

METHODS FOR ESTIMATING NON-ENERGY GREENHOUSE GAS EMISSIONS FROM INDUSTRIAL PROCESSES

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INTRODUCTION

The EIIP guidelines are designed to describe emission estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to facilitate preparation of inventories at the state level. This chapter presents the methodology for estimating greenhouse gases from industrial processes. The methodology presented in this chapter has been revised to reflect new activity data, emission factors, and methods pertaining to this source category. Where possible, the methodology has been updated to be consistent with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*.

Section 2 of this chapter contains a general description of this source category. Section 3 provides a listing of the steps involved in estimating greenhouse gases from the industrial processes. Section 4 presents the preferred estimation method. Section 5 provides an alternative estimation method for sulfur hexafluoride emissions from magnesium production and processing. A summary of uncertainty for sources covered in this chapter is provided in Section 6. References used in developing this chapter are identified in Section 7.

In addition to these guidelines, there are a series of user friendly spreadsheet tools available to assist in the development of emission inventories at the state level. Please consult the Industrial Processes Module of the State Inventory Tool¹ to calculate emissions from this source category using the preferred emission estimation method.

¹ Note: The spreadsheet tool may have a different order of calculations, and may not show all calculations to the user.

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Emissions are often produced as a by-product of various non-energy related industrial activities. Emissions of carbon dioxide (CO₂) from fossil fuel combustion to produce energy for industrial processes are described in Chapter 1 of this volume; other emissions that result from industrial processes are described here. In some industrial sectors, raw materials are chemically transformed from one state to another. This transformation often results in the release of greenhouse gases such as CO₂, nitrous oxide, hydrofluorocarbons, perfluorinated carbons, and sulfur hexafluoride. The production processes addressed in this section are cement production, lime manufacture, limestone and dolomite use (e.g., for iron and steel making, flue gas desulfurization, and glass manufacturing), soda ash manufacture and use, nitric acid production, adipic acid production, aluminum production, HCFC-22 production, the use of substitutes for ozone-depleting substances, semiconductor manufacture, sulfur hexafluoride use in electrical power systems, and magnesium production and processing.²

Greenhouse gases are emitted from several additional industrial processes not covered in this section due in part to a lack of sufficient state data on non-energy uses of fossil fuels for these industrial processes. These sources include:

- Iron and Steel Production (CO₂ and CH₄);
- Ammonia Manufacture and Urea Application (CO₂, CH₄, N₂O, and NMVOCs);
- Aluminum Production (CO₂);
- Titanium Dioxide Production (CO₂);
- Phosphoric Acid Production (CO₂);
- CO₂ Consumption (CO₂);

² CO₂ is also emitted during combustion of biomass fuels (e.g., wood, ethanol, charcoal, bagasse, agricultural wastes, and vegetal fuels such as soybean-based diesel fuel and “black liquor” from wood – a fuel used in paper mills). In the United States, biomass fuels are generally grown on a sustainable basis. Under the greenhouse gas emission estimation guidelines prepared by the Intergovernmental Panel on Climate Change (IPCC), CO₂ emissions from biomass fuels grown sustainably are not counted. Therefore, the method described in this chapter does not address biomass fuels as a source of greenhouse gases. For cases where biomass fuels are not grown sustainably, the greenhouse gas impact should be captured as a land use change; the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD 1997) provides information on how to do so.

- Ferroalloy Production (CO₂);
- Petrochemical Production (CH₄); and
- Silicon Carbide Production (CH₄).

The CO₂ emissions from the above CO₂ sources (other than CO₂ Consumption and Phosphoric Acid Production) result from the non-energy use of fossil fuels. These non-energy emissions of CO₂ are calculated on a national basis, subtracted from the national estimate of CO₂ emissions from fossil fuel combustion, and reported separately in the Industrial Processes chapter of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. However, due to data limitations at the state level, emissions associated with the non-energy uses of fossil fuels at the state level are contained in estimates of CO₂ emissions from fossil fuel combustion in Chapter 1. If state level data on non-energy uses of fuels become available, future guidance updates will include a methodology for removing these emissions from the calculation of CO₂ emissions from fossil fuel combustion. Similarly, future updates to the guidance will reflect improvements in data availability and emission process understanding for any additional industrial processes.

OVERVIEW OF AVAILABLE METHODS

In general, the basic method for estimating emissions from industrial production and consumption processes is to gather information on the various activity levels required for the calculation (i.e., production and/or consumption data) and then to multiply them by their respective emission factors.

$$\text{Amount Emitted} = \text{Activity Level} \times \text{Emission Factor}$$

In some instances, emission control or recovery technologies have been implemented at facilities, which will reduce the amount of gas actually emitted. These avoided emissions should be accounted for by subtracting from emission totals the amount recovered or avoided.

The emission methodologies presented here generally follow the methods developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997). For some sources, the IPCC has not provided specific details (e.g., default emission factors) to calculate emissions, but recommends a basic approach that can be followed for each source category (i.e., multiplying production data for each process by an emission factor per unit of production). The methods provided to estimate emissions in this section generally follow this basic approach. The methods provided here are also consistent with the methods used in preparing the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (U.S. EPA 2004). In some cases, estimation methodologies developed by states have been incorporated as well.

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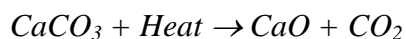
PREFERRED METHOD FOR ESTIMATING EMISSIONS

This section presents the preferred method for estimating greenhouse gas emissions from the following sources;

- Cement Production (CO₂);
- Lime Manufacture (CO₂);
- Limestone and Dolomite Use (CO₂);
- Soda Ash Manufacture and Consumption (CO₂);
- Nitric Acid Production (N₂O);
- Adipic Acid Production (N₂O);
- Aluminum Production (Perfluorocarbons – CF₄ and C₂F₆);
- HCFC-22 Production (HFC-23);
- Consumption of Substitutes for Ozone-Depleting Substances (HFCs and PFCs);
- Semiconductor Manufacturer (PFCs, HFCs, and SF₆);
- Electric Power Transmission and Distribution (SF₆); and
- Magnesium Production and Processing (SF₆).

4.1 CARBON DIOXIDE FROM CEMENT PRODUCTION

Carbon dioxide (CO₂) emitted during the cement production process represents the most significant non-energy source of industrial CO₂ emissions. Cement is produced in most states (and in Puerto Rico) and is used in all of them. CO₂ is created when calcium carbonate (CaCO₃) is heated in a cement kiln to form lime (calcium oxide or CaO) and CO₂. This process is known as *calcination* or *calcining*:



The lime is then combined with silica-containing materials (provided to the kiln as clays or shales) to form dicalcium or tricalcium silicates, two of the four major compounds in cement clinker, an intermediate product from which finished Portland and masonry cement are made (Griffin 1987), while the CO₂ is released into the atmosphere.

To estimate emissions from this source, five steps must be performed: (1) obtain the required data for the state; (2) estimate CO₂ emissions from clinker production; (3) estimate CO₂ emissions from masonry cement; (4) sum the results of Steps 2 and 3; and (5) convert units to metric tons of carbon equivalent (MTCE).

Step (1): Obtain Required Data

- **Required Data.** The data needed to calculate state CO₂ emissions from cement production are (1) annual clinker production and (2) annual masonry cement production (measured in metric tons). Note that for illustrative purposes, national data are presented in the examples; a state should follow the same approach using state data.
- **Data Sources.** In-state sources should be consulted first. Additionally, cement production by state can be found in *Cement: Annual Report*, published by the U.S. Geological Survey (USGS).³

Example	According to the USGS <i>Cement Minerals Yearbook: 2000</i> (USGS 2001e), total U.S. clinker production in 2000 was 79,417,000 metric tons , and total masonry cement production was 4,275,000 metric tons .
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Step (2): Estimate Carbon Dioxide Emissions from Clinker Production

CO₂ emissions are estimated based on an emission factor, in metric tons of CO₂ released per metric ton of clinker (CaO) produced. The emission factor recommended for use by states is the product of the fraction of lime used in the cement clinker, assumed to be 64.6 percent (IPCC 2000), and a constant reflecting the mass of CO₂ released per unit of lime. The emission factor was calculated as follows:

$$\begin{aligned}
 EF_{clinker} &= \text{fraction CaO} \times \left(\frac{44.01 \text{ g/mole CO}_2}{56.08 \text{ g/mole CaO}} \right) \\
 &= 0.646 \times 0.785 \\
 &= 0.507
 \end{aligned}$$

- Multiply clinker production by an emission factor of 0.507 metric tons CO₂/metric ton of clinker produced to yield the CO₂ emissions from clinker production.

$$\text{CO}_2 \text{ Emissions from Clinker Production (metric tons)} = \text{Total Clinker Production (metric tons)} \times 0.507 \text{ (metric tons CO}_2\text{/metric ton of clinker produced)}$$

After the clinker production process is completed, the kiln typically contains some remnants of the precursor material known as cement kiln dust (CKD). CKD is composed of a variety of non-calcinated, partially calcinated, and fully calcinated materials. The calcinated portion

³ The functions of the Department of Interior's Bureau of Mines have been taken over by the Department of Interior's USGS. Many of the data sources listed in this workbook were published by the Bureau of Mines; however, current issues of the same publications are available from USGS in Arlington, VA.

of the CKD is responsible for additional CO₂ emissions that are not included in the above calculation. According to recommendations from the Intergovernmental Panel on Climate Change (IPPC), the additional CKD CO₂ emission quantity is best estimated as 2 percent of the CO₂ emissions calculated from total clinker production (IPCC 2000).

