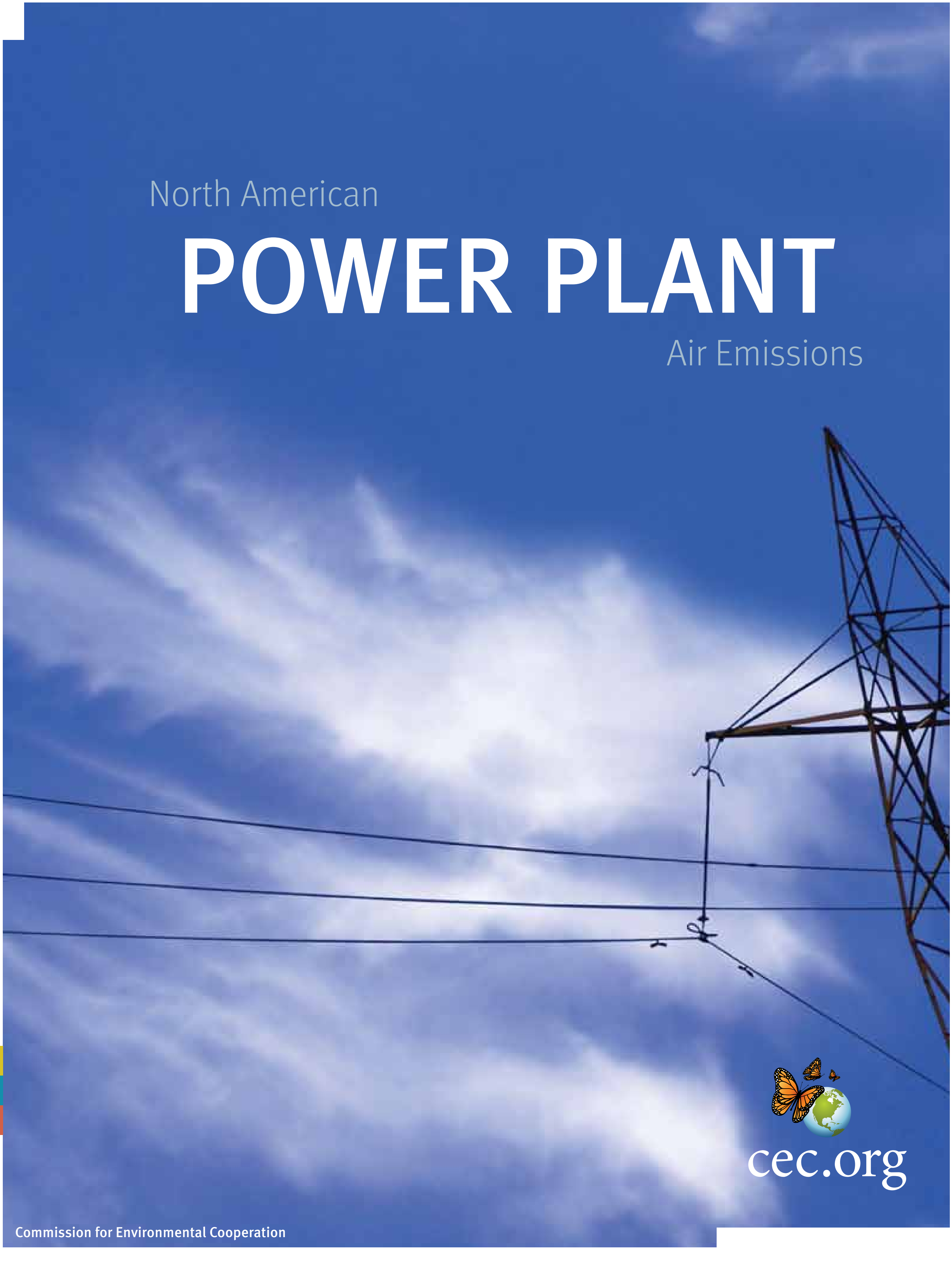

North American

POWER PLANT

Air Emissions

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North American

POWER PLANT

Air Emissions

Preface

The environmental costs and consequences of energy production are central to the discussion of sustainable development in North America. Regardless of the environmental issue—greenhouse gas emissions, air quality, mercury concentrations, or the long-range transport of pollutants—understanding the nature and impact of electricity generation from the burning of fossil fuels is fundamental to making informed decisions in our pursuit of cleaner and more efficient energy options.

A hallmark of the Commission for Environmental Cooperation is the compilation and provision of valuable and comparable information on the core environmental issues facing North America.

North American Power Plant Air Emissions builds upon the first-such CEC assessment (published in 2004) that compiled information on emissions of criteria air pollutants, mercury, and carbon dioxide from power plants in North America for the year 2002. For the first time, data on the release of air pollutants from power plants burning fossil fuels were brought together from different national sources, varying greatly in terms of completeness and accessibility, into one format offering comparable information on fossil fuel power plant emissions in North America.

Both the present report and its predecessor stem from a commitment of the CEC Council to promote the comparability of air emissions inventories in North America, and specifically calling upon the CEC to produce periodic reports summarizing available information from North American air emissions inventories.

This report reflects the ongoing collaboration of Canada, Mexico and the United States to examine the contribution of fossil fuel power plant air emissions to pollution across the region. It presents, in condensed form, updated and publicly available information on the release of specific air pollutants, including greenhouse gases, from individual fossil-fuel power plants across North America.

The scope and level of information on power plants have increased since the publication of the first report. Accordingly this edition presents data for emissions of additional pollutants, including methane, nitrous oxide and particulate matter, as well as more complete coverage of carbon dioxide and mercury emissions. It also includes data from a larger number of facilities per country and thus offers a more complete picture of power plant air emissions across North America. In addition, the complete integrated dataset used in the report can be accessed online at www.cec.org/powerplants.

These latest data, along with information available through other sources, indicate that overall emissions across the region from fossil fuel electricity generating facilities have not changed significantly since the first power plant report. These types of power plants continue to be important sources of emissions of criteria air contaminants, greenhouse gases, and other pollutants of concern. This publication is therefore of relevance to the ongoing discussions concerning this important North American sector. It provides a strong basis for continued work in the areas of harmonizing data on emissions of greenhouse gases and other power plant emissions of concern, such as mercury, and highlights areas for further action to manage and reduce these emissions.

In related efforts, the Commission for Environmental Cooperation is supporting trilateral initiatives such as the North American PRTR Project, which tracks pollutant releases and transfers from industrial facilities, including fossil fuel power plants. These data are presented and analyzed in the annual *Taking Stock* report and are also made accessible via an integrated, online database at www.cec.org/takingstock. The CEC is also working with officials in each of our three countries to complete an assessment of the comparability of GHG emissions inventories, including black carbon inventories, to strengthen climate policy cooperation at a regional scale in support of the CEC Council's 2010–2015 priority, *Climate Change–Low-Carbon Economy*.

We trust this publication and the associated online information will lead to an improved understanding of North American power plant emissions and their associated environmental and human health impacts, at both local and regional levels, and support decision-making relative to reducing and preventing pollution from this sector.

Evan Lloyd
Executive Director

Acknowledgements

The Commission for Environmental Cooperation (CEC) would like to thank Luisa Manzanares Papayanopoulos, Arturo Keer Rendón and Emilio Manzanares Papayanopoulos, the principal authors of this publication. The full breadth of this report would not have been possible without their expertise and tireless efforts in bringing together and making sense of data and statistics on power plants in the three countries—information obtained from a wide variety of sources, and available in very different formats and levels of detail. The CEC also recognizes the valuable support of Claudia Márquez Estrada and Alberto Cruzado in the compilation of the electricity sector portion of Mexico's National Emissions Inventory. The CEC also wishes to acknowledge the diligent oversight and expert contribution of Orlando Cabrera-Rivera, CEC Program Manager for Air Quality/Pollutant Releases, throughout the development of this report. Other individuals were also instrumental in providing information and expert review for this report; they include:

- Members of the CEC's North American Air Working Group
- Officials from the United States Environmental Protection Agency, Air and Radiation Division
- Officials from Environment Canada, Pollutant Inventories and Reporting Division; Air Emissions Priorities Division; and Electricity and Combustion Division
- Officials from Mexico's Secretariat of Environment and Natural Resources (Semarnat), Directorate of Air Quality and Pollutant Releases and Transfers (DGCARETC).
- Nancy Southern (Canadian member of the CEC's Joint Public Advisory Committee)

Leifa Communications, along with Keith Powell and Jean-Sébastien Goulet of the CEC Secretariat's IT staff, were instrumental in developing the NAPPAE website: www.cec.org/powerplants. This site provides access to an electronic version of the report, related information, as well as the integrated dataset used in the development of the report.

And finally, the CEC wishes to thank various members of the CEC Secretariat involved in bringing this project to fruition, including Danielle Vallée, Coordinator of the North American PRTR project; the publications staff of Douglas Kirk, Jacqueline Fortson, and Johanne David, under the guidance of Jeffrey Stoub; and Zakir Jafry, CEC consultant, for his work on creating the maps used in the report. Gray Fraser, of ProductionGray, designed the report layout.

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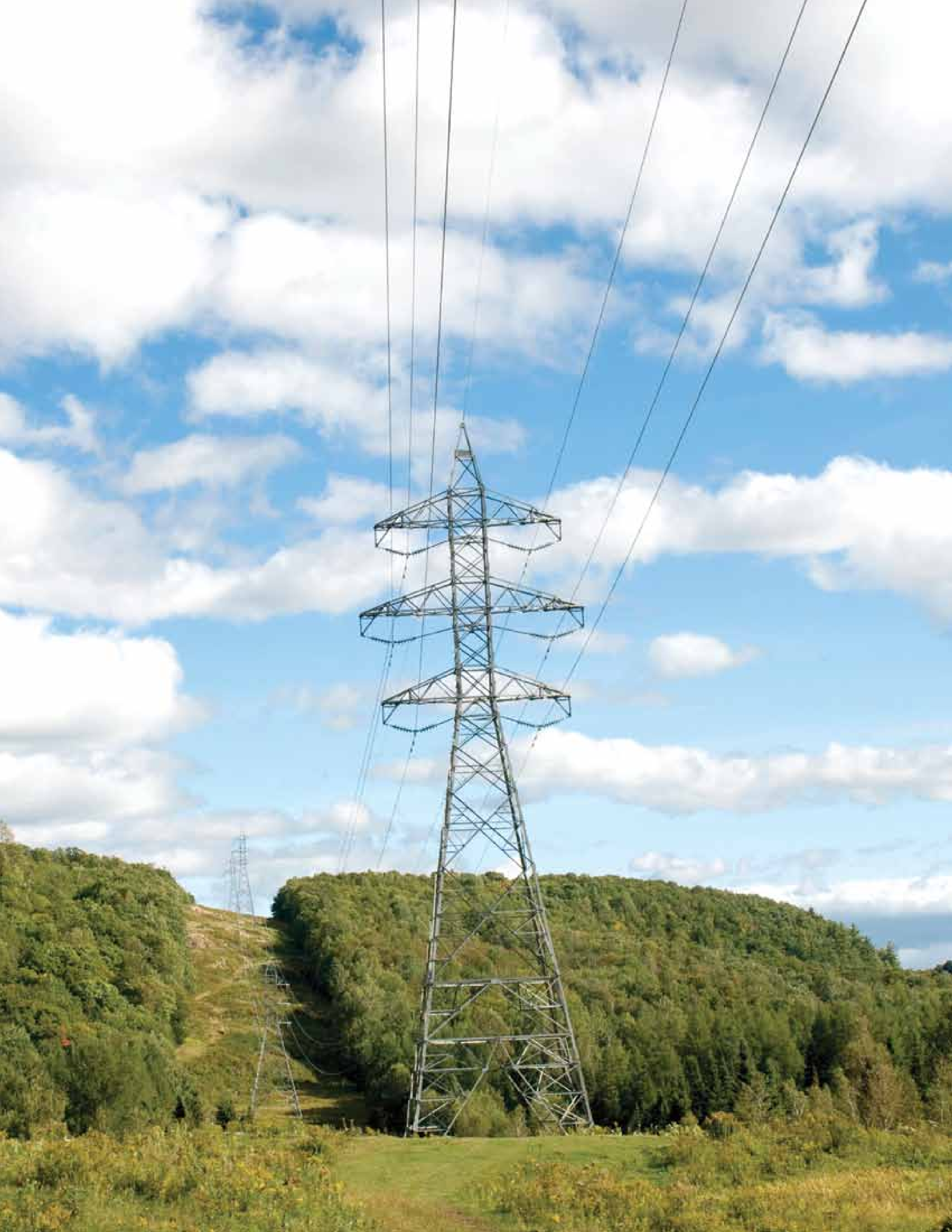


