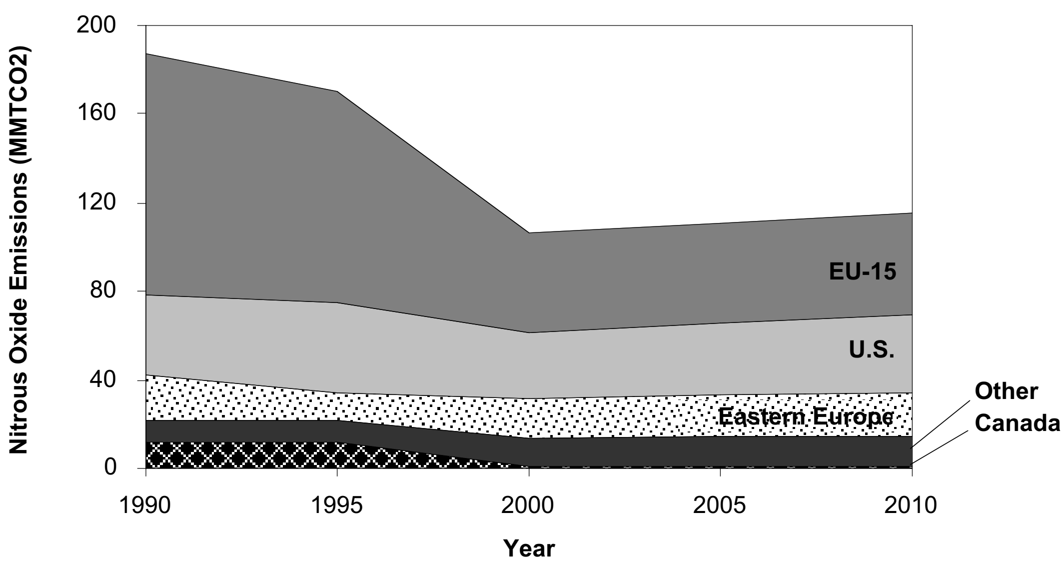
| Year | $MMTCO_2$ | Gg $N_2O$ |
|---|---|---|
| 1990 | 188 | 606 |
| 1995 | 170 | 548 |
| 2000 | 106 | 342 |
| 2005 | 111 | 358 |
| 2010 | 115 | 372 |

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]

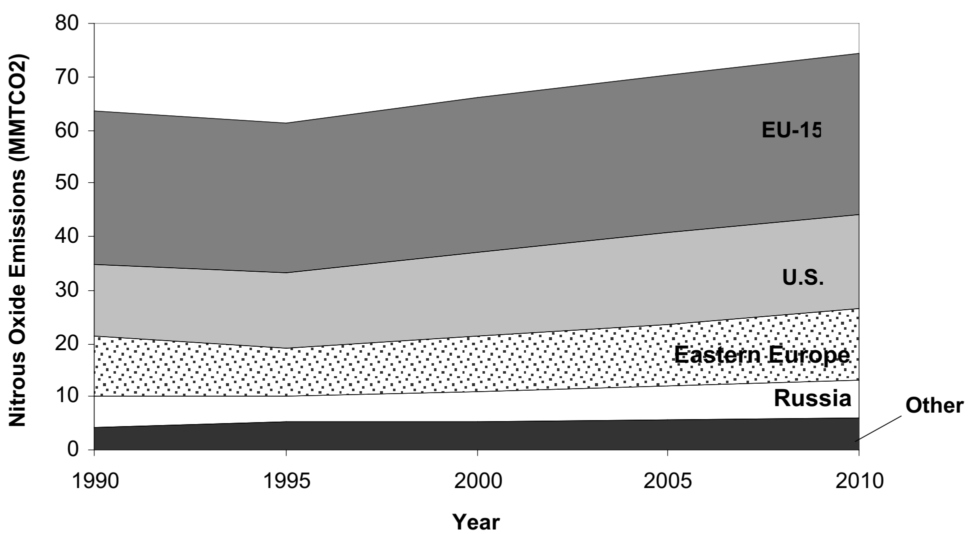
**Total Nitrous Oxide Emissions from Stationary Sources**

| 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

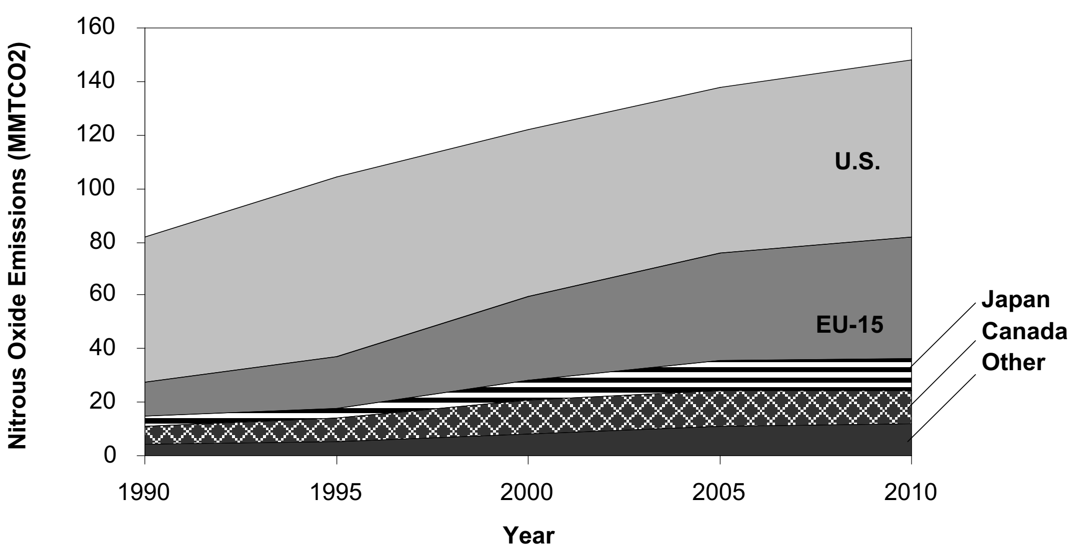
Mobile combustion sources such as automobiles and airplanes emit nitrous oxide. As with stationary sources, nitrous oxide emissions are closely related to air-fuel mixtures and combustion temperature, as well as pollution control equipment on transportation vehicles. The total distance traveled is an 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**

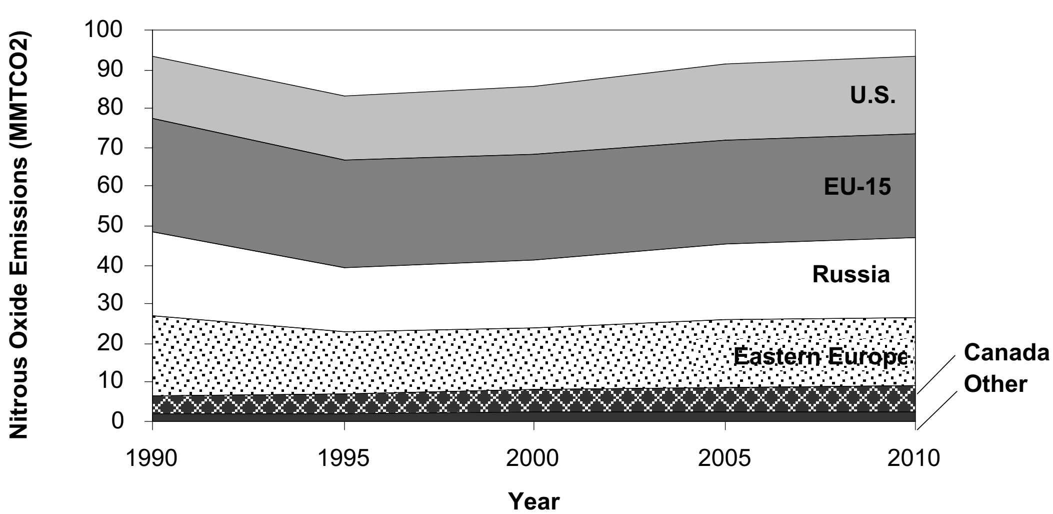
| Year | $MMTCO_2$ | Gg $N_2O$ |
|---|---|---|
| 1990 | 94 | 302 |
| 1995 | 83 | 268 |
| 2000 | 86 | 277 |
| 2005 | 91 | 294 |
| 2010 | 94 | 302 |

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 ($MMTCO_2$)**



# 4. High Global Warming Potential Gases

This chapter presents estimates and projections of high global warming potential (high GWP) emissions in developed countries from 1990 through 2010. High GWP emissions result from the use of substitutes for ozone-depleting substances (ODS) and five additional industrial sectors:

- Several hydrofluorocarbons (HFCs) and, to a lesser extent, perfluorocarbons (PFCs) and hydrofluoroethers (HFEs) are replacing ODS in a wide variety of applications, including as refrigerants, aerosol propellants, solvents, foam blowing agents, medical sterilization carrier gases, and fire extinguishing agents.
- PFCs, $SF_6$, and HFC-23 are used in semiconductor production.
- HFC-23 is released as a byproduct of HCFC-22 production.
- $SF_6$ is used as a dielectric gas and insulator in sealed electric power equipment.
- $SF_6$ is released during its use as a cover gas to protect molten magnesium from burning on contact with air.
- PFCs-$CF_4$, and $C_2F_6$-are produced and released during primary aluminum smelting.

## 4.1 Overview

Exhibit 4-1 summarizes total high GWP emissions by source for 1990 through 2010. Exhibit 4-2 summarizes total high GWP emissions by region. Exhibit 4-3 lists the high GWP gases included in this analysis, along with their associated uses or emission sources, atmospheric lifetime, and global warming potentials. More detailed high GWP emissions and projections are presented in Appendix D.

**Exhibit 4-2: Total High GWP Gas Emissions from Developed Countries ($MMTCO_2$)**

| Region | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| EU-15 | 57 | 46 | 80 | 120 | 160 |
| Other Western Europe | 6 | 4 | 5 | 10 | 18 |
| Russia | 20 | 15 | 18 | 33 | 53 |
| Eastern Europe | 4 | 2 | 2 | 8 | 15 |
| AUS/NZ | 8 | 5 | 6 | 11 | 12 |
| Japan | 15 | 34 | 31 | 58 | 88 |
| Canada | 14 | 11 | 13 | 21 | 27 |
| U.S. | 98 | 100 | 140 | 220 | 310 |
| Total | 223 | 223 | 298 | 489 | 685 |

**Exhibit 4-1: High GWP Gas Emissions by Source ($MMTCO_2$)**

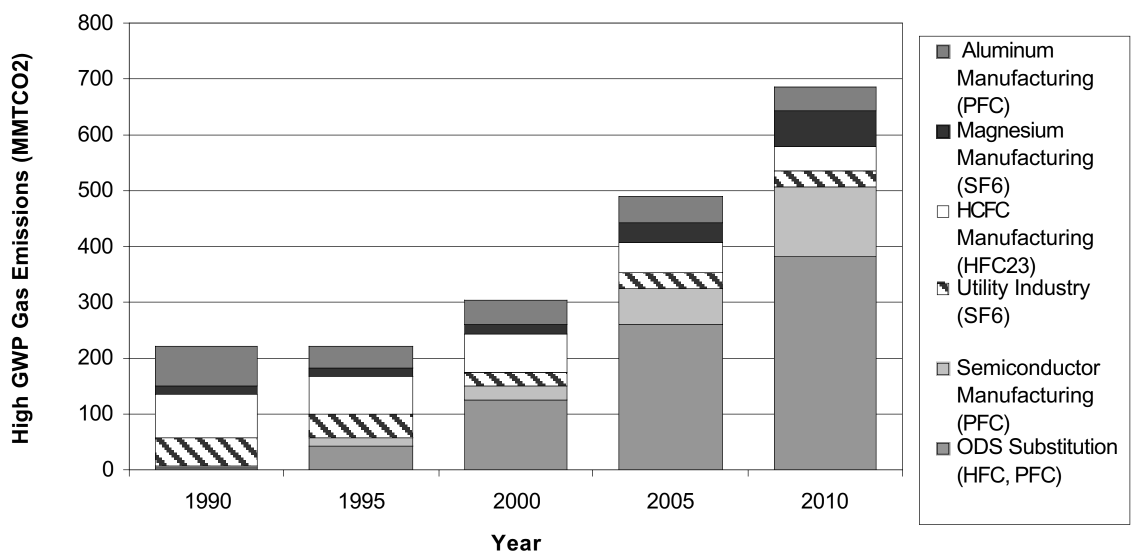


**Exhibit 4-3: High GWP Chemicals**

| Chemical | Life-time (yrs) | GWP (100-yr) | Use |
|---|---|---|---|
| **Hydrofluorocarbons (HFCs)** | | | |
| HFC-23 | 264 | 11,700 | Byproduct of HCFC-22 production, used in very-low temperature refrigeration, blend component in fire suppression, and plasma etching and cleaning in semiconductor production. |
| HFC-32 | 5.6 | 650 | Blend component of numerous refrigerants. |
| HFC-41 | 3.7 | 150 | Not in commercial use today. |
| HFC-43-10mee | 17.1 | 1,300 | Cleaning solvent. |
| HFC-125 | 32.6 | 2,800 | Blend component of numerous refrigerants and a fire suppressant. |
| HFC-134 | 10.6 | 1,000 | Not in commercial use today. |
| HFC-134a | 14.6 | 1,300 | Most widely used HFC refrigerant, blend component of other refrigerants, propellant in metered-dose inhalers and aerosols, and foam blowing agent. |
| HFC-152a | 1.5 | 140 | Blend component of several refrigerant blends. |
| HFC-143 | 3.8 | 300 | Not in commercial use today. |
| HFC-143a | 48.3 | 3,800 | Refrigerant blend. |
| HFC-227ea | 36.5 | 2,900 | Fire suppressant and propellant for metered-dose inhalers. |
| HFC-236fa | 209 | 6,300 | Refrigerant and fire suppressant. |
| HFC-236ea | 8.1[a] | 1,000[a] | Not in commercial use today. |
| HFC-245fa | 7.7[b,c] | 816[b,c] | Foam blowing agent and refrigerant; near commercialization. |
| HFC-245ca | 6.6 | 560 | Not in commercial use today, possible refrigerant in the future. |
| HFC-365mfc | 10.2[a] | 910[a] | Under study for use as foam blowing agent. |
| **Perfluorocarbons (PFCs)** | | | |
| $CF_4$ | 50,000 | 6,500 | Byproduct of aluminum production. Plasma etching and cleaning in semiconductor production and low temperature refrigerant. |
| $C_2F_6$ | 10,000 | 9,200 | Byproduct of aluminum production. Plasma etching and cleaning in semiconductor production. |
| $C_3F_8$ | 2,600 | 7,000 | Low-temperature refrigerant, and fire suppressant. Used in plasma cleaning in semiconductor production. |
| $C_4F_{10}$ | 2,600 | 7,000 | Fire suppressant. |
| $C\text{-}C_4F_8$ | 3,200 | 8,700 | Not in much use, if at all, today. Emerging for plasma etching in semiconductor production. |
| $C_5F_{12}$ | 4,100 | 7,500 | Not in much use, if at all, today. |
| $C_6F_{14}$ | 3,200 | 7,400 | Precision cleaning solvent - low volume use. |
| **Nitrogen Trifluoride ($NF_3$)** | | | |
| $NF_3$ | 740[d] | 10,800[d] | Plasma cleaning in semiconductor production. |
| **Sulfur Hexafluoride ($SF_6$)** | | | |
| $SF_6$ | 3,200 | 23,900 | Cover gas in magnesium production and casting, dielectric gas and insulator in electric power equipment, fire suppression discharge agent in military systems, atmospheric and subterranean tracer gas, sound insulation, process flow-rate measurement, medical applications, and formerly an aerosol propellant. Used for plasma etching in semiconductor production. |
| **Hydrofluoroethers (HFEs)** | | | |
| $C_4F_9OCH_3$ | 5.0[a] | 390[a] | Cleaning solvent and heat transfer fluid. |
| $C_4F_9OC_2H_5$ | 0.77[a] | 55[a] | Near commercialization for use as a cleaning solvent. |

GWPs and atmospheric lives are reprinted from the Intergovernmental Panel on Climate Change, Second Assessment Report, 1995, except as noted below:

[a]WMO, 1999, Scientific Assessment of Ozone Depletion: 1998, World Meteorological Organization, Global Ozone Research and Monitoring Project – Report No. 44, p.10.27.

[b]Junyi Chen, Valerie Young, and Hiromi Niki, Kinematic and Mechanistic Studies for Reaction of $CF_3CH_2CHF_2$ (HFC-245fa) Initiated by H-Atom Abstraction Using Atomic Chlorine, J. Phys. Chem. A 1997, 101, 2648-2653.

[c]Personal communication between Don Wuebbles, University of Illinois at Urbana-Campaign and Reynaldo Forte, US Environmental Protection Agency, August 27, 1998.

[d]IPCC, 2001.

As the exhibits show, emissions of the high GWP gases have increased during the 1990s and are expected to increase through 2010 in every country, primarily due to increasing emissions of the ODS substitutes as countries' phase out ODS production under the Montreal Protocol.

The major source of potential emissions increase among the other industrial gas uses is the semiconductor industry, which is expected to continue dramatic economic growth throughout the forecast period. High GWP emissions will increase more modestly from the utility and magnesium industries. Emissions from HCFC-22 production are expected to decline after non-feedstock HCFC production is phased out. Emissions from aluminum smelting are projected to decrease over time, although aluminum production is increasing, because of on-going efforts to significantly modify operating parameters and reduce the emissions from this source.

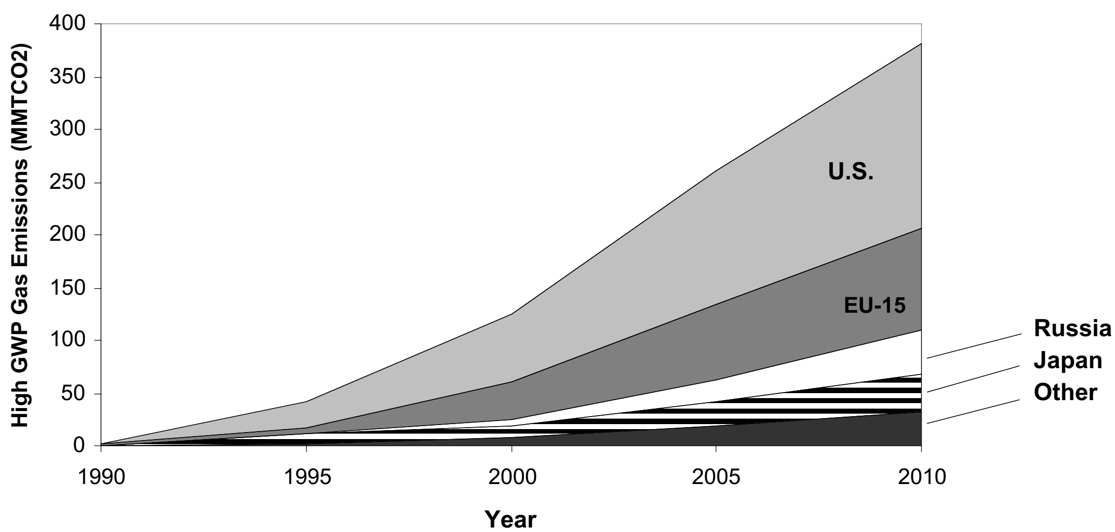
## 4.2 Substitutes for Ozone Depleting Substances

Hydrofluorocarbons (HFCs) and, to a lesser extent, perfluorocarbons (PFCs) and hydrofluoroethers (HFEs) are used as alternatives to several classes of ozone-depleting substances (ODSs) that are being phased out under the terms of the Montreal Protocol. ODSs, which include chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs), have been used for decades in a variety of industrial sectors including refrigeration and air conditioning, aerosols, solvent cleaning, fire extinguishing, foam production, and medical sterilization. Although the HFCs, and PFCs that replace ODSs are not harmful to the stratospheric ozone layer, they are powerful greenhouse gases.

| Total Emissions of ODS Substitutes | |
|---|---|
| Year | $MMTCO_2$ |
| 1990 | 2 |
| 1995 | 42 |
| 2000 | 125 |
| 2005 | 260 |
| 2010 | 382 |

As shown in Exhibit 4-4, the use and subsequent emissions of HFCs and PFCs as ODS substitutes has increased dramatically, from small amounts in 1990, to 127 $MMTCO_2$ in 2000. This trend is expected to continue for many years, and will accelerate in the early part of this century as HCFCs, which are interim substitutes in many applications, are themselves phased out under the provisions of the Copenhagen Amendments to the Montreal Protocol.

**Exhibit 4-4: HFC and PFC Emissions from ODS Substitute Uses 1990 through 2010 ($MMTCO_2$)**



In addition, in some ODS replacement applications, such as solvent cleaning or aerosol applications, the substitutes are emitted immediately, but in others, such as refrigeration and air conditioning applications, the substitutes are replacing ODSs in equipment that slowly releases the gas. Therefore, the rate of increase in ODS substitute emissions is driven by the pace of the phase out in each country and by the emissions profile for the source in which the gas is used.

Significant uncertainty exists in these estimates. In particular, European projections have significantly lower estimates for Europe than those presented here (Ecofys, 2001). Additionally, extrapolating from ODS use in 1990 may be problematic for estimating future HFC use as substitution rates are uncertain.

## 4.3 Semiconductor Manufacturing

The semiconductor industry currently emits fluorocarbons ($CF_4$, $C_2F_6$, $C_3F_8$, $C\text{-}C_4F_8$, HFC-23), and sulfur hexafluoride ($SF_6$) during manufacturing processes. These gases, collectively called perfluorinated carbon compounds (PFCs), are used in two important steps of silicon-based semiconductor manufacturing: (1) plasma etching of thin films; and (2) cleaning of chemical-vapor-deposition (CVD) chambers. Some amount of the chemical used in these processes is emitted to the atmosphere. In addition, a fraction of the heavier PFCs used in these two production processes is converted into $CF_4$ and emitted. The amount of the PFCs used in and emitted during any process varies according to the manufacturer and to the device being manufactured.

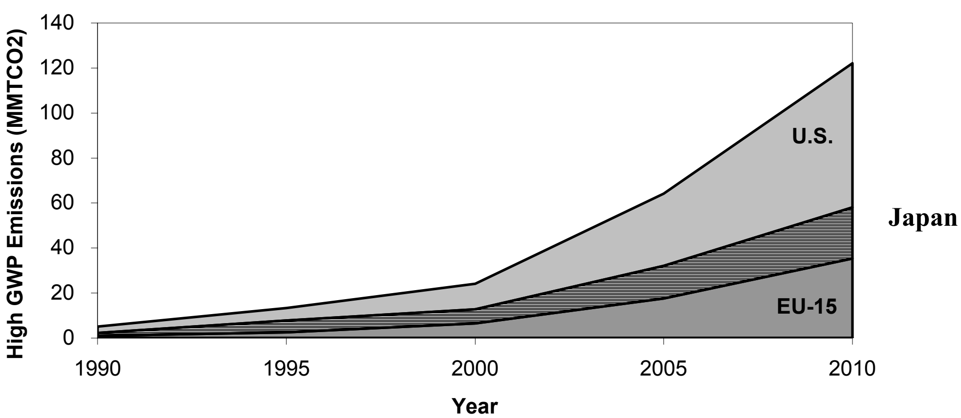
Exhibit 4-5 presents estimates of the total emissions from semiconductor manufacturing for the years 1990 through 2010 for developed countries.

**Total PFC and $SF_6$ Emissions from Semiconductor Manufacturing**

| Year | $MMTCO_2$ |
|---|---|
| 1990 | 5 |
| 1995 | 13 |
| 2000 | 24 |
| 2005 | 65 |
| 2010 | 124 |

Among developed countries, the majority of PFC emissions originate from the three major semiconductor producing regions: the US, EU-15, and Japan. These three regions are projected to remain the major producers of semiconductors through 2010.

**Exhibit 4-5: PFC and $SF_6$ Emissions from Semiconductor Manufacturing 1990 through 2010 ($MMTCO_2$)**



Market demand for semiconductors is projected to continue its current rapid growth. Correspondingly, a rapid growth in PFC emissions from the semiconductor industry in these three regions is projected. It is important to note that these projections are not inclusive of voluntary climate commitments. The semiconductor industry has taken an aggressive target to reduce PFC emissions. In April 1999, the World Semiconductor Council (WSC) agreed to reduce PFC emissions by at least 10 percent below 1995 levels by 2010. WSC members produce over 90 percent of the world's semiconductors.

## 4.4 HCFC-22 Production

Trifluoromethane (HFC-23) is generated and emitted as a by-product during the production of chlorodifluoromethane (HCFC-22). Nearly all producers in developed countries have implemented process optimization or thermal destruction to reduce HFC-23 emissions. In some cases, however, it is collected and used as a substitute for ozone depleting substances, mainly in very-low temperature refrigeration and air conditioning systems.

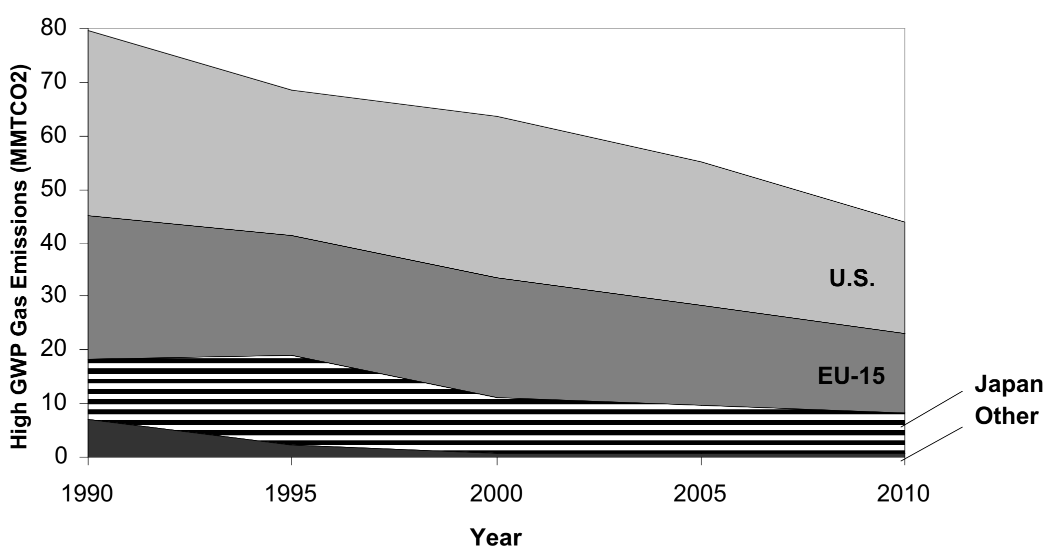
HFC-23 emission factors range from 1 to 5 percent per unit of HCFC-22 produced. HFC-23 exhibits the highest global warming potential of the HFCs, 11,700 over a 100-year time horizon, and it has an atmospheric life of 264 years.

**Total HFC-23 Emissions from HCFC-22 Production**

| Year | $MMTCO_2$ |
|---|---|
| 1990 | 80 |
| 1995 | 69 |
| 2000 | 66 |
| 2005 | 63 |
| 2010 | 56 |

As shown in Exhibit 4-6, HFC-23 emissions from HCFC-22 production deceased overall from 1990 to 2000 with a significant decrease from 1990 to 1995 due to process optimization. Emissions are expected to continue decreasing through 2010. A major reason for the decrease is that HCFC-22 production, for most end-uses, is scheduled to be phased-out by 2030 under the Copenhagen Amendments to the Montreal Protocol. Emissions are not anticipated to decrease to zero, however, because HCFC-22 production for use as a feedstock to other chemicals is permitted to continue indefinitely and feedstock production is anticipated to continue growing steadily, mainly for manufacturing Teflon® and other chemical products.