- Multiply the CO₂ emissions from clinker production by 2 percent to yield the total CO₂ emissions attributable to CKD.

$$CO_2 \text{ Emissions from CKD (metric tons)} = CO_2 \text{ Emissions from Clinker Production (metric tons)} \times 0.02$$

- Add the clinker production CO₂ emissions and the CKD CO₂ emissions to yield the total CO₂ emissions from the entire clinker production process.

$$\text{Total } CO_2 \text{ Emissions from Clinker Production Process (metric tons)} = CO_2 \text{ Emissions from Clinker Production (metric tons)} + CO_2 \text{ Emissions from CKD (metric tons)}$$

Example: To calculate total CO₂ emissions from U.S. clinker production in 2000, perform the following calculations:

Clinker: 79,417,000 metric tons x 0.507 metric tons CO₂/metric ton cement = 40,264,419 metric tons CO₂ (clinker)

CKD: 40,264,419 metric tons CO₂ x 0.02 = 805,288 metric tons CO₂ (CKD)

Total: 40,264,419 metric tons CO₂ (clinker) + 805,288 tons CO₂ (CKD) = **41,069,707 metric tons CO₂**

Step (3): Estimate Carbon Dioxide Emissions from Masonry Cement

Masonry cement requires additional lime, over and above the lime used in the clinker. During the production of masonry cement, non-plasticizer additives such as lime, slag, and shale are added to the cement, increasing its weight by 5 percent. Lime accounts for approximately 60 percent of the added substances. An emission factor for this additional lime can be calculated as follows:

$$\begin{aligned} EF_{mas} &= \left(\frac{\text{fraction of weight added}}{1 + \text{fraction of weight added}} \right) \times \left(\frac{\text{fraction lime in added substance}}{1} \right) \times \left(\frac{44.01 \text{ g/mole } CO_2}{56.08 \text{ g/mole } CaO} \right) \\ &= \left(\frac{0.05}{1 + 0.05} \right) \times 0.60 \times 0.785 \\ &= 0.0224 \end{aligned}$$

Thus, 0.0224 metric tons of additional CO₂ is emitted for every metric ton of masonry cement produced.

- Multiply masonry cement production by an emission factor of 0.0224 metric tons of CO₂/metric ton of masonry cement produced to yield CO₂ emissions attributable to the production of masonry cement.

Total CO₂ Emissions from Masonry Cement Production (metric tons) = Total Masonry Cement Production (metric tons) x 0.0224 (metric tons CO₂/metric ton of masonry cement produced)

Example: To calculate total CO₂ emissions from masonry cement production in 2000, perform the following calculation:

4,275,000 metric tons x 0.0224 metric tons CO₂/metric ton masonry cement =
95,760 metric tons CO₂

Step (4): Sum the Results of Steps 2 and 3

- The total amount of CO₂ emissions attributable to cement production is the sum of the emissions produced by the clinker production process and the emissions produced by the production of masonry cement.

Total CO₂ Emissions from Cement Production (metric tons) = Total CO₂ Emissions from Clinker Production Process (metric tons) + Total CO₂ Emissions from Masonry Cement Production (metric tons)

Example: To calculate total CO₂ emissions from cement production in 2000, perform the following calculation:

41,069,707 metric tons CO₂ (clinker) + 95,760 metric tons CO₂ (masonry cement) =
41,165,467 metric tons CO₂

Some amount of CO₂ is reabsorbed when the cement is used for construction. As cement reacts with water, alkaline substances such as calcium hydroxide are formed. During the curing process, these compounds may react with CO₂ in the atmosphere to create CaCO₃. This reaction only occurs in roughly the outer 0.2 inches of surface area. Since the amount of CO₂ reabsorbed is thought to be minimal, we have not included a methodology for estimating this amount.

Step (5): Convert Units to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the Global Warming Potential (GWP) of the emitted gas. In this case, CO₂ emissions are multiplied by a GWP of 1, and then converted to carbon (C) equivalent by using the molecular ratio of C to CO₂, or 12/44.

Total Emissions from Cement Production (MTCE) = Total CO₂ Emissions from Cement Production (metric tons) x 1 x 12/44

Example: To calculate total emissions from cement production in 2000 in MTCE, perform the following calculation:

$$41,165,461 \text{ metric tons CO}_2 \times 1 \times 12/44 = \mathbf{11,226,946 \text{ MTCE}}$$

4.2 CARBON DIOXIDE FROM LIME MANUFACTURE

Lime is a manufactured product with many chemical, industrial, and environmental uses. In 1990, lime ranked fifth in total production of all chemicals in the United States. Its major uses are in steel making, construction, pulp and paper manufacturing, and water and sewage treatment. Lime is manufactured by heating limestone (mostly CaCO_3) in a kiln, creating CaO and CO_2 . The CO_2 is driven off as a gas and is normally emitted to the atmosphere, leaving behind a product known as quicklime. Some of this quicklime undergoes slaking, which produces hydrated lime. The consumption of lime for certain uses, specifically the production of precipitated CaCO_3 and refined sugar, results in the reabsorption of some airborne CO_2 .

The method provided below requires that states obtain data on the manufacture of various types of lime. If these data are unavailable, states may develop a rough estimate of emissions from this source by apportioning national emissions from lime manufacture (as reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*) to the state using the ratio of state to national lime production.

To estimate emissions from this source, seven steps must be performed: (1) obtain the required data; (2) correct for the moisture in hydrated lime; (3) sum the dolomitic and high-calcium lime types; (4) estimate gross CO_2 emissions from lime manufacture; (5) estimate carbon dioxide reabsorption from sugar refining and precipitated CaCO_3 production; (6) calculate net CO_2 emissions; and (7) convert units to metric tons of carbon equivalent.

Step (1): Obtain Required Data

- **Required Data.** The data needed to calculate CO_2 emissions from the manufacture of lime (chemical formula: CaO) from limestone (CaCO_3) are (1) annual high-calcium quicklime and hydrated lime production in metric tons, (2) annual dolomitic quicklime and hydrated lime production in metric tons, (3) annual dead-burned dolomite production, and (4) the amount used in applications resulting in CO_2 recovery (precipitated calcium carbonate and sugar refining). Note that for illustrative purposes, national data are presented in the examples; a state should follow the same approach using state data.
- **Data Sources.** In-state sources such as the state's environmental agency should be consulted first. Lime production data by state is also available in the *Lime: Minerals Yearbook* (USGS 2001a); however, this data source does not break down lime production by type of lime prior to 1997. In order to compensate for this problem, states should allocate total production for 1990 to 1996 based on the 1997 distribution. Additionally, this source does not distinguish between hydrated and quicklime. If in-state data are not available, an alternate method is discussed below.

Example: According to the USGS (2001a), total U.S. lime production in 2000 was approximately 19,600,000 metric tons and 2,067,000 metric tons were used in sugar refining and precipitated CaCO_3 production. (Note for this table only: Data taken from the USGS are rounded and therefore, may not sum to the totals shown.)

Total lime production	19,600,000
High-calcium quicklime	14,300,000
Dolomitic quicklime	3,000,000
High-calcium hydrated lime	1,550,000
Dolomitic hydrated lime	421,000
Dead-burned dolomite	200,000
Total uses resulting in recovery	2,067,000
Precipitated CaCO_3	1,200,000
Sugar refining	867,000

Step (2): Correct for Moisture in Hydrated Lime

To correct for the water content of hydrated lime, production total is multiplied by the fraction that is not water. The Intergovernmental Panel on Climate Change (IPCC 2000) suggests that the content of water in commercial hydrated lime is 26-28 percent for high-calcium lime and 17-31 percent for dolomitic lime. Using the midpoints as default values, the water content may be assumed to be 27 percent for high-calcium lime and 24 percent for dolomitic lime.

- Multiply the production data for high-calcium hydrated lime and dolomitic hydrated lime by their respective percentages of *dry* lime to find the corrected production numbers for both varieties of hydrated lime.

Corrected Lime Content of High-Calcium Hydrated Lime (metric tons) = High-Calcium Hydrated Lime Production (metric tons) \times (1 – 0.27 metric tons water/metric ton high-calcium hydrated lime)

Corrected Lime Content of Dolomitic Hydrated Lime (metric tons) = Dolomitic Hydrated Lime Production (metric tons) \times (1 – 0.24 metric tons water/metric ton high-calcium hydrated lime)

Example: To correct for the moisture content in the hydrated portion of U.S. lime production in 2000, perform the following calculations:

High-Calcium Hydrated Lime

1,550,000 metric tons \times (1 – 0.27 metric tons water/metric ton high-calcium hydrated lime) = **1,131,500 metric tons high-calcium lime**

Dolomitic Hydrated Lime

421,000 metric tons \times (1 – 0.24 metric tons water/metric ton dolomitic hydrated lime) = **319,960 metric tons dolomitic lime**

Step (3): Sum Dolomitic and High-Calcium Lime Types

- Sum the production data for quicklime and dead-burned dolomite and the corrected data for hydrated lime to determine total high-calcium and dolomitic lime production.

Total High-Calcium Lime (metric tons) = High-Calcium Quicklime Production (metric tons) + High-Calcium Corrected Hydrated Lime Production (metric tons)

Total Dolomitic Lime (metric tons) = Dolomitic Quicklime Production (metric tons) + Dolomitic Corrected Hydrated Lime Production (metric tons) + Dead Burned Dolomitic Lime Production (metric tons)

Example: To calculate total corrected U.S. lime production in 2000, perform the following calculations:

High-Calcium Lime

14,300,000 metric tons quicklime + 1,131,500 metric tons corrected hydrated lime
= 15,431,500 metric tons high-calcium lime

Dolomitic Lime

3,000,000 metric tons quicklime + 319,960 metric tons corrected hydrated lime +
 200,000 metric tons dead-burned dolomite = **3,519,960 metric tons dolomitic lime**

Step (4): Estimate Gross Carbon Dioxide Emissions from Lime Manufacture

Lime production involves three main processes: stone preparation, calcination, and hydration. CO₂ is generated during the calcination stage, when limestone (CaCO₃ or a combination of CaCO₃ and magnesium carbonate) or other CaCO₃ materials are roasted at high temperatures. This process is usually performed in either a rotary or vertical kiln. CO₂ is produced as a by-product of this process, just as CO₂ is released during clinker production (see Section 4.1 on cement production). The CO₂ is driven off as a gas and normally exits the system with the stack gas. The emission factor indicating the mass of CO₂ released per unit of lime produced depends on the type of lime generated. The two varieties of primary concern are high-calcium lime and dolomitic lime. For both types of lime, the emission factor is the product of the constant indicating the mass of CO₂ released per unit of lime produced and the average percentage of lime constituted by CaO plus magnesium oxide (95 percent for both varieties of lime). The two emission factors were calculated as follows:

$$EF_{\text{high-calcium}} = 0.95 \text{ CaO/lime} \times \left(\frac{44.01 \text{ g/mole CO}_2}{56.08 \text{ g/mole CaO}} \right)$$

$$= 0.75$$

$$EF_{\text{dolomitic}} = 0.95 \text{ CaO} \bullet \text{MgO/lime} \times \left(\frac{88.02 \text{ g/mole CO}_2}{96.39 \text{ g/mole CaO} \bullet \text{MgO}} \right)$$

$$= 0.87$$

Therefore, it is recommended that states use emission factors of 0.75 metric tons of CO₂ per metric ton of high-calcium lime manufactured and 0.87 metric tons of CO₂ per metric ton of dolomitic lime manufactured when calculating the CO₂ emissions resulting from the production of these two types of lime.