Abbreviations and Acronyms

AP-42	Compilation of US EPA Air Pollutant Emission Factors
BTU	British Thermal Unit
CACs	Criteria Air Contaminants
CCME	Canadian Council of Ministers of the Environment
CEC	Commission for Environmental Cooperation
CEM	Continuous Emissions Monitoring
CERR	Consolidated Emissions Reporting Rule, United States
CFCs	chlorofluorocarbons
CFE	*Comisión Federal de Electricidad* (Federal Electricity Commission), Mexico
CH_4	methane
COA	*Cédula de Operación Anual* (Annual Report of Operation), Mexico
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-eq	carbon dioxide-equivalent
CRE	*Comisión Reguladora de Energía* (Energy Regulatory Commission), Mexico
CWS	Canada-wide Standards
DNA	deoxyribonucleic acid
eGRID	Emissions and Generation Resource Integrated Database, United States
eGRID2007	eGRID database for 2005 data year, Version 1.1, released in January 2009
EGUs	Electric Generating Units, United States
EIA	Energy Information Administration, United States
EIAG	Emission Inventory and Analysis Group, United States (EPA)
EPA	Environmental Protection Agency, United States
ETS	Emissions Tracking System, United States
FERC	Federal Energy Regulatory Commission, United States
GDP	Gross Domestic Product
GHGRP	Greenhouse Gases Emissions Reporting Program, Canada
GHGs	Greenhouse gases
GW-h	gigawatt-hour
GWP	Global Warming Potential
Hg	mercury
HNO_3	nitric acid
H_2SO_4	sulfuric acid
IEA	International Energy Agency
INEM	*Inventario Nacional de Emisiones de México* (National Emissions Inventory of Mexico)
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
kg	kilograms

kt	kilotonnes
kW-h	kilowatt-hour
LyFC	*Compañía de Luz y Fuerza del Centro* (Central Light and Power Company), Mexico
MJ	megajoules
Mt	megatonnes
MW	megawatt
MW-h	megawatt-hour
NAICS	North American Industry Classification System
NAPPAE	North American Power Plant Air Emissions Report
NEI	National Emissions Inventory, United States
NIH	National Institutes of Health, United States
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	nitrogen oxides [the sum of nitric oxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2]
N_2O	nitrous oxide
NPRI	National Pollutant Release Inventory, Canada
OECD	Organisation for Economic Co-operation and Development
PM	particulate matter
$PM_{2.5}$	Mass of particles with an aerodynamic diameter less than 2.5 microns
PM_{10}	Mass of particles with an aerodynamic diameter less than 10 microns
ppb	parts per billion
ppm	parts per million
RFO	Residual fuel oil (also: Heavy fuel oil)
Semarnat	*Secretaría de Medio Ambiente y Recursos Naturales* (Secretariat of Environment and Natural Resources, Mexico)
Sener	*Secretaría de Energía* (Secretariat of Energy, Mexico)
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_X	sulfur oxides
t	metric tonnes (tonnes)
Tg	teragrams
TPM	Total Particulate Matter
TW-h	terawatt-hour
VOCs	Volatile Organic Compounds
°C	degree Centigrade

Useful Conversion Tables

Energy				
Basic Unit	Joule	J		
Electricity consumption	Watt-hour	Wh	3600	J
British units system	Bristish thermal unit	Btu	1,055.056	J
Mass				
Basic unit	gram	g		
Metric tonne	tonne	t	1,000,000	g
Power				
Basic unit	Watt	W	1	J/s

Common Unit Prefixes		Multiply by
k	kilo	$1x10^3$
M	mega	$1x10^6$
G	giga	$1x10^9$
T	tera	$1x10^{12}$
Global Warming Potential		**CO_2 equivalent**
CO_2	Carbon dioxide	1
CH_4	Methane	21
N_2O	Nitrous oxide	310

Greenhouse gas emissions are usually reported in terms of equivalent mass of CO_2, i.e., the equivalent amount of CO_2 that would be required to produce a similar warming effect in a hundred-year time-frame. The carbon dioxide equivalent (CO_2-eq) value is thus calculated by multiplying the amount of the gas emitted by its associated global warming potential (GWP). For example, the 100-year GWP for methane (CH_4) is 21. Therefore, the CO_2-eq of an emission of 3 tonnes (3 t) of methane equals 21 x 3 t = 63 t CO_2-eq.

Sharyland Utilities Grid Interconnector,
which allows electric power exchange between the state power grid of Texas and the national power grid of Mexico

Introduction

The fossil fuel electricity generation sector is an important component of North America's economy and provides an indispensable commodity. However, this sector is one of the major contributors to atmospheric pollutants in the region, including criteria air contaminants such as sulfur dioxide, nitrogen oxides, and particulate matter; and greenhouse gases such as carbon dioxide and methane. Depending on the fuel used, power plants can also release trace metals such as mercury. There is growing concern about the effects of these pollutants on our local and global environments.

Each of the three North American countries has a unique profile involving private and/or public ownership of electric utilities, combinations of electricity generation technologies, and differences in fuel availability and usage. Interdependencies also exist among and within the three countries, not only in terms of electricity imports and exports to meet energy demand, but also in terms of the production and management of power plant emissions.

Because of these interdependencies, communities and governments across North America can benefit from adopting a regional approach and collaboratively exploring ways to minimize pollution from this sector. The Commission for Environmental Cooperation of North America (CEC) Council directive to promote greater exchange of environmental information of interest to the region led to the adoption of Council Resolution 01-05 (29 June 2001) to promote the comparability of air emissions inventories in North America. In the resolution, the Council called upon the CEC to produce periodic reports summarizing publicly available information from North American air emissions inventories, including greenhouse gases. The 2007 CEC Ministerial Statement reasserted this directive.

In 2004 the first "North American Power Plant Air Emissions" (NAPPAE) report [1] was released in which publicly available data on criteria air pollutants from power plants in North America for base year 2002 were compiled. That report was a North American milestone on the road to supporting trinational decision-making for reinforcing energy linkages among the three countries. The present report is a continuation of this ongoing effort by the CEC. Its aim is to present, in condensed form, updated, publicly available information on the release of specific air pollutants and greenhouse gases from individual plants burning fossil fuels for electricity generation in North America, in order to improve the data collected and increase the comparability and public availability of North American environmental information.

Photo: Courtesy of ABB

The most recent year for which data from the three countries were available at the time of writing was 2005; therefore, all the information presented in this report is for 2005 unless otherwise specified. Only public information on facilities' installed capacity, electricity generation, technologies utilized, and fuels burned is presented; in the absence of available data and where possible, estimates are calculated based on surrogate public information. The scope and level of information of the present report have increased since the 2004 edition, due to the recent availability of public data for emissions of methane (CH_4), nitrous oxide (N_2O) and particulate matter (PM). These were unavailable for the previous report, which was limited to the analysis of data for emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_X), mercury (Hg) and carbon dioxide (CO_2). The present report also covers a larger number of facilities than were included in the 2004 report, thereby offering a more complete picture of the contribution of each country to power plant air emissions across North America. Emissions and operational information on the facilities included in this report can be accessed through the CEC website at www.cec.org/powerplants.

Through the presentation and analysis of the latest available data on the sources, types and amounts of pollutants generated in each of the three countries, this report can improve our understanding of North American power plant emissions and their associated environmental and human health impacts for the region, and support decision-making relative to reducing and preventing pollution from this sector.

1. Overview of the Electric Power System in North America

1.1. Organization and Structure of the Electric Power System

The electric power system in North America is generally composed of three major subsystems: generation, transmission, and distribution (see **Figure 1.1**). Generation is the process whereby electricity is produced from other types of energy or processes that liberate energy; transmission is the process of conveying the electric energy from power plants to the distribution areas; and distribution comprises the local system of low voltage lines, substations and transformers utilized to deliver the electricity to its final consumers. A fraction of the electric energy generated is lost during transmission and distribution.

The most important contribution to emissions of criteria air pollutants (hereafter referred to as criteria air contaminants—CACs) from the electric power system in North America occurs during the generation stage. Electricity is generated from different energy sources. Nuclear and hydroelectric generation technologies are clean with respect to air emissions. Canada is exceptional in this respect for its great hydrological potential; therefore, the contribution from its electricity generation sector to the emissions of CACs is smaller than in the other two countries. However, electricity generation by such clean technologies is insufficient to satisfy demand, and therefore the use of fossil fuel combustion processes is required.

Figure 1.2 shows that generation from nuclear and hydroelectric power plants in North America accounts for only about one-third of the total generation in the region, with the rest having to be generated from fossil fuels. Analyses carried out by the OECD and the IEA reveal that fossil fuels are the main energy sources used for electricity generation in North America [3, 4].