**Exhibit 4-6: HFC-23 Emissions as a Byproduct of HCFC-22 Productions 1990 through 2010 ($MMTCO_2$)**



## 4.5 Electric Utilities

An estimated 80 percent of the worldwide sales of sulfur hexafluoride ($SF_6$) are made to electric utilities and manufacturers of equipment used to enable the transmission and distribution of electricity (Rand, 2000). Sulfur hexaflouride has been employed as an insulating gas by the electric power industry since the 1950's because of its dielectric strength and arc-quenching characteristics. It is used in gas-insulated high voltage circuit breakers, substations, transformers, and transmission lines. Sulfur hexafluoride has replaced flammable insulating oils in many applications and allows for more compact electrical equipment in dense urban areas.

Fugitive $SF_6$ can escape from gas-insulated substations (GIS) and gas-insulated circuit breakers through seals, especially from older equipment. It can also be released when equipment is opened for servicing, which typically occurs every few years or when equipment is disposed. In the past, some utilities vented $SF_6$ to the atmosphere during servicing. Increased awareness and the relatively high cost of the gas have reduced this practice.

**Total $SF_6$ Emissions from Electric Utilities**

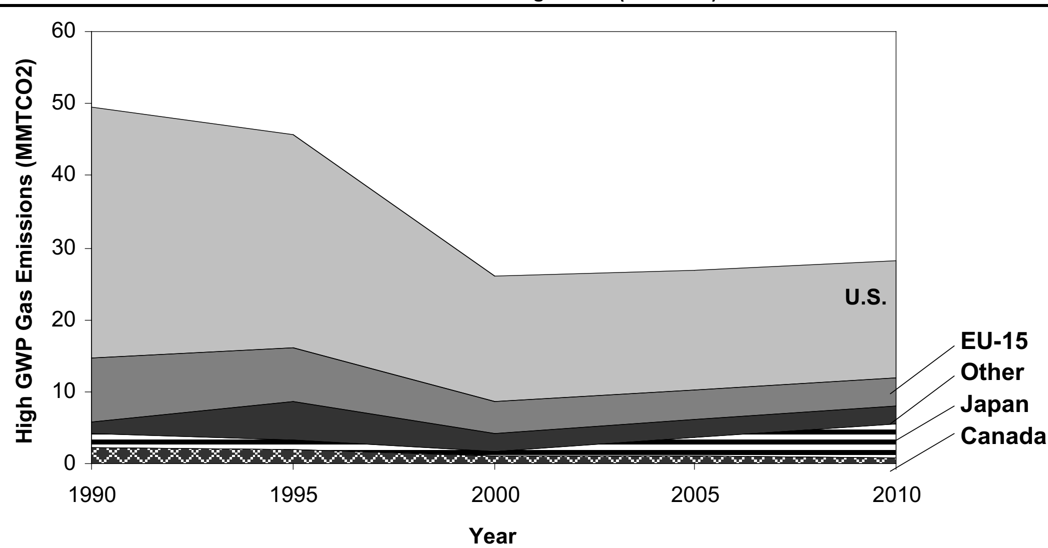
| Year | $MMTCO_2$ |
|---|---|
| 1990 | 50 |
| 1995 | 46 |
| 2000 | 26 |
| 2005 | 27 |
| 2010 | 28 |

As shown in Exhibit 4-7, emissions from electric utilities have steadily decreased since 1990 and are expected to continue decreasing, despite the growth in the electric utility sector. The price increase of $SF_6$ in the mid-90s encouraged electric power systems to improve equipment maintenance and servicing in order to conserve the gas. The use of leak detection and recycling methods has also increased as utilities strive to lower costs and mitigate environmental effects.

## 4.6 Magnesium Production

The magnesium metal production and casting industry uses sulfur hexafluoride ($SF_6$) as a covergas to prevent the violent oxidation of molten magnesium in the presence of air. Small concentrations of $SF_6$ in

**Exhibit 4-7: $SF_6$ Emissions from Electric Utilities 1990 through 2010 ($MMTCO_2$)**



combination with carbon dioxide and air are blown over the molten magnesium metal to induce the formation of a protective crust. The industry adopted the use of $SF_6$ to replace sulfur dioxide ($SO_2$). The $SF_6$ technique is used by producers of primary magnesium metal and most magnesium parts die casters. The recycling industry employs a variety of melt protection techniques including salt fluxes and $SF_6$. Exhibit 4-8 presents total $SF_6$ emissions from magnesium production through the year 2010 for developed countries.

| Total $SF_6$ Emissions from Magnesium Production | |
|---|---|
| **Year** | **$MMTCO_2$** |
| 1990 | 13 |
| 1995 | 12 |
| 2000 | 16 |
| 2005 | 32 |
| 2010 | 55 |

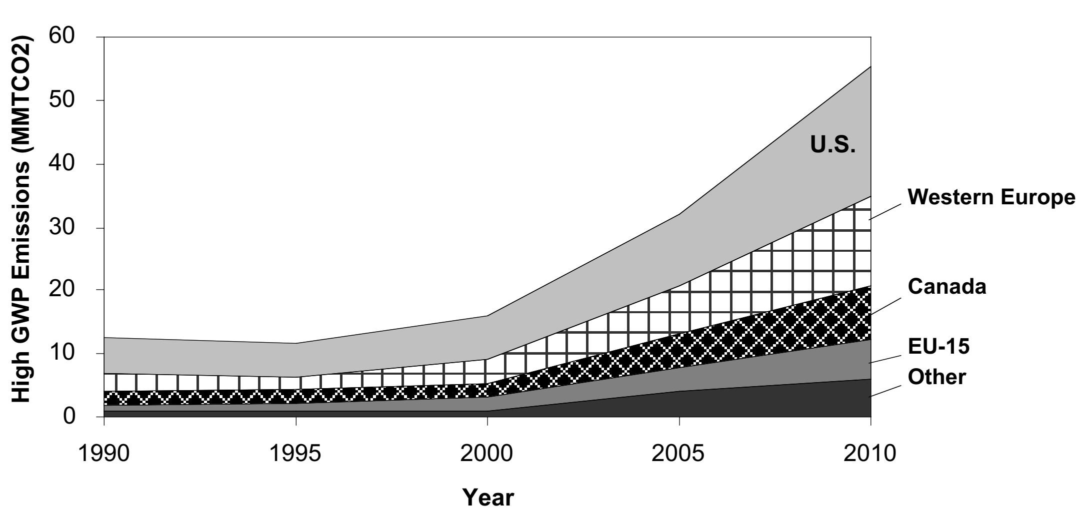
Worldwide, the magnesium production industry is projecting very strong growth between 1990 and 2010. The rate of growth increases after 2000. All regions are projected to experience increased magnesium production, leading to a strong increase in $SF_6$ emissions in every region. For the U.S., there is a leveling of emissions from magnesium production between 1995 and 2000 due to the closing of the largest of the three facilities in the U.S. The two remaining U.S. facilities are expected to regain most of the lost production capacity and resume a trend of net national production growth by 2010, with a corresponding growth in $SF_6$ by 2010.

## 4.7 Aluminum Production

The primary aluminum production industry is currently the largest source of PFC emissions. During the aluminum smelting process, when the alumina ore content of the electrolytic bath falls below critical levels required for electrolysis, rapid voltage increases occur, termed "anode effects" (AEs). These anode effects cause carbon from the anode and fluorine from the dissociated molten cryolite bath to combine, thereby producing fugitive emissions of $CF_4$ and $C_2F_6$. In general, the magnitude of emissions for a given level of production depends on the frequency and duration of these anode effects: the more frequent and long-lasting the anode effects, the greater the emissions. Exhibit 4-9 presents the total aluminum PFC emissions from industrial sources through the year 2010 for developed countries.

Future PFC emissions will be affected by changes in primary aluminum production and changes in the

**Exhibit 4-8: $SF_6$ Emissions from Magnesium Production 1990 through 2010 ($MMTCO_2$)**

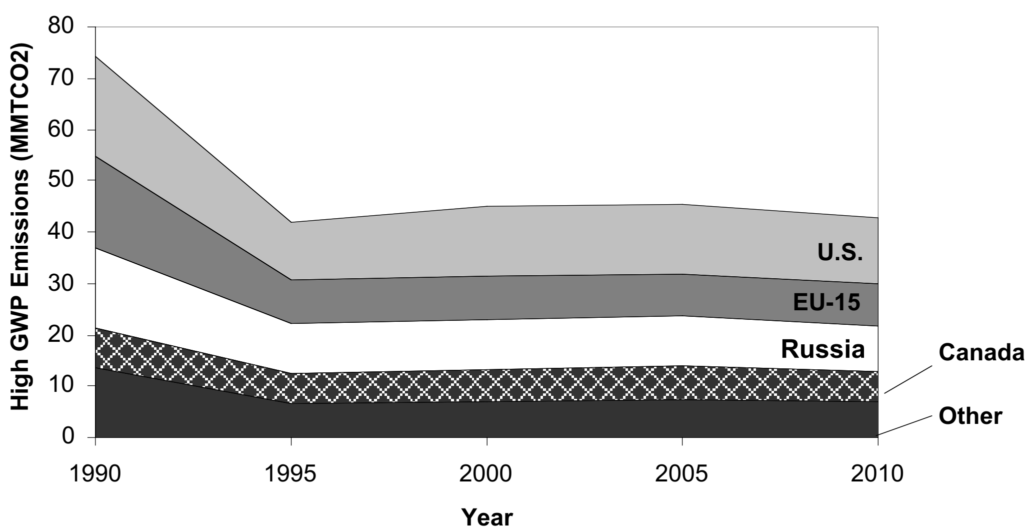


emission rate per ton of aluminum produced. Continued increases in global aluminum production are anticipated through 2010.

| Total PFC Emissions from Aluminum Production | |
|---|---|
| Year | $MMTCO_2$ |
| 1990 | 74 |
| 1995 | 42 |
| 2000 | 41 |
| 2005 | 42 |
| 2010 | 40 |

The production growth results from additions to current aluminum capacity, mostly in the developing world, and improvements in cell technology that increase production efficiency at existing smelters worldwide. Emission rates, on the other hand, are expected to decrease as upgrades in process controls and alumina feeding systems will yield shorter, less frequent anode effects. The developed countries as a whole will see a substantial decrease in emissions because of the combined effect of production moving to developing countries and reduced emission rates. In the U.S. and EU-15, aluminum smelters have realized the environmental and economic benefits of reducing the frequency and duration of anode effects, which cause PFC emissions. This action resulted in a lower emissions rate that will continue into the future.

**Exhibit 4-9: PFC Emissions from Primary Aluminum Production 1990 through 2010 ($MMTCO_2$)**



# 5. Methodologies Used to Compile and Estimate Emissions

This chapter outlines the methodological approach used to compile and estimate emissions and projections. It describes the overall approach and then discusses, by source, any caveats or deviations from this approach. For many countries, the emissions estimates in this report are those reported in National Communications to the UNFCCC or other publicly available documents. This report does not describe the methodologies used to generate these publicly available numbers, but in almost all cases they are consistent with the *Revised 1996 IPCC Guidelines*.

## 5.1 Estimation and Projection Approaches

The general approach was to use country-prepared, publicly available reports wherever possible, with preference given to the most recent report. All estimates were assessed for compatibility with the *Revised 1996 IPCC Guidelines* and to ensure the projections were business–as-usual (BAU). In some cases, EPA made adjustments to the data as emission and particularly projection data were not available from any published sources. An overview of the basic methodology for estimating emissions of methane, nitrous oxide, and high global warming potential (GWP) gases is presented below.

### 5.1.1 Methane and Nitrous Oxide Emissions

For some countries, EPA used estimates provided in country-specific reports that had more updated information than the information provided in the country's most recent National Communications. The methodology for estimating historical and projected emissions for these countries is presented below.

- **Member States of the European Union (except the United Kingdom)**: For historical emissions, the EU-15 submitted a compilation inventory that included all member states for the historical period of 1990 to 1998 (EC, 2000). For projections, three European Commission (EC) reports provide emissions and projections for all the countries (AEA Technology Environment, 2001a, b, c). For a few smaller sources, the Second National Communication projections were used. The historical estimates for 1990-98 in the three EC projection reports are older than the most recent historical estimates in the compilation report. Therefore, to ensure consistency, EPA based projected emissions on the historical estimates in the compilation report and the projected growth rates as determined in the three EC reports (i.e., EPA applied the projected growth rates to the historical estimates).

- **United Kingdom**: For historical and projected emissions, the UK published a country-specific study in 2000 of non-$CO_2$ greenhouse gases for most sources (WS Atkins Environment, 2000). For a few smaller sources not included in that report (wastewater, other agricultural and other non-agricultural) the Second National Communication estimates were used.

- **United States**: For historical and projected emissions, the U.S. baseline emissions estimates for each source reflect the methodologies and data reported for the most recent inventory and projections estimate (EPA 2001a and EPA 2001b draft).

- **Newly Independent States**: For Russia and the Ukraine, detailed country study reports were used for historical and projected emissions for most sources. For a few smaller sources not included in that report (i.e., other non-agricultural) the projections were assumed zero or estimated by EPA, as detailed later in the chapter.

For other countries, EPA primarily used the data provided in the countries National Communications to the UNFCCC because they represent each country's own analysis of its detailed national circumstances. However, in some cases, EPA made adjustments to the estimates, These adjustments and the relevant countries are described below for methane and nitrous oxide.

- **Methane and Industrial Nitrous Oxide**: For the remaining countries, the Second National Communication of each country was the preferred source of emissions data. If "business as usual" (BAU) emission projections were available through 2010, they were used in this report. In a small number of cases, the only available projections included control measures. The methodology that EPA used to exclude the impacts of control measures is described in Section 5.2. If the Second National Communication was not submitted or was incomplete, the First National Communication was consulted, which typically contains projections only to 2000. After assessing the estimates from the National Communications, EPA determined if a more recent inventory was submitted to the UNFCCC. If more recent estimates for a country were available for 1990 and/or 1995, these historical estimates were included and the projections were scaled to reflect the change. At the time of publication, Croatia and Liechtenstein had not yet submitted National Communications. The estimates used for Croatia were reported using the Corinair approach.[1] A 1995 UN-submitted report provided estimates for Liechtenstein. The approach used for each of country is documented in Appendix E.

- **Nitrous Oxide from Agriculture and Fossil Fuel Combustion**: While most countries reported historical and projected emissions of agricultural nitrous oxide ($N_2O$) in their Second National Communications, those estimates typically did not reflect the significantly improved methodologies in the *Revised 1996 IPCC Guidelines*. This approach was particularly apparent for the nitrous oxide emissions from agricultural soils. As discussed above, updated $N_2O$ emission projections were available for the EU-15 and the U.S. Nitrous oxide estimates for the remaining countries were derived as follows:

  - **For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland**, the historical estimates were recent and assumed to be consistent with the *Revised 1996 IPCC Guidelines*. EPA scaled these historical to develop projections. For details see Appendix G.

  - **For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine**, EPA estimated nitrous oxide emissions and projections using the most recent methodological guidelines, internationally recognized data sets, and IPCC emission factors. These methodologies are described in detail in each source section.

### 5.1.2 High Global Warming Potential (High GWP) Gas Emissions

For most countries, emissions and projections were not available for these sources. Therefore, high GWP emissions and projections were estimated using detailed source methodologies described later in this chapter.

## 5.2 Adjustments to Methane Estimates

To ensure consistency and completeness, some of the methane data in this report have been estimated by EPA, or modified from publicly available reports. For example, in some cases, countries reported projections that include the anticipated effects of climate change mitigation efforts. Since the purpose of this report is to provide historical and projected emissions in the absence of climate measures, the anticipated effects of these policies have been added back into the estimates. In other cases, emissions data for certain years were missing and had to be estimated. Some countries presented aggregated projections (e.g., livestock), which had to be disaggregated into their constituents (e.g., enteric fermentation and manure management).

### 5.2.1 Landfilling of Solid Waste

For those countries that included control measures in projections, EPA adjusted the projections to exclude the impacts of the control measures. For those countries with no reported projections, EPA developed estimates. The approach that EPA used for these countries is presented below.

- **Japan, New Zealand, and Switzerland**: These countries included control measures such as methane recovery and waste reduction in their projections. The implementation of mitigation activities for these countries is assumed to result in emissions reductions from the baseline that are similar to those expected to occur in the U.S. from 1990-2010 (30 percent, 61 percent, and 62 percent, respectively , EPA, 1999). To estimate BAU emissions, these anticipated emission reductions associated were added back in to the projections.
- **Russia and European countries without projections**: EPA assumed that future emissions remain constant. In Russia and Eastern Europe this reflects reduced economic activity along with increased use of landfilling.

Exhibit B-2 presents emissions and projections for each country.

### 5.2.2 Coal Mining Activities

Most of the countries that did not report emissions from coal mining do not produce coal domestically, according to the International Energy Outlook (IEA, 1997a). For these countries, EPA assumed methane emissions from coal mining to be zero.

For a few countries, coal-specific reports were available and more recent than other sources. In other countries, no projections were available. The approach used in both cases is outlined below.

- **Russia**: The estimates came from a draft EPA report (EPA, 1999c draft) that focused exclusively on historical and future coal mining methane emissions in Russia. For the majority of underground mines, the methodology was consistent with the IPCC Tier 3 methodology, using measurement data collected by the individual mines. For the remaining underground mines and for surface and post mining, the IPCC Tier 2 methodology was used. To determine the projections, the total projected coal production for a particular year was multiplied by the share of coal production in the region for that year, and then multiplied by the average 1990-1998 emission factor for the specific region. The Russian estimates are the total of these regional estimates.
- **Ukraine**: A Ukrainian coal inventory study provided historical estimates (PEER, 2001 draft). For 2000 to 2010, EPA assumed coal production and, thus related emissions, to decrease by 20 percent, based on a Ukrainian government decision to close 82 of the country's 236 mines by 1999 (EIA, 1997). Economic and social factors are likely to delay completion of these closures until 2005. By 2010, the changes should be implemented and emissions were assumed to stabilize.
- **Poland**: The National Communication reported that emissions are expected to decline sharply by 2010, largely due to anticipated closings of a large number of privatized mines. The pace of mine closures might be slower than anticipated, however, because of social and economic considerations. Unlike Germany and the UK, which are expecting drastic reductions in coal production, the Polish economy is largely coal-based (97 percent of energy consumption, IEA,

1997a), with negligible natural gas and oil reserves. Also, Poland will continue to sell some coal to foreign markets to earn foreign currency. Many of Poland's gassiest mines are located near major industries, where there is increased possibility for methane recovery and use. With the expected closure of highly gassy longwall mines and modest increases in methane recovery and use, EPA assumed emissions will decline 5 percent over each 5-year period to 2010.

In those cases in which a projection of future emissions was not available, EPA used the following two types of assumptions: (1) for Eastern European countries, EPA used Ukraine and Germany as analogue countries (countries with similar circumstances or geography); and (2) for Western European countries, EPA assumed that emissions would remain constant.

Appendix E provides specific information on particular countries. Exhibit B-3 presents emissions estimates and projections data for coal mining.

### 5.2.3 Natural Gas and Oil Systems

In some cases, no projections were available. For these countries, EPA used one of two approaches: (1) for Eastern European countries, EPA assumed emissions remain constant; this assumption balances increased oil and gas production and use with modernization of the system; or (2) for Western European countries, EPA projected historical inventories based on trends in analogue countries.

Appendix E provides specific information on particular countries. Exhibit B-4 presents emissions estimates and projections data for natural gas and oil systems.

### 5.2.4 Livestock Manure Management and Enteric Fermentation

For some countries the emissions associated with livestock manure management and enteric fermentation were reported as combined estimates. EPA disaggregated these emissions for several countries as indicated below.

- **Australia, the Czech Republic, Estonia, Lithuania, New Zealand, Norway, and Switzerland**: EPA disaggregated the projections based on the relative share of each provided in disaggregated historical estimates for each country.
- **Ukraine**: EPA disaggregated the total reported in the mitigation study (Raptsoun, et al., 1996) according to the patterns seen in Poland and Estonia.

For some countries, no projections were available. For these countries, EPA used one of two approaches: (1) for Eastern European countries, EPA assumed they would experience a short-term decline in emissions (to 2000) followed by an increase; this trend is consistent with economic projections, as well as the countries for which projections were available (e.g., Ukraine); or (2) for Western European countries, EPA assumed that emissions would remain constant.

Exhibits B-5 and B-6 present emissions estimates and projections data for each country.

### 5.2.5 Wastewater Treatment

Emissions from this source are typically small, and some countries did not report this category in their inventories. In cases where a suitable analogue country was available, EPA scaled emissions on the basis of the per capita emissions rate of the analogue country. In cases where no projections were available, EPA assumed that emissions would remain constant over time. Where wastewater projections were combined with landfill emissions, EPA disaggregated estimates based on the percentages for each source taken from the latest inventory.

Exhibit B-7 presents emissions estimates and projections data for each country.

### 5.2.6 Other Agriculture Sources

Less than half of the developed countries included categories such as rice cultivation and agricultural residue burning in their inventories. Australia and Japan report the only significant emissions. For countries with historical estimates but no projections, EPA assumed future emissions to be constant.

Exhibit B-8 presents emissions estimates and projections data for each country.

### 5.2.7 Other Non-Agricultural Sources

This category includes emissions sources such as fuel combustion, industrial processes, and waste incineration, which are usually small. Some of the inventory estimates may be incomplete, indicating that the values are not fully comparable. In those cases in which a projection of future emissions was not available, EPA assumed future emissions to remain constant.

Exhibit B-9 presents emissions estimates and projections data for each country.

## 5.3 Methodology and Adjustments to Approaches Used for Nitrous Oxide

To maintain a consistent set of emissions estimates and projections, EPA made adjustments to publicly available $N_2O$ data, and in some cases generated new estimates. This step was necessary particularly for $N_2O$ emissions from agricultural soils and mobile combustion. Unlike the major sources of methane, these sources were significantly revised in the *Revised 1996 IPCC Guidelines*. Many countries were not able to apply the more rigorous methods in time for the Second National Communication. The following sections summarize the methodologies by source, including any adjustments.

### 5.3.1 Nitrous Oxide Emissions from Agricultural Soils

Given the lack of available country-developed information for this source, EPA developed methods of estimating both emissions and projections. For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine, EPA developed both emissions and projections. For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland, the recent historical estimates are available and appear to incorporate the Revised 1996 IPCC Guidelines. EPA developed projections following the method described below, but scaled them to the inventory data.

EPA used the bottom-up approach outlined in the *Revised 1996 IPCC Guidelines* (IPCC, 1997), which made significant methodological improvements in both coverage and emission factors. The methodology outlines three major components: (1) direct emissions from agricultural soils, (2) direct emissions from deposition of animal waste, and (3) indirect emissions. Direct emissions are broken down further into sub-categories including fertilizer application, histosol cultivation, cultivation of nitrogen fixing crops, incorporation of crop residues, and daily spread operations. Histosol cultivation area, alfalfa production, and consumption of commercial organic fertilizers were not available and thus are not included in this report.

The *Revised 1996 IPCC Guidelines* provide default emission factors for different world regions, but require country-specific activity data. The specific approach and data sources used to estimate historical and projected emissions from each sub-component in this source category are presented in Appendix G.

Exhibit C-2 presents total $N_2O$ emission estimates from agricultural soil management for each developed country.

### 5.3.2 Nitrous Oxide Emissions from Industrial Processes

Most countries report $N_2O$ emissions from industrial processes in their Second National Communication or other reports. For the few countries with no estimates for this source, emissions for these countries are not reported.

| Exhibit 5-1: Fuel Types Included in $N_2O$ Emissions from Fossil Fuel Combustion Analysis | | |
|---|---|---|
| **Coal** | **Natural Gas** | **Oil** |
| Hard Coal | Natural Gas | Crude |
| Brown Coal | Refinery Gas in metric tons | Motor Gasoline |
| Coke Oven Coke | Ethane | Aviation Gasoline |
| Gas Coke | Liquefied Petroleum Gases | Gasoline - type Jet Fuel |
| Peat | Gas Works Gas | Kerosene - type Jet Fuel |
| BKB | Coke Oven Gas | Kerosene |
| | Blast Furnace Gas | Gas/Diesel Oil |
| | Oxygen Steel Furnace Gas | Residual Fuel Oil |
| | | Petroleum Coke |
| | | Non-specified Petroleum Products |
| | | Naphtha |
| | | Patent Fuel |

Total nitrous oxide emissions from industrial sources are summarized in Exhibit C-3. The data sources for each country can be found in Appendix F.

### 5.3.3 Nitrous Oxide Emissions from Stationary Fossil Fuel Combustion

Many countries do not report $N_2O$ emissions from fossil fuel combustion. EPA developed methods of estimating both emissions and projections. For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine, EPA developed both emissions and projections. For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland, the recent historical estimates are available and appear to incorporate the *Revised 1996 IPCC Guidelines*. EPA developed projections following the method described below, but scaled them to the inventory data.

#### *Historical Emissions*

EPA collected fossil fuel consumption data by country, fuel product and sector use for all major fuel types as indicated in Exhibit 5-1 (IEA, 1997b). The sectors included in the analysis were the electric utility industry and the manufacturing and construction industries. The consumption was then multiplied by the IPCC Tier 1 $N_2O$ emissions factor for each fuel type and sector. EPA estimated historical data for two countries with no reported historical estimates:

- For Monaco, French data on per capita energy demand was applied to Monaco to estimate fuel consumption by fuel type for each sector (IEA, 1997b).
- For Liechtenstein, EPA applied the average per capita energy demand from Austria and Switzerland to the population of Liechtenstein (IEA, 1997b).

#### *Projected Emissions*

EPA applied region specific average annual growth rates by fuel type (IEA, 1997b) to 1995 consumption data to determine future energy consumption for 2000, 2005, and 2010. The growth factors were only available for industrialized, developing and EE/FSU country categories (IEA, 1997b), as summarized in Exhibit 5-2. The EE/FSU rates were applied to Russia and Eastern Europe and industrialized rates were applied to all other countries. For each country, the projected energy consumption by fuel product and sector use were multiplied by the IPCC Tier 1 emission factors.

**Exhibit 5-2: Annual Growth Rates for Electric Utilities and Manufacturing/Construction Sectors (%/year)**

| Energy Source | Industrialized Countries | Developing and EE/FSU Countries |
|---|---|---|
| Oil | 1.1 | 3.3 |
| Natural Gas | 2.6 | 3.8 |
| Coal | 0.7 | 2.5 |
| Biomass/Waste | 1.3 | 3.1 |

*Note: EE/FSU rates are applied to Russia and Eastern Europe and Industrialized rates are applied to all other Developed Countries in the analysis. Source: IEA (1997b).*

## 5.3.4 Nitrous Oxides Emissions from Mobile Fossil Fuel Combustion

For many developed countries, the estimates provided in the Second National Communications did not reflect the updated emission factors provided by the *Revised 1996 IPCC Guidelines*. These new emission factors incorporated the results of measurement projects, and lead to a significant revision upwards of $N_2O$ emissions. To ensure consistency across sources, and provide more complete estimates for all countries, EPA recalculated emissions for all countries using the updated emission factors.

The basic approach was to estimate fuel consumption for each country, assign the fuel consumption to different classes or categories of vehicles, and then apply the updated emission factors at a disaggregated level. The details are summarized in Appendix H.

Emissions from all modes were summarized and are presented in Exhibit C-7.

## 5.3.5 Nitrous Oxide Emissions from Manure Management

This section addresses emissions and projections of $N_2O$ resulting from the storage or handling of livestock manure (i.e., before the manure is added to soils). $N_2O$ emission levels from manure management systems depend on the type of system and the length of time the waste stored. Similar to agricultural soils, the manure methodology was revised in the *Revised 1996 IPCC Guidelines* and many countries were not able to apply the more rigorous methodologies in time for the Second National Communication.

Given the lack of available country-developed information for this source, EPA developed methods of estimating both emissions and projections. For the Czech Republic, Estonia, Iceland, Latvia, Lithuania, Poland, Romania, Russia, Slovenia, and Ukraine, EPA developed both emissions and projections. For Australia, Bulgaria, Canada, Hungary, Japan, Monaco, New Zealand, Norway, Slovakia, and Switzerland, the recent historical estimates are available and appear to incorporate the *Revised 1996 IPCC Guidelines*. EPA developed projections following the method described below, but scaled them to the inventory data.