- To determine CO₂ emissions from high-calcium lime manufacture, multiply high-calcium lime production by an emission factor⁴ of 0.75 metric tons CO₂/metric ton of high-calcium lime.
- Similarly, to determine the CO₂ emissions from dolomitic lime manufacture, multiply dolomitic lime production by an emission factor³ of 0.87 metric tons of CO₂/metric ton of dolomitic lime.

Gross CO₂ Emissions from Lime Manufacture (metric tons) = Total High-Calcium Lime Production (metric tons) × 0.75 (metric tons CO₂/metric ton of high-calcium lime produced) + Total Dolomitic Lime Production (metric tons) × 0.87 (metric tons CO₂/metric ton of dolomitic lime produced)

Example: To calculate total CO₂ emissions from U.S. lime production in 2000, perform the following calculations:

High-Calcium Lime

15,431,500 metric tons high-calcium lime × 0.75 metric tons CO₂/metric ton high-calcium lime = 11,573,625 metric tons CO₂

Dolomitic Lime

3,519,960 metric tons dolomitic lime × 0.87 metric tons CO₂/metric ton dolomitic lime = 3,062,365 metric tons CO₂

Total CO₂ Emissions from Lime Production

11,573,625 metric tons CO₂ high-calcium + 3,062,365 metric tons CO₂ dolomitic = **14,635,990 metric tons CO₂**

Step (5): Estimate Carbon Dioxide Reabsorption from Sugar Refining and Precipitated Calcium Carbonate Production⁵

- To estimate reabsorbed CO₂, the emissions of lime used for sugar refining and precipitated CaCO₃ production are multiplied by a recovery factor of 0.80. It is assumed that 100 percent of lime used in these applications is high-calcium lime.

Total Reabsorbed CO₂ Emissions (metric tons) = Total Quantity of Lime Used in Sugar Refining and Precipitated CaCO₃ Production (metric tons) × 0.75 (metric tons CO₂/metric ton of high-calcium lime produced) × 0.80 (metric tons CO₂ absorbed/metric ton CO₂ emitted)

Example: To calculate reabsorbed CO₂ from sugar refining and precipitated CaCO₃ production for the United States in 2000, perform the following calculation:

2,067,000 metric tons lime used in sugar refining and precipitated CaCO₃ production × 0.75 metric tons CO₂/metric ton high-calcium lime × 0.80 metric tons CO₂ absorbed/metric ton CO₂ emitted = **1,240,200 metric tons CO₂**

⁴ This emission factor assumes that the lime produced is 100 percent pure.

⁵ This step is omitted in the State Inventory Tool due to limited significance and limited data.

Step (6): Calculate Net Carbon Dioxide Emissions

- To calculate net CO₂ emissions, subtract the quantity of CO₂ reabsorbed from the amount of CO₂ emitted.

$$\text{Net CO}_2 \text{ Emissions from Lime Production (metric tons)} = \text{Total CO}_2 \text{ Emissions from Lime Production (metric tons)} - \text{Total Reabsorbed CO}_2 \text{ Emissions (metric tons)}$$

Example: To calculate net CO₂ emissions for the United States in 2000, perform the following calculation:

14,635,990 metric tons CO₂ emitted - 1,240,200 metric tons CO₂ reabsorbed =
13,395,790 metric tons CO₂

Step (7): Convert Units to Metric Tons of Carbon Equivalent (MTCE)

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, CO₂ emissions are multiplied by a GWP of 1, and then converted to C equivalent by using the molecular ratio of C to CO₂, or 12/44.

$$\text{Net Emissions from Lime Production (MTCE)} = \text{Net CO}_2 \text{ Emissions from Lime Production (metric tons)} \times 1 \times 12/44$$

Example: To calculate total emissions from lime production in 2000 in MTCE, perform the following calculation:

13,395,790 metric tons CO₂ x 1 x 12/44 = **3,653,397 MTCE**

4.3 CARBON DIOXIDE FROM LIMESTONE AND DOLOMITE USE

Limestone (CaCO₃) and dolomite (CaMg(CO₃)₂) are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, glass manufacturing, environmental pollution control, and metallurgical industries such as magnesium (Mg) production. For example, limestone and dolomite can be used as flux stones or purifiers in refining metals such as iron. In this case, the limestone or dolomite is heated in a blast furnace and reacts with impurities in the iron ore and fuels, generating CO₂ as a by-product.

In the event that a state is unable to obtain data on industrial limestone and dolomite consumption, the state may develop estimates based on apportioning national emissions. To do so, the state should obtain national data on emissions from limestone and dolomite use, national data on the total amount of limestone and dolomite consumed by all activities, and state data on the total amount of limestone and dolomite. State emissions from industrial limestone and dolomite consumption can then be estimated by multiplying the ratio of the state's total limestone and dolomite consumption to the total national limestone and dolomite consumption by national emissions from industrial limestone and dolomite consumption.

To estimate emissions from this source, four steps must be performed: (1) obtain the required data; (2) estimate CO₂ emissions for three categories of limestone and dolomite use; (3) calculate total CO₂ emissions from limestone and dolomite use; and (4) convert units to MTCE.

Step (1): Obtain Required Data

- **Required Data.** The required data include the metric tons of limestone (calcite) and dolomite consumed in the state for industrial purposes. These include the consumption of limestone and dolomite for flux stone production, glass manufacturing, flue gas desulfurization (FGD), Mg production through the thermic reduction of dolomite, chemical stone manufacturing, mine dusting or acid water treatment, acid neutralization, and sugar refining. Do not count (1) crushed limestone consumed for road construction or similar uses (because these uses do not result in CO₂ emissions), (2) limestone used for agricultural purposes (because agricultural use of limestone will be counted under the methodology presented in Chapter 12), nor (3) limestone used in cement production (because that has been counted above under section 4.1 of this chapter). Note that for illustrative purposes, national data are presented in the examples; a state should follow the same approach using state data.
- **Dolomite Use in Magnesium Production.** One method of Mg production involves the thermic reduction of dolomite. Although the only U.S. plant to employ this method (located in Washington) was closed in 2001, emission inventories for previous years require calculation of this source. Since Mg production data are not available, operation at maximum capacity is assumed. This overestimation accounts for less than (chemically) ideal production. Capacity data are available from *USGS Minerals Yearbook* (USGS 2001f).
- **Data Sources.** In-state sources should be consulted. State-specific resources and contacts may be found on the Internet at <http://minerals.usgs.gov/minerals/pubs/state/>. Although the federal government makes available data on limestone consumption, these data are not disaggregated to the level of industrial uses by state.

Example: According to the USGS (2001c) and assumptions made in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000* (U.S. EPA 2002), U.S. limestone use for industrial purposes and Mg production from dolomite in 2000 were as follows (metric tons):

Limestone	16,323,000
Flux Stone	9,838,000
Glass Making	153,000
FGD	6,332,000
Dolomite	4,018,000
Flux Stone	3,751,000
Glass Making	267,000
Mg Production from Dolomite	40,000

Step (2): Estimate Carbon Dioxide Emissions for Three Categories of Limestone and Dolomite Use

Heated limestone and dolomite generate CO₂ as a by-product. Carbon emissions can be calculated by multiplying the amount of limestone or dolomite by the respective carbon content

of each stone. Therefore, emission factors recommended for use by states are 0.12 metric tons C per metric ton of limestone consumed and 0.132 metric tons C per metric ton of dolomite consumed.⁶ The production of Mg results in CO₂ emissions through the thermic reduction of dolomite to Mg metal vapor, a process used by only one Mg metal production plant in the United States. Stoichiometrically, one molecule of CO₂ is produced for each Mg molecule, which leads to an emission factor of 0.49 metric tons of C per metric ton of Mg produced. Thus, the activity data required for CO₂ from dolomite use in Mg production is the metric tons of Mg produced using the dolomitic process, rather than the metric tons of dolomite used. Estimates are then multiplied by 44/12 to obtain the amount of C emitted as CO₂.

- Limestone Use

$$CO_2 \text{ Emissions (metric tons)} = \text{Limestone Used (metric tons)} \times 0.12 \text{ metric tons C/metric ton Limestone} \times 44/12 \text{ CO}_2/\text{C}.$$

- Dolomite Use

$$CO_2 \text{ Emissions (metric tons)} = \text{Dolomite Used (metric tons)} \times 0.132 \text{ metric tons C/metric ton Dolomite} \times 44/12 \text{ CO}_2/\text{C}.$$

- Mg Production from Dolomite

$$CO_2 \text{ Emissions (metric tons)} = \text{Mg Produced (metric tons)} \times 0.49 \text{ metric tons C/metric ton Mg} \times 44/12 \text{ CO}_2/\text{C}$$

Example: To calculate total CO₂ emissions from lime consumption in 2000, perform the following calculations:

Limestone Use

$$[16,323,000 \text{ metric tons} \times 0.12 \text{ metric tons C/metric ton limestone}] \times 44/12 \text{ CO}_2/\text{C} = \mathbf{7,182,120 \text{ metric tons CO}_2}$$

Dolomite Use

$$[4,018,000 \text{ metric tons} \times 0.132 \text{ metric tons C/metric ton dolomite}] \times 44/12 \text{ CO}_2/\text{C} = \mathbf{1,944,712 \text{ metric tons CO}_2}$$

Mg Production from Dolomite

$$[40,000 \text{ metric tons} \times 0.49 \text{ metric tons C/metric ton Mg}] \times 44/12 \text{ CO}_2/\text{C} = \mathbf{71,867 \text{ metric tons CO}_2}$$

Step (3): Calculate Total Carbon Dioxide Emissions from Limestone and Dolomite Use

- Emission estimates from each use of limestone and dolomite should be summed to estimate total CO₂ emissions.