The types of fossil fuels commonly used in North American power plants include coal, heavy (residual) fuel oils, and natural gas, along with "other fuels," such as liquefied petroleum gas, diesel, and coke. Each country uses these fuels in varying proportions depending on their availability,

Figure 1.1 Electric Power System in North America [2]

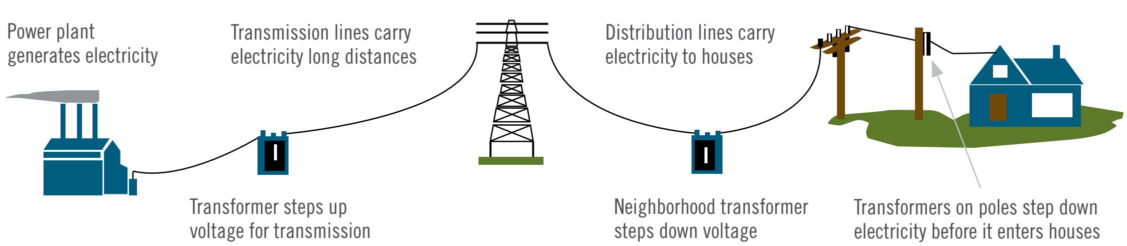
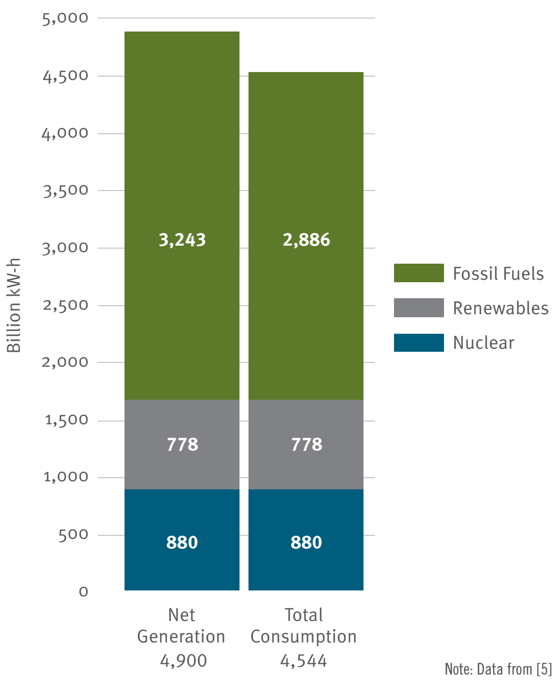


Figure 1.2 North American Total Net Generation and Electricity Consumption and for 2005



Note: Data from [5]

the electricity-generating infrastructure, and so on. Section 3 provides additional details about the characteristics of these fossil fuels.

The current technology used to convert the energy stored in fossil fuels to electricity essentially relies on burning the fuel. It is in this process that air pollutants are generated. How and how much of these pollutants are generated depend on the way the fuels are burned, on the fuels themselves, and on the way the energy released during the burning process is converted to electricity. Throughout North America different kinds of electricity generation systems are used, the most common of which are steam turbines, gas turbines and internal combustion engines, but also combined cycle units as well as cogeneration (or combined heat and power) units. These technologies, along with information about available power plant pollution control technologies, are described in greater detail in Section 3.

1.1.1 Canada

In 2005, the Canadian electric infrastructure was to a large extent under provincial jurisdiction [6] and comprised generation, transmission and distribution. Provincial authorities exercised their jurisdiction through Crown utilities[1] and provincial regulatory agencies. Historically, electricity was supplied by vertically-integrated electric utilities that were often Crown corporations with monopoly rights. At the end of the 1990s, the structure of the industry changed as most provinces began to separate the generation, transmission, and distribution functions into different organizations. Some provinces even allowed participation of the private sector as independent power producers.

At the federal level, Canada's National Energy Board exercised jurisdiction over electricity exports and international and designated interprovincial power lines, whereas the Canadian Nuclear Safety Commission had authority over the nuclear energy sector. The federal government supported research, development and commercialization of emerging technologies, including nuclear.

Electricity in Canada was mainly generated by hydroelectric facilities or nuclear and thermal plants, these last powered by fossil fuels such as coal, oil and natural gas. There was a total of 979 power plants operating in Canada in 2005. Of these, 503 were hydroelectric, 419 were conventional thermal power plants, 49 were wind powered, 7 were nuclear, and one was a tidal-powered plant. Canada was the largest hydroelectric producer for many years. In 2005, Canada had access to about 7% of the world's water flow [7], and was therefore ranked second in the world for hydroelectric power generation, after China. Canada was situated in 2005 among the top 10 electricity producers worldwide, contributing 3.4% of the global electricity production [8].

According to Statistics Canada [9,10], from 2002 to 2005, Canada's total installed capacity had increased by 5.7%, for a total of 121,482 MW, while the net generation of electricity increased by only 4%, reaching 604,500 GW-h. Hydroelectricity continued to be the main type of electricity generation in Canada in 2005, producing 358,446 GW-h (59% of the national total), followed by conventional steam plants with 130,320 GW-h (21.5%) and nuclear sources with 86,830 GW-h (14%). Therefore, approximately 74% of the electricity generated in Canada in 2005 was obtained by processes with no air pollutant emissions [9, 10].

1. Crown utilities refer to those facilities owned by federal or provincial governments and structured like private or independent enterprises. These utilities enjoy greater freedom from direct political control than government departments.

Within the 21.5% of Canada's total electricity generated in 2005 by electric utility thermal plants using fossil fuels, the burning of coal predominated, followed by natural gas and petroleum, with 66.4%, 21.8% and 7.8%, respectively [9].

From 2002 to 2005, electricity production from hydro and nuclear plants increased by 3.5% and 21.9%, respectively, while production from conventional steam plants decreased by 8.0%. The provinces of Quebec and Ontario together contributed approximately 56% of the total electricity generation in Canada in 2005 [9, 10].

1.1.2 Mexico

Unlike Canada, in 2005 the electricity infrastructure in Mexico was under federal jurisdiction, controlled by two state companies: *Comisión Federal de Electricidad* (CFE) and *Compañía de Luz y Fuerza del Centro* (LyFC). Both companies performed similar activities, including generation, transmission and distribution of electricity, but the latter serviced the central region of the country, including Mexico City, the State of Mexico, and some municipalities of Morelos, Tlaxcala and Puebla; whereas the former serviced the remainder of Mexican territory.

In 1992, private investment was allowed in the electricity generation sector; however, it was not until June 2000 that the first independent power producer (IPP) started operations [11]. These independent power producers were not allowed to sell electricity directly to end consumers but rather had to sell their production to CFE or export it. Together, CFE, LyFC and IPPs integrate the public electricity system, while the private sector covers self-supply and small-scale generation (≤30 MW) [12]. A list of privately-owned power plants authorized to operate in 2005 by the *Comisión Reguladora de Energía* (CRE) can be found at the CEC website, www.cec.org/powerplants.

In 2005, the public electric power infrastructure comprised 173 power plants (CFE, LyFC, and IPPs), with an installed capacity of 46,534 MW. The total installed capacity was divided as follows: 27.8% corresponded to oil- or gas-fired power plants, 28.5% to combined cycle, 22.6% to hydro plants, 5.6% to coal-fired power plants, 4.5% to dual-fired plants, 2.9% to nuclear technology, 2.1% to geothermal plants, 6% to combustion turbines and internal combustion (see Section 3 for a description of fossil fuel electricity generation technologies) and a very small percentage to aeolic (wind) energy. According to official data from the *Secretaría de Energía* (Sener) [13, 14], nearly 18% of the installed capacity within the public sector was owned by independent power producers; 13.2% more than in 2002. Most of this increment was due to the construction of 9 power plants by IPPs. The total national installed capacity, which includes both public and private sectors, was 53,858 MW in 2005. In terms of percentage ownership of the installed capacity, CFE and LyFC owned 69.5% and 1.6%, respectively, with IPPs owning 15.3%. Within the private sector, self-supply, cogeneration, and export contributed 7.3%, 2.8% and 2.5%, respectively. This report considers only the public sector because data from most of the privately owned power plants are not reported in detail to the authorities.

In 2005, the gross generation of electricity was 248,079 GW-h [14], to which CFE and LyFC together contributed 69.2%, IPPs 19.1%, and self-supply, cogeneration, export and others, 5.8%, 2.9%, 2.5% and 0.6%, respectively. The public sector's net electricity generation was 208,379 GW-h [14]. However, private sector self-supply and cogeneration concessionaires had increased their share of the overall production by 2005 and owned a significant share of the installed capacity within the national electric system.

In 2005, electricity generation in Mexico was still based on fossil fuels, which contributed approximately 72.4% of total production—with about 43.2% of this generated by the burning of natural gas, 32.7% from burning oil, and the rest from burning coal and other fuels (mainly diesel).

1.1.3 United States

The electric power industry in the United States is composed mainly of "traditional" electric utilities, legal entities that, along with distribution facilities, have the core purpose of delivering electricity to the public. Electric utilities can be investor-owned, municipal, state or federal utilities, as well as rural electricity cooperatives. The US electricity sector also comprises non-traditional participants, such as energy service providers, power marketers, independent power producers, and combined heat and power plants.

In 2005, there were 3,133 electric utilities and 2,800 non-traditional participants, operating a total of 16,807 electricity generating units, of which 81.42% were in the Electric Power sector—that is, electric utilities and independent power producers—

with the rest in the Combined Heat and Power sector. Both sectors provided a total installed capacity of 1,067,010 megawatts [15, 16].

According to data reported by the United States Department of Energy [15, 16], it is estimated that the net generation of electricity increased by 4.8% from 2002 to 2005, reaching 4,055 billion kW-h. The average annual rate of increase for the 12-year period from 1994 to 2005 was 2%. During the same period, approximately 20% of the total electricity generation was provided by nuclear generation, while 65 to 68% of the total net generation was produced by coal and natural gas. The contribution of electricity generated by natural gas increased from 14.2% of the total in 1994 to 18.7% in 2005, whereas the share of coal-fired generation to the total decreased from 52.1% in 1994 to 49.7% in 2005. The decline in the contribution of coal to electricity generation reflects the fact that capacity additions in this period were preferentially natural gas-fired electricity generating units, especially since 2000.

Net generation from hydroelectric plants increased from 256 billion kW-h in 2002 to 270 billion kW-h in 2005 [15, 16]. However, despite this 5.46% increment, hydroelectric generation in 2005 was lower than the observed peak in the preceding decade, when it reached 356 billion kW-h in 1997. The relatively low hydroelectricity production has been attributed to the severe droughts experienced in the western United States from 1999 until 2004 [17]. Other renewable energy sources (biomass, wind, geothermal and solar technologies) contributed 2.3% of the total generation, with biomass comprising the majority of this. The share of wind generation was 17.8 billion kW-h, nearly 19% of the total generated by all renewable energy sources combined.

Petroleum contributed 3% of the United States' electric generating capacity in 2005, producing 123 billion kW-h, while generation from other gaseous fuels (e.g., refinery gas, blast furnace gas) and other miscellaneous sources accounted for the remainder of electricity generation.

In summary, coal, nuclear and hydroelectric generating capacity in the United States remained relatively unchanged over the decade ending in 2005, while the installed capacity for natural gas and other renewable energy sources increased considerably.

1.2 North American Power Plants and Their Impacts

1.2.1 Climate Change

The earth's climate has suffered through many changes over time, with events ranging from ice ages to warm, interglacial periods (such as the present era) documented. However, the most rapid warming period observed has occurred in recent decades and scientists from the Intergovernmental Panel on Climate Change (IPCC) [18, 19] have determined that there is a greater than 90 percent chance that most of the current warming is due to the increases in greenhouse gas (GHG) emissions caused by human activities, with the increase in global average temperatures resulting in severe effects on the Earth's climate.