### *Historical Activity Data*

FAO reported historical animal population data for most countries (FAO, 1998c). The exceptions are described below:

- Luxembourg: EPA used $N_2O$ emissions from agricultural soils, as reported in each country's National Communication, as a proxy (98% Belgium and 2% Luxembourg).
- Croatia, Estonia, Latvia, Lithuania, Russia, and Ukraine: Data for 1990 are reported for the Former Soviet Union. EPA divided the 1990 livestock populations in the Former Soviet Union among Estonia, Lithuania, Russia, and Ukraine based upon each country's relative share in 1995. The 1995 data filled the gap for 1990 for Croatia.
- Czech Republic and Slovakia: In 1990, population statistics were reported for Czechoslovakia. Each country's 1995 population statistics were used to determine relative shares.
- Liechtenstein: No data were available.

### *Historical Emissions*

EPA estimated total livestock nitrogen excretion based on default values for each animal type. The total nitrogen excretion was then divided among animal waste management systems using IPCC default assumptions. To estimate $N_2O$ emissions, the excreted livestock nitrogen for each management system (with the exception of pasture, range and paddock, and daily spread) was multiplied by IPCC default emission factors specific to the animal waste management system.

### *Projected Emissions*

Animal population forecasts were not available for 2000, 2005 and 2010 except for the U.S. To project other countries' emissions, EPA assumed emissions would grow at the same rate as methane emissions from livestock manure.

Direct $N_2O$ emissions from deposition of animal waste are summarized in Exhibit C-8.

## 5.4 Estimation and Projection Approaches Used for High Global Warming Potential Gases

High global warming potential (High GWP) gas emissions result from the use of substitutes for ozone-depleting substances (ODSs) and from other industrial sectors. Until recently, few nations have made significant efforts to track and project use and emissions of HFCs, PFCs, and $SF_6$. If countries did present information on these gases it was often partial estimates or an aggregate estimate. In either their National Communication or more recent literature, Austria, Canada, Germany, Japan, Norway, Russia, the United Kingdom, and the United States provide enough information to incorporate in this analysis.

### 5.4.1 HFC and PFC Emissions from the Use of Substitutes for ODS Substances

This analysis incorporates estimates of the emissions of ODS substitutes available through the National Communications of Japan, Norway, Russia, the United Kingdom, and the U.S.[2] EPA assumed that the U.S. transition pattern from ODS to alternatives can be applied to the remaining countries. Additionally, this analysis uses a U.S. emission profile for each end use application.

The U.S. transition pattern was customized to each region or country using adjustment factors that take into consideration differences in the rates of the phase out and the distribution of ODS consumption across end uses.

### *The Vintaging Model*

EPA uses a "Vintaging Model" of ODS-containing equipment and products to estimate the use and emissions of ODS substitutes in the U.S. (This model is discussed in more detail in Appendix I.) The model tracks the use and emissions of each of the substances separately for each of the ages or "vintages" of equipment.

The consumption of ODS and ODS substitutes are modeled by estimating the amount of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment and products over time. Emissions are estimated by applying annual leak rates and release profiles to each population of equipment or product. By aggregating the data for more than 40 different end-uses, the model estimates and projects annual use and emissions of each compound over time. For this analysis, the model calculates a "business as usual" case that does not incorporate measures to reduce or eliminate the emissions of these gases other than those regulated by U.S. law.

The major end-use categories defined in the Vintaging Model to characterize ODS use in the U.S. are: refrigeration and air conditioning, aerosols, solvent cleaning, fire extinguishing equipment, foam production, and sterilization. The Vintaging Model estimates the use and emissions of ODS alternatives by taking the following steps:

1. Collection of historical emissions data from published sources and industry experts.

2. Simulation of the implementation of control technologies: The Vintaging Model uses detailed characterizations of the existing uses of the ODSs, as well as data on how the substitutes can replace the ODSs, to simulate the implementation of control technologies that ensure compliance with ODS phase out policies. As part of this simulation, the ODS substitutes are introduced in each of the end uses over time as needed to comply with the ODS phase out.

3. Estimation of emissions of the ODS substitutes: The chemical use is estimated from the amount of the substitutes that are required each year for the manufacture, installation, use, or servicing of products. The emissions are estimated from the emission profile for each vintage of equipment or product in each end use.

### *Applying the Vintaging Model to Other Developed Countries*

To apply the Vintaging Model to other countries, EPA used the following methodology:

**Historical ODS activity data:** UNEP provided estimates of 1990 ODS consumption by country. The estimates for the European Economic Community (EEC) were provided in aggregate and GDP was used as a proxy to divide the consumption of the individual member nations from the EEC total.[3] The UNEP report provided consumption data in terms of ozone depletion potential (ODP) weighted totals for the major types of ozone depleting substances: CFCs, HCFCs, halons, carbon tetrachloride, and methyl chloroform. To obtain unweighted ODS consumption values, EPA followed the methodology outlined below:

- CFCs: EPA applied the U.S. pattern of CFC consumption for each individual CFC compound to the aggregate ODP-weighted totals for each country. As a check, the proportions of CFCs produced globally in 1990 were also used to estimate the unweighted total of CFCs from the ODP-weighted totals (AFEAS, 1997). The total unweighted CFC consumption calculated with the U.S. and AFEAS proportions differed by less than 1 percent.
- HCFCs: EPA applied the U.S. average ODP for 1989 HCFC consumption, which was 0.056.
- Methyl chloroform and carbon tetrachloride: EPA used a straight conversion from ODP-weighted totals to unweighted totals.
- Halons: Three different halons (Halon 1211, Halon 1301, and Halon 2402) comprised the ODP-weighted halons totals in the UNEP estimates. EPA assumed that all of the countries use both Halon 1211 and Halon 1301 but only the Former Soviet Union countries use Halon 2402. The ODP-weighted values were separated into unweighted totals of Halon 1211 and Halon 1301 using ratios of 1211 production to 1301 production in 1990 (UNEP, 1998). For the Former Soviet Union, the total was separated into all three halons based upon the 1990 consumption reported for the Russian Federation (Russia MPENR, 1994).

**Apportionment of historical ODS consumption to end-use sectors:** Data on the end-use distributions of ozone depleting substances in 1990 were available for the United States, the United Kingdom, and the Russian Federation, as shown in Exhibit 5-3. The 1990 end-use sector distribution for the United States was used for Canada. The United Kingdom's distribution was applied to the EU-15, Australia and New Zealand. The Russian Federation's distribution was applied to the Former Soviet Union countries and the non-EU-15 European countries.

**ODS substitute emissions:** EPA assumed for this report that all countries will transition from ODS to ODS substitutes in the same way as the United States, with adjustments in later steps to account for regional differences. Using the U.S. data, EPA developed a relationship between the 1990 ODS consumption and ODS substitute emissions using two ratios: (1) the U.S. ratio of unweighted base year

**Exhibit 5-3: End-Use Sector Distribution of 1990 Unweighted ODS Consumption (%)**

| | CFCs | | | | | | HCFCs[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Refrigerant | MDI Aerosols[b] | Non-MDI Aerosols | Solvents | Foams | Sterilization | Refrigerant | Aerosols | Foams |
| United States | 21.2% | 1.8% | 0.0% | 41.1% | 16.2% | 19.8% | 100% | 0.0% | 0.0% |
| Russia | 16.7% | 0.9% | 53.7% | 21.1% | 7.5% | 0.0% | 80% | 10.0% | 10.0% |
| United Kingdom | 21.3% | 1.5% | 27.6% | 26.7% | 21.5% | 1.4% | 69% | 5.1% | 25.9% |

[a] The breakout of HCFCs in Russia is an estimate based on the fact that Russia had CFC use in refrigeration, aerosols, and foams, and that in both the U.S. and U.K., HCFC use was more heavily weighted toward refrigeration than the other end-use sectors

[b] The pharmaceutical use of aerosols in Russia in 1990 is taken directly from Table 3.4.b of *Phaseout of Ozone Depleting Substances in Russia*. EPA estimated the MDI use in United Kingdom to be 5 percent of the total 1990 CFC aerosol use. Though MDIs are expected to account for the majority of HFC use in aerosols, limited HFC aerosol uses in other specialized applications are likely to include such products as office equipment dusters.

Sources: U.S. end-use sector breakouts are calculated from results of EPA's Vintaging Model.
Russia's end-use sector breakouts are taken from MPNER (1994), pp. x-xi, 27-28.
U.K. end-use sector breakouts are from UK DEP (1996), pp. 4.4,4.6.

(1990) ODS consumption to unweighted substitute consumption in a given year, for each of the twelve end-use sectors; and (2) the U.S. ratio of unweighted U.S. ODS substitute consumption in a given year to GWP-weighted U.S. ODS substitute emissions in the same year. The two ratios, when multiplied together, form a ratio of unweighted 1990 U.S. ODS consumption (metric tons) to weighted U.S. ODS substitute emissions ($MMTCO_2$) in a given year. However, these two ratios are valid only if they result in real, non-zero numbers, therefore, the U.S. substitute emissions and the 1990 U.S. ODS consumption values must both be non-zero. This criteria was not met in two instances and adjustments were made:

- Non-medical dose inhaler (Non-MDI) aerosols: The U.S. phased out non-MDI use of CFCs in aerosols prior to 1990, therefore, the 1990 consumption was zero. In order to determine a non-zero ratio for this step, the unweighted U.S. consumption of non-MDI ODS substitutes (including a large market segment that transitioned into non-GWP, non-ODP substances) was used as a proxy for U.S. 1990 non-MDI ODS consumption, for this step only. This assumption is valid if the market size of U.S. non-MDI aerosols was not affected by the transition from ODS to ODS substitutes. The result is that this analysis assumes that the transition of non-MDI aerosols out of ODS was completed by 1995 for both Russia and the United Kingdom, where CFC usage in non-MDI aerosols is significant.
- HCFCs in foam blowing and non-MDI aerosols: In 1990, the U.S. was not using HCFCs in foam blowing or in non-MDI aerosols, leading to a zero value for HCFC consumption. For the purposes of developing these ratios, EPA assumed that the ODS substitutes for HCFCs in these two markets would follow the same transition scenarios as U.S. CFC-blown foams and non-MDI aerosols, respectively.

The country-specific unweighted 1990 consumption of ODS is divided by the ratio of unweighted 1990 ODS consumption to GWP-weighted substitute emissions, as described above. This calculation is performed for each of the twelve end-use sectors for each country for each year.

**Transition adjustment factors**: To account for country differences in the transition from ODS to ODS substitutes, EPA adjusted other countries' emissions estimates based upon qualitative information about how their substitution will likely

| Exhibit 5-4: Adjustment Factors Applied to ODS Emissions for Each Country | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | CFCs | | | | | HCFCs | | | Halons | CT | MCF |
| | Refrig-erant | Aerosol | Solvent | Foams | Steril-ization | Refrig-erant | Aerosol | Foams | Fire Extingu-ishing | Solvent | Solvent |
| Australia and New Zealand | 0.90 | 1.00 | 1.00 | 0.50 | 1.00 | 0.90 | 1.00 | 0.50 | 1.00 | 1.00 | 1.00 |
| Canada | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| FSU | 0.75 | 1.00 | 0.50 | 0.20 | 0.50 | 0.75 | 1.00 | 0.20 | 1.00 | 0.50 | 0.50 |
| EU-15 | 0.80 | 1.00 | 0.80 | 0.40 | 0.90 | 0.80 | 1.00 | 0.40 | 1.00 | 0.80 | 0.80 |
| Europe (non-EU-15) | 0.75 | 1.00 | 0.50 | 0.20 | 0.50 | 0.75 | 1.00 | 0.20 | 1.00 | 0.50 | 0.50 |
| Japan | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

differ from that of the US. Each country's emissions were multiplied by an adjustment factor, which is between 0 and 1.0. In other words, the U.S. substitution in each end-use sector was assumed to be a maximum. For example, an adjustment factor of less than one was applied to end-uses such as refrigerants in Europe, because EPA is aware that European appliances are more likely to use hydrocarbon refrigerants in place of HFCs. Overseas foam use is also adjusted downward in some cases because of the use of cyclopentane in lieu of HFCs. Exhibit 5-4 presents the adjustment factors that were applied for each country or group of countries.

**Timing factors**: In addition to the adjustment factors for each end-use sector, a timing adjustment was applied for the Former Soviet Union countries (FSU) and non-EU-15 European countries. Since these nations will transition to substitutes more slowly, EPA multiplied the emission estimates by a timing factor to reflect the anticipated delay in their transition. Exhibit 5-5 shows the timing factors applied to the emissions in each year.

| Exhibit 5-5: Timing Factors Applied to ODS Emissions Estimates | | | | | |
|---|---|---|---|---|---|
| Country/ Country Group | 1990 | 1995 | 2000 | 2005 | 2010 |
| FSU | 0 | 0 | 0.25 | 0.5 | 0.75 |
| Europe (non-EU-15) | 0 | 0 | 0.25 | 0.5 | 0.75 |

**Adjustment factor for refrigerant recycling:** A third adjustment was required to account for increased emissions, compared to the U.S., which may result from a lack of recycling or recovery of refrigerants in non-EU-15 European countries and the FSU. Exhibit 5-6 presents these adjustment factors.

| Exhibit 5-6: Recycling Adjustment Applied to Refrigeration Emissions Estimates | |
|---|---|
| Country/Country Group | Adjustment |
| Australia and New Zealand | 1.0 |
| Canada | 1.0 |
| FSU | 1.1 |
| EU-15 | 1.0 |
| Europe (non-EU-15) | 1.1 |
| Japan | 1.0 |

### 5.4.2 HFC-23 Emissions as a Byproduct of HCFC-22 Production

For Norway, Japan, the U.K., and the U.S., emissions estimates are available and taken directly from national reports (Norway MOE, 1997; METI, 2001; WS Atkins Environment , 2000; and EPA, 2001a, c).

#### *Historical HFC-23 Emissions*

For developed countries without estimates, consumption and production data of HCFC-22 were available for 1989 and all years from 1992 to 1998, as reported to the Secretariat by the Parties to the Montreal Protocol (UNEP, 1999). The reported production and consumption is expressed in ozone depletion potential (ODP) weighted units and was aggregated with all HCFCs.[4] EPA developed estimates for 1990 by linearly interpolating between 1989 and 1992. The Alternative Fluorocarbon

Environmental Acceptability Study (AFEAS, 1999) was used to compare 1990 HCFC-22 production estimates with UNEP production data by country. In addition, EPA made the following assumptions:

1. As the consumption estimates from UNEP do not include HCFC-22 produced for use as feedstock, EPA adjusted reported estimates to include an additional 35 percent of HCFC-22 production (AFEAS, 1999).[5]

2. The 1995 and 1998 HCFC consumption numbers from UNEP included more than HCFC-22. The AFEAS study used sales of HCFC-22, HCFC-142b, and HCFC-141b to determine the proportion of HCFC-22 within total HCFC sales. This proportion by region was then applied to HCFC consumption reported under UNEP. Again, the estimates were adjusted for 35 percent to account for feedstock.

### *HFC-23 Projected Emissions*

EPA used 1998 HFC-23 emissions as a baseline to project emissions into the future. The method for projecting the baseline data was as follows:

- End-use breakdown of HCFC-22 for 1998. EPA assumed that 65 percent of current global HCFC-22 production is used to produce refrigeration, air-conditioning, and foam products. The other 35 percent of HCFC-22 production was assumed to be used as feedstock material, which is not controlled by the Montreal Protocol. Manufacturers have the incentive to increase production for feedstock material use to keep plants producing at capacity.

- Growth rate for feedstock and other uses: EPA assumed that production of HCFC-22 for feedstock materials would grow at a 1.5 percent annual rate in each country. The rate of growth for production of HCFC-22 for regulated end-uses (i.e., for refrigeration) was determined by linearly decreasing production so that complete phase-out occurred based on the phase-out schedule for each country.

- Emissions for each country through 2010: Since production and HFC-23 emissions are directly linked, emissions related to non-feedstock uses were decreased at the phase-out rate while the emissions related to feedstock use were increased at the 1.5 percent annual rate, for each country.

The resulting emissions estimates are presented in Exhibit D-3.

## 5.4.3 Perfluorocarbon (PFC) Emissions from Primary Aluminum Production

The emissions estimates for Austria, Canada, Germany, Norway, Japan, the UK, and the U.S. are taken directly from National Communications or country reports (Radunsky, 2000, Environment Canada 1997, Germany FME 1997, Norway MOE 1997, WS Atkins Environment 2000, and EPA, 2001a, c). The methodologies employed included smelter-specific information and provided estimates and projections with a lower level of uncertainty.

**Exhibit 5-7: 1990 and 1995 HCFC-22 Production in Developed Countries (metric tons)**

| Country | 1990 HCFC-22 Production | 1995 HCFC-22 Production |
|---|---|---|
| Australia | 2,352 | 1,259 |
| Canada | 3,570 | 480 |
| France | 22,000 | 47,141 |
| Germany | 9,800 | 5,212 |
| Greece | 1,606 | 3,065 |
| Italy | 6,824 | 3,764 |
| Netherlands | 10,479 | 6,862 |
| Russia | 16,091 | 3,345 |
| Spain | 8,267 | 6,025 |
| UK | 12,952 | 11,123 |

Source: UNEP (1997), AFEAS

The methodology used to estimate PFC emissions from aluminum production for the remaining countries was as follows.

### Historical Primary Aluminum Production by Country

Primary aluminum production data for developed countries for 1990 and 1995 was taken from the background materials used for the report entitled *Greenhouse Gas Emissions from the Aluminum Industry* (IEA, 2000). EPA adjusted the data for countries in Western Europe, Eastern Europe, and the Former Soviet Union based upon personal communication with Eirik Nordheim from the European Aluminum Association (1999).

### Projected Primary Aluminum Production by Country

This analysis aggregated individual smelter production data to provide regional-level, technology-specific production projections through 2010. Projections are based upon anticipated smelter openings, smelter closings, and changes in aluminum demand, which was modeled using regional Gross Domestic Product estimates. Within each region and technology type, production totals were divided among the respective countries depending upon their historically reported proportion of regional production. Exhibit 5-8 shows aluminum producing countries within each region.

For Western Europe, Eastern Europe, and the Former Soviet Union, the regional production totals could not be used since the historical data were adjusted. Expected smelter opening and closing information was combined with technology-specific growth rates (2.5 percent per year for prebake cells, 0.5 percent per year for Soderberg cells) to forecast future regional production. The regional production was then apportioned according to each country's historical share of regional production within a given technology type, as stated above.

**Exhibit 5-8: Regional Categories for Developed Countries**

| Region | Aluminum Producing Developed Countries |
|---|---|
| Asia | Japan |
| Australasia | Australia, New Zealand |
| Eastern Europe and the Former Soviet Union | Croatia, Poland, Romania, Russia, Slovakia, Slovenia, Ukraine |
| North America | Canada, United States |
| Western Europe | Austria, France, Germany, Greece, Hungary, Iceland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom |

### PFC Emission Factors

The *Aluminum Annual Review 1998* (Anthony Bird Associates 1998) provides the cell technology type for individual smelters within each country; by combining this information with forecasts of regional technology upgrades, emission factors gained both regional and technological sensitivity.

EPA estimated emission factors using the Tier 2 IPCC good practice methodology for calculating PFC emissions from primary aluminum production (IPCC, 2000). This methodology is shown mathematically below:

$$\textit{Emission Factor (kg } CF_4 \textit{ or } C_2F_6 \textit{ per tonne Al)} = \textit{Slope-coefficient x AE Minutes/Cell-Day}$$

Where,

AE Minutes/Cell-Day = Anode Effect Frequency x Anode Effect Duration

Anode Effect Frequency = Number of Anode Effects per Cell-Day

Anode Effect Duration = Average Anode Effect Duration in Minutes

Since operating parameter (i.e. average anode effect (AE) duration and AE frequency) and slope-coefficient (S-value) information were not available for all smelters, technology-specific regional default values for AE Minutes/Cell-Day (IPAI, 1999) and technology-specific S-values were used (IPCC, 2000).

The emission factors were projected through 2010 by extending recent trends in AE Minutes/Cell-Day. The future AE Minutes/Cell-Day values differ among the various regions according to estimated technology diffusion rates.

**Exhibit 5-9: 1990 and 1995 AE Minutes/Cell-Day Values By Tech Type**

| Technology Type | AE Minutes/Cell-Day | |
|---|---|---|
| | 1990 | 1995 |
| Vertical Stud-Soderberg (VSS) | 10.3 | 7.1 |
| Horizontal Stud-Soderberg (HSS) | 3.5 | 3.1 |
| Side Work-Prebake (SWPB) | 6.5 | 5.3 |
| Center Work-Prebake (CWPB) | 3.4 | 1.6 |
| Point Feed-Prebake (PFPB) | 2.3 | 1.1 |

Source: IPAI, 1999.

### *PFC Emissions*

EPA calculated emissions by multiplying the emission factors by the aluminum production.

A summary of emissions is presented in Exhibit D-4.

## 5.4.4 Sulfur Hexafluoride ($SF_6$) Emissions from Magnesium Production

Austria, Canada, Germany, Japan, Norway, the United Kingdom, and the U.S. included partial or complete $SF_6$ estimates from magnesium. EPA used these estimates to replace or inform the estimates for those countries (Radunsky, 2000, Environment Canada 1997, Germany FME 1997, Norway MOE 1997, WS Atkins Environment 2000, and EPA, 2001c). For the remaining countries, the following method was used:

### *Historical Magnesium Production by Country*

The U.S. Geological Survey publishes data for primary production of magnesium by country through 1998 (USGS, 1999). For those countries that produce magnesium, die casting production was estimated by applying the U.S. proportion of primary production to diecasting consumption, shown in Exhibit 5-10, to each country's primary production for each year. Estimates of magnesium diecasting production for countries with no primary magnesium production (i.e., importers) were taken from their National Communications to the United Nations Framework Convention on Climate Change, information on commerce activities from the USGS (1999), and estimates of magnesium casting activities in car producing countries. These countries include Austria, Germany, Japan, Sweden, and the United Kingdom. Additionally, total die casting production is in agreement with the USGS' estimate that die casting accounts for roughly 30 percent of magnesium consumption globally.

**Exhibit 5-10: Portion of U.S. Primary Magnesium Production Processed by Die Casting Industry (%)**

| Year | Percent |
|---|---|
| 1990 | 6.5% |
| 1991 | 7.4% |
| 1992 | 7.5% |
| 1993 | 9.5% |
| 1994 | 12.2% |
| 1995 | 10.7% |
| 1996 | 12.3% |
| 1997 | 16.5% |
| 1998 | 23.9% |

### *Historical and Projected Emission Factors*

The emission factor for diecasting (4.1 kg $SF_6$/metric ton Mg) was taken from Gjestland and Magers (1996). The primary production emission factor (0.95 kg $SF_6$/metric ton Mg) was estimated by dividing the total sales of $SF_6$ to the magnesium industry by the total magnesium primary production in each country. (Global sales data were voluntarily provided by major chemical manufacturers.) Although the Russian Federation is a major producer of magnesium metal, EPA assumed it did not transition to $SF_6$ from the older method, which used sulfur dioxide ($SO_2$), during the time frame of the analysis. EPA assumed these emission factors remained constant over time.

### $SF_6$ Emissions

EPA assumed that all the $SF_6$ used is emitted. Emissions were calculated by multiplying the primary magnesium production data and die-casting production data by the corresponding emission factor for each country for each year.

Exhibit D-5 presents the emissions estimates.

## 5.4.5 Sulfur Hexafluoride ($SF_6$) Emissions from Electric Utilities

Estimates for the UK, Japan and the United States were taken directly from recent country reports (WS Atkins Environment, 2000; METI, 2001; and EPA 2001b, c). These recent estimates were made using country-specific data, and are considered more reliable than the results of the global apportionment outlined below. Several countries report emissions from this sector in their National Communications but these data were not used in the current analysis because the National Communications do not take into consideration recent $SF_6$ sales information.

The following methodology was used to determine $SF_6$ emissions from utilities.

### Countries That Use $SF_6$ in Their Utilities Industry

This list was determined from conversations with equipment manufacturers and from National Communications.

### Electricity Consumption

EIA provides country specific electricity consumption, region specific growth rates, and a few country specific growth rates (EIA, 2001). Individual countries have their electricity consumption estimated using the region specific growth rates or, where available, country-specific growth rates. Each country's electricity consumption was normalized as a fraction of the world total.

### Historical and Projected Global $SF_6$ Emissions

Historical global emissions of $SF_6$ from electrical utilities for 1990 to 1999 were estimated from global sales of $SF_6$ to electrical utilities (Rand, 2000). Future global emissions are projected assuming a 4.5 percent annual decrease for 1999 through 2002 (Rand, 2000) and a 0.7 percent annual increase for 2002 through 2020. The 0.7 percent growth rate is a combination of (1) a growth rate of 1.7 percent for U.S. electric generating capability between 1999 and 2020 (EIA, 2001) and (2) a growth rate of -1.0 percent per year for the charge of $SF_6$ contained in a typical piece of electrical equipment of a given voltage capacity (Sauer, 2001). The sum of gas purchases from electric utilities is assumed to equal the total global emissions of $SF_6$ from electrical equipment.

### Global $SF_6$ Emission Apportionment

EPA assumed that $SF_6$ emissions are proportional to electricity consumption. Emissions of $SF_6$ are allocated to each country based on their share of total world electricity consumption.

Exhibit D-6 presents $SF_6$ emissions estimates from electric utilities.

## 5.4.6 Emissions from Semiconductor Production

Estimates for Canada, Japan, and the U.S. are taken from country submitted reports (Environment Canada 1997; METI, 2001; and EPA, 2001b, c). For the remaining countries, the following methodology was used to estimate emissions of high GWP gases (PFCs) from the semiconductor industry.

1. **Analytical Approach**: Throughout this analysis, EPA assumed that emissions from semiconductor manufacturing are proportional to MSI-Si layers processed[6] (and to MSI-Si layer processing capacity) in the world and in each country. In its analyses of the U.S. industry, EPA has found that emissions are closely correlated with MSI-Si layers processed.

2. **Global Emissions**: To develop estimates of global emissions from 1990 through 2010, EPA began with estimates of U.S. emissions for 1990

through 2010. These U.S. estimates have been developed based on emissions information supplied by participants in EPA's PFC Reduction/Climate Partnership with the semiconductor industry, and on estimates of MSI-Si layers processed in the U.S. To scale up these estimates to the global level, EPA estimated the share of world MSI-Si layer capacity accounted for by the U.S. World and U.S. MSI-Si layer capacity were estimated using SEMI's 2001 Fabs on Disk database for the linewidth technologies in place in 2000. The International Technology Road map (SEMATECH, 2000) provided the number of layers associated with each linewidth technology. EPA then divided the emissions projections for the U.S. by the U.S. share of MSI-Si layers to obtain emissions projections for the world.

3. **Country-Specific Apportionment:** EPA used the sources cited above to develop country-by-country estimates of MSI-Si layer capacity. EPA then multiplied the emissions projections for the world by the country-specific shares of world MSI-Si layers to obtain the country-by-country emissions estimates.

Emissions from semiconductor production are presented in Exhibit D-7.

## 5.5 Explanatory Notes

1. The Corinair method is an emissions inventory methodology developed by the European Union. A description of the methodology can be found at the following website:

   http://www.ptl-ae.atmoterm.pl/index.html

2. Norway's National Communication provided an emission estimate for 1990 and 1995; however the 1995 estimate was projected from earlier estimates based on results of "significant" efforts by the magnesium industry to reduce $SF_6$ emissions. To be consistent with "business as usual," only the 1990 estimate was used. Estimates for the years 1991-1994 were interpolated to the 1995 value that resulted from this analysis. Estimates for 1995 forward were consistent with the methodology outlined in this chapter.

3. In 1990, the European Economic Community (EEC) included 12 nations: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and United Kingdom. The EEC is now called the European Union (EU). The EU currently has 15 members, the 12 from the EEC plus Austria, Finland, and Sweden.