⁶ Limestone (CaCO₃) and dolomite (CaMg(CO₃)₂) are collectively referred to as limestone by the industry, and intermediate varieties are seldom distinguished.

$$\text{Total CO}_2 \text{ Emissions from Limestone and Dolomite Use} = \text{CO}_2 \text{ from Limestone use (metric tons CO}_2\text{)} + \text{CO}_2 \text{ from Dolomite use (metric tons CO}_2\text{)} + \text{CO}_2 \text{ from Mg Production from Dolomite (metric tons CO}_2\text{)}$$

Example: To calculate total CO₂ emissions from limestone and dolomite use in 2000, perform the following calculation:

7,182,120 metric tons CO₂ limestone use + 1,944,712 metric tons CO₂ dolomite use + 71,867 metric tons CO₂ magnesium production from dolomite =
9,198,699 metric tons CO₂

Step (4): Convert Units to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, CO₂ emissions are multiplied by a GWP of 1, and then converted to C equivalent by using the molecular weight ratio of C to CO₂, or 12/44.

$$\text{Total Emissions from Limestone and Dolomite Use (MTCE)} = \text{Total CO}_2 \text{ Emissions from Limestone and Dolomite Use} \times 1 \times 12/44$$

Example: To calculate total emissions from limestone use in 2000 in MTCE, perform the following calculation:

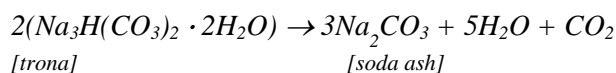
$9,198,699 \text{ metric tons CO}_2 \times 1 \times 12/44 = \mathbf{2,508,736 \text{ MTCE}}$

4.4 CARBON DIOXIDE FROM SODA ASH MANUFACTURE AND CONSUMPTION

Although only three states produced soda ash at the time of publication (Wyoming, California, and Colorado), all states consumed it. Thus, all states should estimate CO₂ emissions from soda ash consumption.

Commercial soda ash (sodium carbonate or Na_2CO_3) is used in many familiar consumer products such as glass, soap and detergents, paper, textiles, and food. About 75 percent of world production is synthetic ash made from sodium chloride; the remaining 25 percent is produced from natural sources. The United States produces only natural soda ash, using one of three methods.

Under the soda ash production method used in Wyoming, trona (an ore from which natural soda ash is made) is calcined in a rotary kiln and chemically transformed into a crude soda ash that requires further processing. CO₂ and water are generated as a by-product of the calcination process. CO₂ emissions from the calcination of trona can be estimated based on the following chemical reaction:



Based on this formula, it takes approximately 10.27 metric tons of trona to generate 1 metric ton of CO₂, or 0.0974 metric tons of CO₂ per metric ton of trona produced.

The soda ash production method used in California uses NaCO_3 -bearing brines. To extract the NaCO_3 , the complex brines are first treated with CO_2 in carbonation towers to convert the NaCO_3 into sodium bicarbonate (NaHCO_3), which precipitates. The precipitated NaHCO_3 is then calcined back into sodium carbonate. Although CO_2 is generated as a by-product, the CO_2 is recovered and recycled for use in the carbonation stage and is not released. Thus, this process does not result in CO_2 emissions.

A relatively new plant in Colorado produces soda ash from nahcolite, a natural sodium bicarbonate. Although CO_2 is generated as a by-product, not enough information about this process is currently available to provide a methodology for estimating emissions from this specific process.

CO_2 is also released when soda ash is consumed. Glass manufacture represents about 49 percent of domestic soda ash consumption, with smaller amounts used for chemical manufacture, soap and detergents, flue gas desulfurization, and other miscellaneous uses. In each of these applications, one molecule of carbon is released for every molecule of soda ash used. Thus, approximately 0.113 metric tons of carbon or 0.415 metric tons of CO_2 are released for every metric ton of soda ash consumed.

To estimate emissions from this source, five steps must be performed: (1) obtain the required data; (2) estimate CO_2 emissions from soda ash manufacture (Wyoming only); (3) estimate CO_2 from soda ash consumption; (4) calculate total CO_2 emissions from soda ash consumption; and (5) convert units to MTCE.

Step (1): Obtain Required Data

- **Required Data.** For Wyoming, the data required are the amount of trona (the principal ore from which natural soda ash is made) produced in metric tons. For all states, the data required are the amount of finished soda ash consumed. If state consumption data are unavailable, national consumption may be apportioned based on state population. The required data are national population, state population, and national soda ash consumption.
- **Data Sources.** In-state sources should be consulted first. Additionally, trona production and soda ash consumption by state may be found in *Soda Ash: Minerals Yearbook* (USGS 2001d) and the Bureau of the Census' *Current Industrial Reports* at Internet address <http://www.census.gov/cir/www>. States unable to locate consumption data may estimate consumption of soda ash by apportioning national consumption based on state population. State soda ash consumption is estimated to be equal to national consumption times state population divided by national population. For estimates based on national soda ash consumption, the national and state population data are available from the U.S. Census Bureau (www.census.gov), while national soda ash consumption is available in *Soda Ash: Minerals Yearbook* (USGS 2001d).

Example: Trona production in Wyoming in 2000 was approximately **15,700,000 metric tons**, while total U.S. soda ash consumption in 2000 was **6,390,000 metric tons**.

Step (2): Estimate Carbon Dioxide Emissions from Soda Ash Manufacture (Wyoming Only)

- Multiply the amount of trona produced by the emission factor 0.0974 metric tons CO₂/metric ton trona.

$$\text{Total CO}_2 \text{ Emissions (metric tons)} = \text{Trona Produced (metric tons)} \times 0.0974 \text{ metric tons CO}_2/\text{metric ton Trona}$$

Example: To calculate CO₂ emissions from trona production in Wyoming in 2000, perform the following calculation:

15,700,000 metric tons trona x 0.0974 metric tons CO₂/metric ton trona =
1,529,180 metric tons CO₂

Step (3): Estimate Carbon Dioxide from Soda Ash Consumption

- Multiply the amount of soda ash consumed by the emission factor 0.415 metric tons CO₂/metric ton soda ash consumed.

$$\text{Total CO}_2 \text{ Emissions (metric tons)} = \text{Soda Ash Consumed (metric tons)} \times 0.415 \text{ metric tons CO}_2/\text{metric ton Soda Ash}$$

Example: To calculate total U.S. CO₂ emissions from soda ash consumption in 2000, perform the following calculation:

6,390,000 metric tons x 0.415 metric tons CO₂/metric ton soda ash =
2,651,850 metric tons CO₂

Step (4): Calculate Total Carbon Dioxide Emissions from Soda Ash Consumption

- To calculate total emissions from soda ash consumption, sum CO₂ emissions from soda ash production (where applicable) and CO₂ emissions from soda ash consumption.

$$\text{Total CO}_2 \text{ Emissions from Soda Ash Manufacture and Use (metric tons)} = \text{Total CO}_2 \text{ from Trona Production (metric tons)} + \text{Total CO}_2 \text{ from Soda Ash Consumption (metric tons)}$$

Step (5): Convert Units to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, CO₂ emissions are multiplied by a GWP of 1, and then converted to C equivalent by using the molecular weight ratio of C to CO₂, or 12/44.

$$\text{Total Emissions from Soda Ash Manufacture and Use (MTCE)} = \text{Total CO}_2 \text{ Emissions from Soda Ash Manufacture and Use (metric tons)} \times 1 \times 12/44$$

Example: To calculate total emissions from soda ash manufacture and use in the U.S. in 2000 in MTCE, perform the following calculation:

$$(1,529,180 \text{ metric tons CO}_2 \text{ from production} + 2,651,850 \text{ metric tons CO}_2 \text{ from use}) \times 1 \times 12/44 = \mathbf{1,140,281 \text{ MTCE}}$$

4.5 NITROUS OXIDE FROM NITRIC ACID PRODUCTION

The production of nitric acid (HNO_3) produces nitrous oxide (N_2O) as a by-product, via the oxidation of ammonia. Nitric acid is a raw material used primarily to make synthetic commercial fertilizer. It is also a major component in the production of adipic acid (a feedstock for nylon) and explosives. Relatively small quantities of nitric acid are also employed for stainless steel pickling, metal etching, rocket propellants, and nuclear fuel processing. In 1990, this inorganic chemical ranked thirteenth in total production of all chemicals in the United States. Virtually all of the nitric acid produced in the United States is manufactured by the catalytic oxidation of ammonia (U.S. EPA 1985). During this reaction, N_2O is formed as a by-product and is released from reactor vents into the atmosphere. At present, the nitric industry controls for oxides of nitrogen through two technologies: non-selective catalytic reduction (NSCR) and selective catalytic reduction (SCR). Only one of these technologies, NSCR, is effective at destroying N_2O emissions in the process of destroying NO_x emissions. NSCR technology was widely installed in nitric acid plants built between 1971 and 1977. Due to high-energy costs and associated high gas temperatures, this technology has not been popular with modern plants. Only about 20 percent of the current plants have NSCR technology installed. All other plants have installed SCR technology (Choe et al. 1993).

To estimate emissions from this source, three steps must be performed: (1) obtain the required data; (2) estimate N_2O emissions from nitric acid production; and (3) convert units to MTCE.

Step (1): Obtain Required Data

- **Required Data.** N_2O emissions from nitric acid production can be calculated based on the state's annual nitric acid production in metric tons. States unable to find these data may estimate nitric acid production based on the ratio of state nitric acid production capacity to national nitric acid production capacity.
- **Data Sources.** In-state sources should be consulted for the state's annual nitric acid production. (There are no known national data sources that provide, free of charge, state-level data on nitric acid production.) If no in-state sources provide data on nitric acid production, then obtain data on (1) national nitric acid production, (2) state nitric acid production capacity, and (3) national nitric acid production capacity. Data on national nitric acid production may be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (U.S. EPA 2004) or *Chemical & Engineering News*. Data on national and state nitric acid capacity may be found in the *Directory of Chemical Producers* (SRI 2000). This is an annual publication that only reports capacity data for the year of publication.

Example: According to the U.S. EPA (2002), U.S. nitric acid production in 2000 was **7,980,500 metric tons**.