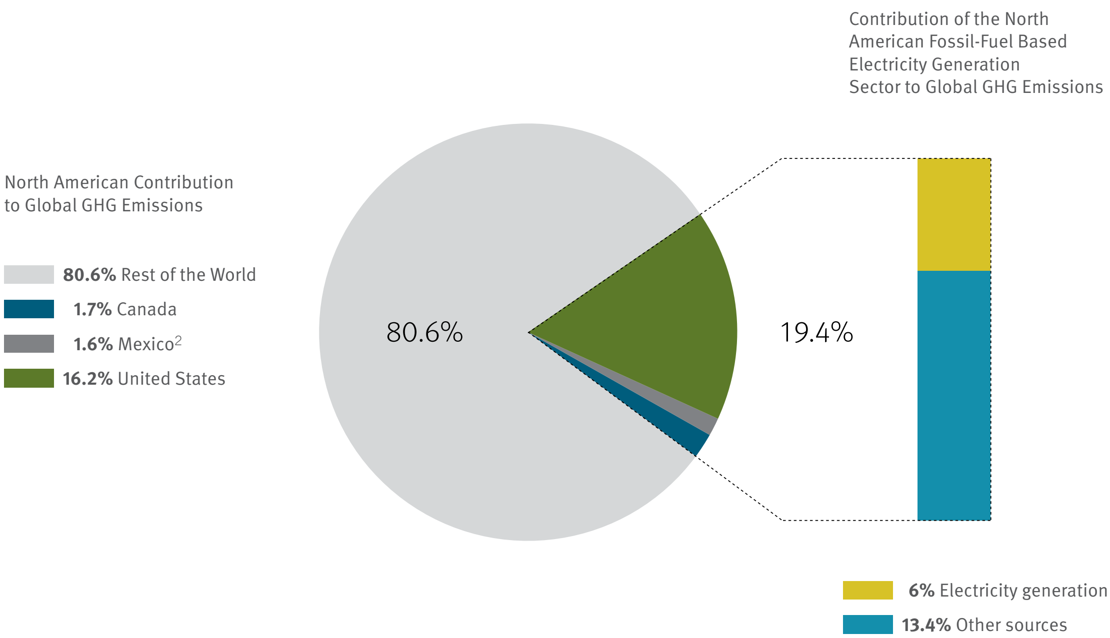
Data reported by the IPCC show that the concentration of atmospheric CO_2 has increased from a pre-industrial age value of approximately 280 to 379 ppm in 2005 (see **Table 1.1**), with emissions from fossil fuel combustion being the main source of this greenhouse gas. The energy sector is central to this, accounting for over 60% [20] of the world's greenhouse gas emissions. As indicated in Section 3.3.5, the energy sector generates emissions of all the principal GHGs and, in particular, carbon dioxide, methane and nitrous oxide, throughout the whole fuel life-cycle, from extraction to combustion. Emissions of GHGs also depend on external factors, such as weather conditions, economic growth, and fuel prices, among others.

According to data from the International Energy Agency [8], in 2005 the United States ranked first in CO_2 emissions from fuel combustion, while Canada and Mexico were seventh and twelfth, respectively. North America was therefore one of the major contributors of greenhouse gases in the world. **Figure 1.3** shows that the contribution of North America to global GHG emissions was 19.4% that year. Canada

Table 1.1 Concentration of the Most Abundant GHGs and Their Variation since 1998

GHG	Concentration in 2005	Change in Concentration since 1998
CO_2	379 ± 0.65 ppm	+ 13 ppm
CH_4	1,774 ± 1.8 ppb	+ 11 ppb
N_2O	319 ± 0.12 ppb	+ 5 ppb

Figure 1.3 North American Contribution to Global GHG Emissions from All Six IPCC Categories in 2005



Note: Six percent of global GHG emissions were from fossil–fuel-based electricity generation in North America [graph created with data from the national GHG inventories [22, 23, 24] and estimates from World Resources Institute [21].

and Mexico each contributed less than 2% and the United States contributed 16%. GHG emissions from electricity generation using fossil fuels in North America accounted for 6% of the global GHG emissions in 2005. Data in this figure were compiled based on the six major IPCC categories (energy, industrial processes, solvent use, agriculture, land-use change and forestry, and waste); and the global GHG emissions estimate from the World Resources Institute [21].

Figure 1.4 shows CO_2 emissions per capita for 1990–2007 from fossil fuel-based electricity generation in North America. The emissions data used to create this graph were taken from the GHG emissions inventory reports of each country [22, 23, 24]. A slight decreasing trend is observed after year 2000 in all three countries but the data also suggest that per capita emissions increased from 1990 to 2000. The per capita CO_2 emission values estimated on the basis of the 2005 data used for the present report were 3.75, 1.12 and 8.07 t/capita for Canada, Mexico and the United States, respectively; these are in close agreement with the values shown in this figure.

1.2.2 Canada

In the period from 1990 to 2005, total national GHG emissions increased by 23.5% [22]. In 2005, Canada contributed 2% of the total worldwide emissions of GHGs, but it was one of the highest per capita emitters, with 22.7 t CO_2-eq of GHGs per capita. However, a slight reduction of 1.3% in GHG emissions was observed between 2004 and 2005. Among all the greenhouse gases, CO_2 comprised the largest portion of Canada's emissions from all GHG sources, with 78% [22].

2. Data for Mexico are for 2006 (see footnote 4).

3. GDP taken at current prices, current Purchasing Power Parities (PPPs), 2005 US dollars (US$). OECD. http://stats.oecd.org/Index.aspx. Consulted 18 February 2011.

As in Mexico and the United States, energy-related activities, such as stationary combustion sources, transport, mining, and oil and gas exploration activities generated by far the largest portion of GHG emissions in Canada, with 81% of the total. Electricity generation (including utilities and industry) contributed 17% of that total, with CO_2 accounting for over 99% of the GHG emissions from this sector [22]. Per capita CO_2 emissions from electricity generation in 2005 were 3.85 t CO_2 (see **Figure 1.4**), whereas the per capita share of CO_2 emissions per Gross Domestic Product (GDP) was 110 g/US$.[3]

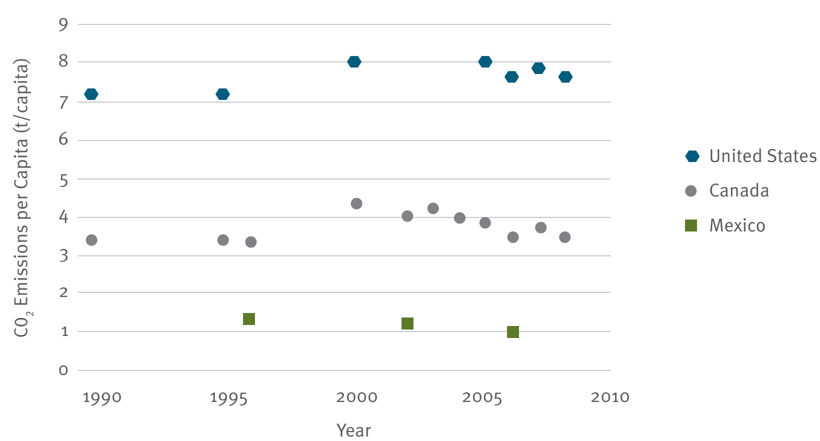
1.2.3 Mexico

In the period from 1990 to 2006, Mexico's GHG emissions increased by about 40%, at an average annual rate of 2.1%. In both 2005 and 2006,[4] Mexico ranked twelfth in the world in CO_2 emissions from fuel combustion processes [8]. As shown in **Figure 1.3**, Mexico's contribution to global GHG emissions was similar to Canada's. Mexico's GHG per capita emissions in 2006 were approximately 6.76 t CO_2-eq, for a total of 709 Mt CO_2-eq [23], of which 69.5% were emissions of CO_2. The major contribution to total GHG emissions was from energy-related activities (60.7%), with the electricity generation sector accounting for 26.1% of these emissions. Within the energy sector, transportation and electricity generation were responsible for major emissions of CO_2, with a contribution to total CO_2 emissions of 27.2 and 22.8%, respectively [23]. Emissions of CO_2 accounted for 99.8% of the GHG emissions from the electricity generation sector. Per capita emissions of CO_2 from the same sector were 1.07 t (see **Figure 1.4**), whereas CO_2 emissions per capita per GDP were 78 g/US$.[5]

1.2.4 United States

In the 1990–2005 period, emissions of GHGs in the United States increased by about 16%, placing this country at the head of the world's major emitters, with over 16% of global GHG emissions [21, 24]. The increase in GHG emissions since 1990 had been steady (1.5% per year, on average), but as of 2000 GHG emissions started to slow down significantly, increasing only by 2% in the five years from 2000 to 2005, which can be associated with a reverse in the emission trends in the industrial and transportation sectors.

Figure 1.4 Per Capita CO_2 Emissions from the Electricity Generation Sector in North America, 1990-2007



4. Statistics for year 2006 are employed in this section, as no specific data are available for 2005 in the "*Cuarta Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*" [23].
5. GDP taken at current prices, current PPPs, 2005 US dollars (US$). OECD. http://stats.oecd.org/Index.aspx. Consulted 18 February 2011.

GHG emissions per capita in 2005 were 23.8 t CO_2-eq. Of the total GHG emissions in the United States that year, CO_2 accounted for 85.6%.

The United States is the largest CO_2 emitter in the world, with 21% of the global total of CO_2 from fuel combustion in 2005 [8]. The major contribution to total US GHG emissions was from energy-related activities, with 86.7%. The electricity generation sector accounted for 39.1% of the energy sector's GHG emissions [24]; thus, one-third of the total GHG emissions in the United States were from electricity generation in 2005. The electricity generation sector contributed 39.3% of the national emissions of CO_2 [24]. Emissions of CO_2 accounted for 99.4% of the GHG emissions from the electricity generation sector. Per capita emissions of CO_2 from the same sector were 8.01 t in 2005 (see **Figure 1.4**), whereas CO_2 emissions per GDP were 191 g/US$.[6]

1.2.5 Other Impacts

In Section 3.2, **Figure 3.1** shows that depending on the type of fuel burned, fossil fuel power plants can emit a number of other pollutants in addition to GHGs. These include criteria air contaminants such as oxides of nitrogen, sulfur dioxide, and particulate matter; heavy metals; and others not shown in this figure, such as volatile organic compounds (VOCs), semi-volatile organic compounds, condensable organic compounds and certain halogenated compounds. These pollutants can have a variety of impacts on the environment and human health—including the creation of smog, acid rain and regional haze, and the development of respiratory illnesses.

Mercury, a heavy metal, is a known persistent, bioaccumulative and toxic (PBT) substance that occurs naturally in coal. Air releases of mercury are associated with a variety of important environmental and human health consequences (as described in greater detail in Section 3.3).

6. GDP taken at current prices, current PPPs, in 2005 US dollars (US$). OECD. http://stats.oecd.org/Index.aspx. Consulted 18 February 2011.

Puerto Libertad Power Plant
Sonora, Mexico

2. Emissions Data

2.1 Information Sources

In general, emissions data are collected through the national emissions inventories; however, other parameters proper to the electricity generation sector are usually not published in the emissions inventories, and were thus taken from diverse sources, ranging from the ministries of energy or statistics of each country to public information available through the electricity corporations. For some facilities such as co-generation plants (where the primary business is not to supply power to the grid and thus the electricity is for self-supply), the reported electricity generation values do not correspond to the reported emissions data. The information used in the present report comes entirely from public information sources. The first report of this series for the year 2002 was limited by the paucity of information from Mexico and Canada. Reporting on emissions of criteria air contaminants (CACs) was required for the first time for the year 2002 under the National Pollutant Release Inventory of Canada. The first National Emissions Inventory of Mexico (INEM) was published for the year 1999, but there was no update for 2002. Each country has different mechanisms to gather the data and these are constantly evolving and improving. Therefore, more information was available for the development of the present report, as described in the following subsections.