4. Ozone depletion potentials (ODPs) are used to quantify the relative damage done to the ozone layer by different compounds. By definition, CFC-11 is assigned an ODP of 1. The use of ODPs, with CFC-11 assigned the value 1, is similar to the use of global warming potentials (GWP) to quantify the relative impact of compounds on radiative forcing, with carbon dioxide assigned a global warming potential of 1.

5. In the UNEP report, the consumption for European Union member nations are aggregated into one EU consumption estimate. In addition, in this analysis the results for the nations that are designated countries with economies in transition (CEIT) are grouped together as one, Australia and New Zealand are reported as one, and the non-EU European countries are reported together as one.

6. MSI-Si layers processed refers to millions of square inches of silicon processed times the number of interconnect layers contained in the semiconductors produced.

# 6. References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# Appendix A: Summary of Total Emissions Estimates and Projections for Non-$CO_2$ Gases

Appendix A summarizes total emissions estimates and projections for non-$CO_2$ gases in the following exhibits:

- Exhibit A-1: Combined Methane, Nitrous Oxide, and High Global Warming Potential Gas Emissions ($MMTCO_2$)
- Exhibit A-2: Total Methane, Nitrous Oxide, and High Global Warming Potential Gas Emissions for Developed Countries ($MMTCO_2$)

**Exhibit A-1: Combined Methane, Nitrous Oxide, and High Global Warming Potential Gas Emissions ($MMTCO_2$)**

| Developed Country | Total Emissions: Methane, Nitrous Oxide, High GWP ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 136 | 134 | 148 | 165 | 176 |
| Austria | 12 | 11 | 12 | 13 | 14 |
| Belgium | 21 | 22 | 23 | 24 | 25 |
| Bulgaria | 53 | 36 | 42 | 48 | 54 |
| Canada | 146 | 163 | 159 | 174 | 187 |
| Croatia | 5 | 5 | 5 | 6 | 6 |
| Czech Republic | 26 | 19 | 20 | 23 | 25 |
| Denmark | 17 | 16 | 17 | 17 | 18 |
| Estonia | 3 | 2 | 2 | 3 | 3 |
| Finland | 12 | 10 | 12 | 12 | 13 |
| France | 158 | 150 | 138 | 144 | 150 |
| Germany | 190 | 152 | 154 | 166 | 175 |
| Greece | 17 | 17 | 18 | 18 | 18 |
| Hungary | 17 | 17 | 17 | 18 | 19 |
| Iceland | 1 | 1 | 1 | 2 | 2 |
| Ireland | 22 | 23 | 24 | 27 | 29 |
| Italy | 87 | 86 | 98 | 107 | 115 |
| Japan | 63 | 82 | 88 | 118 | 149 |
| Latvia | 4 | 3 | 3 | 4 | 5 |
| Liechtenstein | 0 | 0 | 0 | 0 | 0 |
| Lithuania | 10 | 9 | 9 | 10 | 11 |
| Luxembourg | 1 | 1 | 1 | 1 | 1 |
| Monaco | - | - | - | - | - |
| Netherlands | 55 | 51 | 55 | 57 | 59 |
| New Zealand | 48 | 46 | 44 | 45 | 45 |
| Norway | 18 | 16 | 18 | 21 | 26 |
| Poland | 80 | 71 | 73 | 77 | 80 |
| Portugal | 17 | 17 | 17 | 17 | 18 |
| Romania | 64 | 44 | 48 | 53 | 60 |
| Russia | 636 | 563 | 592 | 642 | 686 |
| Slovakia | 14 | 10 | 10 | 12 | 13 |
| Slovenia | 4 | 5 | 5 | 5 | 5 |
| Spain | 82 | 80 | 81 | 86 | 89 |
| Sweden | 15 | 9 | 10 | 11 | 13 |
| Switzerland | 9 | 8 | 9 | 9 | 9 |
| Ukraine | 246 | 174 | 186 | 188 | 184 |
| UK | 153 | 133 | 108 | 109 | 110 |
| US | 1,132 | 1,185 | 1,205 | 1,307 | 1,415 |
| **EU-15** | 858 | 778 | 766 | 809 | 846 |
| **Other Western Europe** | 27 | 25 | 28 | 32 | 38 |
| **Russia** | 636 | 563 | 592 | 642 | 686 |
| **Other Eastern Europe** | 526 | 393 | 422 | 445 | 464 |
| **AUS/NZ** | 183 | 180 | 193 | 210 | 221 |
| **Japan** | 63 | 82 | 88 | 118 | 149 |
| **Canada** | 146 | 163 | 159 | 174 | 187 |
| **US** | 1,132 | 1,185 | 1,205 | 1,307 | 1,415 |
| **Total** | 3,573 | 3,354 | 3,454 | 3,739 | 4,009 |

**Exhibit A-2: Total Methane, Nitrous Oxide, and High Global Warming Potential Gas Emissions for Developed Countries ($MMTCO_2$)**

| Developed Country | Methane Emissions ($MMTCO_2$) | | | | | Nitrous Oxide Emissions ($MMTCO_2$) | | | | | Total High GWP Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 1990 | 1995 | 2000 | 2005 | 2010 | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 112 | 110 | 120 | 129 | 138 | 18 | 19 | 23 | 27 | 27 | 6 | 5 | 6 | 10 | 11 |
| Austria | 10 | 9 | 10 | 10 | 10 | 2 | 2 | 2 | 2 | 2 | 1 | <0.5 | 1 | 1 | 2 |
| Belgium | 12 | 12 | 12 | 12 | 11 | 8 | 9 | 9 | 9 | 10 | <0.5 | <0.5 | 2 | 3 | 4 |
| Bulgaria | 30 | 19 | 22 | 25 | 27 | 24 | 17 | 20 | 23 | 26 | - | - | <0.5 | <0.5 | 1 |
| Canada | 73 | 86 | 82 | 84 | 87 | 60 | 66 | 64 | 69 | 73 | 14 | 11 | 13 | 21 | 27 |
| Croatia | 4 | 3 | 3 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Czech Republic | 16 | 13 | 13 | 13 | 14 | 9 | 6 | 7 | 8 | 9 | - | - | <0.5 | 1 | 2 |
| Denmark | 6 | 6 | 6 | 6 | 6 | 11 | 10 | 10 | 10 | 9 | <0.5 | <0.5 | 1 | 2 | 2 |
| Estonia | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | - | - | - | - | - |
| Finland | 7 | 6 | 6 | 6 | 6 | 4 | 4 | 5 | 5 | 5 | <0.5 | <0.5 | 1 | 1 | 1 |
| France | 61 | 57 | 56 | 56 | 56 | 87 | 82 | 68 | 69 | 70 | 11 | 11 | 14 | 19 | 25 |
| Germany | 116 | 82 | 94 | 90 | 86 | 65 | 63 | 43 | 45 | 45 | 8 | 7 | 17 | 31 | 43 |
| Greece | 7 | 8 | 8 | 8 | 8 | 9 | 8 | 8 | 8 | 8 | 1 | 1 | 2 | 2 | 3 |
| Hungary | 15 | 16 | 16 | 16 | 16 | 1 | 1 | 1 | 1 | 1 | <0.5 | <0.5 | <0.5 | 1 | 2 |
| Iceland | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1 | 2 |
| Ireland | 13 | 13 | 14 | 14 | 15 | 9 | 9 | 10 | 10 | 10 | <0.5 | <0.5 | 1 | 2 | 4 |
| Italy | 39 | 39 | 42 | 43 | 44 | 42 | 42 | 44 | 45 | 46 | 6 | 5 | 11 | 19 | 25 |
| Japan | 32 | 31 | 34 | 33 | 33 | 16 | 18 | 24 | 28 | 29 | 15 | 34 | 31 | 58 | 88 |
| Latvia | 4 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | - | - | <0.5 | 1 | 2 |
| Liechtenstein | - | - | - | - | - | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | - | - | - | - | - |
| Lithuania | 7 | 7 | 7 | 7 | 7 | 2 | 2 | 2 | 2 | 2 | - | - | <0.5 | 1 | 2 |
| Luxembourg | 1 | <0.5 | <0.5 | <0.5 | <0.5 | - | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Monaco | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Netherlands | 27 | 25 | 26 | 26 | 26 | 19 | 21 | 22 | 22 | 22 | 9 | 5 | 7 | 10 | 11 |
| New Zealand | 35 | 34 | 32 | 33 | 33 | 12 | 12 | 11 | 11 | 12 | 1 | 1 | 1 | 1 | 1 |
| Norway | 7 | 7 | 8 | 8 | 7 | 5 | 5 | 5 | 5 | 5 | 6 | 4 | 5 | 8 | 14 |
| Poland | 59 | 52 | 51 | 51 | 51 | 21 | 20 | 22 | 25 | 28 | <0.5 | <0.5 | <0.5 | 1 | 2 |
| Portugal | 13 | 13 | 13 | 13 | 13 | 3 | 3 | 4 | 4 | 4 | <0.5 | <0.5 | 1 | 1 | 1 |
| Romania | 42 | 31 | 34 | 37 | 42 | 19 | 12 | 13 | 14 | 16 | 3 | 1 | 1 | 2 | 2 |
| Russia | 537 | 497 | 517 | 542 | 559 | 79 | 51 | 57 | 67 | 74 | 20 | 15 | 18 | 33 | 53 |
| Slovakia | 8 | 6 | 6 | 7 | 7 | 6 | 3 | 4 | 4 | 5 | <0.5 | <0.5 | <0.5 | <0.5 | 1 |

**Exhibit A-2: Total Methane, Nitrous Oxide, and High Global Warming Potential Gas Emissions for Developed Countries ($MMTCO_2$) (Continued)**

| Developed Country | Methane Emissions ($MMTCO_2$) | | | | | Nitrous Oxide Emissions ($MMTCO_2$) | | | | | Total High GWP Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 | 1990 | 1995 | 2000 | 2005 | 2010 | 1990 | 1995 | 2000 | 2005 | 2010 |
| Slovenia | 4 | 4 | 4 | 4 | 4 | <0.5 | 1 | 1 | 1 | 1 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Spain | 34 | 38 | 35 | 36 | 36 | 40 | 37 | 38 | 39 | 40 | 8 | 5 | 8 | 11 | 13 |
| Sweden | 6 | 6 | 6 | 6 | 6 | 8 | 2 | 2 | 3 | 3 | 1 | 1 | 1 | 2 | 3 |
| Switzerland | 5 | 5 | 5 | 5 | 4 | 3 | 3 | 3 | 3 | 3 | <0.5 | <0.5 | <0.5 | 1 | 2 |
| Ukraine | 201 | 147 | 152 | 147 | 138 | 44 | 25 | 33 | 40 | 44 | 1 | 1 | 1 | 2 | 2 |
| UK | 77 | 61 | 52 | 48 | 44 | 65 | 55 | 43 | 43 | 44 | 11 | 10 | 14 | 20 | 25 |
| US | 645 | 659 | 642 | 645 | 649 | 389 | 423 | 424 | 437 | 454 | 98 | 100 | 140 | 220 | 310 |
| **EU-15** | 430 | 375 | 379 | 373 | 367 | 371 | 347 | 307 | 314 | 318 | 57 | 46 | 80 | 120 | 160 |
| **Other Western Europe** | 12 | 12 | 13 | 13 | 11 | 8 | 8 | 8 | 8 | 8 | 6 | 4 | 5 | 10 | 18 |
| **Russia** | 537 | 497 | 517 | 542 | 559 | 79 | 51 | 57 | 67 | 74 | 20 | 15 | 18 | 33 | 53 |
| **Other Eastern Europe** | 391 | 301 | 312 | 314 | 313 | 130 | 89 | 106 | 122 | 136 | 4 | 2 | 2 | 8 | 15 |
| **AUS/NZ** | 147 | 144 | 152 | 162 | 171 | 29 | 31 | 34 | 38 | 39 | 8 | 5 | 6 | 11 | 12 |
| **Japan** | 32 | 31 | 34 | 33 | 33 | 16 | 18 | 24 | 28 | 29 | 15 | 34 | 31 | 58 | 88 |
| **Canada** | 73 | 86 | 82 | 84 | 87 | 60 | 66 | 64 | 69 | 73 | 14 | 11 | 13 | 21 | 27 |
| **US** | 645 | 659 | 642 | 645 | 649 | 389 | 423 | 424 | 437 | 454 | 98 | 100 | 140 | 220 | 310 |
| **Total** | 2,267 | 2,105 | 2,131 | 2,164 | 2,189 | 1,082 | 1,033 | 1,024 | 1,083 | 1,130 | 223 | 223 | 298 | 489 | 685 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

# Appendix B: Methane Emissions for Years 1990-2010 for Developed Countries

Appendix B summarizes methane emissions for developed countries from 1990 through 2010 in the following exhibits:

- Exhibit B-1: Total Methane Emissions from Developed Countries ($MMTCO_2$)
- Exhibit B-2: Methane Emissions from Landfilling of Solid Waste 1990-2010 ($MMTCO_2$)
- Exhibit B-3: Methane Emissions from Coal Mining Activities 1990-2010 ($MMTCO_2$)
- Exhibit B-4: Methane Emissions from Combined Natural Gas/Oil Systems 1990-2010 ($MMTCO_2$)
- Exhibit B-5: Methane Emissions from Livestock Manure Management 1990-2010 ($MMTCO_2$)
- Exhibit B-6: Methane Emissions from Livestock Enteric Fermentation 1990-2010 ($MMTCO_2$)
- Exhibit B-7 Methane Emissions from Wastewater Treatment 1990-2010 ($MMTCO_2$)
- Exhibit B-8: Methane Emissions from Other Agricultural Sources 1990-2010 ($MMTCO_2$)
- Exhibit B-9: Methane Emissions from Other Non-Agricultural Sources 1990-2010 ($MMTCO_2$)

**Exhibit B-1: Total Methane Emissions from Developed Countries ($MMTCO_2$)**

| Developed Country | Methane Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 112 | 110 | 120 | 129 | 138 |
| Austria | 10 | 9 | 10 | 10 | 10 |
| Belgium | 12 | 12 | 12 | 12 | 11 |
| Bulgaria | 30 | 19 | 22 | 25 | 27 |
| Canada | 73 | 86 | 82 | 84 | 87 |
| Croatia | 4 | 3 | 3 | 3 | 3 |
| Czech Republic | 16 | 13 | 13 | 13 | 14 |
| Denmark | 6 | 6 | 6 | 6 | 6 |
| Estonia | 2 | 1 | 1 | 2 | 2 |
| Finland | 7 | 6 | 6 | 6 | 6 |
| France | 61 | 57 | 56 | 55 | 55 |
| Germany | 116 | 82 | 94 | 90 | 86 |
| Greece | 7 | 8 | 8 | 8 | 8 |
| Hungary | 15 | 16 | 16 | 16 | 16 |
| Iceland | 0 | 0 | 0 | 0 | 0 |
| Ireland | 13 | 13 | 14 | 14 | 15 |
| Italy | 39 | 39 | 42 | 43 | 44 |
| Japan | 32 | 31 | 34 | 33 | 33 |
| Latvia | 4 | 2 | 2 | 2 | 2 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 7 | 7 | 7 | 7 | 7 |
| Luxembourg | 1 | 0 | 0 | 0 | 0 |
| Monaco | - | - | - | - | - |
| Netherlands | 27 | 25 | 26 | 26 | 26 |
| New Zealand | 35 | 34 | 32 | 33 | 33 |
| Norway | 7 | 7 | 8 | 8 | 7 |
| Poland | 59 | 52 | 51 | 51 | 50 |
| Portugal | 13 | 13 | 13 | 13 | 13 |
| Romania | 42 | 31 | 34 | 37 | 42 |
| Russia | 537 | 497 | 517 | 542 | 559 |
| Slovakia | 8 | 6 | 6 | 7 | 7 |
| Slovenia | 4 | 4 | 4 | 4 | 4 |
| Spain | 34 | 38 | 35 | 36 | 36 |
| Sweden | 6 | 6 | 6 | 6 | 6 |
| Switzerland | 5 | 5 | 5 | 5 | 4 |
| Ukraine | 201 | 147 | 152 | 147 | 138 |
| UK | 77 | 61 | 52 | 48 | 44 |
| US | 645 | 651 | 642 | 646 | 651 |
| **EU-15** | 430 | 376 | 380 | 373 | 367 |
| **Other Western Europe** | 12 | 12 | 13 | 13 | 12 |
| **Russia** | 537 | 497 | 517 | 542 | 559 |
| **Other Eastern Europe** | 391 | 301 | 312 | 313 | 313 |
| **AUS/NZ** | 147 | 144 | 152 | 161 | 171 |
| **Japan** | 32 | 31 | 34 | 33 | 33 |
| **Canada** | 73 | 86 | 82 | 84 | 87 |
| **US** | 645 | 651 | 642 | 646 | 651 |
| **Total** | 2,267 | 2,098 | 2,131 | 2,165 | 2,192 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-2: Methane Emissions from Landfilling of Solid Waste 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Landfilling of Waste ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 13.6 | 14.0 | 15.0 | 16.1 | 18.2 |
| Austria | 5.4 | 4.9 | 5.7 | 5.8 | 5.9 |
| Belgium | 3.6 | 3.9 | 3.7 | 3.8 | 3.9 |
| Bulgaria | 15.1 | 8.4 | 12.4 | 14.1 | 15.8 |
| Canada | 18.5 | 20.4 | 20.0 | 21.1 | 21.8 |
| Croatia | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Czech Republic | 1.7 | 1.7 | 2.1 | 2.7 | 3.4 |
| Denmark | 1.3 | 1.3 | 1.2 | 1.2 | 1.3 |
| Estonia | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| Finland | 4.8 | 3.2 | 3.7 | 3.8 | 3.9 |
| France | 16.4 | 13.9 | 17.0 | 17.5 | 18.0 |
| Germany | 38.7 | 21.6 | 40.6 | 42.1 | 42.9 |
| Greece | 2.2 | 2.2 | 2.3 | 2.4 | 2.4 |
| Hungary | - | 1.4 | 1.4 | 1.4 | 1.4 |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 1.8 | 1.9 | 1.8 | 1.9 | 1.9 |
| Italy | 9.1 | 9.7 | 9.1 | 9.2 | 9.3 |
| Japan | 8.1 | 7.7 | 8.5 | 8.7 | 8.6 |
| Latvia | 0.4 | 0.5 | 1.1 | 1.1 | 1.1 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |
| Luxembourg | 0.1 | <0.05 | 0.1 | 0.1 | 0.1 |
| Monaco | - | - | - | - | - |
| Netherlands | 11.8 | 10.1 | 11.6 | 12.0 | 12.3 |
| New Zealand | 2.9 | 2.8 | 2.3 | 2.4 | 2.5 |
| Norway | 3.8 | 4.0 | 4.5 | 4.9 | 4.0 |
| Poland | 16.1 | 15.9 | 15.9 | 15.9 | 15.9 |
| Portugal | 5.6 | 5.9 | 5.7 | 5.8 | 5.8 |
| Romania | 4.4 | 4.4 | 4.5 | 4.7 | 4.8 |
| Russia | 37.8 | 37.8 | 37.8 | 37.8 | 37.8 |
| Slovakia | 1.1 | 1.1 | 1.2 | 1.4 | 1.6 |
| Slovenia | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Spain | 8.7 | 12.0 | 8.5 | 8.6 | 8.7 |
| Sweden | 1.8 | 1.3 | 1.6 | 1.7 | 1.7 |
| Switzerland | 1.4 | 1.4 | 1.7 | 1.5 | 1.0 |
| Ukraine | 18.6 | 20.2 | 20.5 | 22.7 | 25.0 |
| UK | 23.5 | 19.2 | 14.0 | 10.3 | 7.5 |
| US | 217.0 | 223.0 | 209.0 | 203.0 | 202.0 |
| **EU-15** | 135 | 111 | 127 | 126 | 126 |
| **Other Western Europe** | 5 | 5 | 6 | 6 | 5 |
| **Russia** | 38 | 38 | 38 | 38 | 38 |
| **Other Eastern Europe** | 63 | 59 | 65 | 69 | 75 |
| **AUS/NZ** | 17 | 17 | 17 | 19 | 21 |
| **Japan** | 8 | 8 | 8 | 9 | 9 |
| **Canada** | 19 | 20 | 20 | 21 | 22 |
| **US** | 217 | 223 | 209 | 203 | 202 |
| **Total** | 501 | 481 | 490 | 492 | 496 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-3: Methane Emissions from Coal Mining Activities 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Coal Mining Activities ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 15.9 | 16.7 | 19.7 | 22.6 | 28.6 |
| Austria | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Belgium | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Bulgaria | 1.6 | 1.4 | 1.2 | 1.2 | 1.2 |
| Canada | 1.9 | 1.7 | 1.4 | 1.3 | 1.3 |
| Croatia | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Czech Republic | 7.6 | 5.8 | 5.0 | 4.7 | 3.8 |
| Denmark | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Estonia | - | - | - | - | - |
| Finland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| France | 4.3 | 4.4 | 1.0 | 0.4 | 0.3 |
| Germany | 25.8 | 17.6 | 14.7 | 12.8 | 10.9 |
| Greece | 0.9 | 1.0 | 1.1 | 1.0 | 0.9 |
| Hungary | 3.5 | 2.2 | 2.2 | 2.2 | 2.2 |
| Iceland | - | - | - | - | - |
| Ireland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Italy | 0.1 | 0.1 | <0.05 | <0.05 | <0.05 |
| Japan | 2.2 | 1.9 | 1.9 | 2.0 | 2.1 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | - | - | - | - | - |
| Monaco | - | - | - | - | - |
| Netherlands | - | - | - | - | - |
| New Zealand | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 |
| Norway | 0.1 | 0.1 | 0.1 | 0.1 | <0.05 |
| Poland | 16.8 | 15.6 | 14.8 | 14.1 | 13.4 |
| Portugal | 0.1 | <0.05 | 0.1 | 0.1 | 0.1 |
| Romania | 4.4 | 5.5 | 6.3 | 6.5 | 6.5 |
| Russia | 53.2 | 38.2 | 31.9 | 31.3 | 30.5 |
| Slovakia | 0.7 | 0.5 | - | 0.5 | 0.5 |
| Slovenia | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Spain | 2.3 | 1.9 | 1.7 | 1.7 | 1.4 |
| Sweden | <0.05 | NO | <0.05 | <0.05 | <0.05 |
| Switzerland | - | - | - | - | - |
| Ukraine | 55.4 | 30.1 | 28.1 | 26.1 | 24.1 |
| UK | 17.2 | 7.6 | 5.2 | 5.0 | 4.9 |
| US | 87.9 | 74.6 | 77.9 | 81.8 | 82.0 |
| **EU-15** | 51 | 33 | 24 | 21 | 19 |
| **Other Western Europe** | 0 | 0 | 0 | 0 | <0.05 |
| **Russia** | 53 | 38 | 32 | 31 | 30 |
| **Other Eastern Europe** | 91 | 62 | 59 | 56 | 53 |
| **AUS/NZ** | 16 | 17 | 20 | 23 | 29 |
| **Japan** | 2 | 2 | 2 | 2 | 2 |
| **Canada** | 2 | 2 | 1 | 1 | 1 |
| **US** | 88 | 75 | 78 | 82 | 82 |
| **Total** | 303 | 229 | 216 | 217 | 216 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-4: Methane Emissions from Combined Natural Gas/Oil Systems 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Combined Natural Gas/Oil Systems ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 6.9 | 6.9 | 8.2 | 9.5 | 12.0 |
| Austria | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Belgium | 0.7 | 0.7 | 0.9 | 0.9 | 0.9 |
| Bulgaria | 3.7 | 3.2 | 2.5 | 2.5 | 2.7 |
| Canada | 26.2 | 35.1 | 28.9 | 26.3 | 25.9 |
| Croatia | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Czech Republic | 0.7 | 0.8 | 0.7 | 0.8 | 0.9 |
| Denmark | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Estonia | - | - | - | - | - |
| Finland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| France | 2.2 | 2.1 | 2.2 | 2.2 | 2.2 |
| Germany | 7.0 | 7.5 | 6.7 | 6.8 | 6.8 |
| Greece | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Hungary | 4.2 | 6.1 | 6.1 | 6.1 | 6.1 |
| Iceland | - | - | - | - | - |
| Ireland | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| Italy | 7.0 | 5.9 | 8.4 | 8.6 | 8.8 |
| Japan | 1.2 | 1.7 | 1.7 | 1.8 | 1.8 |
| Latvia | 1.1 | 0.5 | <0.05 | <0.05 | <0.05 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | - | - | - | - | - |
| Netherlands | 3.8 | 3.7 | 3.8 | 3.8 | 3.8 |
| New Zealand | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| Norway | 0.3 | 0.5 | 0.4 | 0.4 | 0.3 |
| Poland | 4.1 | 3.9 | 3.2 | 2.5 | 1.8 |
| Portugal | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Romania | 19.4 | 12.3 | 13.4 | 14.9 | 19.2 |
| Russia | 338.0 | 338.0 | 361.0 | 376.0 | 391.0 |
| Slovakia | 1.8 | 1.8 | 2.2 | 2.4 | 2.6 |
| Slovenia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Spain | 1.0 | 1.5 | 1.6 | 1.8 | 2.0 |
| Sweden | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Switzerland | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 |
| Ukraine | 71.8 | 55.2 | 60.3 | 50.0 | 39.5 |
| UK | 11.3 | 10.6 | 9.7 | 9.5 | 9.2 |
| US | 148.0 | 149.0 | 154.0 | 156.0 | 157.0 |
| **EU-15** | 33 | 32 | 34 | 34 | 34 |
| **Other Western Europe** | 1 | 1 | 1 | 1 | 1 |
| **Russia** | 338 | 338 | 361 | 376 | 391 |
| **Other Eastern Europe** | 107 | 84 | 89 | 80 | 73 |
| **AUS/NZ** | 7 | 7 | 9 | 10 | 12 |
| **Japan** | 1 | 2 | 2 | 2 | 2 |
| **Canada** | 26 | 35 | 29 | 26 | 26 |
| **US** | 148 | 149 | 154 | 156 | 157 |
| **Total** | 663 | 648 | 678 | 684 | 696 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-5: Methane Emissions from Livestock Manure Management 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Livestock Manure Management ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 1.6 | 1.6 | 1.8 | 1.8 | 1.8 |
| Austria | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| Belgium | 2.7 | 2.7 | 2.7 | 2.6 | 2.5 |
| Bulgaria | 1.5 | 0.7 | 1.4 | 1.5 | 1.6 |
| Canada | 4.6 | 5.0 | 5.5 | 6.3 | 6.8 |
| Croatia | 0.5 | 0.4 | 0.4 | 0.5 | 0.5 |
| Czech Republic | 1.0 | 0.8 | 1.0 | 1.0 | 1.0 |
| Denmark | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Estonia | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| Finland | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| France | 3.5 | 3.6 | 3.6 | 3.6 | 3.7 |
| Germany | 13.2 | 10.8 | 10.1 | 9.4 | 8.7 |
| Greece | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 |
| Hungary | 0.9 | - | - | - | - |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 1.3 | 1.4 | 1.5 | 1.5 | 1.6 |
| Italy | 4.0 | 3.9 | 3.7 | 3.5 | 3.4 |
| Japan | 2.5 | 2.3 | 2.8 | 2.5 | 2.5 |
| Latvia | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 |
| Luxembourg | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | - | - | - | - | - |
| Netherlands | 2.2 | 2.1 | 2.0 | 1.9 | 1.8 |
| New Zealand | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 |
| Norway | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Poland | 1.2 | 1.0 | 1.1 | 1.1 | 1.1 |
| Portugal | 3.5 | 3.2 | 3.1 | 3.0 | 2.9 |
| Romania | 1.6 | 1.3 | 1.4 | 1.5 | 1.6 |
| Russia | 10.3 | 7.8 | 8.1 | 9.2 | 9.5 |
| Slovakia | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 |
| Slovenia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Spain | 7.0 | 7.8 | 8.2 | 8.6 | 9.0 |
| Sweden | 0.3 | 0.4 | 0.4 | 0.4 | 0.3 |
| Switzerland | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Ukraine | 4.7 | 3.6 | 3.7 | 4.2 | 4.4 |
| UK | 2.3 | 2.3 | 2.2 | 2.1 | 2.0 |
| US | 26.4 | 31.0 | 34.5 | 36.2 | 38.5 |
| **EU-15** | 42 | 40 | 40 | 39 | 38 |
| **Other Western Europe** | 1 | 1 | 1 | 1 | 1 |
| **Russia** | 10 | 8 | 8 | 9 | 10 |
| **Other Eastern Europe** | 13 | 9 | 10 | 11 | 11 |
| **AUS/NZ** | 2 | 2 | 2 | 2 | 2 |
| **Japan** | 2 | 2 | 3 | 2 | 2 |
| **Canada** | 5 | 5 | 6 | 6 | 7 |
| **US** | 26 | 31 | 35 | 36 | 39 |
| **Total** | 102 | 98 | 107 | 107 | 109 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-6: Methane Emissions from Livestock Enteric Fermentation 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Livestock Enteric Fermentation ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 64.4 | 60.4 | 64.3 | 67.2 | 65.3 |
| Austria | 3.2 | 2.8 | 2.8 | 2.7 | 2.6 |
| Belgium | 5.0 | 4.5 | 4.2 | 4.0 | 3.8 |
| Bulgaria | 3.8 | 1.7 | 2.5 | 2.8 | 2.9 |
| Canada | 16.0 | 18.1 | 20.2 | 22.7 | 24.9 |
| Croatia | 1.5 | 1.2 | 1.2 | 1.4 | 1.4 |
| Czech Republic | 3.3 | 2.1 | 2.5 | 2.5 | 2.5 |
| Denmark | 3.2 | 3.0 | 3.0 | 3.0 | 3.1 |
| Estonia | 1.2 | 0.6 | 0.7 | 0.8 | 0.8 |
| Finland | 1.7 | 1.5 | 1.4 | 1.4 | 1.3 |
| France | 30.0 | 28.5 | 27.9 | 27.3 | 26.7 |
| Germany | 26.2 | 21.4 | 19.7 | 18.1 | 16.4 |
| Greece | 2.9 | 3.0 | 2.8 | 2.7 | 2.5 |
| Hungary | 2.6 | 2.4 | 2.4 | 2.4 | 2.4 |
| Iceland | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Ireland | 9.5 | 9.8 | 10.3 | 10.8 | 11.2 |
| Italy | 13.6 | 13.4 | 12.8 | 12.3 | 11.7 |
| Japan | 7.3 | 7.1 | 9.0 | 8.4 | 8.3 |
| Latvia | 2.1 | 0.8 | 1.1 | 1.1 | 1.1 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 3.3 | 3.0 | 3.0 | 3.0 | 3.0 |
| Luxembourg | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Monaco | - | - | - | - | - |
| Netherlands | 8.4 | 7.9 | 7.6 | 7.4 | 7.1 |
| New Zealand | 31.0 | 29.8 | 28.4 | 28.7 | 28.8 |
| Norway | 1.8 | 1.9 | 1.9 | 1.9 | 1.9 |
| Poland | 16.7 | 11.9 | 12.3 | 14.0 | 14.5 |
| Portugal | 2.6 | 2.5 | 2.5 | 2.4 | 2.4 |
| Romania | 9.5 | 6.7 | 7.0 | 7.9 | 8.8 |
| Russia | 92.6 | 70.3 | 72.9 | 82.7 | 85.9 |
| Slovakia | 2.4 | 1.5 | 1.4 | 1.4 | 1.4 |
| Slovenia | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Spain | 12.4 | 12.1 | 12.3 | 12.6 | 12.9 |
| Sweden | 3.1 | 3.8 | 3.7 | 3.6 | 3.6 |
| Switzerland | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 |
| Ukraine | 42.3 | 32.1 | 33.3 | 37.8 | 39.3 |
| UK | 19.2 | 18.9 | 18.6 | 18.4 | 18.1 |
| US | 130.0 | 136.0 | 129.0 | 130.0 | 132.0 |
| **EU-15** | 141 | 133 | 130 | 127 | 124 |
| **Other Western Europe** | 5 | 5 | 5 | 5 | 5 |
| **Russia** | 93 | 70 | 73 | 83 | 86 |
| **Other Eastern Europe** | 90 | 65 | 68 | 76 | 79 |
| **AUS/NZ** | 95 | 90 | 93 | 96 | 94 |
| **Japan** | 7 | 7 | 9 | 8 | 8 |
| **Canada** | 16 | 18 | 20 | 23 | 25 |
| **US** | 130 | 136 | 129 | 130 | 132 |
| **Total** | 576 | 525 | 527 | 547 | 552 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-7: Methane Emissions from Wastewater Treatment 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Wastewater ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 1.2 | 1.3 | 1.4 | 1.5 | 1.7 |
| Austria | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Belgium | <0.05 | 0.1 | <0.05 | <0.05 | <0.05 |
| Bulgaria | 3.5 | 3.0 | 2.3 | 2.3 | 2.3 |
| Canada | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Croatia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Czech Republic | 0.5 | 0.4 | 0.5 | 0.6 | 0.8 |
| Denmark | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Estonia | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 |
| Finland | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| France | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Germany | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 |
| Greece | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Hungary | 3.9 | 3.9 | 3.9 | 3.8 | 3.8 |
| Iceland | - | - | - | - | - |
| Ireland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Italy | 2.4 | 2.6 | 3.1 | 3.1 | 3.1 |
| Japan | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Luxembourg | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Netherlands | 0.1 | <0.05 | <0.05 | <0.05 | <0.05 |
| New Zealand | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| Norway | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Poland | 2.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| Portugal | 0.9 | 1.1 | 1.1 | 1.1 | 1.1 |
| Romania | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Russia | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| Slovakia | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 |
| Slovenia | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Spain | 0.9 | 1.1 | 1.1 | 1.1 | 1.1 |
| Sweden | <0.05 | - | - | - | - |
| Switzerland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ukraine | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 |
| UK | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| US | 11.2 | 11.8 | 12.4 | 12.9 | 13.5 |
| **EU-15** | 7 | 7 | 8 | 7 | 7 |
| **Other Western Europe** | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| **Russia** | 3 | 3 | 3 | 3 | 3 |
| **Other Eastern Europe** | 14 | 12 | 11 | 12 | 12 |
| **AUS/NZ** | 1 | 1 | 2 | 2 | 2 |
| **Japan** | 0 | 0 | 0 | 0 | 0 |
| **Canada** | 0 | 0 | 0 | 0 | 0 |
| **US** | 11 | 12 | 12 | 13 | 13 |
| **Total** | 37 | 36 | 36 | 37 | 38 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-8: Methane Emissions from Other Agricultural Sources 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Other Agricultural Sources ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 5.8 | 6.6 | 6.9 | 7.1 | 7.0 |
| Austria | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Belgium | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Bulgaria | 0.1 | <0.05 | <0.05 | 0.1 | 0.1 |
| Canada | - | - | - | - | - |
| Croatia | - | - | - | - | - |
| Czech Republic | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Denmark | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Estonia | - | - | - | - | - |
| Finland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| France | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 |
| Germany | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Greece | 0.2 | 0.3 | 0.4 | 0.5 | 0.7 |
| Hungary | 0.1 | - | - | - | - |
| Iceland | - | - | - | - | - |
| Ireland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Italy | 1.6 | 1.7 | 1.9 | 2.1 | 2.4 |
| Japan | 7.9 | 8.1 | 7.3 | 6.8 | 6.8 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | - | - | - | - | - |
| Netherlands | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| New Zealand | <0.05 | - | - | - | - |
| Norway | - | - | - | - | - |
| Poland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Portugal | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 |
| Romania | 0.6 | - | - | - | - |
| Russia | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| Slovakia | - | - | - | - | - |
| Slovenia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Spain | 0.3 | 0.2 | 0.1 | 0.1 | <0.05 |
| Sweden | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Switzerland | - | - | - | - | - |
| Ukraine | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 |
| UK | 0.3 | <0.05 | <0.05 | <0.05 | <0.05 |
| US | 9.2 | 10.0 | 11.5 | 10.5 | 10.3 |
| **EU-15** | 3 | 3 | 3 | 3 | 4 |
| **Other Western Europe** | - | - | - | - | - |
| **Russia** | 2 | 2 | 2 | 2 | 2 |
| **Other Eastern Europe** | 1 | 0 | 0 | 0 | 0 |
| **AUS/NZ** | 6 | 7 | 7 | 7 | 7 |
| **Japan** | 8 | 8 | 7 | 7 | 7 |
| **Canada** | - | - | - | - | - |
| **US** | 9 | 10 | 12 | 11 | 10 |
| **Total** | 29 | 30 | 31 | 30 | 30 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit B-9: Methane Emissions from Other Non-Agricultural Sources 1990-2010 ($MMTCO_2$)**