Step (2): Estimate Nitrous Oxide Emissions from Nitric Acid Production

Plants with SCR technology have an emission factor of 0.0095 metric tons N₂O/metric ton of nitric acid, while plants with NSCR technology have an emission factor of 0.002 metric tons N₂O/metric ton of nitric acid. Since 80 percent of the current plants have SCR technology installed and 20 percent have NSCR technology, the weighted average emission factor is equal to $(0.0095 \times 0.80) + (0.002 \times 0.20) = 0.008$ metric tons N₂O/metric ton of nitric acid (U.S. EPA 2004).

- States that can identify the type of technology in place at nitric acid production facilities should use the appropriate emission factor (e.g., 0.002 metric tons N₂O/metric ton of nitric acid for plants with NSCR). Alternatively, states can modify the weighted average emission factor provided above to reflect state circumstances. For example if plants responsible for 60 percent of state production have SCR technology, and the remainder have NSCR technology, then the emission factor can be recalculated as $(0.0095 \times 0.60) + (0.002 \times 0.40) = 0.0065$ metric tons N₂O/metric ton of nitric acid. To calculate emissions multiply state nitric acid production by this emission factor.
- If specific information on control technologies is unavailable, multiply state nitric acid production by the weighted average emission factor of 0.008 metric tons N₂O/metric ton of nitric acid. This will yield total N₂O emissions from nitric acid production.
- If state data on nitric acid production are unavailable, estimate production by multiplying national nitric acid production for the year in question by the ratio of the state nitric acid capacity to the national nitric acid capacity. Then, multiply estimated state nitric acid production by an emission factor of 0.008 metric tons N₂O/metric ton of nitric acid produced to yield total N₂O emissions from nitric acid production.

Total N₂O Emissions (metric tons) = Total nitric acid Production (metric tons) x State Specific or Default Emission Factor (metric tons N₂O/metric ton of nitric acid produced)

Example: In 2000, national nitric acid production capacity was 11,321,000 metric tons and national nitric acid production was 7,980,500 metric tons. Nebraska's nitric acid production capacity in 2000 was 200,000 metric tons.

The proportion of U.S. nitric acid production capacity in 2000 that is attributable to Nebraska was $(200,000 \text{ metric tons} / 11,321,000 \text{ metric tons}) = 0.018 = 1.8\%$

$7,980,500 \text{ metric tons} \times 0.018 \times (0.008 \text{ metric tons N}_2\text{O/metric ton of nitric acid})$
= 1,149 metric tons N₂O

Step (3): Convert Units to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, N₂O emissions are multiplied by a GWP of 310, and then converted to C equivalent by using the molecular weight ratio of C to CO₂, or 12/44.

Total N₂O Emissions from nitric acid Production (MTCE) = Total N₂O Emissions from nitric acid Production (metric tons) x 310 x 12/44

Example: To calculate total emissions from nitric acid production in Nebraska in 2000 in MTCE, perform the following calculation:

$$1,149 \text{ metric tons N}_2\text{O} \times 310 \times 12/44 = \mathbf{97,143 \text{ MTCE}}$$

4.6 NITROUS OXIDE FROM ADIPIC ACID PRODUCTION

As of this writing, three states in the United States—Texas, Florida, and Virginia—produce adipic acid. Adipic acid is a white crystalline solid used 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. About 90 percent of all adipic acid produced in the United States is used in the production of nylon 6,6, as well as production of some low-temperature lubricants. It is also used to provide foods with a “tangy” flavor. The United States accounts for approximately one-third of global production of adipic acid.

Adipic acid is produced through a two-stage process. The first stage involves the oxidation of cyclohexane to form a cyclohexanone/cyclohexanol mixture. The second stage involves the oxidation of ketone-alcohol with nitric acid. N₂O is generated as a by-product of this reaction and enters the waste gas stream. In the United States, this waste gas is treated to remove NO_x and other regulated pollutants (and, in some cases, N₂O as well) and is then released into the atmosphere. There are currently four plants in the United States that produce adipic acid. In 1998, three of these plants had emission control measures in place. Overall abatement for these technologies varies and depends upon the N₂O destruction factor and the abatement system utility factor, which varies by plant (U.S. EPA 2004).

To estimate emissions from this source, three steps must be performed: (1) obtain the required data; (2) estimate N₂O emissions from adipic acid production; and (3) convert units to MTCE.

Step (1): Obtain Required Data

- **Required Data.** N₂O emissions from adipic acid production can be calculated based on annual adipic acid production (in metric tons) and the effectiveness of pollution control equipment, which includes the N₂O destruction factor and the abatement system utility factor, used at production facilities in the state. Note that for illustrative purposes, national data are presented in the examples; a state should follow the same approach using state data.
- **Data Sources.** Emissions data may be available from an in-state source such as the air-permitting department. States should attempt to contact in-state sources (e.g., the adipic acid plants) to obtain emissions data. Note that plants may consider this data confidential and could be reluctant to disclose it, in which case, states should use the adipic acid production capacity data in the *Chemical Market Reporter* (data were last provided in the June 16, 2001 issue and are updated about every three years). Plant production capacity is generally larger than actual production, therefore using capacity data as a basis for estimating emissions will tend to over-estimate emissions.

Example: According to U.S. EPA (2002), total U.S. adipic acid production in 2000 was approximately **1,128,600 metric tons**.

If data are available on N₂O emissions controls, which include both the N₂O destruction factor and the abatement system utility factor, the amount of N₂O reductions should also be recorded.

Step (2): Estimate Nitrous Oxide Emissions from Adipic Acid Production

Because emissions of N₂O in the United States are not currently regulated, very little emissions data exist. However, based on the overall reaction stoichiometry for adipic acid, it is estimated that approximately 0.3 metric tons of N₂O are generated for every metric ton of adipic acid produced (Thiemens and Trogler 1991). Because N₂O emissions are controlled in some adipic acid production facilities, the amount of N₂O that is actually released will depend on the level of emission controls in place at a specific production facility.

- Estimate state production of adipic acid by multiplying the state's adipic acid capacity by the ratio of total U.S. production to total U.S. capacity. As of this writing, Texas had two plants with combined adipic acid capacity of 1,210 million lbs. per year; Florida had capacity of 850 million lbs. per year; and Virginia had capacity of 60 million lbs. per year. Thus the total U.S. capacity—the sum of the state capacities—was 2,120 million lbs. National production in 2000 was 2,488 million lbs. (U.S. EPA 2004). Thus, in 2000, the ratio of national production to national capacity was 2,488 to 2,120, or 117 percent.⁷ Adipic acid production in Texas is equal to 1,210 million lbs. capacity multiplied by 117 percent, or 1,415 million lbs. To convert to metric tons, multiply production in million lbs. by 453.6 metric tons per 1 million lbs.
- Multiply adipic acid production by an emission factor of 0.3 metric tons N₂O/metric ton of adipic acid produced to yield total N₂O emissions from adipic acid production. Multiply this amount by the percent of N₂O that is released after pollution control equipment has been applied. Pollution control equipment includes the N₂O destruction factor and the abatement system utility factor.

Total N₂O Emissions from Adipic Acid Production (metric tons) = Total Adipic Acid Production (metric tons) x 0.3 metric tons N₂O/metric ton of adipic acid produced x Percent of N₂O Released After Pollution Control

⁷ In this example, national production data are higher than national capacity data because the *U.S. Inventory of Greenhouse Gas Emissions and Sinks* uses different sources for calculating production and capacity rates. At times, these data conflict with each other but they are still utilized because they are the best available data.

Example: To calculate total N₂O emissions from U.S. adipic acid production in 2000, perform the following calculation:

1,128,600 metric tons x 0.3 metric tons N₂O/metric ton adipic acid x percent of N₂O released after pollution control = **338,580 metric tons N₂O** x percent of N₂O released after pollution control⁸

Step (3): Convert Units to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, N₂O emissions are multiplied by a GWP of 310, and then converted to C equivalent by using the ratio of C to CO₂, or 12/44.

Total N₂O Emissions from Adipic Acid Production (MTCE) = Total N₂O Emissions from Adipic Acid Production (metric tons) x 310 x 12/44

Example: To calculate total emissions from adipic acid production in 2000 in MTCE, perform the following calculation:

338,580 metric tons N₂O x 310 x 12/44 = **28,625,400 MTCE**

4.7 PERFLUOROCARBONS FROM ALUMINUM PRODUCTION

The aluminum production industry is thought to be the largest source of two perfluorocarbons (PFCs) – tetrafluoromethane (CF₄) and hexafluoroethane (C₂F₆). Emissions of these two potent greenhouse gases occur during the reduction of alumina in the primary smelting process.⁹ Aluminum (Al) is produced by the electrolytic reduction of alumina (Al₂O₃) in the Hall-Heroult reduction process, whereby Al₂O₃ is dissolved in molten cryolite (Na₃AlF₆), which acts as the electrolyte and is the reaction medium. PFCs are formed during disruptions of the production process known as anode effects, which are characterized by a sharp rise in voltage across the production vessel. The PFCs can be produced through two mechanisms: direct reaction of fluorine (F) with the carbon anode and electrochemical formation. In both cases the fluorine originates from dissociation of the molten cryolite.

Because CF₄ and C₂F₆ are inert, and therefore pose no health or local environmental problems, historically there has been little study of the processes by which emissions occur and the factors controlling the magnitude of emissions. In general, however, the magnitude of emissions for a given level of production depends on the frequency and duration of the anode effects during that production period. In general, the emissions rise as the anode effects become more frequent and long-lasting.

The methodology described below combines production data with empirically determined emission factors to calculate annual emissions. These emission factors are based on data

⁸ The percent of N₂O released after pollution control is plant-specific, so there is no national default for this value.

⁹ Perfluorinated carbons are not emitted during the smelting of recycled aluminum.

provided by the Al smelters participating in the EPA Climate Protection Partnerships Division's Voluntary Aluminum Industrial Partnership (VAIP). VAIP partners provide data on their emission reduction progress to EPA on an annual basis. Using this data, which generally consists of either frequency or duration of anode effects, along with Al production estimates, EPA has developed estimates of national PFC emissions from Al smelting. The method is based on facility-specific estimates for VAIP partners and estimates of emissions—based on an average emission factor, in terms of emissions per metric ton of production—for other facilities.

Because the facility-specific data are confidential, the method below relies on estimating emissions within a state as a function of primary Al production. Because actual production may also be regarded as confidential, but capacity is not, the method also provides a basis for estimating state emissions as a function of capacity.