2.1.1 Canada

The National Pollutant Release Inventory (NPRI) [25] of Environment Canada collects data on pollutant releases and transfers and compiles and reports comprehensive emission summaries and trends for key air pollutants, based on facility-reported data and emission estimates for other sources. Comprehensive emission summaries are available for the following CACs: particulate matter (Total PM, PM_{10} and $PM_{2.5}$); sulfur dioxide (SO_2); nitrogen oxides (sum of NO and NO_2); volatile organic compounds (VOC); and carbon monoxide (CO). The NPRI also contains data for a number of persistent, bioaccumulative and toxic (PBT) organic pollutants and metals, including mercury.

Facilities in Canada are required to report their emissions of CACs to the NPRI if the emissions of a given contaminant exceed the specified reporting threshold. Reporting threshold levels for CACs were issued in 2002 and were still in effect in 2005. The reporting thresholds were as follows: 20 tonnes (air release-based) for CO, NO_X, SO_2 and Total PM; 10 tonnes for VOCs; and 0.5 and 0.3 tonnes for PM_{10} and $PM_{2.5}$, respectively. These reporting requirements were expected to cover 90% of all facilities [26]. The threshold for mercury and its compounds was set at 5 kg and applied not only to emissions, but also to manufacturing, processing or otherwise using the substance.

Emissions data for greenhouse gases (GHGs) are not included in the NPRI. Facility-specific GHG emissions data are gathered through the Greenhouse Gas Emissions Reporting Program (GHGRP)[27], which was established in Canada in 2004 and requires reporting from all facilities emitting more than 100 kt CO_2-eq of GHGs annually (in 2009, the GHGRP reporting threshold was lowered to 50 kt CO_2-eq [28]).

Another important source of information is Statistics Canada. This government agency issues periodic reports on Electric Power Generation, Transmission and Distribution that contain valuable information about technologies used, installed capacity and the geographical distribution of generating stations. From one of these reports [29] were obtained total provincial and national values relative to electricity generation, fuel utilization, and greenhouse gas emissions.

Plant-level annual electricity generation data were obtained for several facilities directly from their parent companies' annual reports, environmental performance reports or other publicly available corporate documents (see Annex for further references).

Electricity in Canada is also produced by cogeneration. Thus, electricity can be produced in plants that are not exclusively dedicated to this purpose. In 2005, there were numerous facilities taking advantage of the higher efficiencies obtained via processes such as combined heat and power to produce the heat and electricity they require and even put some back into the grid. Therefore, a number of electricity producers are classified in industry categories other than the NAICS code 221112, corresponding to "fossil fuel electric power generation." However, for this report, only the 189 facilities classified under that code were considered.

Annual electricity generation figures for some Canadian power plants were not published. In those cases, the electricity generation was estimated on the basis of the CO_2 emissions, typical heat rates for the technology involved, and taking into account the overall generation by province. Further details on the estimation methodology and specific data sources can be found in the Annex.

With the variety of independent sources of information, it was expected that each might yield different data, which was indeed the case. For example, some of the facilities that reported to the NPRI did not report to the GHGRP and vice versa, and some of the facilities listed in the Statistics Canada database do not report to the NPRI or the GHGRP. Nevertheless, with the information obtained from the sources previously mentioned, a single, unified database was created using the facility IDs included in the GHGRP and the NPRI databases.

This database includes the following parameters: industry sector (NAICS) code, location, fuels and technology used, generating unit details, installed capacity, emissions, annual electricity generation, and pollution control data.

2.1.2 Mexico

The information for Mexico that is presented in this section was obtained from publicly available databases and reports corresponding to the year 2005, which are part of the INEM 2005. Mexico emissions data and general information about the Mexican power system were compiled from the following sources:

Comisión Reguladora de Energía (CRE)

The CRE grants the authorizations to IPP and private producers to generate electricity. These authorizations become public information that can be consulted through the CRE website. Companies authorized to produce electricity should report their emissions to the appropriate authority.

Since until recently, electricity production in Mexico was centralized, electricity producers were still under strict control by the CRE in 2005. Therefore, it was possible to gather information from all of the electric utilities. However, in most cases, self-supply and cogeneration plants only reported their total emissions in 2005, without any specific details about the portion corresponding to electricity production.

The information available through the CRE for these plants includes: the authorized plant generation capacity, the authorized annual electricity generation, operation starting date, primary fuel and technology; however, there were no data for the actual electricity generation, nor the amount of fuel consumed. Therefore, it was not possible to determine the emissions from the power generation activities of these plants.

Secretaría de Energía (Sener)

The national energy balance is compiled and published by Sener. The energy balance was used to verify overall generation by fuel type and geographical distribution. The Mexican electric system description was also obtained from Sener [14].

Comisión Federal de Electricidad (CFE)

This source allowed us to verify the number of facilities that operated in 2005, and to identify if there were facilities that did not report their emissions in that year. Thus, data for 102 Mexican facilities are included in the present report.

CEC Report

Most of the emissions information was obtained from a database generated for reports commissioned by the CEC [30, 31] to support the development of the 2005 Mexican National Emissions Inventory (INEM). In that report, the emissions generated by Mexican power plants were estimated using United States EPA emission factors (AP-42), along with the information supplied by the power plants through the Annual Report of Operation (COA) on fuel consumption, generation and other operating characteristics. COA reports are submitted to the Secretariat of Environment and Natural Resources (Semarnat) during the first third of the year following the reporting year. For some greenhouse gases, emissions factors developed by Sener were used [30, 31].

2.1.3 United States

Emissions and Generation Resource Integrated Database (eGRID2007)

The United States air pollution data for CO_2, NO_X, SO_2, CH_4, N_2O and Hg were obtained from the United States EPA emissions and Generation Resource Integrated Database (eGRID2007). The eGRID2007 is a broad inventory of environmental features for all the electricity generating plants that provide power to the electric grid and report data to the United States government.

The eGRID2007 data are collected from a variety of federal sources, including various reports and databases compiled by the United States Environmental Protection Agency (EPA) (e.g., the EPA Emissions Tracking System/Continuous Emissions Monitoring, and the EPA Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2005); reports by the Energy Information Administration (EIA) (e.g., the Annual Electric Generator Report, form EIA-860), as well as monthly reports published by the Federal Energy Regulatory Commission (FERC) (e.g., the Monthly Report of Cost and Quality of Fuels for Electric Plants, FERC 423).

The power plant operational data obtained for this report from the eGRID2007 database include: the annual fossil fuel consumption as heat input, annual electricity generation, plant capacity factor, nameplate generation capacity, and type of fossil fuel burned at the power plant (including the relative proportion of the fuel mixture if more than one type of fuel was burned). Data about the combustion technology (boiler type) and the air pollution control techniques used to reduce emissions were also used, when available.

The 2,834 facilities registered under NAICS code 221112 in the eGRID were considered for this report, but 105 of them reported a zero or negative net electricity generation; thus, a total of 2,728 facilities were included. It should be pointed out that all 2,728 facilities reported emissions of NO_X and CO_2; however, not all of them reported emissions of the other pollutants examined in this report.

National Emissions Inventory (NEI)

Data on $PM_{2.5}$ and PM_{10} for a number of facilities were obtained from the 2005 National Emissions Inventory (NEI, version 2), an inventory created by the EPA's Emission Inventory and Analysis Group (EIAG) and covering all criteria air pollutants and hazardous air pollutants for every area of the United States. The criteria air pollutant emissions data for the NEI are collected under the Consolidated Emissions Reporting Rule (CERR) (40 CFR Part 51) by each state. The EIAG prepared 2005 emissions data for Electric Generating Units (EGUs) using data obtained from the Department of Energy's EIA, EPA's Emission Tracking System/Continuous Emissions Monitoring (ETS/CEM), and the data reported by state air pollution control agencies under the CERR.

The NEI included data on releases of PM_{10} and $PM_{2.5}$ for 1,182 of the facilities in the eGRID database; hence, the subsequent analysis is only partial and cannot be considered fully representative of the electricity generation sector in the US. However, it is important to note that these facilities accounted for 75% of the total electricity generation; 85% of that was generated from coal [which is the fuel that generates the largest (uncontrolled) PM emissions], 51% was generated from oil, and 55% from natural gas.

2.2 Overview of Power Plant Emissions Data

2.2.1 Canada

Table 2.1 shows a summary of the information obtained for this report for the 189 fossil fuel-based power stations in Canada for year 2005. Data for electricity generation were only available for 91 of 189 facilities, as indicated in the table footnote. However, all 189 facilities operated in 2005, with each plant reporting emissions of at least one of the pollutants under consideration in this report.

The 2005 national average plant capacity factor was estimated at 0.53. It should be borne in mind that, in Canada, fossil-fuelled power plants are often used for back up or for electricity supply during peak times. For this report the category of "other fuels" was introduced and accounted for 2% of the total generated electricity considered in this report; the main fuel in this category was diesel, mostly used in relatively small internal combustion engines.

According to Statistics Canada [9] the total generating capacity of thermal plants including steam, internal combustion and combustion turbine in the utility sector (private and public) was 32,098 MW for Canada in 2005. This figure suggests that the coverage of this report was around 95% (**Table 2.1**). In terms of actual electricity generated from the same sector, the datum given by Statistics Canada [9] was 135,643 GW-h, which is virtually identical to the value obtained in this report. The installed capacity of the plants for which the electricity generation data could not be obtained from public information represents only 3.7% of the total installed capacity of all the plants considered for this report.

Total CO_2 emissions from the 70 plants that reported to the GHGRP for year 2005 were 121,282 kt, and information found in corporate documentation for two other plants that did not report to the GHGRP for 2005 added only 17 kt, whereas the national inventory reports 118,800 kt [22], a 2% difference.

Of the 25 plants (with NAICS code 221112) that reported mercury (Hg) emissions in 2005, 23 also reported in 2002. Of these 23 plants, 10 reported increases in mercury emissions from 2002 to 2005, 12 reported reductions and one reported no change.

Emissions of CH_4 and N_2O, as well as of PM_{10} and $PM_{2.5}$, were not available for the 2004 NAPPAE report, but are included in this edition in order to start a record for future analysis.

2.2.2 Mexico

In the present report, 102 power plants in Mexico were included; 31 of these were independent power producers (IPP) already reporting their emissions through the COA. A summary of the information from these power plants is shown in **Table 2.2**.

In addition to the data shown in the table, **Table 2.3** shows that supplemental generation capacity and electricity generation were authorized for private self-generators, cogeneration and exporting plants for which emissions could not be estimated for this report due to lack of data. In addition, CFE was authorized to operate some mobile plants for which there was no further information.

2.2.3 United States

For the present report, data for a total of 2,834 power plants in the United States were analyzed; however, as explained earlier and, as shown in **Table 2.4** ("total (non-negative)"), only data for 2,728 of those facilities were ultimately used for this report.