| Developed Country | Methane from Other Non-Agricultural Sources ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 2.4 | 2.5 | 2.5 | 2.9 | 3.3 |
| Austria | 0.4 | 0.4 | 0.3 | 0.3 | 0.2 |
| Belgium | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 |
| Bulgaria | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 |
| Canada | 5.4 | 5.8 | 5.8 | 5.8 | 5.8 |
| Croatia | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Czech Republic | 1.5 | 0.9 | 1.0 | 1.1 | 1.2 |
| Denmark | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| Estonia | 0.1 | <0.05 | <0.05 | <0.05 | <0.05 |
| Finland | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 |
| France | 3.7 | 3.8 | 3.8 | 3.9 | 4.0 |
| Germany | 4.5 | 2.3 | 1.2 | 0.6 | 0.3 |
| Greece | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 |
| Hungary | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| Iceland | - | - | - | - | - |
| Ireland | 0.1 | 0.1 | 0.1 | <0.05 | <0.05 |
| Italy | 1.5 | 2.1 | 2.8 | 3.7 | 5.0 |
| Japan | 2.9 | 2.1 | 2.2 | 2.3 | 2.4 |
| Latvia | 0.1 | 0.1 | <0.05 | <0.05 | <0.05 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Luxembourg | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Netherlands | 0.8 | 0.8 | 0.9 | 0.9 | 1.0 |
| New Zealand | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Norway | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Poland | 1.1 | 1.4 | 1.5 | 1.7 | 1.8 |
| Portugal | 0.5 | 0.5 | 0.4 | 0.4 | 0.3 |
| Romania | 1.2 | 0.6 | 0.7 | 0.8 | 0.9 |
| Russia | - | - | - | - | - |
| Slovakia | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 |
| Slovenia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Spain | 1.6 | 1.4 | 1.3 | 1.2 | 1.1 |
| Sweden | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 |
| Switzerland | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Ukraine | 6.4 | 4.6 | 5.0 | 4.5 | 4.6 |
| UK | 2.5 | 1.9 | 1.9 | 1.9 | 1.9 |
| US | 14.7 | 15.3 | 14.2 | 15.1 | 15.8 |
| **EU-15** | 18 | 15 | 15 | 15 | 16 |
| **Other Western Europe** | 0 | 0 | 0 | 0 | 0 |
| **Russia** | - | - | - | - | - |
| **Other Eastern Europe** | 12 | 9 | 9 | 9 | 10 |
| **AUS/NZ** | 3 | 3 | 3 | 3 | 4 |
| **Japan** | 3 | 2 | 2 | 2 | 2 |
| **Canada** | 5 | 6 | 6 | 6 | 6 |
| **US** | 15 | 15 | 14 | 15 | 16 |
| **Total** | 55 | 51 | 50 | 51 | 54 |

*Note: Other non-agriculture includes: fossil fuel combustion, industrial processes, biomass fuel combustion. Dashes indicate that emissions for the respective country were not analyzed.*

# Appendix C: Nitrous Oxide Emissions for Years 1990-2010 for Developed Countries

Appendix C summarizes nitrous oxide emissions for developed countries from 1990 through 2010 in the following exhibits:

- Exhibit C-1: Total Nitrous Oxide Emissions from Developed Countries ($MMTCO_2$)
- Exhibit C-2: Nitrous Oxide Emissions from Agricultural Soils 1990-2010 ($MMTCO_2$)
- Exhibit C-3: Nitrous Oxide Emissions from Industrial Processes 1990-2010 ($MMTCO_2$)
- Exhibit C-4: Nitrous Oxide Emissions from Manufacturing and Construction 1990-2010 ($MMTCO_2$)
- Exhibit C-5: Nitrous Oxide Emissions from Electric Utilities 1990-2010 ($MMTCO_2$)
- Exhibit C-6: Nitrous Oxide Emissions from Stationary Sources 1990-2010 ($MMTCO_2$)
- Exhibit C-7 Nitrous Oxide Emissions from Mobile Sources 1990-2010 ($MMTCO_2$)
- Exhibit C-8: Nitrous Oxide Emissions from Manure Management 1990-2010 ($MMTCO_2$)

**Exhibit C-1: Total Nitrous Oxide Emissions from Developed Countries ($MMTCO_2$)**

| Developed Country | Nitrous Oxide Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 18 | 19 | 23 | 27 | 27 |
| Austria | 2 | 2 | 2 | 2 | 2 |
| Belgium | 8 | 9 | 9 | 9 | 10 |
| Bulgaria | 24 | 17 | 20 | 23 | 26 |
| Canada | 60 | 66 | 64 | 69 | 73 |
| Croatia | 1 | 1 | 2 | 2 | 2 |
| Czech Republic | 9 | 6 | 7 | 8 | 9 |
| Denmark | 11 | 10 | 10 | 10 | 9 |
| Estonia | 1 | 1 | 1 | 1 | 1 |
| Finland | 4 | 4 | 5 | 5 | 5 |
| France | 87 | 82 | 68 | 69 | 70 |
| Germany | 65 | 63 | 43 | 45 | 45 |
| Greece | 9 | 8 | 8 | 8 | 8 |
| Hungary | 1 | 1 | 1 | 1 | 1 |
| Iceland | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Ireland | 9 | 9 | 10 | 10 | 10 |
| Italy | 42 | 42 | 44 | 45 | 46 |
| Japan | 16 | 18 | 24 | 28 | 29 |
| Latvia | 1 | 1 | 1 | 1 | 1 |
| Liechtenstein | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Lithuania | 2 | 2 | 2 | 2 | 2 |
| Luxembourg | - | <0.5 | <0.5 | <0.5 | <0.5 |
| Monaco | - | - | - | - | - |
| Netherlands | 19 | 21 | 22 | 22 | 22 |
| New Zealand | 12 | 12 | 11 | 11 | 12 |
| Norway | 5 | 5 | 5 | 5 | 5 |
| Poland | 21 | 20 | 22 | 25 | 28 |
| Portugal | 3 | 3 | 4 | 4 | 4 |
| Romania | 19 | 12 | 13 | 14 | 16 |
| Russia | 79 | 51 | 57 | 67 | 74 |
| Slovakia | 6 | 3 | 4 | 4 | 5 |
| Slovenia | <0.5 | 1 | 1 | 1 | 1 |
| Spain | 40 | 37 | 38 | 39 | 40 |
| Sweden | 8 | 2 | 2 | 3 | 3 |
| Switzerland | 3 | 3 | 3 | 3 | 3 |
| Ukraine | 44 | 25 | 33 | 40 | 44 |
| UK | 65 | 55 | 43 | 43 | 44 |
| US | 389 | 423 | 424 | 438 | 455 |
| **EU-15** | 371 | 347 | 307 | 314 | 318 |
| **Other Western Europe** | 8 | 8 | 8 | 8 | 8 |
| **Russia** | 79 | 51 | 57 | 67 | 74 |
| **Other 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 |
| **US** | 389 | 423 | 424 | 438 | 455 |
| **Total** | 1,082 | 1,033 | 1,024 | 1,084 | 1,131 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit C-2: Nitrous Oxide Emissions from Agricultural Soils 1990-2010 ($MMTCO_2$)**

| Developed Country | Nitrous Oxide from Agricultural Soils ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 14.5 | 14.6 | 15.8 | 16.8 | 16.7 |
| Austria | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Belgium | 3.4 | 2.9 | 2.9 | 2.9 | 2.9 |
| Bulgaria | 16.7 | 11.5 | 13.3 | 15.7 | 17.7 |
| Canada | 36.0 | 39.1 | 42.8 | 46.8 | 50.6 |
| Croatia | 0.9 | 1.1 | 1.4 | 1.7 | 2.0 |
| Czech Republic | 5.8 | 3.0 | 3.8 | 4.5 | 5.1 |
| Denmark | 9.8 | 8.6 | 8.4 | 8.1 | 7.9 |
| Estonia | 0.6 | 0.4 | 0.5 | 0.6 | 0.7 |
| Finland | 3.1 | 2.9 | 2.8 | 2.6 | 2.5 |
| France | 53.0 | 50.3 | 49.8 | 49.4 | 48.9 |
| Germany | 26.4 | 23.7 | 23.1 | 22.5 | 21.9 |
| Greece | 6.4 | 5.7 | 5.4 | 5.1 | 4.8 |
| Hungary | 1.2 | 0.6 | 0.7 | 0.9 | 1.0 |
| Iceland | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Ireland | 6.4 | 6.9 | 7.1 | 7.3 | 7.4 |
| Italy | 20.2 | 20.9 | 20.6 | 20.4 | 20.1 |
| Japan | 1.2 | 1.0 | 1.2 | 1.3 | 1.3 |
| Latvia | 0.5 | 0.5 | 0.7 | 0.8 | 1.0 |
| Liechtenstein | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Lithuania | 1.3 | 0.9 | 1.1 | 1.3 | 1.4 |
| Luxembourg | - | 0.1 | 0.1 | 0.1 | 0.1 |
| Monaco | - | - | - | - | - |
| Netherlands | 6.7 | 8.3 | 8.0 | 7.7 | 7.4 |
| New Zealand | 11.5 | 11.5 | 11.1 | 11.3 | 11.5 |
| Norway | 2.8 | 2.8 | 2.7 | 2.6 | 2.6 |
| Poland | 9.9 | 10.0 | 12.2 | 14.5 | 16.8 |
| Portugal | 2.5 | 2.2 | 2.2 | 2.2 | 2.1 |
| Romania | 11.5 | 7.0 | 8.2 | 9.5 | 10.8 |
| Russia | 49.8 | 29.0 | 33.8 | 40.5 | 45.3 |
| Slovakia | 4.0 | 2.2 | 2.5 | 2.9 | 3.3 |
| Slovenia | 0.4 | 0.4 | 0.6 | 0.7 | 0.8 |
| Spain | 18.0 | 15.8 | 15.9 | 15.9 | 16.0 |
| Sweden | 4.7 | 0.1 | 0.1 | 0.1 | 0.1 |
| Switzerland | 2.5 | 2.2 | 2.1 | 2.1 | 2.0 |
| Ukraine | 24.5 | 13.4 | 16.1 | 20.3 | 23.8 |
| UK | 29.5 | 28.1 | 27.4 | 26.7 | 26.1 |
| US | 269.0 | 285.0 | 299.0 | 308.0 | 317.0 |
| **EU-15** | 191 | 178 | 175 | 172 | 169 |
| **Other Western Europe** | 5 | 5 | 5 | 5 | 5 |
| **Russia** | 50 | 29 | 34 | 40 | 45 |
| **Other Eastern Europe** | 77 | 51 | 61 | 73 | 84 |
| **AUS/NZ** | 26 | 26 | 27 | 28 | 28 |
| **Japan** | 1 | 1 | 1 | 1 | 1 |
| **Canada** | 36 | 39 | 43 | 47 | 51 |
| **US** | 269 | 285 | 299 | 308 | 317 |
| **Total** | 656 | 614 | 645 | 675 | 701 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

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

| Developed Country | Nitrous Oxide from Industrial Processes ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 |
| Austria | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Belgium | 3.6 | 4.3 | 4.3 | 4.4 | 4.4 |
| Bulgaria | 2.2 | 1.9 | 2.0 | 2.4 | 3.0 |
| Canada | 11.5 | 11.5 | 1.3 | 1.3 | 1.3 |
| Croatia | - | - | - | - | - |
| Czech Republic | 1.0 | 1.1 | 0.9 | 0.9 | 0.9 |
| Denmark | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Estonia | - | - | - | - | - |
| Finland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| France | 27.8 | 25.3 | 9.8 | 9.9 | 10.1 |
| Germany | 25.7 | 25.4 | 2.6 | 2.7 | 2.8 |
| Greece | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| Hungary | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Iceland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ireland | 1.0 | 0.8 | 0.8 | 0.8 | 0.8 |
| Italy | 7.3 | 7.3 | 8.4 | 8.9 | 9.3 |
| Japan | 7.7 | 7.8 | 9.9 | 10.7 | 10.7 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Luxembourg | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Monaco | - | - | - | - | - |
| Netherlands | 9.8 | 9.8 | 9.9 | 9.9 | 10.0 |
| New Zealand | - | - | - | - | - |
| Norway | 2.2 | 1.6 | 2.0 | 2.0 | 2.0 |
| Poland | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Portugal | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Romania | 4.0 | 1.9 | 1.9 | 1.9 | 1.9 |
| Russia | - | - | - | - | - |
| Slovakia | 0.6 | 0.6 | 0.7 | 0.8 | 0.9 |
| Slovenia | - | - | - | - | - |
| Spain | 2.9 | 2.3 | 2.3 | 2.3 | 2.3 |
| Sweden | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Switzerland | - | - | - | - | - |
| Ukraine | 7.1 | 2.2 | 7.0 | 8.0 | 8.0 |
| UK | 29.1 | 18.9 | 5.6 | 4.9 | 4.9 |
| US | 36.1 | 40.2 | 29.7 | 32.0 | 34.6 |
| **EU-15** | 110 | 95 | 45 | 45 | 46 |
| **Other Western Europe** | 2 | 2 | 2 | 2 | 2 |
| **Russia** | - | - | - | - | - |
| **Other Eastern Europe** | 20 | 13 | 18 | 19 | 20 |
| **AUS/NZ** | 1 | 0 | 0 | 0 | 0 |
| **Japan** | 8 | 8 | 10 | 11 | 11 |
| **Canada** | 11 | 11 | 1 | 1 | 1 |
| **US** | 36 | 40 | 30 | 32 | 35 |
| **Total** | 188 | 170 | 106 | 111 | 115 |

*Note: Dashes indicate that emissions for the respective country were not analyzed. Industrial processes emissions includes emissions from nitric acid and adipic acid production.*

**Exhibit C-4: Nitrous Oxide Emissions from Manufacturing and Construction 1990-2010 ($MMTCO_2$)**

| Developed Country | Nitrous Oxide from Manufacturing and Construction ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Austria | <0.05 | 0.1 | 0.1 | 0.1 | 0.1 |
| Belgium | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 |
| Bulgaria | 0.6 | 0.3 | 0.4 | 0.4 | 0.5 |
| Canada | 0.3 | 0.6 | 0.7 | 0.7 | 0.8 |
| Croatia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Czech Republic | 0.6 | 0.2 | 0.2 | 0.2 | 0.2 |
| Denmark | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Estonia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Finland | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 |
| France | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Germany | 1.9 | 1.3 | 1.4 | 1.4 | 1.4 |
| Greece | 0.5 | 0.4 | 0.4 | 0.5 | 0.5 |
| Hungary | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Italy | 3.1 | 2.2 | 2.2 | 2.2 | 2.3 |
| Japan | 1.4 | 1.7 | 1.8 | 1.9 | 2.0 |
| Latvia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Luxembourg | - | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | - | - | - | - | - |
| Netherlands | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| New Zealand | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Poland | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 |
| Portugal | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Romania | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Russia | 1.8 | 0.9 | 1.0 | 1.1 | 1.3 |
| Slovakia | - | - | - | - | - |
| Slovenia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Spain | 1.8 | 2.1 | 2.1 | 2.2 | 2.2 |
| Sweden | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 |
| Switzerland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ukraine | 1.4 | 0.6 | 0.7 | 0.8 | 0.9 |
| UK | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| US | - | - | - | - | - |
| **EU-15** | 10 | 9 | 9 | 9 | 9 |
| **Other Western Europe** | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| **Russia** | 2 | 1 | 1 | 1 | 1 |
| **Other Eastern Europe** | 3 | 1 | 2 | 2 | 2 |
| **AUS/NZ** | 0 | 0 | 0 | 0 | 0 |
| **Japan** | 1 | 2 | 2 | 2 | 2 |
| **Canada** | 0 | 1 | 1 | 1 | 1 |
| **US** | - | - | - | - | - |
| **Total** | 17 | 14 | 14 | 15 | 16 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit C-5: Nitrous Oxide Emissions from Electric Utilities 1990-2010 ($MMTCO_2$)**

| Developed Country | Nitrous Oxide from Electric Utilities ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 |
| Austria | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Belgium | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Bulgaria | 3.1 | 2.8 | 3.2 | 3.6 | 4.1 |
| Canada | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 |
| Croatia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Czech Republic | 0.9 | 1.1 | 1.2 | 1.4 | 1.6 |
| Denmark | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Estonia | 0.0 | 0.2 | 0.3 | 0.3 | 0.4 |
| Finland | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 |
| France | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Germany | 4.4 | 3.9 | 4.2 | 4.2 | 4.2 |
| Greece | 0.8 | 1.0 | 1.0 | 1.1 | 1.1 |
| Hungary | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 0.4 | 0.5 | 0.6 | 0.6 | 0.6 |
| Italy | 6.0 | 6.3 | 6.7 | 6.7 | 6.8 |
| Japan | 0.6 | 1.1 | 1.2 | 1.2 | 1.3 |
| Latvia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.1 | <0.05 | <0.05 | <0.05 | <0.05 |
| Luxembourg | - | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| New Zealand | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Poland | 0.9 | 0.9 | 1.1 | 1.2 | 1.3 |
| Portugal | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Romania | 0.9 | 0.9 | 1.0 | 1.2 | 1.3 |
| Russia | 4.4 | 4.1 | 4.6 | 5.3 | 6.1 |
| Slovakia | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Slovenia | <0.05 | 0.1 | 0.1 | 0.1 | 0.1 |
| Spain | 0.9 | 1.0 | 1.1 | 1.1 | 1.1 |
| Sweden | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 |
| Switzerland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ukraine | 1.7 | 1.5 | 1.7 | 1.9 | 2.2 |
| UK | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| US | - | - | - | - | - |
| **EU-15** | 15 | 16 | 16 | 16 | 17 |
| **Other Western Europe** | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| **Russia** | 4 | 4 | 5 | 5 | 6 |
| **Other Eastern Europe** | 8 | 8 | 9 | 10 | 11 |
| **AUS/NZ** | 0 | 0 | 0 | 1 | 1 |
| **Japan** | 1 | 1 | 1 | 1 | 1 |
| **Canada** | 1 | 1 | 1 | 1 | 1 |
| **US** | - | - | - | - | - |
| **Total** | 29 | 30 | 32 | 34 | 37 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit C-6: Nitrous Oxide Emissions from Stationary Sources 1990-2010 ($MMTCO_2$)**