To estimate emissions from this source, three steps must be performed: (1) obtain the required data; (2) estimate PFC emissions from Al production; and (3) convert units to MTCE.

Step (1): Obtain Required Data

- **Required Data.** Required data include the metric tons of primary Al produced in the state from raw materials. (Al production from recycled inputs does not result in PFC emissions.) If state Al production data are unavailable, use state Al production capacity data and the ratio of national Al production to national Al capacity to form an estimate. Note that for illustrative purposes, national data are presented in the examples; a state should follow the same approach using state data.

Example: According to the USGS (2001b), national production of primary Al in 2000 was approximately **3,468,000 metric tons**.

- **Data Sources.** In-state sources should be consulted first. Additionally, primary Al production capacity by state can be found in *Minerals Yearbook: Aluminum* (USGS 2001b) and the Bureau of Census' *Current Industrial Reports* at Internet address <http://www.census.gov/cir/www>. The ratio of national production to national capacity is available in Table 6.4-1. If desired, the individual national primary Al production capacity and national primary Al production data are also available in the *Minerals Yearbook: Aluminum* and *Current Industrial Reports*.

Table 6.4-1: Ratio of National Production to National Capacity
(%)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Ratio	98.41	98.37	96.17	87.92	78.10	79.89	84.69	85.76	88.27	88.46	85.91	60.34	65.70

Step (2): Estimate PFC Emissions from Aluminum Production

Average emissions of PFCs per metric ton of Al have declined since 1990, due in large part to the efforts of Al companies in the VAIP, as shown below. The emission factors provide the rates for total PFC emissions (both CF₄ and C₂F₆) in MTCE per metric ton of Al produced. The table below lists the PFC emission factors for Al production in the United States.

Table 6.4-2: Emission Factors
(MTCE/metric ton of aluminum produced)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Emission Factor	1.22	1.03	0.97	1.01	1.00	0.95	0.95	0.83	0.66	0.65	0.66	0.41	0.53

Given the emission factors displayed above, calculate state PFC emissions from Al production using the method that follows.

- If state Al production data are unavailable, construct an estimate by multiplying state Al production capacity for a particular year by the ratio of national Al production to national Al production capacity from that year (available in Table 6.4-1).

State Al Production for Year A (metric tons) = State Al Production Capacity for Year A (metric tons) x Ratio of National Al Production to National Al Production Capacity for Year A (%), available in Table 6.4-1)

- Multiply the state Al production for a particular year by the PFC emission factor for the same year to find the state's PFC emissions from Al production for that year.

Total PFC Emissions for Year A (MTCE) = Al Production for Year A (metric tons) x Emission Factor for Year A (MTCE/metric ton of Al produced)

Example: To calculate total national PFC emissions (both CF₄ and C₂F₆) from Al production from virgin inputs in 2000, perform the following calculation:

3,468,000 metric tons Al produced nationally x 0.63 MTCE of PFC/metric ton Al produced = **2,184,840 MTCE of perfluorocarbon emissions**

Because emission factors are already weighted by the GWPs of the CF₄ and C₂F₆, there is no need for an additional step to convert emissions into MTCE, as there is in other sections.

4.8 HFC-23 FROM HCFC-22 PRODUCTION

Hydrofluorocarbons (HFCs) are chemicals containing hydrogen (H), F, and C. Only recently have they been produced on a large scale. As some of the primary alternatives to the ozone depleting substances (ODSs) being phased out under the Montreal Protocol and subsequent amendments, the use of HFCs is expected to increase in the future. Sources of HFC emissions can be categorized as follows:

- Emissions of HFCs produced as by-products of chemical production processes, and
- Emissions of HFCs used as substitutes for ODSs in refrigeration, foam blowing, solvent, aerosol, and fire extinguishing applications (these are “consumptive” uses of HFCs).

One type of HFC known to be emitted in significant quantities is HFC-23, which is emitted as a by-product of HCFC-22 production. The methodology for estimating these emissions is described below; the methodology for estimating HFCs from consumptive uses appears in Section 4.9.

To estimate emissions from this source, three steps must be performed: (1) obtain the required data; (2) estimate HFC-23 emissions from HCFC-22 production; and (3) convert units to MTCE.

Step (1): Obtain Required Data

- *Required Data.* Required data include the metric tons of HCFC-22 produced in a state.
- *Data Sources.* In-state manufacturers of HCFC-22 should be consulted first. Additionally the Chemical Manufacturers Association (Washington, D.C.), Alliance for Responsible CFC Policy (Arlington, VA), and Grant Thornton Consulting (Washington, D.C.) can be contacted for information on state-by-state production numbers.

Step (2): Estimate HFC-23 Emissions from HCFC-22 Production

The suggested methodology for estimating emissions from this source is to obtain estimates of HCFC-22 production from in-state chemical manufacturers and multiply this production by 0.02 metric tons of HFC-23 per metric ton of HCFC-22 produced. Many companies now have empirical measurements of HFC-23 emissions from the production of HCFC-22. Where available, states should use such measurements rather than the emission factor provided here.

- Multiply the amount of HCFC-22 produced by the appropriate emission factor: 0.02 metric tons HFC-23/metric ton HCFC-22 produced (or 2 percent of total HCFC-22 production).

Total HFC-23 Emissions (metric tons) = HCFC-22 Produced (metric tons) x 0.02 metric tons HFC-23/metric ton HCFC-22 produced

Example: To calculate total HFC emissions from HCFC-22 production for a state that produced 75,000 metric tons of HCFC-22 in 2000, perform the following calculation:

50,000 metric tons HCFC-22 x 0.02 metric tons HFC-23/metric ton HCFC-22 produced = **1,000 metric tons HFC-23**

Step (3): Convert Units to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, HFC-23 emissions are multiplied by a GWP of 11,700, and then converted to C equivalent by using the ratio of C to CO₂, or 12/44.

Total HFC-23 Emissions from HCFC-22 Production (MTCE) = Total HFC-23 Emissions from HCFC-22 Production (metric tons) x 11,700 x 12/44

Example: To calculate total emissions from HCFC-22 production in 2000 in MTCE, perform the following calculation:

1,000 metric tons HFC-23 x 11,700 x 12/44 = **3,190,909 MTCE**

4.9 HFCs AND PFCs FROM CONSUMPTION OF SUBSTITUTES FOR OZONE-DEPLETING SUBSTANCES

Hydrofluorocarbons (HFCs) are used primarily as alternatives to several classes of ozone-depleting substances (ODSs) that are being phased out under the terms of the Montreal Protocol and the Clean Air Act Amendments of 1990. ODSs, which include chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs), are used in a variety of industrial applications including refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam blowing, and sterilization. Although their substitutes, HFCs, are not harmful to the stratospheric ozone layer, they are powerful greenhouse gases.

The major end-use categories used to characterize ODS-substitute use in the United States include:

- motor vehicle air conditioning;
- commercial and industrial refrigeration and air conditioning;
- residential refrigeration and air conditioning;
- aerosols;
- solvent cleaning;
- fire extinguishing equipment;
- foam production; and
- sterilization.

U.S. EPA develops annual estimates of the use and emissions of HFCs as ODS substitutes in the United States. Using the EPA method to estimate state-level emissions of HFCs used as ODS substitutes would require data that may not be available at that level of disaggregation. Much of the data used for estimating emissions at the national level are from trade associations and industry sources that provide national totals. However, a rough approximation of state-level emissions of HFCs used as ODS substitutes can be calculated using a per capita estimate.

To estimate emissions from this source, two steps must be performed: (1) obtain the required data; and (2) estimate state-level emissions based on national emissions.

Step (1): Obtain Required Data

- *Required Data.* The data elements required are (1) the national emissions of HFCs used as ODS substitutes in MTCE, and (2) annual state and national populations.

- **Data Sources.** The national emissions of HFCs used as ODS substitutes are reported for each year in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (U.S. EPA 2004).¹⁰ State and national population data may be found at the web site for the U.S. Census: <http://www.census.gov/>.

Step (2): Estimate State-Level Emissions Based on National Emissions

State-level emissions of HFCs used as ODS substitutes may be estimated by calculating per-capita emissions of HFCs used as ODS substitutes and then multiplying per-capita emissions by state population.

- To find per-capita emissions, divide the national emissions by the national population.¹¹

$$\text{Per-Capita Emissions (MTCE/person)} = \text{National Emissions (MTCE)} / \text{National Population (people)}$$

- To obtain ODS substitute emissions for a state, multiply per-capita emissions by the state population.

$$\text{State-Level Emissions (MTCE)} = \text{Per-Capita Emissions (MTCE/person)} \times \text{State Population (people)}$$

Example: To calculate per-capita emissions of HFCs as ODS substitutes, divide the estimate of national emissions by number of people in the United States. In 2000, U.S. emissions were estimated at 15.8 million MTCE. The 2000 U.S. population was 281,421,906. Thus, the per-capita emissions were approximately the following:

$$15.8 \text{ million MTCE} / 281.4 \text{ million people} = 0.06 \text{ MTCE/person.}$$

To calculate total HFC emissions from ODS substitutes for a state with a population of 5 million people in 1990,

$$5,000,000 \text{ persons} \times 0.06 \text{ MTCE/person} = \mathbf{300,000 \text{ MTCE}}$$

Because national emissions are already weighted by the GWPs of individual gases used as ODS substitutes, there is no need for an additional step to convert emissions into MTCE as there is in other sections.

¹⁰ Because the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* reports data in teragrams of CO₂ equivalent (TgCO₂E), data should be converted to MTCE by multiplying TgCO₂E times 1,000,000 metric tons per teragram times 12/44.

¹¹ The State Inventory Tool calculates state emissions by multiplying the national emissions by the state's proportion of national population.

4.10 PFC, HFC, AND SULFUR HEXAFLUORIDE EMISSIONS FROM SEMICONDUCTOR MANUFACTURE

The semiconductor industry employs multiple long-lived fluorinated gases in the plasma etching and chemical vapor deposition processes. These include the PFCs CF_4 , C_2F_6 , and C_3F_8 ; HFC-23; and sulfur hexafluoride (SF_6). With present industry growth and the increasing complexity of microchips, emissions from the semiconductor industry are expected to increase significantly.