Table 2.4 shows a summary of the information gathered for these plants, which appears to be in close agreement with published values. Plant generation

Table 2.1 Summary of Information on the Canadian Electricity Generation Sector and Its Emissions, 2005

Canada Fossil Fuel Based Electricity Generation Facilities Summary for Year 2005		
INSTALLED CAPACITY	MW	No. of Facilities
TOTAL	30,495	189
ELECTRICITY GENERATION	MW-h	No. of Facilities*
Coal	97,527,348	21
Oil	9,251,151	6
Natural Gas	25,691,285	41
Other fuels	3,219,253	23
TOTAL	135,689,037	91
EMISSIONS	tonnes (except Hg)	Reporting Facilities
SO_2	516,695	38
NO_x	229,658	160
Hg (kg)	2,079	25
PM_{10}	13,448	161
$PM_{2.5}$	7,208	166
CO_2	121,299,282	72
CH_4	2,465	58
N_2O	3,501	58

* Data for electricity generation were only available for 91 of 189 facilities. Figures generated from data in [25, 27, 29], according to the methodology described in the Annex.

Table 2.2 Summary of Information on the Mexican Electricity Generation Sector and Its Emissions, 2005 [32, 33]

Mexico Fossil Fuel Based Electricity Generation Facilities Summary for Year 2005		
INSTALLED CAPACITY	MW	No. of Facilities
TOTAL	34,179	102
ELECTRICITY GENERATION	MW-h	No. of Facilities
Coal	32,629,166	3
Oil	56,080,476	24
Natural Gas	81,760,574	50
Other fuels	10,525,414	25
TOTAL	180,995,630	102
EMISSIONS	tonnes (except Hg)	Reporting Facilities
SO_2	1,403,015	102
NO_x	356,273	102
Hg (kg)	2,285	102
PM_{10}	67,710	102
$PM_{2.5}$	50,255	102
CO_2	117,737,070	102
CH_4	2,569	102
N_2O	1,745	102

Table 2.3 Additional Electricity Generation Capacity in Mexico, 2005 [34]

Type	Authorized Generation Capacity (MW)	Authorized Electricity Generation (GW-h/Year)	Number of Plants
Self-supply	2,184	10,575	256
Cogeneration	1,060	5,431	26
Exporter	1,330	11,251	4
Mobile units	120	n.a.	30

capacity is approximately 1% higher than the value quoted in the Electric Power Annual 2005 [35]. On the other hand, the total net electricity generation from fossil fuels exceeds the quoted value by 2%.

The information in **Table 2.4** was mainly obtained from the eGRID2007 database [36], which has no data on emissions of particulate matter. **Table 2.5** provides a summary of the information relating to emissions of particulate matter taken primarily from the 2005 US National Emissions Inventory [37].

All of the plants considered in **Table 2.5** are also included in **Table 2.4**; however, some of the plants in the eGRID2007 database are not required to report particulate emissions to the NEI. There are differences related to generation and fuel utilization between the NEI and the eGRID2007 databases. For consistency, the information from eGRID2007 was given preference over the NEI except when such information was lacking in the eGRID2007 database. Thus the available information on particulate matter emissions was not representative of the whole US electricity sector, since it covered only 43% of the number of plants considered in **Table 2.4**, 71% of the installed capacity and 75% of total electricity generation.

As can be observed in **Table 2.5**, coal-fired power stations accounted for approximately 95% of the reported emissions of particulate matter from the electricity generation sector. Additional details are provided in Section 2.3.

2.2.4 Per Capita Emissions, North American Power Plants

Table 2.6 shows the per capita emissions summary for the North American power plants considered in this report. These values were calculated on the basis of total populations (for 2005) of 32.31, 104.87 and 300.00

Table 2.4 Summary of the United States Electricity Generation Sector and Its Emissions, 2005

United States Fossil Fuel Based Electricity Generation Facilities Summary for Year 2005		
INSTALLED CAPACITY	MW	No. of Facilities
TOTAL	847,439	2,834
ELECTRICITY GENERATION	MW-h	No. of Facilities
Coal	2,074,026,004	585
Oil	95,891,083	77
Natural Gas	728,270,837	1,363
Other fuels	69,322,899	703
TOTAL NET	2,967,523,219	2,834
TOTAL (non-negative)	2,967,510,824	2,728
EMISSIONS	tonnes (except Hg)	Reporting Facilities
SO_2	9,611,608	2,724
NO_x	3,489,075	2,728
Hg (kg)	49,133	632
CO_2	2,419,514,935	2,728
CH_4	33,591	2,718
N_2O	35,428	2,718

Totals obtained with data from eGRID2007 except for Hg, for which 430 facilities were from eGRID2007 and 202 facilities were from the NEI [37].

Table 2.5 Summary of Particulate Emissions from the United States Electricity Generation Sector, 2005

United States Fossil Fuel Based Electricity Generation Facilities Particulate Matter Emissions Summary for Year 2005		
PM_{10} EMISSIONS	tonnes	No. of Facilities
Coal	487,004	393
Oil	7,898	40
Natural Gas	15,810	572
Other fuels	3,444	177
TOTAL	514,156	1,182
$PM_{2.5}$ EMISSIONS	tonnes	No. of Facilities
Coal	398,017	393
Oil	6,779	40
Natural Gas	14,329	572
Other fuels	2,751	177
TOTAL	421,877	1,182

Totals obtained with data from NEI [37].

Table 2.6 Summary of Per Capita Emissions from the Electricity Generation Sector in North America, 2005

Pollutant	Units	Canada	Mexico	United States	North America
SO_2	kg/capita	16.0	13.4	32.0	26.4
NO_x	kg/capita	7.1	3.4	11.6	9.3
Hg	mg/capita	64.3	21.8	163.8	122.4
PM_{10}	kg/capita	0.42	0.65	1.71	1.4
$PM_{2.5}$	kg/capita	0.22	0.48	1.41	1.1
CO_2	t/capita	3.75	1.12	8.07	6.1
CH_4	kg/capita	0.08	0.02	0.11	0.09
N_2O	kg/capita	0.11	0.02	0.12	0.10

million for Canada [38], Mexico [39] and the United States [24], respectively. The data show some significant differences—with the United States showing high per capita emissions with respect to Canada and Mexico for pollutants such as mercury. These values reflect the number of facilities as well as the mix of technologies and fuels used. It should be noted that for certain pollutants, such as CO_2, on average US facilities had lower emissions per unit of electricity produced than facilities in Canada and Mexico (see Section 2.3.5).

2.3 Detailed Emissions Data

2.3.1 Sulfur Dioxide (SO_2) Emissions

Emissions of SO_2 from fossil fuel-based electricity generation in each country are summarized in **Tables 2.7–2.9**, along with other parameters such as electricity generation, emission rates and fuel type. Fuel types have been classified as Coal, Heavy Fuel Oil, Natural Gas and "Other Fuels" (the latter category includes fuels such as Liquefied Petroleum Gas, diesel, or coke). In the tables, data are sorted by SO_2 emissions.

In Canada**,** only 38 plants (of 189 in total) reported emissions of SO_2 to the NPRI, and 17 of those plants accounted for 90% of the total SO_2 emissions reported by Canadian power plants for 2005. Each of them emitted more than 9,000 tonnes of SO_2. The five plants with the highest reported SO_2 emissions were in the range of 39,000 to 68,000 tonnes of SO_2, and they were all coal-fired power stations with emission rates ranging from 3.8 to 10.6 kg/MW-h. Two of these five power plants were in Saskatchewan, with the three others located in the following provinces: Ontario, Nova Scotia, and Alberta. The top 10 facilities, ranked by SO_2 emissions, accounted for 74% of the SO_2 emissions from these 38 Canadian power plants (**Table 2.7**).

A plant-by-plant comparison of Canadian power plant SO_2 emissions between 2002 [1] and 2005 showed that five plants accounted for the entire decrease in the total SO_2 emissions between those two years. For example, one of the plants, Coleson Cove, underwent an extensive refurbishment to have the output of all the units pass through a scrubber for flue gas desulfurization, thus achieving a 77% reduction in SO_2 emission rates [40]. At the same time, NO_X emission rates were reduced by 70% through modifications to the boiler.

Similar to the situation in Canada, the top 19 SO_2-emitting facilities of a total of 102 in Mexico contributed 95% of that country's total SO_2 emissions from fossil fuel electricity generation. The five highest-emitting plants had emissions ranging from 114,000 to just over 190,000 tonnes of SO_2. Three of these were oil-fired and two were coal-fired power plants. Their emission rates ranged from 8 to 20 kg/MW-h, possibly indicating a lack of environmental controls for this pollutant in Mexico.

The top 10 facilities, ranked by SO_2 emissions, accounted for 78% of the SO_2 emissions from all 102 Mexican power plants in 2005 (**Table 2.8**). It should be pointed out that the figures for Mexico are based on estimations using emissions factors only; however, these estimates for SO_2 are supported by mass and energy balance calculations.

In the United States, there were data on SO_2 emissions from 2,724 out of 2,728 power plants, of which 263 plants accounted for 90% of the total SO_2 emissions from fossil fuel electricity generation. Individual emissions of these 263 plants ranged from 9,000 to 170,000 tonnes of SO_2 during the year. The emission rates of more than 82.5% of those 263 plants were below 10 kg/MW-h, but some values as high as 100 kg/MW-h were found—for example, for the LaFarge Alpena power plant in Michigan. Only 15 plants exceeded the 15 kg/MW-h emission rate. All but 15 of the 263 plants were coal-fired, one was gas-fired and the rest were fueled with oil.

Table 2.7 Canada SO_2 Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	Province	Electricity Generation (MW-h)	SO_2 (t)	SO_2 Emission Rate (kg/MW-h)	Primary Fuel
1	**Ontario Power Generation** Nanticoke Generating St	Ontario	17,778,061	67,947	3.82	Coal
2	**SaskPower** Boundary Dam Power Station	Saskatchewan	6,066,671	49,296	8.13	Coal
3	**Nova Scotia Power** Lingan Generating Station	Nova Scotia	4,653,774	40,805	8.77	Coal
4	**SaskPower** Poplar River Power Station	Saskatchewan	3,699,109	39,347	10.64	Coal
5	**Alberta Power (2000) Ltd.** Sheerness Generating Station	Alberta	5,892,719	39,187	6.65	Coal
6	**Nova Scotia Power** Trenton Generating Station	Nova Scotia	2,095,581	37,809	18.04	Coal
7	**TransAlta Utilities Corporation** Sundance Thermal Generating Station	Alberta	15,116,034	30,532	2.02	Coal
8	**Ontario Power Generation** Lambton Generating Station	Ontario	9,532,953	29,343	3.08	Coal
9	**New Brunswick Power Generation Corporation** Grand Lake	New Brunswick	274,085	23,236	84.78	Coal
10	**Alberta Power (2000) Ltd.** Battle River Generating Station	Alberta	5,077,593	22,961	4.52	Coal
Total, top 10 plants			70,186,579*	380,463		
Total, 38 plants			116,420,983*	516,694		