| Developed Country | Nitrous Oxide from Stationary Sources ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.7 | 0.7 | 0.8 | 0.8 | 0.9 |
| Austria | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Belgium | 1.2 | 1.3 | 1.3 | 1.3 | 1.4 |
| Bulgaria | 3.7 | 3.1 | 3.5 | 4.0 | 4.5 |
| Canada | 1.2 | 1.6 | 1.6 | 1.7 | 1.8 |
| Croatia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Czech Republic | 1.6 | 1.3 | 1.4 | 1.6 | 1.8 |
| Denmark | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 |
| Estonia | <0.05 | 0.3 | 0.3 | 0.3 | 0.4 |
| Finland | 0.7 | 1.0 | 1.1 | 1.1 | 1.1 |
| France | 1.3 | 1.4 | 1.4 | 1.4 | 1.5 |
| Germany | 6.3 | 5.3 | 5.5 | 5.6 | 5.6 |
| Greece | 1.3 | 1.4 | 1.5 | 1.5 | 1.5 |
| Hungary | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 0.5 | 0.6 | 0.7 | 0.7 | 0.7 |
| Italy | 9.1 | 8.5 | 8.9 | 8.9 | 9.1 |
| Japan | 2.0 | 2.9 | 3.0 | 3.1 | 3.3 |
| Latvia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.2 | <0.05 | <0.05 | <0.05 | <0.05 |
| Luxembourg | - | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| New Zealand | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Poland | 1.2 | 1.2 | 1.4 | 1.6 | 1.8 |
| Portugal | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |
| Romania | 1.0 | 1.0 | 1.1 | 1.2 | 1.4 |
| Russia | 6.1 | 4.9 | 5.6 | 6.4 | 7.4 |
| Slovakia | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Slovenia | <0.05 | 0.1 | 0.1 | 0.1 | 0.1 |
| Spain | 2.7 | 3.1 | 3.2 | 3.3 | 3.3 |
| Sweden | 0.9 | 1.0 | 1.1 | 1.1 | 1.1 |
| Switzerland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ukraine | 3.1 | 2.1 | 2.3 | 2.7 | 3.0 |
| UK | 3.8 | 3.5 | 3.7 | 3.8 | 3.9 |
| US | 13.6 | 14.3 | 15.7 | 17.0 | 17.8 |
| **EU-15** | 29 | 28 | 29 | 30 | 30 |
| **Other Western Europe** | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| **Russia** | 6 | 5 | 6 | 6 | 7 |
| **Other Eastern Europe** | 11 | 9 | 10 | 12 | 13 |
| **AUS/NZ** | 1 | 1 | 1 | 1 | 1 |
| **Japan** | 2 | 3 | 3 | 3 | 3 |
| **Canada** | 1 | 2 | 2 | 2 | 2 |
| **US** | 14 | 14 | 16 | 17 | 18 |
| **Total** | 64 | 61 | 66 | 70 | 74 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit C-7: Nitrous Oxide Emissions from Mobile Sources 1990-2010 ($MMTCO_2$)**

| Developed Country | Nitrous Oxide from Mobile Sources ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 1.6 | 3.1 | 5.6 | 8.1 | 8.7 |
| Austria | 0.3 | 0.6 | 0.7 | 0.8 | 0.9 |
| Belgium | 0.2 | 0.4 | 0.6 | 0.7 | 0.7 |
| Bulgaria | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Canada | 6.5 | 8.7 | 12.5 | 13.3 | 12.8 |
| Croatia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Czech Republic | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| Denmark | 0.1 | 0.3 | 0.5 | 0.6 | 0.7 |
| Estonia | 0.0 | <0.05 | <0.05 | <0.05 | <0.05 |
| Finland | 0.5 | 0.6 | 0.9 | 1.3 | 1.6 |
| France | 1.2 | 2.1 | 3.9 | 5.2 | 5.9 |
| Germany | 3.2 | 5.4 | 9.3 | 11.6 | 12.3 |
| Greece | 0.2 | 0.3 | 0.4 | 0.5 | 0.7 |
| Hungary | - | - | - | - | - |
| Iceland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ireland | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| Italy | 1.1 | 1.7 | 2.6 | 3.6 | 4.5 |
| Japan | 4.0 | 4.4 | 7.7 | 11.0 | 11.8 |
| Latvia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | 0.1 | <0.05 | <0.05 | <0.05 | <0.05 |
| Luxembourg | - | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 2.0 | 2.3 | 3.2 | 3.5 | 3.8 |
| New Zealand | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| Poland | 0.3 | 0.3 | 0.4 | 0.6 | 0.9 |
| Portugal | 0.1 | 0.3 | 0.5 | 0.8 | 1.0 |
| Romania | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Russia | 1.4 | 0.6 | 0.6 | 0.6 | 0.7 |
| Slovakia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Slovenia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Spain | 0.9 | 1.3 | 2.3 | 3.3 | 4.1 |
| Sweden | 0.9 | 0.9 | 1.2 | 1.5 | 1.8 |
| Switzerland | 0.3 | 0.6 | 0.9 | 0.9 | 0.9 |
| Ukraine | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| UK | 1.3 | 2.8 | 4.7 | 6.4 | 7.1 |
| US | 54.3 | 66.8 | 62.2 | 61.8 | 65.9 |
| **EU-15** | 12 | 19 | 31 | 40 | 46 |
| **Other Western Europe** | 1 | 1 | 1 | 1 | 1 |
| **Russia** | 1 | 1 | 1 | 1 | 1 |
| **Other Eastern Europe** | 1 | 1 | 1 | 1 | 1 |
| **AUS/NZ** | 2 | 3 | 6 | 8 | 9 |
| **Japan** | 4 | 4 | 8 | 11 | 12 |
| **Canada** | 7 | 9 | 13 | 13 | 13 |
| **US** | 54 | 67 | 62 | 62 | 66 |
| **Total** | 82 | 104 | 122 | 137 | 148 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit C-8: Nitrous Oxide Emissions from Manure Management 1990-2010 ($MMTCO_2$)**

| Developed Country | Nitrous Oxide from Manure Management ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.3 | 0.5 | 0.5 | 0.6 | 0.6 |
| Austria | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Belgium | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 |
| Bulgaria | 0.9 | 0.6 | 0.6 | 0.7 | 0.8 |
| Canada | 4.3 | 5.0 | 5.5 | 6.2 | 6.8 |
| Croatia | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 |
| Czech Republic | 1.0 | 0.8 | 1.0 | 1.0 | 1.0 |
| Denmark | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Estonia | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Finland | - | - | - | - | - |
| France | 3.2 | 3.1 | 3.1 | 3.1 | 3.1 |
| Germany | 3.4 | 2.7 | 2.5 | 2.4 | 2.3 |
| Greece | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| Hungary | - | - | - | - | - |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 |
| Italy | 3.8 | 3.8 | 3.6 | 3.5 | 3.3 |
| Japan | 1.5 | 1.4 | 1.7 | 1.6 | 1.6 |
| Latvia | 0.0 | 0.2 | 0.2 | 0.2 | 0.2 |
| Liechtenstein | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Lithuania | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| Luxembourg | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Monaco | - | - | - | - | - |
| Netherlands | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| New Zealand | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | - | - | - | - | - |
| Poland | 4.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Portugal | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Romania | 2.7 | 1.7 | 1.7 | 1.7 | 1.7 |
| Russia | 21.3 | 16.6 | 17.2 | 19.5 | 20.3 |
| Slovakia | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| Slovenia | 0.0 | 0.2 | 0.2 | 0.2 | 0.2 |
| Spain | 15.2 | 14.5 | 14.5 | 14.5 | 14.5 |
| Sweden | 0.6 | - | - | - | - |
| Switzerland | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Ukraine | 9.4 | 7.3 | 7.6 | 8.6 | 9.0 |
| UK | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| US | 16.0 | 16.4 | 17.4 | 19.0 | 19.9 |
| **EU-15** | 29 | 27 | 27 | 27 | 27 |
| **Other Western Europe** | 0 | 0 | 0 | 0 | 0 |
| **Russia** | 21 | 17 | 17 | 20 | 20 |
| **Other Eastern Europe** | 21 | 16 | 16 | 17 | 17 |
| **AUS/NZ** | 0 | 1 | 1 | 1 | 1 |
| **Japan** | 1 | 1 | 2 | 2 | 2 |
| **Canada** | 4 | 5 | 6 | 6 | 7 |
| **US** | 16 | 16 | 17 | 19 | 20 |
| **Total** | 94 | 83 | 86 | 91 | 94 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

# Appendix D: High GWP Gas Emissions for Years 1990-2010 for Developed Countries

Appendix D summarizes high GWP gas emissions for developed countries from 1990 through 2010 in the following exhibits:

- Exhibit D-1: Total High GWP Gas Emissions from Developed Countries ($MMTCO_2$)
- Exhibit D-2: ODS Substitute Emissions 1990-2010 ($MMTCO_2$)
- Exhibit D-3: HFC-23 Fugitive Emissions 1990-2010 ($MMTCO_2$)
- Exhibit D-4: Aluminum PFC Emissions 1990-2010 ($MMTCO_2$)
- Exhibit D-5: $SF_6$ Emissions from Magnesium 1990-2010 ($MMTCO_2$)
- Exhibit D-6: $SF_6$ Emissions from Electric Utilities 1990-2010 ($MMTCO_2$)
- Exhibit D-7 Emissions from Semiconductor Production 1990-2010 ($MMTCO_2$)

**Exhibit D-1: Total High GWP Gas Emissions from Developed Countries ($MMTCO_2$)**

| Developed Country | High GWP Gas Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 6.2 | 4.5 | 5.5 | 9.7 | 10.8 |
| Austria | 0.6 | 0.3 | 0.7 | 1.4 | 2.1 |
| Belgium | 0.3 | 0.5 | 1.5 | 2.8 | 3.7 |
| Bulgaria | 0.0 | 0.0 | 0.1 | 0.4 | 0.8 |
| Canada | 13.6 | 10.8 | 12.8 | 20.5 | 26.7 |
| Croatia | 0.3 | 0.1 | 0.1 | 0.2 | 0.3 |
| Czech Republic | 0.0 | 0.0 | 0.3 | 1.1 | 2.0 |
| Denmark | 0.2 | 0.2 | 0.9 | 1.8 | 2.3 |
| Estonia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Finland | 0.3 | 0.4 | 0.6 | 1.1 | 1.4 |
| France | 10.7 | 11.2 | 13.9 | 19.4 | 25.2 |
| Germany | 8.3 | 6.9 | 16.8 | 30.6 | 43.4 |
| Greece | 1.0 | 1.4 | 2.0 | 2.3 | 2.5 |
| Hungary | 0.1 | 0.1 | 0.4 | 1.0 | 1.9 |
| Iceland | 0.2 | 0.1 | 0.4 | 1.3 | 2.0 |
| Ireland | 0.1 | 0.4 | 0.9 | 2.3 | 4.3 |
| Italy | 6.4 | 4.9 | 11.4 | 19.1 | 25.2 |
| Japan | 14.6 | 33.7 | 30.9 | 58.2 | 88.1 |
| Latvia | - | - | 0.3 | 0.9 | 1.7 |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | 0.2 | 0.8 | 1.5 |
| Luxembourg | <0.05 | <0.05 | 0.1 | 0.2 | 0.2 |
| Monaco | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 9.4 | 5.4 | 7.4 | 9.8 | 11.3 |
| New Zealand | 1.3 | 0.7 | 0.8 | 0.9 | 1.1 |
| Norway | 6.1 | 3.8 | 5.1 | 8.1 | 14.4 |
| Poland | 0.2 | 0.1 | 0.4 | 1.1 | 2.0 |
| Portugal | 0.1 | 0.2 | 0.5 | 1.0 | 1.2 |
| Romania | 3.5 | 1.1 | 1.3 | 1.5 | 1.8 |
| Russia | 20.4 | 14.7 | 18.2 | 33.0 | 52.6 |
| Slovakia | 0.1 | 0.1 | 0.2 | 0.5 | 0.8 |
| Slovenia | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| Spain | 7.8 | 5.2 | 8.2 | 10.9 | 12.8 |
| Sweden | 1.0 | 1.0 | 1.3 | 2.2 | 3.4 |
| Switzerland | 0.4 | 0.3 | 0.4 | 0.9 | 1.6 |
| Ukraine | 1.1 | 1.3 | 0.9 | 1.5 | 2.3 |
| UK | 10.6 | 10.1 | 14.3 | 19.6 | 25.1 |
| US | 98.2 | 104.0 | 139.0 | 223.0 | 308.0 |
| **EU-15** | 57 | 48 | 81 | 124 | 164 |
| **Other Western Europe** | 7 | 4 | 6 | 10 | 18 |
| **Russia** | 20 | 15 | 18 | 33 | 53 |
| **Other Eastern Europe** | 5 | 3 | 4 | 9 | 15 |
| **AUS/NZ** | 7 | 5 | 6 | 11 | 12 |
| **Japan** | 15 | 34 | 31 | 58 | 88 |
| **Canada** | 14 | 11 | 13 | 21 | 27 |
| **US** | 98 | 104 | 139 | 223 | 308 |
| **Total** | 223 | 223 | 298 | 489 | 685 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit D-2: ODS Substitute Emissions 1990-2010 ($MMTCO_2$)**

| Developed Country | ODS Substitute Emisisons ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | - | 0.7 | 1.9 | 3.8 | 5.2 |
| Austria | - | 0.1 | 0.4 | 0.8 | 1.1 |
| Belgium | - | 0.2 | 1.3 | 2.5 | 3.5 |
| Bulgaria | - | 0.0 | 0.1 | 0.4 | 0.8 |
| Canada | - | 1.0 | 3.3 | 7.3 | 10.7 |
| Croatia | - | 0.0 | <0.05 | 0.1 | 0.2 |
| Czech Republic | - | 0.0 | 0.3 | 1.1 | 2.0 |
| Denmark | - | 0.1 | 0.8 | 1.7 | 2.3 |
| Estonia | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Finland | - | 0.1 | 0.4 | 0.9 | 1.2 |
| France | - | 0.5 | 3.6 | 8.1 | 11.8 |
| Germany | - | 1.6 | 10.9 | 21.3 | 28.7 |
| Greece | - | 0.1 | 0.6 | 1.1 | 1.5 |
| Hungary | - | 0.0 | 0.3 | 1.0 | 1.9 |
| Iceland | - | 0.0 | 0.0 | <0.05 | 0.1 |
| Ireland | - | <0.05 | 0.3 | 0.6 | 0.8 |
| Italy | - | 1.1 | 7.3 | 14.2 | 19.1 |
| Japan | - | 9.6 | 10.6 | 22.3 | 37.3 |
| Latvia | - | 0.0 | 0.3 | 0.9 | 1.7 |
| Liechtenstein | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Lithuania | - | 0.0 | 0.2 | 0.8 | 1.5 |
| Luxembourg | - | 0.0 | 0.1 | 0.1 | 0.2 |
| Monaco | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 0.4 | 0.3 | 1.9 | 3.7 | 5.0 |
| New Zealand | - | 0.1 | 0.2 | 0.4 | 0.6 |
| Norway | - | 0.0 | 0.1 | 0.2 | 0.6 |
| Poland | - | 0.0 | 0.3 | 1.0 | 1.9 |
| Portugal | - | 0.1 | 0.4 | 0.9 | 1.2 |
| Romania | - | 0.0 | 0.1 | 0.3 | 0.7 |
| Russia | - | 0.0 | 6.0 | 20.9 | 40.8 |
| Slovakia | - | 0.0 | 0.1 | 0.4 | 0.7 |
| Slovenia | - | 0.0 | <0.05 | 0.1 | 0.1 |
| Spain | - | 0.5 | 3.3 | 6.4 | 8.7 |
| Sweden | - | 0.1 | 0.4 | 1.0 | 1.4 |
| Switzerland | - | 0.0 | 0.2 | 0.6 | 1.1 |
| Ukraine | - | 0.0 | 0.3 | 0.9 | 1.7 |
| UK | 0.7 | 1.3 | 5.0 | 8.4 | 9.6 |
| US | 0.9 | 24.7 | 64.0 | 125.0 | 176.0 |
| **EU-15** | 1 | 6 | 37 | 72 | 96 |
| **Other Western Europe** | - | 0 | 0 | 1 | 2 |
| **Russia** | - | 0 | 6 | 21 | 41 |
| **Other Eastern Europe** | - | 0 | 2 | 7 | 13 |
| **AUS/NZ** | - | 1 | 2 | 4 | 6 |
| **Japan** | - | 10 | 11 | 22 | 37 |
| **Canada** | - | 1 | 3 | 7 | 11 |
| **US** | 1 | 25 | 64 | 125 | 176 |
| **Total** | 2 | 42 | 125 | 260 | 382 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit D-3: HFC-23 Fugitive Emissions 1990-2010 ($MMTCO_2$)**

| Developed Country | HFC-23 Fugitive Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.7 | 0.4 | - | - | - |
| Austria | - | - | - | - | - |
| Belgium | - | - | - | - | - |
| Bulgaria | - | - | - | - | - |
| Canada | 1.1 | 0.2 | 0.2 | 0.1 | 0.1 |
| Croatia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Czech Republic | - | - | - | - | - |
| Denmark | - | - | - | - | - |
| Estonia | - | - | - | - | - |
| Finland | - | - | - | - | - |
| France | 7.0 | 7.5 | 7.0 | 5.8 | 4.6 |
| Germany | 3.1 | 1.7 | 1.9 | 1.6 | 1.3 |
| Greece | 0.5 | 1.0 | 1.2 | 1.0 | 0.8 |
| Hungary | - | - | - | - | - |
| Iceland | - | - | - | - | - |
| Ireland | - | - | - | - | - |
| Italy | 2.2 | 1.2 | 1.6 | 1.3 | 1.0 |
| Japan | 11.2 | 17.0 | 12.4 | 16.8 | 19.5 |
| Latvia | - | - | - | - | - |
| Liechtenstein | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lithuania | - | - | - | - | - |
| Luxembourg | - | - | - | - | - |
| Monaco | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 3.3 | 2.2 | 2.5 | 2.1 | 1.6 |
| New Zealand | - | - | - | - | - |
| Norway | - | - | - | - | - |
| Poland | - | - | - | - | - |
| Portugal | - | - | - | - | - |
| Romania | - | - | - | - | - |
| Russia | 5.1 | 1.6 | 0.6 | 0.5 | 0.5 |
| Slovakia | - | 0.0 | 0.0 | 0.0 | 0.0 |
| Slovenia | 0.0 | - | - | - | - |
| Spain | 2.6 | 1.9 | 2.3 | 1.9 | 1.5 |
| Sweden | - | - | - | - | - |
| Switzerland | - | - | - | - | - |
| Ukraine | - | - | - | - | - |
| UK | 8.2 | 7.0 | 6.0 | 4.9 | 3.9 |
| US | 34.8 | 27.1 | 30.2 | 27.1 | 20.9 |
| **EU-15** | 27 | 22 | 22 | 19 | 15 |
| **Other Western Europe** | 0 | 0 | 0 | 0 | 0 |
| **Russia** | 5 | 2 | 1 | 1 | 0 |
| **Other Eastern Europe** | 0 | 0 | 0 | 0 | 0 |
| **AUS/NZ** | 1 | 0 | - | - | - |
| **Japan** | 11 | 17 | 12 | 17 | 20 |
| **Canada** | 1 | 0 | 0 | 0 | 0 |
| **US** | 35 | 27 | 30 | 27 | 21 |
| **Total** | 80 | 69 | 66 | 63 | 56 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit D-4: Aluminum PFC Emissions 1990-2010 ($MMTCO_2$)**

| Developed Country | Aluminum PFC Emissions ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 4.7 | 2.7 | 3.2 | 3.5 | 3.1 |
| Austria | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Belgium | - | - | - | - | - |
| Bulgaria | - | - | - | - | - |
| Canada | 8.0 | 5.7 | 6.0 | 6.6 | 6.1 |
| Croatia | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 |
| Czech Republic | - | - | - | - | - |
| Denmark | - | - | - | - | - |
| Estonia | - | - | - | - | - |
| Finland | - | - | - | - | - |
| France | 1.6 | 0.9 | 1.0 | 1.0 | 1.0 |
| Germany | 2.2 | 0.7 | 0.7 | 0.8 | 0.8 |
| Greece | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 |
| Hungary | 0.1 | 0.1 | 0.1 | 0.1 | <0.05 |
| Iceland | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 |
| Ireland | - | - | - | - | - |
| Italy | 2.8 | 1.4 | 1.4 | 1.4 | 1.4 |
| Japan | <0.05 | <0.05 | 0.1 | 0.1 | 0.1 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | - | - | - | - | - |
| Monaco | - | - | - | - | - |
| Netherlands | 5.3 | 2.5 | 2.6 | 2.6 | 2.6 |
| New Zealand | 1.1 | 0.5 | 0.6 | 0.5 | 0.4 |
| Norway | 2.5 | 1.4 | 1.3 | 1.2 | 1.2 |
| Poland | 0.2 | 0.1 | 0.1 | 0.1 | <0.05 |
| Portugal | - | - | - | - | - |
| Romania | 3.5 | 1.1 | 1.1 | 1.2 | 1.1 |
| Russia | 15.4 | 10.0 | 9.8 | 9.5 | 8.7 |
| Slovakia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Slovenia | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Spain | 4.4 | 2.1 | 2.1 | 2.2 | 2.1 |
| Sweden | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 |
| Switzerland | 0.1 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ukraine | 0.4 | 0.3 | 0.3 | 0.3 | 0.2 |
| UK | 0.7 | 0.4 | 0.2 | 0.1 | 0.1 |
| US | 19.3 | 11.2 | 9.7 | 10.2 | 10.4 |
| **EU-15** | 18 | 8 | 8 | 8 | 8 |
| **Other Western Europe** | 3 | 2 | 1 | 1 | 2 |
| **Russia** | 15 | 10 | 10 | 10 | 9 |
| **Other Eastern Europe** | 5 | 2 | 2 | 2 | 2 |
| **AUS/NZ** | 6 | 3 | 4 | 4 | 4 |
| **Japan** | 0 | 0 | 0 | 0 | 0 |
| **Canada** | 8 | 6 | 6 | 7 | 6 |
| **US** | 19 | 11 | 10 | 10 | 10 |
| **Total** | 74 | 42 | 41 | 42 | 40 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit D-5: $SF_6$ Emissions from Magnesium 1990-2010 ($MMTCO_2$)**

| Developed Country | $SF_6$ Emissions from Magnesium ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | - | - | - | 2.0 | 2.1 |
| Austria | - | - | - | - | - |
| Belgium | - | - | - | - | - |
| Bulgaria | - | - | - | - | - |
| Canada | 2.1 | 2.1 | 2.3 | 5.3 | 8.6 |
| Croatia | - | - | - | - | - |
| Czech Republic | - | - | - | - | - |
| Denmark | - | - | - | - | - |
| Estonia | - | - | - | - | - |
| Finland | - | - | - | - | - |
| France | 0.4 | 0.4 | 0.6 | 0.9 | 1.6 |
| Germany | - | 0.2 | 0.4 | 0.8 | 1.6 |
| Greece | - | - | - | - | - |
| Hungary | - | - | - | - | - |
| Iceland | - | - | 0.2 | 1.1 | 1.6 |
| Ireland | - | - | - | - | - |
| Italy | 0.1 | - | - | - | - |
| Japan | 0.3 | 0.5 | 1.0 | 2.0 | 4.0 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | - | - | - | - | - |
| Monaco | - | - | - | - | - |
| Netherlands | - | - | - | 0.6 | 0.6 |
| New Zealand | - | - | - | - | - |
| Norway | 3.1 | 2.0 | 3.5 | 6.5 | 12.5 |
| Poland | - | - | - | - | - |
| Portugal | - | - | - | - | - |
| Romania | - | - | - | - | - |
| Russia | - | - | - | - | - |
| Slovakia | - | - | - | - | - |
| Slovenia | - | - | - | - | - |
| Spain | - | - | - | - | - |
| Sweden | - | 0.2 | 0.4 | 0.8 | 1.6 |
| Switzerland | - | - | - | - | - |
| Ukraine | 0.6 | 0.3 | <0.05 | <0.05 | <0.05 |
| UK | 0.5 | 0.6 | 0.8 | 0.8 | 0.8 |
| US | 5.5 | 5.5 | 6.8 | 11.3 | 20.3 |
| **EU-15** | 1 | 1 | 2 | 4 | 6 |
| **Other Western Europe** | 3 | 2 | 4 | 8 | 14 |
| **Russia** | - | - | - | - | - |
| **Other Eastern Europe** | 1 | 0 | 0 | 0 | 0 |
| **AUS/NZ** | - | - | - | 2 | 2 |
| **Japan** | 0 | 0 | 1 | 2 | 4 |
| **Canada** | 2 | 2 | 2 | 5 | 9 |
| **US** | 6 | 6 | 7 | 11 | 20 |
| **Total** | 13 | 12 | 16 | 32 | 55 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit D-6: $SF_6$ Emissions from Electric Utilities 1990-2010 ($MMTCO_2$)**

| Developed Country | $SF_6$ Emissions from Electric Utilities ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | 0.7 | 0.6 | 0.4 | 0.4 | 0.3 |
| Austria | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |
| Belgium | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| Bulgaria | - | - | - | - | - |
| Canada | 2.3 | 2.0 | 1.1 | 1.1 | 1.0 |
| Croatia | - | - | - | - | - |
| Czech Republic | - | - | - | - | - |
| Denmark | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| Estonia | - | - | - | - | - |
| Finland | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 |
| France | 1.7 | 1.5 | 0.9 | 0.9 | 0.8 |
| Germany | 2.6 | 2.0 | 1.1 | 1.1 | 1.0 |
| Greece | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |
| Hungary | - | - | - | - | - |
| Iceland | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ireland | 0.1 | 0.1 | <0.05 | <0.05 | <0.05 |
| Italy | 1.2 | 1.0 | 0.6 | 0.6 | 0.5 |
| Japan | 1.8 | 1.4 | 0.5 | 2.5 | 4.5 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Monaco | - | - | - | - | - |
| Netherlands | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 |
| New Zealand | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| Norway | 0.5 | 0.4 | 0.2 | 0.2 | 0.2 |
| Poland | - | - | - | - | - |
| Portugal | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Romania | - | - | - | - | - |
| Russia | 0.0 | 3.1 | 1.6 | 1.4 | 1.4 |
| Slovakia | - | - | - | - | - |
| Slovenia | - | - | - | - | - |
| Spain | 0.7 | 0.6 | 0.4 | 0.4 | 0.3 |
| Sweden | 0.7 | 0.6 | 0.3 | 0.2 | 0.2 |
| Switzerland | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 |
| Ukraine | 0.0 | 0.7 | 0.3 | 0.3 | 0.3 |
| UK | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 |
| US | 34.8 | 29.5 | 17.3 | 16.6 | 16.1 |
| **EU-15** | 9 | 8 | 4 | 4 | 4 |
| **Other Western Europe** | 1 | 1 | 0 | 0 | 0 |
| **Russia** | <0.05 | 3 | 2 | 1 | 1 |
| **Other Eastern Europe** | 0 | 1 | 0 | 0 | 0 |
| **AUS/NZ** | 1 | 1 | 0 | 0 | 0 |
| **Japan** | 2 | 1 | 1 | 3 | 5 |
| **Canada** | 2 | 2 | 1 | 1 | 1 |
| **US** | 35 | 30 | 17 | 17 | 16 |
| **Total** | 50 | 46 | 26 | 27 | 28 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