The U.S. EPA estimates PFC emissions from semiconductor manufacture using data reported by the participants in the PFC Emission Reduction Partnership for the Semiconductor Industry. This information was used to develop a time series of emission factors that are variable by the number of layers per chip. These emission factors were then applied to the industry as a whole. Because this methodology requires a complex set of data that is not disaggregated by state, it is recommended that states apportion national emissions based on the total value of semiconductors produced in each state. Because chip value correlates with the number of layers per chip, this method may serve as an acceptable substitute.

To estimate emissions from this source, two steps must be performed: (1) obtain the required data for the state and (2) estimate PFC, HFC, and SF_6 emissions from semiconductor manufacture.

Step (1): Obtain Required Data

- *Required Data.* The data required are (1) total national emissions of PFC, HFC, and SF_6 from semiconductor manufacture in MTCE, (2) the value of semiconductor shipments from the state, and (3) the value of total U.S. semiconductor shipments.
- *Data Sources.* The national PFC, HFC, and SF_6 emissions from the semiconductor industry for each year may be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (U.S. EPA 2004).¹² The value of semiconductor shipments produced at the state and national levels may be found in the U.S. Census Bureau's Economic Census, available online at <http://www.census.gov/epcd/ec97/us/US000.HTM>. Information is listed by NAICS Code Number. The NAICS Code for "Semiconductor and Related Device Manufacturing" is 334413.

Step (2): Estimate PFC, HFC, and Sulfur Hexafluoride Emissions from Semiconductor Manufacture

- Multiply national emissions of PFCs, HFCs, and SF_6 by the ratio of the value of state semiconductor shipments to the value of national semiconductor shipments.

¹² Because the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* reports data in teragrams of CO_2 equivalent (TgCO_2E), data should be converted to MTCE by multiplying TgCO_2E times 1,000,000 metric tons per teragram times 12/44.

Total State PFC, HFC, and SF₆ Emissions from Semiconductor Manufacture = National PFC, HFC, and SF₆ emissions from Semiconductor Manufacture (MTCE) x Value of State Semiconductor Shipments (\$) / Value of National Semiconductor Shipments (\$)

Example: To calculate PFC, HFC, and SF₆ emissions from semiconductor manufacturing for Oregon in 2000, perform the following calculation:

2,100,000 MTCE PFC, HFC, and SF₆ national emissions x (\$7,859,672,000 of semiconductors produced in Oregon/ \$78,539,562,000 of semiconductors produced nationally) = **210,153 MTCE**

Because national emissions are already weighted by the GWPs of individual gases used in semiconductor manufacturing, there is no need for an additional step to convert emissions into MTCE, as there is in other sections.

4.11 SULFUR HEXAFLUORIDE EMISSIONS FROM ELECTRIC POWER TRANSMISSION AND DISTRIBUTION

SF₆ is the most potent greenhouse gas, with a GWP 23,900 times greater than that of CO₂. SF₆ is used in several industries, primarily electric utilities and semiconductor manufacturing (addressed in Section 4.10, above). Other uses of SF₆ include (1) Mg metal production and casting (addressed in Section 4.12, below), (2) use as a tracing gas for various atmospheric and oceanic scientific studies, and for laboratory hood testing, (3) use in tandem accelerators, and (4) limited use in several consumer products (such as tennis balls and automotive shock absorbers).

The largest use for SF₆, both domestically and internationally, is as an electrical insulator in electricity transmission and distribution equipment, such as gas-insulated high-voltage circuit breakers, substations, transformers, and transmission lines. Approximately eighty percent of worldwide use of SF₆ is in electrical transmission and distribution systems (Maiss and Brenninkmeijer 1998). The electric utility industry uses the gas because of its high dielectric strength and arc-quenching abilities. Not all of the electric utilities in the United States use SF₆; use of the gas is more common in urban areas where the space occupied by electrical distribution and transmission facilities is more valuable.

The data concerning the use and emissions of this chemical are difficult to obtain. National emission estimates are developed by the U.S. EPA's Global Programs Division in cooperation with companies that participate in the SF₆ Emissions Reduction Partnership for Electric Power Systems and with producers of SF₆. However, this data are confidential and therefore not available for use in states' inventories.

Short of detailed SF₆ leakage data from the companies themselves, the best alternative method estimates these emissions by pro-rating national emissions, based on the ratio of state electricity consumption to national electricity consumption. Electricity consumption is used to pro-rate national emissions because utility SF₆ emissions result from leaks in the transformers used in the electricity distribution system, and electricity consumption is the best available proxy for calculating a state's share of national SF₆ leaks from transformers.

To estimate emissions from this source, two steps must be performed: (1) obtain the required data and (2) estimate SF₆ emissions from electricity consumption.

Step (1): Obtain Required Data

- *Required Data.* The data required are (1) total national emissions of SF₆ from the electric utility sector in MTCE, (2) the state's electricity consumption in million kilowatt hours, and (3) national electricity consumption in million kilowatt hours.
- *Data Sources.* The national SF₆ emissions from the electric utility sector for each year may be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (U.S. EPA 2004).¹³ State and national electricity consumption may be found in the U.S. Department of Energy, Energy Information Administration report, *Electric Power Annual 2000 Vol. I* (EIA 2001). (In this edition, electricity consumption data may be found on page 39, Table A-21.)
- *Units for Reporting Data.* Data for electricity consumption are given in million kilowatt hours (million kWh).

Step (2): Estimate Sulfur Hexafluoride Emissions from Electricity Consumption

- To estimate state SF₆ emissions, multiply national SF₆ emissions by the ratio of state electricity consumption to national electricity consumption

$$\text{Total State SF}_6 \text{ Emissions (MTCE)} = \text{National SF}_6 \text{ Emissions (MTCE)} \times \frac{\text{State Electricity Consumption (million kWh)}}{\text{National Electricity Consumption (million kWh)}}$$

Example: To calculate SF₆ emissions from electric utilities for New Jersey in 2000, perform the following calculation:
 3,900,000 MTCE SF₆ national emissions x (70,882 million kWh consumed by New Jersey/3,412,766 million kWh consumed nationally) = **81,002 MTCE**

Because national emissions are already weighted by the GWP of SF₆, there is no need for an additional step to convert emissions into MTCE, as there is in other sections.

SF₆ can leak from electrical equipment through seals, especially in older equipment. It is also released when equipment is opened for servicing. Several practices can reduce emissions of SF₆ from the electric utility industry, including (1) improved work practices by those servicing and maintaining the equipment, (2) discontinuing the practice of venting to the atmosphere, (3) recycling SF₆ gas, (4) improving monitoring of equipment for leaks and repairing or replacing leaking units, (5) installing new equipment with lower leak rates, and (6) replacing SF₆ with acceptable substitutes.

¹³ Because the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* reports data in teragrams of CO₂ equivalent (Tg CO₂ Eq.), data should be converted to MTCE by multiplying Tg CO₂ Eq. times 1,000,000 metric tons per teragram times 12/44.

4.12 SULFUR HEXAFLUORIDE EMISSIONS FROM MAGNESIUM PRODUCTION AND PROCESSING

(Note: Section 5.1 presents an alternative method for estimating SF₆ emissions from this source.)

Only two facilities—Utah and Washington—produced primary Mg at the beginning of 2001, and the Washington plant ceased operations by the end of the year.¹⁴ Mg casting firms are found throughout the United States. Castings and wrought magnesium products accounted for 30 percent of U.S. consumption of primary metal in 2001, according to the U.S. Geological Survey (USGS 2002).

The Mg metal production and casting industry uses SF₆ as a cover gas to prevent the violent oxidation of molten Mg in the presence of air. A gas mixture consisting of CO₂, air, and a small concentration of SF₆ is blown over the molten Mg metal to induce the formation of a protective crust. Most producers of primary Mg metal and most Mg part casters use this technique. Sulfur dioxide was previously used for this process, but SF₆ replaced it due to the numerous health and safety risks associated with sulfur dioxide. (The Mg recycling industry, for the most part, continues to employ sulfur dioxide as a cover gas.) Because of the high cost of SF₆, firms in the industry are voluntarily seeking to reduce their use of the gas. In addition, control systems that more accurately regulate the concentration and flow rate of SF₆ over the melt could reduce overall gas usage, as could better process enclosures and capture of the gas.

Emissions from this source are estimated by using emission factors and activity data for Mg metal primary and secondary (recycling) production and casting. Due to technological improvements and emission reduction initiatives in the Mg industry, emission factors have declined since 1990. Information from participants in the SF₆ Emission Reduction Partnership for the Magnesium Industry and a study by Gjestland and Magers (1996) were used to compile the following time series of emission factors for primary and secondary Mg production and die-casting.

To estimate emissions from this source, two steps must be performed: (1) obtain the required data; (2) estimate SF₆ emissions using Mg production and casting data; and (3) convert units to MTCE.

Step (1): Obtain Required Data

- *Required Data.* Data are required for the amount of Mg metal produced in the state, the amount of secondary production or Mg metal recycling in the state, and the amount of Mg metal cast in the state (all in metric tons).
- *Data Sources.* In-state sources should be consulted first. State-specific resources and contacts for Mg metal production and casting may be found on the Internet at <http://minerals.er.usgs.gov/minerals/pubs/state/index.html#contact>. Although the USGS

¹⁴ Demand for Mg metal for die-casting, however, has the potential to expand if auto manufacturers design future vehicle models with more Mg parts.

makes available data on Mg production and casting on the Internet at <http://minerals.er.usgs.gov/minerals/pubs/commodity/magnesium/>, these data are not disaggregated by state.

Example: A hypothetical state might, in a given year, produce **80,000 metric tons** of virgin Mg, **50,000 metric tons** of recycled Mg, and **10,000 metric tons** of cast Mg.

Step (2): Estimate Sulfur Hexafluoride Emissions Using Magnesium Production and Casting Data

- SF₆ Emissions from Mg production and casting can be estimated by multiplying the amount of Mg produced through primary and secondary production in metric tons by the appropriate emission factor listed in Table 6.4-3, and then adding in the product of the amount of Mg cast and the appropriate casting emission factor (also listed in Table 6.4-3).