* Data on electricity generation were not publicly available for 4 of the 38 Canadian power plants. Due to rounding, totals may vary slightly.
Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.8 Mexico SO_2 Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	SO_2 (t)	SO_2 Emission Rate (kg/MW-h)	Primary Fuel
1	**CFE CT Pdte.** Adolfo López Mateos	Veracruz	10,547,560	190,123	18.025	Oil
2	**CFE CT Gral. Manuel Álvarez Moreno** (Manzanillo I)	Colima	8,783,848	175,279	19.955	Oil
3	**CFE CT Francisco Pérez Ríos**	Hidalgo	8,741,955	132,374	15.142	Oil
4	**CFE CT José López Portillo** (Río Escondido)	Coahuila	9,357,259	115,763	12.371	Coal
5	**CFE CT Pdte. Plutarco Elías Calles** (Petacalco)	Guerrero	14,275,114	114,818	8.043	Coal
6	**CFE CT Carbón II**	Coahuila	8,996,793	103,319	11.484	Coal
7	**CFE CT Altamira**	Tamaulipas	3,776,214	69,479	18.399	Oil
8	**CFE CT José Aceves Pozos**	Sinaloa	3,693,831	65,434	17.715	Oil
9	**CFE CT Villa de Reyes**	San Luis Potosí	3,243,039	65,205	20.106	Oil
10	**CFE CT Puerto Libertad**	Sonora	3,517,521	62,713	17.829	Oil
Total, top 10 plants			74,933,133	1,094,507		
Total, 102 plants			180,995,630	1,403,015		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.9 United States SO_2 Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	SO_2 (t)	SO_2 Emission Rate (kg/MW-h)	Primary Fuel
1	Bowen	Georgia	22,337,864	169,167	7.573	Coal
2	Keystone	Pennsylvania	13,488,615	162,179	12.023	Coal
3	Gibson	Indiana	22,442,805	139,922	6.235	Coal
4	Hatfields Ferry Power Station	Pennsylvania	8,672,997	132,108	15.232	Coal
5	Muskingum River	Ohio	7,403,428	122,075	16.489	Coal
6	Homer City Station	Pennsylvania	13,599,227	119,771	8.807	Coal
7	EC Gaston	Alabama	11,273,347	115,812	10.273	Coal
8	PPL Montour	Pennsylvania	10,399,362	115,754	11.131	Coal
9	Cardinal	Ohio	11,372,176	105,097	9.242	Coal
10	John E Amos	West Virginia	18,887,395	101,980	5.399	Coal
Total, top 10 plants			139,877,216	1,283,865		
Total, 2,724 plants			2,967,468,884	9,611,608		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Figure 2.1 Facility Contribution to Power Plant SO_2 Emissions in Canada, Mexico and the United States

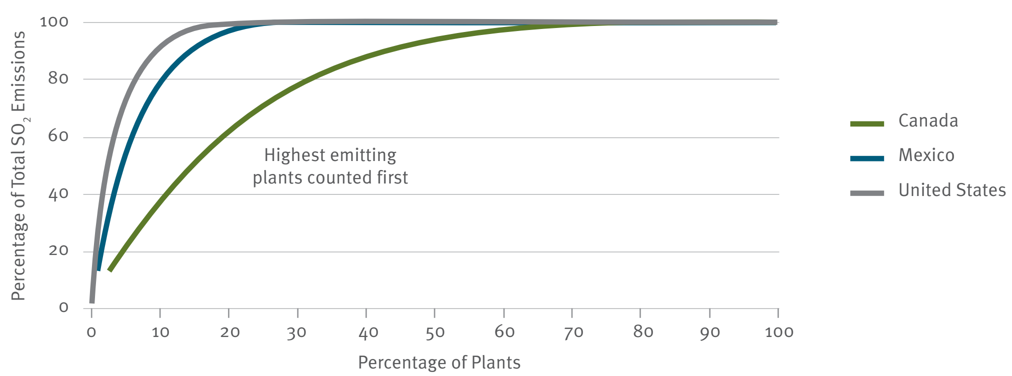
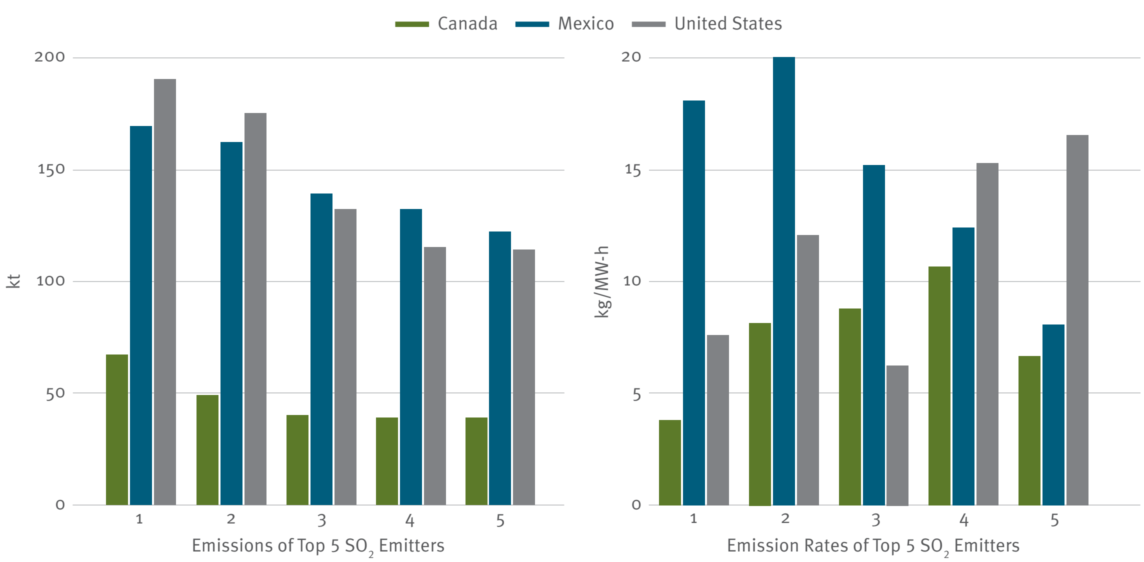


Figure 2.2 SO_2 Emissions from the Top Five Emitters in Each Country



The top 10 facilities, ranked by SO_2 emissions, accounted for 13% of the SO_2 emissions from the 2,724 US power plants in 2005 (**Table 2.9**).

In relative terms, **Figure 2.1** shows the contribution to SO_2 emissions of all of the plants considered in this report, from the largest to the smallest emitters. The number of plants has been represented as a percentage of the total number of plants in each country. It should be borne in mind that plant emissions are dependent on the fuels and technologies used, and that the total number of plants significantly differs from country to country. In a graph of this type a straight line would represent equal contribution from all plants. It can be seen that only 10% of all the plants in the United States accounted for roughly 90% of that country's total SO_2 emissions; for Mexico, it was around 15%, and for Canada, 45%.

The emission rate is a simple way to assess the overall environmental performance of a power plant. Lower emission rates indicate a better environmental performance. The emission rates depend on many factors, including fuel, combustion technology, electricity generation technology and environmental control technologies. In general, emission rates for natural gas are lower than for fuel oil, which in turn are lower than for coal, but plants with leading edge technologies for coal cleaning and flue gas desulfurization may have lower SO_2 emission rates than some natural gas-fired power plants. An example of a coal-fired power plant with outstanding technology for sulfur capture and with the lowest emission rates in the United States for coal (0.676 kg/MW-h) is the Cedar Bay Generating Plant, in Florida, which uses three fluidized bed boilers where almost all the sulfur from the fuel is trapped. In the eGRID database, there were six plants with data that resulted in exceedingly high emission rates (up to more than 100,000 kg/MW-h), which is obviously inconsistent. In the case of Mexico, oil- and coal-fired power plants have an average SO_2 emission rate of 17.5 kg/MW-h, while diesel and natural gas based plants have an average SO_2 emission rate of 0.1 kg/MW-h (excluding plants that use a combination of natural gas and fuel oil).

Figure 2.2 shows the emissions of the top five SO_2-emitting plants in each country (graph on left), and their emission rates (graph on right). It can be seen that the emissions of the top five SO_2 emitters of Mexico and the United States were very similar, and were also significantly higher than the emissions of the top five SO_2 emitters of Canada (see **Figure 2.2**). However, the three highest emitters of Mexico had considerably higher emission rates than the highest three emitters of Canada and the United States.

The distribution of SO_2 emissions from power plants considered in this report is shown in **Figure 2.3**. In this figure, the size of the dots represents the scale of emissions and the color represents the type of primary fuel used. SO_2 emission sources related to electricity generation in Canada are highly localized. The most important ones, with emissions ranging from 10,000 to 100,000 t/year, are five coal-fired power plants in Alberta, one in New Brunswick, one in Nova Scotia, one in Prince Edward Island, and one oil-fired power plant in each of the provinces of New Brunswick, Nova Scotia and Newfoundland and Labrador.

In Mexico, there are six important SO_2 sources, three of which are oil-fired and three coal-fired power plants; their emissions range from 100,000 to 195,000 t/year. SO_2 sources with emissions in the range of 10,000 to 100,000 t/year are distributed across the whole country; most are oil-fired power plants, but two use other fuels.

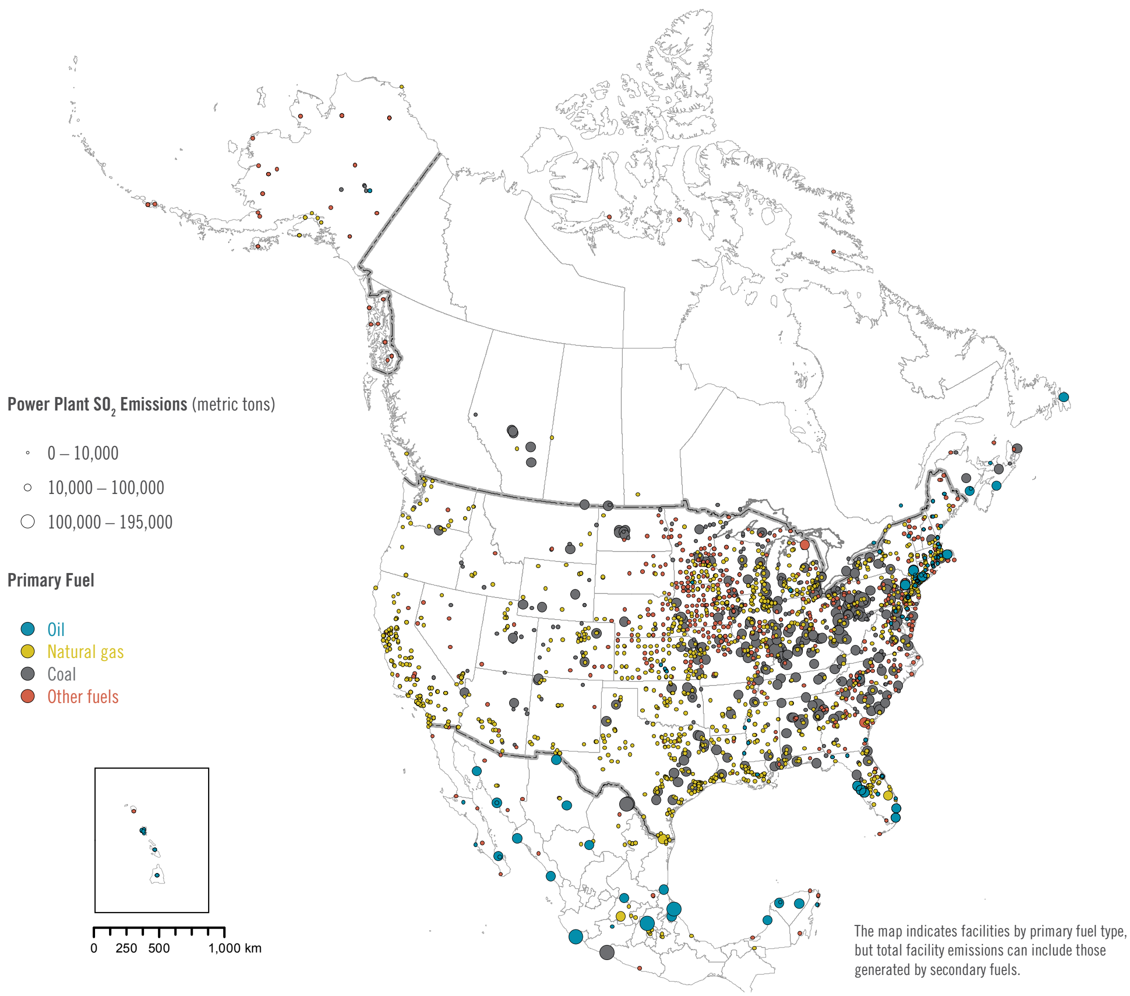
A very large number of power plants emitting SO_2 are located in the eastern United States, with a significant concentration in California as well. In the northeast and the southeast of the country, oil-fired power plants emit SO_2 emissions typically between 10,000 and 100,000 t/year. On the other hand, coal-fired power plants emitting up to 195,000 t/year of SO_2 are more widespread in the whole eastern side of the United States, with some in the central part of the country.