**Exhibit D-7: Emissions from Semiconductor Production 1990-2010 ($MMTCO_2$)**

| Developed Country | Emissions from Semiconductor Production ($MMTCO_2$) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1995 | 2000 | 2005 | 2010 |
| Australia | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Austria | <0.05 | 0.1 | 0.2 | 0.5 | 0.9 |
| Belgium | <0.05 | <0.05 | <0.05 | 0.1 | 0.2 |
| Bulgaria | - | - | - | - | - |
| Canada | <0.05 | <0.05 | <0.05 | 0.1 | 0.3 |
| Croatia | - | - | - | - | - |
| Czech Republic | - | - | - | - | - |
| Denmark | - | - | - | - | - |
| Estonia | - | - | - | - | - |
| Finland | - | - | - | - | - |
| France | 0.1 | 0.4 | 1.0 | 2.8 | 5.5 |
| Germany | 0.3 | 0.8 | 1.8 | 5.1 | 10.2 |
| Greece | - | - | - | - | - |
| Hungary | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Iceland | - | - | - | - | - |
| Ireland | <0.05 | 0.3 | 0.6 | 1.7 | 3.4 |
| Italy | 0.1 | 0.2 | 0.6 | 1.6 | 3.2 |
| Japan | 1.3 | 5.2 | 6.3 | 14.5 | 22.7 |
| Latvia | - | - | - | - | - |
| Liechtenstein | - | - | - | - | - |
| Lithuania | - | - | - | - | - |
| Luxembourg | - | - | - | - | - |
| Monaco | - | - | - | - | - |
| Netherlands | 0.1 | 0.1 | 0.2 | 0.7 | 1.3 |
| New Zealand | - | - | - | - | - |
| Norway | - | - | - | - | - |
| Poland | - | - | - | - | - |
| Portugal | - | - | - | - | - |
| Romania | - | - | - | - | - |
| Russia | <0.05 | 0.1 | 0.2 | 0.6 | 1.2 |
| Slovakia | - | - | - | - | - |
| Slovenia | - | - | - | - | - |
| Spain | <0.05 | <0.05 | <0.05 | 0.1 | 0.2 |
| Sweden | <0.05 | <0.05 | <0.05 | 0.1 | 0.1 |
| Switzerland | <0.05 | <0.05 | 0.1 | 0.2 | 0.4 |
| Ukraine | - | - | - | - | - |
| UK | 0.4 | 0.7 | 2.1 | 5.1 | 10.3 |
| US | 2.9 | 5.5 | 11.3 | 32.0 | 64.2 |
| **EU-15** | 1 | 2 | 6 | 15 | 35 |
| **Other Western Europe** | <0.05 | <0.05 | 0 | 0 | 0 |
| **Russia** | <0.05 | 0 | 0 | 1 | 1 |
| **Other Eastern Europe** | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| **AUS/NZ** | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| **Japan** | 1 | 5 | 6 | 15 | 23 |
| **Canada** | <0.05 | <0.05 | 0 | 0 | 0 |
| **US** | 3 | 6 | 11 | 32 | 64 |
| **Total** | 5 | 13 | 24 | 65 | 124 |

*Note: Dashes indicate that emissions for the respective country were not analyzed.*

# Appendix E: Methane Emissions: Data Sources and Methods

Appendix E summarizes the data sources and methods used to project methane emissions in the following exhibits:

- Exhibit E-1: Methane Emissions from Landfills, Data Sources and Methods
- Exhibit E-2: Methane Emissions from Coal Mining Activities, Data Sources and Methods
- Exhibit E-3: Methane Emissions from Natural Gas and Oil Systems, Data Sources and Methods
- Exhibit E-4: Methane Emissions from Livestock Manure Management, Data Sources and Methods
- Exhibit E-5: Methane Emissions from Livestock Enteric Fermentation, Data Sources and Methods
- Exhibit E-6: Methane Emissions from Wastewater Treatment, Data Sources and Methods
- Exhibit E-7: Methane Emissions from Other Agricultural Sources, Data Sources and Methods
- Exhibit E-8: Methane Emissions from Other Non-Agricultural Sources, Data Sources and Methods

**Exhibit E-1: Methane Emissions from Landfills, Data Sources and Methods**

| Country | Data Sources | Method / Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Austria | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Croatia | Corinair | Landfill emissions estimates for 1990 were broken out of the 1990 Corinair aggregate waste estimates using Hungary's disaggregated percentages. Future emissions were estimated by applying Croatia's population growth rate to 1990 emission estimates. |
| Czech Republic | Second NC / 1999 Inventory Submission | Projections from Second National Communication scaled to 1999 Inventory submission. Projected landfill emissions were broken out of aggregate waste projections using 1995 percentages. |
| Denmark | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Estonia | Second NC | 1990 and 1995 reported for municipal landfills. Emissions assumed to remain constant at 1995 levels for the period 2000-2010. |
| Finland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Iceland | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Italy | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Japan | Second NC | Second NC reported emissions estimates for 1990-1994, and projections for 2000, 2005, and 2010. The 1994 estimate was used for 1995. Projected emissions were adjusted to account for mitigation efforts. Refer to Chapter 5 for a discussion of the approach. |
| Latvia | Second NC | Second National Communication provided estimates only to 2000. Estimates from 2005 -2010 kept constant at 2000 levels. |

**Exhibit E-1: Methane Emissions from Landfills, Data Sources and Methods (Continued)**

| Country | Data Sources | Method / Adjustments |
|---|---|---|
| Liechtenstein | ------- | No reported data. |
| Lithuania | First NC / 1999 Inventory Submission | First National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Luxembourg | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Monaco | ------ | No reported data. |
| Netherlands | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission | Second National Communication scaled to the 2000 Inventory Submission. Projections were adjusted to account for mitigation efforts. Refer to Chapter 5 for a detailed discussion of the approach. |
| Poland | Second NC / 2000 Inventory Submission | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Portugal | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Romania | Second NC | Emissions and Projections from Second National Communication. 1995-2010 aggregate waste numbers broken down by 1990 percentages. |
| Russia | Country Study | Emissions and Projections from Country Study. |
| Slovakia | Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Slovenia | First NC | First National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Spain | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in Waste in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. Landfill emissions estimates were calculated by applying the 1995 landfill percentage of waste to projected waste emissions. Projections reflect measures to divert waste and were adjusted to Business As Usual. Refer to Chapter 5 for a discussion of the approach. |
| Ukraine | Mitigation Study | Mitigation Study emissions and projections. |
| UK | 2000 Inventory Submission / UK Study | Emissions and Projections from UK study – 'Projections of Non-CO2 Greenhouse Gases for the UK', March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-2: Methane Emissions from Coal Mining Activities, Data Sources and Methods**

| Country | Data Sources | Method/ Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Second National Communication projections scaled to 2000 Inventory Submission. Estimates for 2000 and 2005 were interpolated. |
| Austria | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / Second NC | Projections from Second National Communication aggregate projections of fugitive emissions broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Croatia | ----- | No reported data. |
| Czech Republic | 1999 Inventory Submission / Second NC | Projections from Second National Communication scaled to 1999 Inventory submission. |
| Denmark | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Estonia | Second NC | No reported data. |
| Finland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Iceland | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |

**Exhibit E-2: Methane Emissions from Coal Mining Activities, Data Sources and Methods (Continued)**

| Country | Data Sources | Method/ Adjustments |
|---|---|---|
| Italy | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Japan | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to 2000 Inventory Submission. Projections were a part of aggregate emissions from fugitive fuels (coal & oil/gas). These estimates were broken down using 1995 fugitive emission proportions. |
| Latvia | Second NC | No reported data. |
| Liechtenstein | ----- | No reported data. |
| Lithuania | Second NC | No reported data. |
| Luxembourg | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Monaco | 2000 Inventory Submission | No reported data. |
| Netherlands | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to 2000 Inventory Submission. 2000, 2005, and 2010 projections are aggregate fugitive emissions, broken down using 1995 percentages. |
| Norway | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to 2000 Inventory Submission. 2000, 2005, and 2010 projections are aggregate fugitive emissions, broken down using 1995 percentages. |
| Poland | Second NC / 2000 Inventory Submission | Emissions from second National Communication and are projected to decrease by 15% from 1995 levels by 2010, a 5% reduction every 5 years. Refer to Chapter 5 for details. |
| Portugal | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Romania | Second NC | Emissions and Projections from Second National Communication. |
| Russia | 2000 Russian Coalbed EPA Study | Emissions and Projections from EPA study. |
| Slovakia | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to 2000 Inventory Submission. |
| Slovenia | First NC | First National Communication provided only 1990l emissions. Estimates from 1995-2010 kept constant at 1990 levels. Nearby countries also have constant emission projections. |
| Spain | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |

**Exhibit E-2: Methane Emissions from Coal Mining Activities, Data Sources and Methods (Continued)**

| Country | Data Sources | Method/ Adjustments |
|---|---|---|
| Switzerland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Ukraine | Mitigation Study / PEER (2001) | Projections from mitigation study scaled to Ukrainian historical emission estimates. |
| UK | 2000 Inventory Submission / UK Study | Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-3: Methane Emissions from Natural Gas and Oil Systems, Data Sources and Methods**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Second National Communication 2010 projection broken down using historical percentages and then scaled to 2000 Inventory Submission. Estimates for 2000 and 2005 were interpolated. |
| Austria | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to the 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / EU Sector Report | Projections from Second National Communication aggregate projections of fugitive emissions broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Croatia | Corinair | No reported data. |
| Czech Republic | 1999 Inventory Submission | Projections from Second National Communication scaled to 1999 Inventory submission. |
| Denmark | 2000 Inventory Submission / Second NC | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Estonia | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Finland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission numbers. |
| Iceland | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |

**Exhibit E-3: Methane Emissions from Natural Gas and Oil Systems, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Italy | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Japan | 2000 Inventory Submission / EU Sector Report | Second National Communication scaled to 1999 Inventory submission numbers. Future emissions were a part of aggregate emissions from fugitive fuels. These estimates were broken down using 1995 emissions. |
| Latvia | Second NC | Second National Communication reports fugitive emissions for 2000. All fugitive emissions attributed to natural gas systems. 2000 emissions estimates were held constant for 2005 and 2010. |
| Liechtenstein | ----- | No reported data. |
| Lithuania | First NC | No reported data. |
| Luxembourg | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Monaco | ----- | No reported data. |
| Netherlands | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission / Second NC | Second National Communication projections for fugitive emissions broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication projections for fugitive emissions broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Poland | 2000 Inventory Submission / Second NC | Second National Communication projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Portugal | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Romania | Second NC | Second National Communication provided emissions and projections. |
| Russia | Country Study | The Country Study reports disaggregate fugitive emissions for 1990. The 1990 estimates were scaled to the consumption of natural gas fuel use in Russia for 1995 and projected use through 2010. |
| Slovakia | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Slovenia | First NC | Second National Communication provided only 1990 emissions. Estimates from 1995 -2010 kept constant at 1990 levels. |
| Spain | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | Projections from 'Economic Evaluation of Emission Reductions of Methane in the Extraction, Transport, and Distribution of Fossil Fuels in the EU' (AEA Technology Environment, 2001) scaled to the 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission / Second NC | Second National Communication projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Ukraine | Mitigation study | Emissions and Projections from mitigation study. |

**Exhibit E-3: Methane Emissions from Natural Gas and Oil Systems, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| UK | 2000 Inventory Submission / UK Study | Emissions and Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-4: Methane Emissions from Livestock Manure Management, Data Sources and Methods**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Second National Communication projections broken down using historical percentages and then scaled to 2000 Inventory Submission. Consistent with livestock production data. |
| Austria | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission / Second NC | Second National Communication projections then scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / Second NC | Second National Communication projections then scaled to 2000 Inventory Submission. |
| Croatia | Corinair | No reported data. |
| Czech Republic | 1999 Inventory Submission / Second NC | Projections from Second National Communication were aggregate. Projections for 2000, 2005, and 2010 were disaggregated based on 1995 breakout of aggregate projections. |
| Denmark | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Estonia | Second NC | Projections for agricultural emissions assumed to be enteric and manure only and Manure is 13% of total. Projections estimated by applying Ukrainian growth rate to 1995 emission estimate. |
| Finland | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission / Second NC | Second National Communication projections scaled to 2000 Inventory Submission. |
| Iceland | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Italy | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Japan | 2000 Inventory Submission / Second NC | Second National Communication projections then scaled to 2000 Inventory Submission. |
| Latvia | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Liechtenstein | ----- | No reported data. |

**Exhibit E-4: Methane Emissions from Livestock Manure Management, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Lithuania | First NC | First National Communication provided aggregate agricultural projections, which were broken down by 1990 percentages. 1995 and 2005 interpolated. Used scenario II of projections for 2010. |
| Luxembourg | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Monaco | ----- | No reported data. |
| Netherlands | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission / Second NC | Second National Communication aggregate projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication aggregate projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Poland | 2000 Inventory Submission | Projections estimated by applying Ukrainian growth rate to 1995 estimates. |
| Portugal | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Romania | Second NC | Emissions and Projections from Second National Communication. |
| Russia | First NC | Historical emissions from First National Communication. Projections were based on the Ukrainian growth pattern. Emissions estimates were consistent with available livestock production data. |
| Slovakia | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Slovenia | First NC | Second National Communication provided only 1990 emissions. Estimates from 1995-2010 kept constant at 1990 levels. |
| Spain | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission / second NC | Second National Communication projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Ukraine | Mitigation Study | Reported aggregate emissions from the Mitigation Study were broken out using Estonia and Poland's breakdown of agricultural emissions. Emissions estimates were consistent with available livestock production data. |
| UK | 2000 Inventory Submission / UK Study | Emissions and Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-5: Methane Emissions from Livestock Enteric Fermentation, Data Sources and Methods**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Second National Communication projections broken down using historical percentages and then scaled to 2000 Inventory Submission. Consistent with livestock production data. |
| Austria | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission / Second NC | Second National Communication projections then scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / Second NC | Second National Communication projections then scaled to 2000 Inventory Submission. |
| Croatia | Corinair | No reported data. |
| Czech Republic | 1999 Inventory Submission / Second NC | Projections from Second National Communication were aggregate. Projections for 2000, 2005, and 2010 were disaggregated based on 1995 breakout of aggregate projections. |
| Denmark | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Estonia | Second NC | Projections for agricultural emissions assumed to be enteric and manure only and Manure is 13% of total. Projections estimated by applying Ukrainian growth rate to 1995 emission estimate. |
| Finland | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission / Second NC | Second National Communication projections scaled to 2000 Inventory Submission. |
| Iceland | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Italy | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Japan | 2000 Inventory Submission / Second NC | Second National Communication projections then scaled to 2000 Inventory Submission. |
| Latvia | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Liechtenstein | ----- | No reported data. |

**Exhibit E-5: Methane Emissions from Livestock Enteric Fermentation, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Lithuania | First NC | First National Communication provided aggregate agricultural projections, which were broken down by 1990 percentages. 1995 and 2005 interpolated. Used scenario II of projections for 2010. |
| Luxembourg | Second NC | Second National Communication provided only historical emissions. Estimates from 2000-2010 kept constant at 1995 levels. |
| Monaco | ----- | No reported data. |
| Netherlands | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission / Second NC | Second National Communication aggregate projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication aggregate projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Poland | 2000 Inventory Submission | Projections estimated by applying Ukrainian growth rate to 1995 estimates. |
| Portugal | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Romania | Second NC | Emissions and Projections from Second National Communication. |
| Russia | First NC | Historical emissions from First National Communication. Projections were based on the Ukrainian growth pattern. Emissions estimates were consistent with available livestock production data. |
| Slovakia | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Slovenia | First NC | Second National Communication provided only 1990 emissions. Estimates from 1995-2010 kept constant at 1990 levels. |
| Spain | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | 'Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU' (AEA Technology Environment, 2001) scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission / Second NC | Second National Communication projections broken down using historical percentages and then scaled to 2000 Inventory Submission. |
| Ukraine | Mitigation Study | Reported emissions broken out using Estonia and Poland's breakdown of agricultural emissions. |
| UK | 2000 Inventory Submission / UK Study | Emissions and Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-6: Methane Emissions from Wastewater Treatment, Data Sources and Methods**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | The 2000 Inventory Submissions reports disaggregated waste estimates for 1995, aggregate waste emissions for 1990 and a wastewater emissions growth rate for 1995 to 2010. The 1990 wastewater emissions were calculated by applying the 1995 waste breakdown to the 1990 total waste emissions. Projections were estimated using the 1995 to 2010 reported growth rate. |
| Austria | 2000 Inventory Submission / Second NC | No projections were available from the Second National Communication. |
| Belgium | 2000 Inventory Submission / Second NC | Projections from Second National Communication for 2000 scaled to 2000 Inventory Submissions with 2005 and 2010 held constant at 2000 levels. |
| Bulgaria | 2000 Inventory Submission / Second NC | Projections from Second National Communication for 2000 scaled to 2000 Inventory Submissions with 2005 and 2010 held constant at 2000 levels. |
| Canada | Second NC | Projections from Second National Communication for aggregate waste emissions for 2000, 2005, and 2010. Waste projections disaggregated by applying the 1995 breakout. |
| Croatia | Corinair | No reported data. |
| Czech Republic | Second NC | Projections from Second National Communication for aggregate waste emissions for 2000, 2005, and 2010. Waste projections disaggregated by applying the 1995 breakout. |
| Denmark | 2000 Inventory Submission / Second NC | Projections from Second National Communication scaled to 2000 Inventory Submission. |
| Estonia | Second NC | Emissions from Second National Communication for 1990 and 1995 municipal and industrial wastewater. Estimates for 2000 – 2010 held constant at 1995 levels. |
| Finland | 2000 Inventory Submission / Second NC | Emissions from 2000 Inventory Submissions. Estimates for 2000, 2005, and 2010 kept constant at 1995 levels. |
| France | 2000 Inventory Submission / Second NC | Emissions from 2000 Inventory Submissions. Estimates for 2000, 2005, and 2010 kept constant at 1995 levels. |
| Germany | 2000 Inventory Submission / Second NC | Second National Communication aggregate waste projections scaled to 2000 Inventory Submission. Disaggregated waste percentages from 1990 used to disaggregate 2000-2010. |
| Greece | 2000 Inventory Submission / Second NC | Emissions from 2000 Inventory Submissions. Estimates for 2000, 2005, and 2010 kept constant at 1995 levels. |
| Hungary | 2000 Inventory Submission / Second NC | Emissions from 2000 Inventory Submissions. Estimates for 2000, 2005, and 2010 kept constant at 1995 levels. |
| Iceland | Second NC | Emissions from Second National Communication. Estimates for 2000, 2005, and 2010 kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission / Second NC | No reported data. |
| Italy | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. 2005 interpolated from 2000 and 2010. |
| Japan | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. Japan reported disaggregated waste emissions for 1990 and 1994 and aggregate "all other" emissions for 2000, 2005, and 2010. 1995 emissions were assumed to be the 1994 estimates. Aggregate projections for "all other" emissions broken down using 1994 breakdown of emissions that make up this category in Second NC. |

**Exhibit E-6: Methane Emissions from Wastewater Treatment, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Latvia | Second NC | Emissions and Projections from Second National Communication. |
| Liechtenstein | ----- | No reported data. |
| Lithuania | 1999 Inventory Submission / First NC | Projections from First National Communication scaled to 1999 Inventory submission. Scenario II projections for 2000 and 2010with 2005 interpolated. |
| Luxembourg | Second NC | Emissions from Second National Communication. Projections for 2000, 2005, and 2010 kept constant at 1995 levels. |
| Monaco | ----- | No reported data. |
| Netherlands | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Poland | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. 1994 estimate used for 1995. Projections for 2000, 2005, and 2010 kept constant at 1995 levels. |
| Portugal | 2000 Inventory Submission / Second NC | Emissions from 2000 Inventory Submission. Projections for 2000, 2005, and 2010 kept constant at 1995 levels, similar to France/Spain. |
| Romania | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Russia | Country Study | The Russia Country study reports disaggregated waste emissions for 1990. Estimates for 1995-2010 kept constant at 1990 levels. |
| Slovakia | Second NC | Emissions from Second National Communication |
| Slovenia | First NC | Emissions from First National Communication with 1995-2010 held constant at 1990 levels, similar to nearby countries of Hungary and Austria. |
| Spain | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission / Second NC | Estimates from Second National Communication. 1995 breakout used to disaggregate waste emissions estimates for 2000, 2005, and 2010. |
| Ukraine | Mitigation Study | Emissions and projections from Mitigation Study. |
| UK | 2000 Inventory Submission / UK Study | Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-7: Methane Emissions from Other Agricultural Sources, Data Sources and Methods**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Second National Communication with 2010 broken down according to 1995 proportions. 2000 and 2005 interpolated. |
| Austria | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Belgium | 2000 Inventory Submission | Only includes rice for 1995. |
| Bulgaria | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission | Second national Communication scaled to 2000 Inventory Submission. |
| Croatia | Corinair | No reported data. |
| Czech Republic | Second NC | |
| Denmark | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Estonia | Second NC | Second National Communication |
| Finland | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| France | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Germany | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Greece | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Hungary | Second NC | Emissions and Projections from Second National Communication. |
| Iceland | Second NC | Kept constant in projections. |
| Ireland | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Italy | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Japan | 1999 Inventory Submission | Second National Communication scaled to 1999 Inventory submission. |
| Latvia | Second NC | No reported data. |
| Liechtenstein | ----- | No reported data. |
| Lithuania | 1999 Inventory Submission | |
| Luxembourg | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Monaco | ----- | No reported data. |
| Netherlands | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| New Zealand | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission |
| Poland | Second NC | Second National Communication provides 1994 data, used for 1995. Projections for 2000-2010 held constant at 1995 levels. |
| Portugal | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Romania | 1999 Inventory Submission | Emissions from 1999 submission, which includes rice and field burning. No projections for 1995, 2000, 2005, and 2010. |
| Russia | Country Study | The Russia Country study reports disaggregate agricultural emissions for 1990. The 1990 estimate was held constant into the future. |
| Slovakia | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission |

**Exhibit E-7: Methane Emissions from Other Agricultural Sources, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Spain | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Sweden | 2000 Inventory Submission | No reported data. |
| Switzerland | 2000 Inventory Submission | Second National Communication scaled to 2000 Inventory Submission |
| Ukraine | Mitigation Study | Emissions and Projections from the Mitigation Study. |
| UK | 2000 Inventory Submission | Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

**Exhibit E-8: Methane Emissions from Other Non-Agricultural Sources, Data Sources and Methods**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Australia | 2000 Inventory Submission | Second National Communication scaled to 2000 Inventory. |
| Austria | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Belgium | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Bulgaria | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / Second NC | Projections from Second National Communication. Kept constant from 2000-2010 at 1995 levels. |
| Croatia | Corinair | Corinair provided disaggregate 1990 other non-agricultural emissions estimates. These estimates were held constant into the future. |
| Czech Republic | Second NC | |
| Denmark | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Estonia | Second NC | Emissions from Second National Communication, with 1995 emissions held constant for 2000, 2005, and 2010. |
| Finland | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| France | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Germany | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Greece | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Hungary | First NC | First National Communication provides emission estimates. Emissions for 2000, 2005, and 2010 held constant at 1995 levels. |
| Iceland | Second NC | Emissions from Second National Communication, with projections kept constant at 1995 levels. |
| Ireland | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Italy | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Japan | 1999 Inventory Submission | Second national Communication projections scaled to 1999 Inventory. 2000, 2005, and 2010 disaggregated by 1995 historical proportions. |
| Latvia | Second NC | Emissions and projections from Second National Communication. |
| Liechtenstein | ----- | No reported data. |
| Lithuania | 1999 Inventory Submission / Second NC | Second National Communication using Scenario II, then scaled to 1999 Inventory submission. |
| Luxembourg | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Monaco | ----- | No reported data. |
| Netherlands | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| New Zealand | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory. |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory. |

**Exhibit E-8: Methane Emissions from Other Non-Agricultural Sources, Data Sources and Methods (Continued)**

| Country | Data Source | Inventory/Projection Estimate Adjustments |
|---|---|---|
| Poland | Second NC | Second National Communication. 1990 includes fuel combustion and industrial. 1994 emissions used for 1995. 2000-2010 projections by Czech growth pattern. |
| Portugal | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Romania | Second NC | Emissions and projections from Second NC. |
| Russia | Country Study | The Russia Country study does not report emissions from other non-agricultural sources. |
| Slovakia | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory. |
| Slovenia | First NC | Held constant after 1995 based on similar nearby countries such as Italy, Austria, and Hungary. |
| Spain | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Sweden | 2000 Inventory Submission | Emissions from 2000 Inventory Submissions, with 1990-1995 growth rate used to calculate future rates. |
| Switzerland | 2000 Inventory Submission | Second National Communication scaled to 2000 Inventory. |
| Ukraine | Mitigation Study | Emissions and projections from the Mitigation Study were disaggregated. |
| UK | 2000 Inventory Submission | Projections from *Projections of Non-$CO_2$ Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / EPA 2001b, draft | Projections from EPA 2001b, draft. |

# Appendix F: Nitrous Oxide Emissions: Data Sources and Methods

Appendix F summarizes the data sources and methods used to project nitrous oxide emissions in the following exhibits:

- Exhibit F-1: Nitrous Oxide Emissions from Agricultural Soils, Data Sources and Methods
- Exhibit F-2: Nitrous Oxide Emissions from Industrial Processes, Data Sources and Methods
- Exhibit F-3: Nitrous Oxide Emissions from Stationary Fossil Fuel Combustion (Electric Utilities, Manufacturing and Construction Industries), Data Sources and Methods
- Exhibit F-4: Nitrous Oxide Emissions from Mobile Fossil Fuel, Data Sources and Methods
- Exhibit F-5: Nitrous Oxide Emissions from Manure Management, Data Sources and Methods

**Exhibit F-1: Nitrous Oxide Emissions from Agricultural Soils, Data Sources and Methods**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Australia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Austria | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Croatia | | Refer to the methodologies described in Section 5 of this report. |
| Czech Republic | | Refer to the methodologies described in Section 5 of this report. |
| Denmark | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Estonia | | Refer to the methodologies described in Section 5 of this report. |
| Finland | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Iceland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Ireland | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Italy | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Japan | 1999 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 1999 Inventory Submission. |
| Latvia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Liechtenstein | ----- | Refer to the methodologies described in Section 5 of this report. |
| Lithuania | ----- | Refer to the methodologies described in Section 5 of this report. |
| Luxembourg | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Monaco | ----- | Refer to the methodologies described in Section 5 of this report. |

**Exhibit F-1: Nitrous Oxide Emissions from Agricultural Soils, Data Sources and Methods (Continued)**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Netherlands | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Poland | | Refer to the methodologies described in Section 5 of this report. |
| Portugal | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Romania | ----- | Refer to the methodologies described in Section 5 of this report. |
| Russia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Slovakia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Slovenia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Spain | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Ukraine | | Refer to the methodologies described in Section 5 of this report. |
| UK | 2000 Inventory Submission / UK Study | Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / Third NC | Emissions and Projections from draft Third National Communication |

**Exhibit F-2: Nitrous Oxide Emissions from Industrial Processes, Data Sources and Methods**

| Country | Data Source | Estimation/Projection Methods |
|---|---|---|
| Australia | 2000 Inventory Submission / Second NC | Projections from the Second National Communication scaled to 2000 Inventory Submission. Emissions from 2000-2010 held constant at 1995 levels as Australia reported in 2 NC that no emissions abatement options were being considered. |
| Austria | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission / Second NC | Canada expects to reduce emissions from adipic acid production by 95% with new technology phase in during 1997 through 2000. The 2000 emissions projection was held constant to 2010. |
| Croatia | Corinair | No reported data. |
| Czech Republic | Second NC | No reported data. |
| Denmark | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Estonia | Second NC | No reported data. |
| Finland | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission | No reported data. |
| Iceland | Second NC | No reported data. |
| Ireland | Corinair | Emissions are reported for 1994 and kept constant at 1994 levels through 2010. |
| Italy | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Japan | 1999 Inventory Submission / Second NC | Second National Communication scaled to 1999 Inventory Submission. |
| Latvia | Second NC | No reported data. |
| Liechtenstein | ----- | No reported data. |
| Lithuania | ----- | No reported data. |
| Luxembourg | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Monaco | | No reported data. |
| Netherlands | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission | No reported data. |
| Norway | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory. Reported emissions for 2000. Emissions for 2005-2010 held constant at 2000 levels. |
| Poland | 2000 Inventory Submission | Emissions from 2000-2010 kept constant from 2000-2010 at 1995 levels. |
| Portugal | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Romania | Second NC | Second National Communication. |
| Russia | Second NC | No reported data. |

**Exhibit F-2: Nitrous Oxide Emissions from Industrial Processes, Data Sources and Methods (Continued)**

| Country | Data Source | Estimation/Projection Methods |
|---|---|---|
| Slovakia | 2000 Inventory Submission / Second NC | Second National Communication scaled to 2000 Inventory Submission. |
| Slovenia | First NC | No reported data. |
| Spain | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Report | Options to Reduce Nitrous Oxide Emissions - Final Report: November 1998 (AEA Technology) scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission | Second National Communication scaled to 2000 Inventory Submission. |
| Ukraine | Second NC | Second National Communication. $N_2O$ emissions are not expected to drop due to the increase of nitric acid and adipic acid production after 1995. |
| UK | 2000 Inventory Submission | Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission/ EPA 2001c | Projections from EPA 2001c. |