Total SF₆ emissions = Primary Mg Production (metric tons) x 0.001 metric tons SF₆ emitted/metric ton primary Mg Produced + Secondary/Recycled Mg Production (metric tons) x 0.001 metric tons SF₆ emitted/metric ton Secondary Mg Produced + Mg Cast (metric tons) x 0.0021 metric tons SF₆ emitted/metric ton Mg Cast

Example: To calculate SF₆ emissions by the hypothetical state's Mg industry in the year 2000, perform the following calculation:

80,000 metric tons Mg produced x 0.001 metric tons SF₆ per metric ton + 50,000 metric tons recycled Mg x 0.001 metric tons SF₆ per metric ton Mg recycled + 10,000 metric tons Mg cast x 0.0021 metric tons SF₆ per metric ton Mg cast = **151 metric tons SF₆ emissions**

Table 6.4-3: Magnesium Production and Casting Emission Factors

(metric tons SF₆ emitted/metric ton of magnesium produced or processed)

Year	Primary	Secondary	Casting
1990	0.0012	0.001	0.0041
1991	0.0012	0.001	0.0041
1992	0.0012	0.001	0.0041
1993	0.0012	0.001	0.0041
1994	0.0011	0.001	0.0041
1995	0.0011	0.001	0.0041
1996	0.0011	0.001	0.0041
1997	0.0011	0.001	0.0034
1998	0.0010	0.001	0.0028
1999	0.0010	0.001	0.0021
2000	0.0010	0.001	0.0007
2001	0.0010	0.001	0.0007
2002	0.0010	0.001	0.0007

Step (3): Convert Emissions to Metric Tons of Carbon Equivalent

- For consistency among emissions of all gases, emissions from each source must be converted into a standard unit. As a final step, all emissions must be weighted by the GWP of the emitted gas. In this case, SF₆ emissions are multiplied by a GWP of 23,900, and then converted to C equivalent by using the molecular weight ratio of C to CO₂, or 12/44.

Total SF₆ Emissions from Mg Production (MTCE) = Total SF₆ Emissions from Mg Production (metric tons) x 23,900 x 12/44

Example: To calculate total emissions from Mg production in 2000 in MTCE, perform the following calculation:

$$151 \text{ metric tons SF}_6 \times 23,900 \times 12/44 = \mathbf{984,245 \text{ MTCE}}$$

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

The Greenhouse Gas Committee of the Emission Inventory Improvement Program has approved an alternative method for estimating sulfur hexafluoride (SF₆) emissions from magnesium (Mg) production and processing. The method, which is based on pro-rating national emissions, may be used if state-level data are unavailable.

5.1 SULFUR HEXAFLUORIDE EMISSIONS FROM MAGNESIUM PRODUCTION AND PROCESSING

Background information on SF₆ emissions from Mg production and processing, and the preferred method for estimating SF₆ emissions from this source may be found in Section 4.12. This alternate method estimates these emissions by pro-rating national emissions from Mg production and processing. National production emissions are pro-rated based on the ratio of state production capacity to national production capacity. In states where Mg processing capacity data are not available, national processing emissions are pro-rated based on the ratio of state population to national population.

To estimate emissions from this source, four steps must be performed: (1) obtain the required data; (2) estimate SF₆ emissions from primary Mg production; (3) estimate SF₆ emissions from Mg processing; and (4) estimate total SF₆ emissions from Mg production and processing.

Step (1): Obtain Required Data

- *Required Data.* The required data include (1) national primary production of Mg (metric tons), (2) state capacity for primary Mg production (metric tons), (3) national capacity for primary Mg production (metric tons), (4) total national emissions of SF₆ from primary Mg production and processing (MTCE), (5) state population, and (6) national population.
- *Data Source.* Information on national primary production of Mg as well as state and national primary Mg production capacity is available on the Internet at the following site: <http://minerals.er.usgs.gov/minerals/pubs/commodity/magnesium/>. The site's *Minerals Yearbook and Mineral Commodity Summaries* contain the necessary information in their respective tables.

The USGS does not disclose data on national primary Mg production from 1999 forward to avoid releasing company proprietary data. Therefore, for 1999 and all subsequent years, estimate national primary Mg production by multiplying the national primary production

capacity by 0.854, which represents the ten-year average of the ratio of national primary production to national primary capacity from 1989 to 1998.

National SF₆ emissions may be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004* (U.S. EPA 2004).¹⁵ National and state population data can be found on the Internet at the following sites: <http://eire.census.gov/popest/archives/state/st-99-3.txt> and <http://quickfacts.census.gov/qfd/>. The latter provides the population of the United States in 2000 and access to state population data for 2000, while the former contains data on national and state populations for 1990-1999.

Step (2): Estimate Sulfur Hexafluoride Emissions from Primary Magnesium Production

- Multiply the national primary Mg production by the ratio of state to national primary Mg production capacity, by the primary Mg production emissions factor for the chosen year (available in Table 6.4-3) to estimate SF₆ emissions from primary Mg production, by the mass ratio of C to CO₂ and by the GWP for SF₆ (23,900).

State SF₆ Emissions from Primary Mg Production (MTCE) = National Primary Production of Mg (metric tons) x State Primary Mg Production Capacity (metric tons) / National Primary Mg Production Capacity (metric tons) x 0.0011 metric ton SF₆ emitted/metric ton Mg produced (specific to 1998, for other years see Table 6.4-3) x 12/44 x 23,900

Example: To calculate 1998 SF₆ emissions from Mg production for Utah, perform the following calculation:

National primary Mg production of 106,000 metric tons x (40,000 metric tons Utah primary Mg production capacity / 145,000 metric tons national primary Mg production capacity) x 0.001 metric ton SF₆ emitted/metric ton Mg produced x 12/44 x 23,900 = **190,601 MTCE**

Step (3): Estimate Sulfur Hexafluoride Emissions from Magnesium Processing

- Subtract the national SF₆ emissions arising from Mg production from national SF₆ emissions produced by Mg production and processing to estimate national SF₆ emissions from Mg processing. National primary production of Mg needs to be multiplied by the emission factor, the mass ratio of C to CO₂, and the GWP of SF₆ (23,900).

¹⁵ Because the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* reports data in teragrams of CO₂ equivalent (TgCO₂E), data should be converted to MTCE by multiplying TgCO₂E times 1,000,000 metric tons per teragram times 12/44.

National SF₆ Emissions from Mg Processing (MTCE) = National SF₆ Emissions from Mg Production and Processing (MTCE) - [National Primary Production of Mg (metric tons) x 0.001 metric ton SF₆ emitted/metric ton Mg produced (specific to 1998, for other years see Table 6.4-3) x 12/44 x 23,900]

Example: To calculate 1998 national SF₆ emissions from Mg processing, perform the following calculation:

1.7 million MTCE national SF₆ emissions from Mg production and processing
 – [national primary Mg production of 106,000 metric tons x (0.001 metric ton SF₆ emitted/metric ton Mg produced) x (12/44) x 23,900] = 1.7 million MTCE
 – 0.7 million MTCE = **1.0 million MTCE**

- Multiply the national Mg processing SF₆ by the ratio of state to national population to estimate SF₆ emissions from Mg processing for the state.

State SF₆ Emissions from Mg Processing (MTCE) = National SF₆ Emissions from Mg Processing (MTCE) x State Population (people) / National Population (people)

Example: To calculate Utah's SF₆ emissions from Mg processing, perform the following calculation:

1.0 million MTCE national SF₆ emissions from Mg processing x (2,100,562 people / 270,248,003 people) = **7,773 MTCE**

Step (4): Estimate Total Sulfur Hexafluoride Emissions from Magnesium Production and Processing

- Sum the state emissions of SF₆ from Mg production and state emissions of SF₆ from Mg processing to determine total state emissions of SF₆ from Mg production and processing.

State SF₆ Emissions from Mg Production and Processing (MTCE) = State SF₆ Emissions from Primary Mg Production (MTCE) + State SF₆ Emissions from Mg Processing (MTCE)

Example: To estimate SF₆ emissions from Mg production and processing in Utah, perform the following calculation:

190,601 MTCE SF₆ + 7,773 MTCE SF₆ = **198,374 MTCE**

UNCERTAINTY SUMMARY

This chapter details the methodology for calculating greenhouse gas emissions from industrial processes. In particular, the chapter covers cement production, lime manufacture, limestone and dolomite use, soda ash manufacture and use, nitric acid production, adipic acid production, aluminum production, HCFC-22 production, the use of substitutes for ozone-depleting substances, semiconductor manufacture, sulfur hexafluoride use in electrical power systems, and magnesium production and processing. This section highlights the major sources of uncertainty associated with the methodologies for calculating emissions from each of these sources. Further details on uncertainties associated with estimating emissions from the industrial processes sector can be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002* (U.S. EPA 2004).

- The greatest uncertainty associated with calculating emissions from cement manufacture is the variance in the portion of calcinated cement kiln dust and the percentage of clinker constituted by lime.
- Uncertainty in emissions from lime manufacture relates to the variable chemical composition of lime (different manufacturers produce limes with differing amounts of trace impurities) and the possibility that carbon dioxide reabsorption could occur during the consumption of lime by the steel industry (the largest lime consumer).
- The estimation of emissions for limestone and dolomite use contains some inherent uncertainty based on limestone's variable composition.
- The low uncertainty associated with the calculation of emissions from soda ash manufacture and consumption is based on the variance in emissions by end-use.
- Uncertainty in emissions from nitric acid production is high for two reasons: the effect of abatement measures on N₂O emissions differs among plants, and the nitric acid plants are often part of larger production facilities, which undermines the accuracy of production figures.
- The estimation of emissions from adipic acid production contains inherent uncertainty from the use of an old emission factor based on industrial emission replications and the use of plant production capacity data that over-estimate production levels.
- Aluminum production is a relatively well-studied emission category, but the method for states introduces some uncertainty by applying a national-scale emission factor and national-production-capacity ratio to a given state.

- Uncertainty is inherent in the calculation of emissions from the HCFC-22 production because the emission factor actually varies over time.
- Although the model used to generate national emission estimates from the consumption of ozone depleting substances substitutes is comprehensive, significant uncertainties exist and are exacerbated by the use of population to disaggregate national emissions.
- The uncertainty associated with emissions from semiconductor manufacture is primarily based on the inherent uncertainties in the national emissions.
- Uncertainties in emission estimates for electric power transmissions and distribution can be attributed to apportioning national emissions based on electricity sales because this method incorporates a low probability assumption that various industry emission reduction practices occur evenly throughout the country.
- The inherent uncertainty in the magnesium production and processing emissions calculation lies in the assumption that the SF₆ cover gas is not degraded.

7

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