**Exhibit F-3 Nitrous Oxide Emissions from Stationary Fossil Fuel Combustion (Electric Utilities; Manufacturing and Construction Industries), Data Sources and Methods**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Australia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Austria | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission | 1990 and 1995 emission estimates for manufacturing and construction industries, as well as all Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Croatia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Czech Republic | ----- | Refer to the methodologies described in Section 5 of this report. |
| Denmark | 2000 Inventory Submission | Refer to the methodologies described in Section 5 of this report. |
| Estonia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Finland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission |
| Iceland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Ireland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission |
| Italy | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Japan | 1999 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 1999 Inventory Submission. |
| Latvia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Liechtenstein | ----- | Refer to the methodologies described in Section 5 of this report. |
| Lithuania | ----- | Refer to the methodologies described in Section 5 of this report. |
| Luxembourg | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Monaco | ----- | Refer to the methodologies described in Section 5 of this report. |
| Netherlands | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Poland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Portugal | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Romania | ----- | Refer to the methodologies described in Section 5 of this report. |

**Exhibit F-3 Nitrous Oxide Emissions from Stationary Fossil Fuel Combustion (Electric Utilities; Manufacturing and Construction Industries), Data Sources and Methods (Continued)**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Russia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Slovakia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Slovenia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Spain | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Ukraine | ----- | Refer to the methodologies described in Section 5 of this report. |
| UK | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| US | 2001 Inventory Submission / Third NC | Emissions and Projections from draft Third National Communication. |

**Exhibit F-4: Nitrous Oxide Emissions from Mobile Fossil Fuel, Data Sources and Methods**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Australia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Austria | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Croatia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Czech Republic | ----- | Refer to the methodologies described in Section 5 of this report. |
| Denmark | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Estonia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Finland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Iceland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Ireland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Italy | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Japan | 1999 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 1999 Inventory Submission. |
| Latvia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Liechtenstein | ----- | Refer to the methodologies described in Section 5 of this report. |
| Lithuania | ----- | Refer to the methodologies described in Section 5 of this report. |
| Luxembourg | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 1999 Inventory Submission. |
| Monaco | ----- | Refer to the methodologies described in Section 5 of this report. |
| Netherlands | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Poland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Portugal | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Romania | ----- | Refer to the methodologies described in Section 5 of this report. |

**Exhibit F-4: Nitrous Oxide Emissions from Mobile Fossil Fuel, Data Sources and Methods (Continued)**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Russia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Slovakia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Slovenia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Spain | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Ukraine | ----- | Refer to the methodologies described in Section 5 of this report. |
| UK | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| US | 2001 Inventory Submission / Third NC | Emissions and Projections from draft Third National Communication. |

**Exhibit F-5: Nitrous Oxide Emissions from Manure Management, Data Sources and Methods**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Australia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Austria | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Belgium | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Bulgaria | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Canada | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Croatia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Czech Republic | ----- | Refer to the methodologies described in Section 5 of this report. |
| Denmark | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Estonia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Finland | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| France | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Germany | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Greece | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Hungary | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Iceland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Ireland | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Italy | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Japan | 1999 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 1999 Inventory Submission. |
| Latvia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Liechtenstein | ----- | Refer to the methodologies described in Section 5 of this report. |
| Lithuania | ----- | Refer to the methodologies described in Section 5 of this report. |
| Luxembourg | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Monaco | ----- | Refer to the methodologies described in Section 5 of this report. |

**Exhibit F-5: Nitrous Oxide Emissions from Manure Management, Data Sources and Methods (Continued)**

| Country | Historical Data Source (if not estimated by USEPA) | Estimation/Projection Methods |
|---|---|---|
| Netherlands | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| New Zealand | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Norway | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Poland | ----- | Refer to the methodologies described in Section 5 of this report. |
| Portugal | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Romania | ----- | Refer to the methodologies described in Section 5 of this report. |
| Russia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Slovakia | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Slovenia | ----- | Refer to the methodologies described in Section 5 of this report. |
| Spain | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Sweden | 2000 Inventory Submission / EU Sector Report | Projections from *Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU* (AEA Technology, 2001) scaled to 2000 Inventory Submission. |
| Switzerland | 2000 Inventory Submission | Projections determined as described in Section 5 of this report, scaled to 2000 Inventory Submission. |
| Ukraine | ----- | Refer to the methodologies described in Section 5 of this report. |
| UK | 2000 Inventory Submission / UK Study | Projections from *Projections of Non-CO2 Greenhouse Gases for the UK*, March 2000. |
| US | 2001 Inventory Submission / Third NC | Emissions and Projections from draft Third National Communication |

# APPENDIX G: Methodology and Adjustments to Approaches Used to Estimate Nitrous Oxide Emissions from Agricultural Soils

This appendix presents the methodology and country-specific approaches that EPA used to estimate $N_2O$ emissions from agricultural soils. EPA estimated $N_2O$ for five components of $N_2O$ emissions from agricultural soils:

- Direct Emissions from Commercial Synthetic Fertilizer Application;
- Direct Emissions from Cultivation of Nitrogen-Fixing Crops;
- Direct Emissions from the Incorporation of Crop Residues;
- Direct Emissions from Daily Spread Operations and Direct Deposition; and
- Indirect Emissions from Agricultural Soils.

### *Direct Emissions from Commercial Synthetic Fertilizer Application*[1]

**Historical activity data**: FAO publishes historical commercial synthetic fertilizer consumption data for most developed countries (FAO, 1998a). The following assumptions were made for countries without data:

- Luxembourg: FAO reported fertilizer consumption statistics for Belgium and Luxembourg together. The $N_2O$ emissions from agricultural soils, as reported in each country's National Communications, were used as a proxy to divide consumption among the two countries. This resulted in 98 percent of the fertilizer consumption attributed to Belgium and 2 percent to Luxembourg.
- Croatia, Estonia, Latvia, Lithuania, Russia, Ukraine: The data for these countries were aggregated in 1990, as they were part of the Former Soviet Union. Disaggregated 1992 data replaced the data used for 1990.
- Czech Republic and Slovakia: In 1990, the Czech Republic and Slovakia were part of Czechoslovakia, and the fertilizer consumption data was reported jointly. The disaggregated 1995 data served as a model to determine 1990 values for the Czech Republic.
- Liechtenstein: No data are available.

**Projected activity data**: Using the 1995 and 2000 regional fertilizer consumption data from FAO, EPA determined the 1995-2000 growth rate for each region (FAO, 1998d). These regional growth rates were used to linearly extrapolate fertilizer consumption to 2010.

**Historical and Projected Emissions**: As recommended in the *Revised 1996 IPCC Guidelines*, the assumption for this analysis was that 1.25 percent of all nitrogen from fertilizer consumption, excluding the 10 percent of nitrogen in fertilizer that volatilizes as $NO_x$ and $NH_3$, is directly emitted as $N_2O$ (IPCC, 1997). Therefore, emissions were calculated as follows:

[1] Organic fertilizer application was not included due to a lack of available data.

$$N_2O = [F_{country} - (F_{country} * 10\%)] * 1.25\%$$

Where,

$F_{country}$ is the nitrogen from fertilizer consumption for the specified year and country.

### *Direct Emissions from Cultivation of Nitrogen-Fixing Crops*[2]

**Historical activity data**: The FAOSTAT database provided historical crop production statistics for soybeans and pulses (FAO, 1998b).

*Soybeans*. In 1995, eighteen developed countries produced soybeans. For 1990, FAO reported data for the Czech Republic and Slovakia together. Similarly, FAO only provided data for the former Soviet Republics as a whole. In all cases, the disaggregated 1993 data served as a model to disaggregate the combined 1990 data.

*Total Pulses*. In 1995, 32 developed countries produced pulses.

- Croatia, Czech Republic, Slovakia, Estonia, Latvia, Lithuania, Russia, and Ukraine: Data for 1992 was used to determine production shares in 1990.
- Luxembourg: The Belgian pulse production data included Luxembourg. To determine percentage allocations, EPA used $N_2O$ emissions from all agricultural sources, as reported in their individual National Communications, as a proxy (98 percent Belgium; 2 percent Luxembourg).

**Projected activity data**:

*Soybeans*. FAPRI reported projected soybean production data for 2000 and 2005 for regions and a limited number of countries, and at the global level (FAPRI, 1997). For countries without production projections, EPA used the regional growth rates. The growth rates were also used from 2005 to 2010.

*Total Pulses.* In the absence of pulse production projections, EPA assumed that pulse production grew at the same rate as soybean production. For countries growing pulses only, EPA applied the regional soybean production growth rates (Exhibit F-9).

**Historical and projected emissions**: The crop production statistics account for only the mass of the crop product rather than the entire plant. The data were expanded to total crop mass, in units of dry matter, by applying residue to crop mass ratios and dry matter fractions for residue (Strehler and Stutzle, 1987). To convert to units of nitrogen, EPA applied the IPCC recommendation that 3 percent of the total crop dry mass for all crops was nitrogen (IPCC, 1997).

### *Direct Emissions from the Incorporation of Crop Residues*

**Historical activity data**: Residues from corn, wheat, beans and pulses are typically incorporated into soils. Bean and pulse production were estimated in the previous section. FAO provided historical production data for corn and wheat for most countries (FAO, 1998b). EPA made adjustments for several countries' corn and wheat production:

- Luxembourg: The Belgian production data included Luxembourg. To determine percentage allocations, EPA used $N_2O$ emissions from all agricultural sources, as reported in their individual National Communications, as a proxy (98 percent Belgium; 2 percent Luxembourg).
- Czech Republic and Slovakia: FAO provided the individual country's production statistics for 1995, which were used to determine relative shares that EPA applied to the 1990 data reported for Czechoslovakia.

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[2] Alfalfa was not included in the analysis due to lack of data.

- Latvia, Lithuania, Russian Federation, Slovenia, Ukraine: The data reported for 1995 filled in the gap for 1990.
- Croatia, Iceland, Liechtenstein: No data were available.

**Historical emissions**: As recommended in the *Revised 1996 IPCC Guidelines,* EPA assumed that 55 percent of all crop residues are returned to the soils (IPCC, 1997). Crop residue biomass, in dry matter mass units, was calculated by applying residue to crop mass ratios and dry matter fractions for residue (Strehler and Stutzle, 1987). For beans and pulses, an estimated 3 percent of the total crop residue was nitrogen (IPCC, 1997). For wheat and corn, Barnard and Kristoferson (1985) report nitrogen contents. Using the IPCC default, 1.25 percent of all nitrogen from incorporated residues is directly emitted as $N_2O$.

**Projected Emissions**: Nitrous oxide emissions from incorporation of crop residue grew in proportion to production. Using the growth rates from FAPRI and assuming that the growth-rate from 2000-2005 remains constant through 2010, EPA projected emissions to 2010.

### *Direct Emissions from Daily Spread Operations and Direct Deposition*

Direct nitrous oxide emissions result from livestock wastes that do not enter the commercial fertilizer market but are instead "applied" to soils, either through daily spread operations or direct deposition on pastures and paddocks by grazing livestock.

**Historical activity data**: FAO reported historical animal population data for most countries (FAO, 1998c), with the following exceptions:

- Luxembourg: The Belgian population data included Luxembourg. To determine percentage allocations, EPA used $N_2O$ emissions from all agricultural sources, as reported in their individual National Communications, as a proxy (98 percent Belgium; 2 percent Luxembourg).
- Croatia, Estonia, Latvia, Lithuania, Russia, and Ukraine: Data for 1990 are reported for the Former Soviet Union. EPA allocated the 1990 livestock populations in the Former Soviet Union among Estonia, Lithuania, Russia, and Ukraine based upon each country's relative share in 1995. The 1995 data filled the gap for 1990 for Croatia.
- Czech Republic and Slovakia: In 1990, production statistics were reported for Czechoslovakia. Each country's 1995 production statistics were used to determine relative shares.
- Liechtenstein: No data were available.

**Historical emissions**: EPA divided total livestock nitrogen excretion, calculated for each animal type, among animal waste management systems using IPCC default assumptions. EPA applied the IPCC default that 20 percent of total annual excreted livestock nitrogen was volatilized (IPCC, 1997). Finally, the remainder of the excreted livestock nitrogen was multiplied by IPCC default emission factors specific to the animal waste management system.

**Projected Emissions**: Animal population forecasts were not available. EPA assumed that emissions would grow at the same rate as methane emissions from manure, as reported in the National Communication.

### *Indirect Emissions from Agricultural Soils*

This component accounts for $N_2O$ that is emitted indirectly from nitrogen applied as fertilizer and excreted by livestock. Nitrous oxide enters the atmosphere indirectly through one of two pathways: 1) leaching and runoff of nitrogen from fertilizer applied to agricultural fields and from livestock excretion; and 2) atmospheric deposition of $NO_x$ and $NH_3$ (originating from fertilizer use and livestock excretion of nitrogen). Emissions from each of these pathways are described below.

- **Emissions from fertilizer consumption**: Nitrogen consumption data and forecasts, determined for the fertilizer application section, were used to calculate indirect $N_2O$ emissions. The IPCC recommends that 10 percent of the applied synthetic fertilizer nitrogen volatilizes to $NH_3$ and $NO_x$, and 1 percent of the total volatilized nitrogen is emitted as $N_2O$ (IPCC, 1997). To estimate emissions from leaching and run-off, EPA uses the IPCC recommendation that 30 percent of the total nitrogen applied is lost to leaching and surface runoff, and 2.5 percent of this lost nitrogen is emitted as $N_2O$ (IPCC, 1997).
- **Emissions from livestock excretion**: Historical estimates of total livestock excretion, as calculated under the nitrous oxide emissions from livestock manure section, were used to calculate the historical emissions. According to the IPCC, 20 percent of nitrogen in livestock excretion volatilizes to $NH_3$ and $NO_x$, and one percent of the total volatilized nitrogen is emitted as $N_2O$ (IPCC, 1997). To estimate emissions from leaching and run-off, EPA used the IPCC recommendation that 30 percent of the total nitrogen applied is lost to leaching and surface runoff, and 2.5 percent of this lost nitrogen is emitted as $N_2O$ (IPCC, 1997). Livestock excretion projections for 2000, 2005, and 2010 were not available. Therefore, the indirect emissions from animal waste were expected to grow at the same rate as direct emissions from animal waste, as determined in the methane emissions from livestock manure section.

# APPENDIX H: Methodology and Adjustments to Approaches Used to Estimate Nitrous Oxide Emissions from Mobile Sources

This appendix presents methodology and country-specific approaches that EPA used to estimate $N_2O$ emissions from mobile sources. To estimate emissions of $N_2O$ from mobile sources, EPA estimated fuel consumption for each country, assigned fuel consumption to different categories of vehicles, and then applied the *Revised 1996 IPCC Guidelines* emission factors by vehicle type. The data sources and methodology are described below.

### *Historical Fossil Fuel Consumption Data*

IEA (IEA, 1997b) reported transport-related fuel consumption for road transport and non-road transport for all countries for 1995. The data are further divided by fuel-type, including gasoline and diesel for road vehicles, and coal, oil, natural gas, and aviation fuel for other forms of transport.

### *Road Fleet Composition*

The IPCC emission factors are technology-specific, consequently, EPA needed to assign the fuel consumption data to different vehicles on the basis of the fleet composition in each country, and also the distance traveled by each vehicle type. For road fleet composition, EPA divided each country's road fleet into gasoline and diesel vehicles. The category of gasoline vehicles includes passenger cars, trucks, or motorcycles, and diesel vehicles include passenger cars and trucks. For 1990 and 1995, EPA used the American Automobile Manufacturers Association total vehicle registration data that is assembled for each country (AAMA, 1998). To estimate the size of the gas and diesel vehicle fleets, total vehicle registrations for each country were disaggregated according to the share of gasoline versus diesel car production in major car producing countries (AAMA, 1998). Japan's production breakdown was applied to Japan, Australia and New Zealand. United Kingdom's production breakdown was applied to all of Western Europe, Eastern Europe and Russia. Canada's fleet characteristics were based on default national values (EPA, 1993b). Motorcycle population percentages were applied across all countries similarly, using the EPA assumption that motorcycles are 0.5 percent of the passenger car population. (EPA, 1993b).

### *Fuel Consumption by Type*

Using the fleet composition for each country as determined from the steps above, EPA estimated how much of each fuel type was consumed by each road transport category and sub-category. To weight the shares of gasoline and diesel consumed by heavy-duty vehicles and light-duty vehicles, EPA used the US Federal Highway Administration (FWHA) ratio of vehicle miles traveled by each vehicle type. The FWHA estimated that heavy-duty vehicles travel 2.3 miles for each mile traveled by a light-duty vehicle.

### *Projected Activity Data*

EPA projected fuel consumption by fuel type and transport mode.

- Growth Rates: For both road and non-road transport modes, growth rates for fuel consumption for each country (based on regional estimates) were taken from Schafer and Victor (1997). For road transport, average annual growth rates from Schafer and Victor are based upon projected increases in personal income in industrialized, transitioning, and developing countries, using the historical precedent that rising income leads to increased demand for mobility. Aircraft use was assumed to grow at the same rate as that used for road transport, based upon the idea that personal income growth affects the use of this travel mode in a manner that is similar to road transportation.

- These growth rates were applied to 1995 baseline consumption estimates to get 2000, 2005, and 2010 consumption by fuel type and transport mode.

### *Emissions Factors*

For non-road transport, Tier 1 IPCC emission factors were assembled by transport mode. For road transport, emissions factors were determined as follows:

- Technology Usage: Since $N_2O$ emission factors are highly dependent on pollution-abatement technology, EPA needed to estimate the types of catalytic converters used in each country's vehicle fleet. Six types of model fleets were developed to account for different patterns of catalyst usage. The technology options considered included early three-way catalysts, advanced three-way catalysts, oxidation catalysts, non-catalysts, uncontrolled and low-emitting vehicles (LEV).

- Projected Technology Use: Countries were divided into these technology groups based on type of technology currently in place, type of technology planned for or anticipated, region of the world, and the relative availability of leaded gasoline. This grouping was supported by information in *Motor Vehicle Emission Regulations and Fuel Specifications in Europe and the United States: 1995 Update* (CONCAWE, 1995). Countries with similar vehicle emissions legislation and available fuel types were grouped together.

- Emissions factors by technology, transport mode, and fuel type: IPCC emissions factors by technology, transport mode, and fuel type were assembled and used for nearly every country except Australia, Canada, Japan, New Zealand and Sweden (IPCC, 1996). These countries have advanced emissions control programs similar to the U.S., and therefore, the most recent US emissions factors were used (EPA, 1999b).

- Technology adjustment: For each country, the emissions factors were weighted by the technology composition assumed for the appropriate model fleet for each year.

### *Historical and Projected Emissions*

For non-road transport, fuel consumption over time was multiplied by the IPCC emissions factors assembled by transport mode and fuel type. For road transport, the technology-adjusted emissions factors were multiplied by the fuel consumption projections by fuel type and transport mode for each year.

# APPENDIX I: U.S. EPA Vintaging Model Framework

## I.1 Vintaging Model Overview

The Vintaging Model estimates emissions from six industrial sectors: refrigeration and air-conditioning, foams, aerosols, solvents, fire extinguishing, and sterilization. Within these sectors, over 40 independently modeled end-uses exist. The model requires information on the market growth for each of the end-uses, as well as a history of the market transition from ozone depleting substances (ODS) to alternatives. As ODS are phased out, a percentage of the market share originally filled by the ODS is allocated to each of its substitutes.

The model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, is a "bottom-up" model. It models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment. The Vintaging Model makes use of this market information to build an inventory of the in-use stocks of the equipment in each of the end-uses. Emissions are estimated by applying annual leak rates, service emission rates, and disposal emission rates to each population of equipment. By aggregating the emission and consumption output from the different end-uses, the model produces estimates of total annual use and emissions of each chemical. For the purpose of projecting the use and emissions of chemicals into the future, the available information about probable evolutions of the end-use market is incorporated into the model.

The following sections discuss the forms of the emission estimating equations used in the Vintaging Model for each broad end-use category. These equations are applied separately for each chemical used within each of approximately 40 different end-uses. In the majority of these end-uses, more than one ODS substitute chemical is used.

In general, the modeled emissions are a function of the amount of chemical consumed in each end-use market. Estimates of the consumption of ODS alternatives can be inferred by extrapolating forward in time from the amount of regulated ODS used in the early 1990s. Using data gleaned from a variety of sources, assessments are made regarding which alternatives will likely be used, and what fraction of the ODS market in each end-use will be captured by that alternative. By combining this information with estimates of the total end-use market growth, a consumption value is estimated for each chemical used within each end-use.

## I.2 Emissions Equations

### I.2.1 Refrigeration and Air-Conditioning

For refrigeration and air conditioning products, emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. Equation 1 calculates the lifetime emissions from leakage and service, and Equation 2 calculates the emissions resulting from disposal of the equipment. These lifetime emissions and disposal emissions are added to calculate the total emissions from refrigeration and air-conditioning (Equation 3). As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates.

Lifetime emissions from any piece of equipment include both the amount of chemical leaked during equipment operation and during service recharges. Emissions from leakage and servicing can be expressed as follows:

$$Es_j = (l_a + l_s) \_ \_ Qc_{j-i+1} \quad for\ i=1\_k \qquad \text{Eq. 1}$$

Where:

$Es_j$ = *Emissions from Equipment Serviced.* Emissions in year $j$ from normal leakage and servicing (recharging) of equipment.

$l_a$ = *Annual Leak Rate.* Average annual leak rate during normal equipment operation (expressed as a percentage of total chemical charge).

$l_s$ = *Service Leak Rate.* Average leakage during equipment servicing (expressed as a percentage of total chemical charge).

$Qc_j$ = *Quantity of Chemical in New Equipment.* Total amount of a specific chemical used to charge new equipment in a given year, $j$, by weight.

$k$ = *Lifetime*. The average lifetime of the equipment.

The disposal emission equations assume that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment fleet and the proportion of chemical released at disposal:

$$Ed_j = Qc_{j-k+1} \_ [1 - (rm \_ rc)] \quad \text{Eq. 2}$$

Where:

$Ed_j$ = *Emissions from Equipment Disposed*. Emissions in year $j$ from the disposal of equipment.

$Qc_j$ = *Quantity of Chemical in New Equipment.* Total amount of a specific chemical used to charge new equipment in a given year, $j$, by weight.

$rm$ = *Chemical Remaining*. Amount of chemical remaining in equipment at the time of disposal (expressed as a percentage of total chemical charge)

$rc$ = *Chemical Recovery Rate*. Amount of chemical that is recovered just prior to disposal (expressed as a percentage of chemical remaining at disposal *(rm)*)

$k$ = *Lifetime*. The average lifetime of the equipment.

$$E_j = Es_j + Ed_j \quad \text{Eq. 3}$$

Where:

$E_j$ = *Total Emissions*. Emissions from refrigeration and air conditioning equipment in year $j$.

$Es_j$ = *Emissions from Equipment Serviced.* Emissions in year $j$ from normal leakage and servicing (recharging) of equipment.

$Ed_j$ = *Emissions from Equipment Disposed*. Emissions in year $j$ from the disposal of equipment.

## I.2.2 Aerosols

All HFCs and PFCs used in aerosols are assumed to be emitted in the year of manufacture. Since there is currently no aerosol recycling, it is assumed that all of the annual production of aerosol propellants is released to the atmosphere. Equation 4 describes the emissions from the aerosols sector.

$$E_j = Qc_j \quad \text{Eq. 4}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year *j* from use in aerosol products, by weight.

$Qc_j$ = *Quantity of Chemical*. Total quantity of a specific chemical contained in aerosol products sold in year *j*, by weight.

### I.2.3 Solvents

Generally, most solvents are assumed to remain in the liquid phase and are not emitted as gas. Thus, emissions are considered "incomplete," and are a fixed percentage of the amount of solvent consumed in a year. The remainder of the consumed solvent is assumed to be reused or disposed without being released to the atmosphere. Equation 5 calculates emissions from solvent applications.

$$E_j = l \_ Qc_j \qquad \text{Eq. 5}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year *j* from use in solvent applications, by weight.

$l$ = *Percent Leakage*. The percentage of the total chemical that is leaked to the atmosphere.

$Qc_j$ = *Quantity of Chemical*. Total quantity of a specific chemical sold for use in solvent applications in the year j, by weight.

### I.2.4 Fire Extinguishing

Total emissions from fire extinguishing are assumed, in aggregate, to equal a percentage of the total quantity of chemical in operation at a given time. For modeling purposes, it is assumed that fire extinguishing equipment leaks at a constant rate for an average equipment lifetime. This percentage varies for streaming (Equation 6) and flooding (Equation 7) equipment.

#### *Streaming Equipment*

$$E_j = l \_ \_\_ Qc_{j-i+1} \quad for\ i=1\_k \qquad \text{Eq. 6}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year *j* for streaming fire extinguishing equipment, by weight.

$l$ = *Percent Leakage*. The percentage of the total chemical in operation that is leaked to the atmosphere.

$Qc_j$ = *Quantity of Chemical.* Total amount of a specific chemical used in new streaming fire extinguishing equipment in a given year, *j*, by weight.

$k$ = *Lifetime.* The average lifetime of the equipment.

#### *Flooding Equipment*

$$E_j = l \_ \_\_ Qc_{j-i+1} \quad for\ i=1\_k \qquad \text{Eq. 7}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year $j$ for streaming fire extinguishing equipment, by weight.

$l$ = *Percent Leakage*. The percentage of the total chemical in operation that is leaked to the atmosphere.

$Qc_j$ = *Quantity of Chemical.* Total amount of a specific chemical used in new streaming fire extinguishing equipment in a given year, $j$, by weight.

$k$ = *Lifetime.* The average lifetime of the equipment.

## I.2.5 Foam Blowing

Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100 percent emissive in the year of manufacture. Closed cell foams are assumed to emit a portion of their total HFC or PFC content upon manufacture, a portion at a constant rate over the lifetime of the foam, and a portion at disposal.

### Open-Cell Foam

$$E_j = Qc_j \qquad \text{Eq. 8}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year $j$ used for open-cell foam blowing, by weight.

$Qc_j$ = *Quantity of Chemical.* Total amount of a specific chemical used for open-cell foam blowing in year $j$, by weight.

### Closed-Cell Foam

$$E_j = \_\_ (ef_i \_ Qc_{j-i+1}) \quad \textit{for } i=1\_k \qquad \text{Eq. 9}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year $j$ for closed-cell foam blowing, by weight.

$ef_i$ = *Emission Factor.* Percent of foam's original charge emitted in each year (1 _$k$). This emission factor is generally variable, including a rate for manufacturing emissions (occurs in the first year of foam life), annual emissions (every year throughout the foam lifetime), and disposal emissions (occurs during the final year of foam life).

$Qc_j$ = *Quantity of Chemical.* Total amount of a specific chemical used in closed-cell foams in year $j$.

$k$ = *Lifetime*. Average lifetime of foam product.

## I.2.6 Sterilization

For sterilization applications, all chemicals that are used in the equipment in any given year are assumed to be emitted in that year, as shown in Equation 10.

$$E_j = Qc_j \qquad \text{Eq. 10}$$

Where:

$E_j$ = *Emissions*. Total emissions of a specific chemical in year $j$ from use in sterilization equipment, by weight.

$Qc_j$ = *Quantity of Chemical.* Total quantity of a specific chemical used in sterilization equipment in year $j$, by weight.

## I.3 Model Output

By repeating these calculations from the years 1985-2030, the Vintaging Model creates annual profiles of use and emissions for ODS and ODS substitutes. The results can be shown for each year in two ways: 1) on a chemical-by-chemical basis, summed across the end-uses, or 2) on an end-use basis. Values for use and emissions are calculated both in metric tons and in million metric tons of carbon dioxide equivalents ($MMTCO_2$). The conversion of metric tons of chemical to $MMTCO_2$ is accomplished through a linear scaling of tonnage by the global warming potential (GWP) of each chemical. The GWP values that are used in the model correspond to those published in the IPCC Second Assessment Report.