2.3.2 Nitrogen Oxide (NO_X) Emissions

Emissions of NO_X from fossil fuel-based electricity generation in the three countries are summarized in **Tables 2.10–2.12**. (complete tables can be found at www.cec.org/powerplants). In these tables, data are sorted by NO_X emissions; other parameters such as electricity generation, emission rates and fuel type are also included.

In Canada**,** 160 plants (of the total of 189) reported their NO_X emissions to the NPRI, and 27 of those plants accounted for 90% of the total NO_X emissions reported by Canadian power plants for 2005. These 27 facilities emitted a total of around 207,000 tonnes of NO_X. The five plants with the highest reported NO_X emissions were each in the range of 13,600 to 26,000 tonnes of NO_X, with emission rates of 1.5 to 4.0 kg/MW-h, and they were all coal-fired power stations. Two of these five power stations were in Alberta, with the other three located in the provinces of Ontario,

Figure 2.3 Distribution of Power Plant SO_2 Emission Sources in North America. 2005



Saskatchewan, and Nova Scotia. The top 10 facilities, as ranked by NO_X emissions, accounted for 64% of the NO_X emissions from the 160 Canadian power plants (**Table 2.10**). However, it should be noted that data on electricity generation were not publicly available for nearly half of the plants.

In Mexico, total NO_X emissions from all 102 power plants amounted to nearly 360,000 tonnes, with the top five emitters (three coal-fired and two oil-fired) contributing 44.5% of the total. Their emissions ranged from 13,800 to 56,000 tonnes, with emission rates ranging between 1.4 and 6.0 kg/MW-h. The NO_X emission rates for Mexico should be regarded with some caution, as emissions were calculated based on EPA AP-42 emission factors, rather than on observed or sampled values. The top 10 facilities, ranked by NO_X emissions, accounted for 58% of the NO_X emissions from all 102 Mexican power plants in 2005 (**Table 2.11**).

In the United States, all 2,728 power plants considered emitted a total of nearly 3,500,000 tonnes of NO_X. Of these plants, 364 accounted for 90% of the total, with individual plant emissions ranging from 2,000 to 37,870 tonnes. Of these 364 plants, 97% had a NO_X emission rate below 10 kg/MW-h; the highest value was 17.28 kg/MW-h. Among them, 95.5% were coal-fired and 3.2% and 1.3% were oil- and natural gas-fired, respectively.

Table 2.12 shows the top 10 US facilities, ranked by NO_X emissions; these accounted for 9% of the NO_X emissions from all 2,728 US power plants in 2005.

Figure 2.4 illustrates the contribution to total NO_X emissions of all the power plants in each country. It can be observed that for the United States and Canada, 10% of the total number of plants (246 in the United States

Table 2.10 Canada NO_x Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	Province	Electricity Generation (MW-h)	NO_x (t)	NO_x Emission Rate (kg/MW-h)	Primary Fuel
1	**TransAlta Utilities Corporation** Sundance Thermal Generating Station	Alberta	15,116,034	25,787	1.7	Coal
2	**Ontario Power Generation** Nanticoke Generating St	Ontario	17,778,061	23,171	1.3	Coal
3	**SaskPower** Boundary Dam Power Station	Saskatchewan	6,066,671	18,174	3.0	Coal
4	**Nova Scotia Power** Lingan Generating Station	Nova Scotia	4,653,774	15,888	3.4	Coal
5	**EPCOR Generation** Genesee Thermal Generating Station	Alberta	9,301,772	13,635	1.5	Coal
6	**TransAlta Utilities Corporation** Keephills Thermal Generating Station	Alberta	5,762,554	11,008	1.9	Coal
7	**SaskPower** Poplar River Power Station	Saskatchewan	3,699,109	10,748	2.9	Coal
8	**Alberta Power (2000) Ltd.** Sheerness Generating Station	Alberta	5,892,719	10,287	1.7	Coal
9	**Alberta Power (2000) Ltd.** Battle River Generating Station	Alberta	5,077,593	9,926	2.0	Coal
10	**Ontario Power Generation** Lambton Generating Station	Ontario	9,532,953	8,991	0.9	Coal
Total, top 10 plants			82,881,240*	147,615		
Total, 160 plants			133,166,407	229,658		

* Data on electricity generation were not publicly available for 78 of the 160 Canadian power plants. Due to rounding, totals may vary slightly.
Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.11 Mexico NO_x Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	NO_x (t)	NO_x Emission Rate (kg/MW-h)	Primary Fuel
1	**CFE CT José López Portillo** (Río Escondido)	Coahuila	9,357,259	55,871	5.971	Coal
2	**CFE CT Carbón II**	Coahuila	8,996,793	49,915	5.548	Coal
3	**CFE CT Pdte. Plutarco Elías Calles** (Petacalco)	Guerrero	14,275,114	24,024	1.683	Coal
4	**CFE CT Pdte. Adolfo López Mateos**	Veracruz	10,547,560	14,983	1.421	Oil
5	**CFE CT Gral. Manuel Álvarez Moreno** (Manzanillo I)	Colima	8,783,848	13,808	1.572	Oil
6	**CFE CD General Agustín Olachea Avilés**	Baja California Sur	488,572	12,733	26.061	Oil
7	**CFE CT Francisco Pérez Ríos**	Hidalgo	8,741,955	10,973	1.255	Oil
8	**Iberdrola Energía Monterrey**	Nuevo León	6,200,268	9,077	1.464	Natural Gas
9	**Iberdrola Energía Altamira**	Tamaulipas	6,654,124	9,052	1.360	Other Fuels
10	**Fuerza y Energía de Tuxpan**	Veracruz	5,463,761	7,271	1.331	Natural Gas
Total, top 10 plants			79,509,254	207,708		
Total, 102 plants			180,995,630	356,273		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.12 United States NO_x Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	NO_x (t)	NO_x Emission Rate (kg/MW-h)	Primary Fuel
1	Four Corners	New Mexico	15,616,040	37,870	2.425	Coal
2	Crystal River	Florida	22,237,071	35,158	1.581	Coal
3	General James M Gavin	Ohio	19,142,304	35,112	1.834	Coal
4	Colstrip	Montana	16,240,783	33,470	2.061	Coal
5	Paradise	Kentucky	13,974,043	32,549	2.329	Coal
6	Monroe	Michigan	18,710,600	32,113	1.716	Coal
7	John E Amos	West Virginia	18,887,395	31,407	1.663	Coal
8	Navajo	Arizona	17,030,674	30,138	1.770	Coal
9	Jeffrey Energy Center	Kansas	15,145,728	29,552	1.951	Coal
10	New Madrid	Missouri	7,000,958	29,248	4.178	Coal
Total, top 10 plants			63,985,596	326,617		
Total, 2,728 plants			2,967,510,824	3,489,075		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

and 17 in Canada) accounted for approximately 80% of each country's total NO_x emissions. For Mexico, 26 plants (around 25% of facilities) contributed a similar percentage to Mexico's NO_x emissions from fossil fuel power plants. Emissions from these plants were 286,339 tonnes for Mexico, 184,626 tonnes for Canada and 2,791,896 tonnes for the United States.

The geographical distribution of the NO_x sources considered in this report is shown in **Figure 2.5**. The size of the dots represents the scale of emissions and the color represents the type of primary fuel used. In Canada, the most important NO_x source is a coal-fired power plant in Alberta. There are other important sources in this province, also coal-fired power plants, emitting between 7,000 and 20,000 t of NO_x per year. There are also two coal-fired power plants in Nova Scotia with emissions in the same range. Scattered emissions sources, mainly diesel- and natural gas-fueled power plants, can also be seen across the country.

In Mexico the main NO_x emissions sources are coal-fired power plants, two of which are in Coahuila near the US-Mexico border, and one located in Guerrero on the Pacific coast. Four other NO_x sources with emissions in the 10,000 to 100,000 t/year range, all oil-

Figure 2.4 Facility Contribution to Power Plant NO_x Emissions in Canada, Mexico and the United States

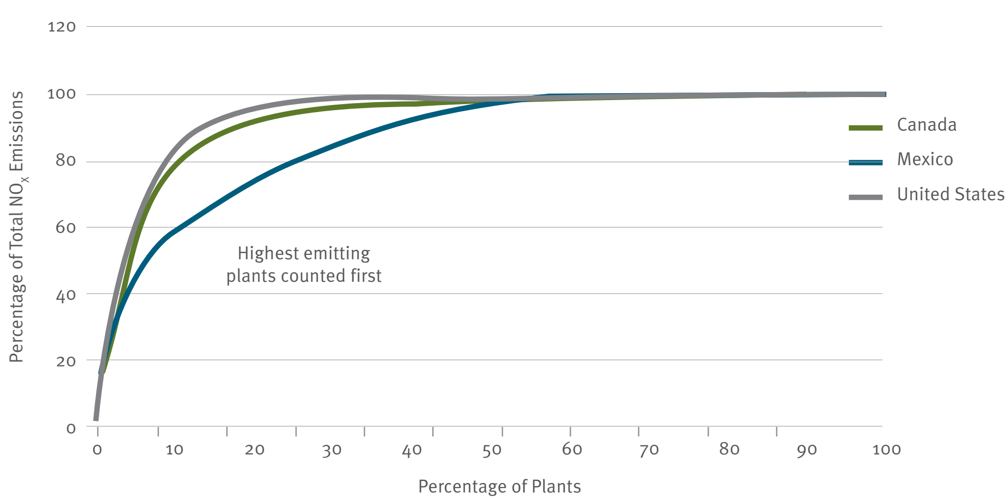
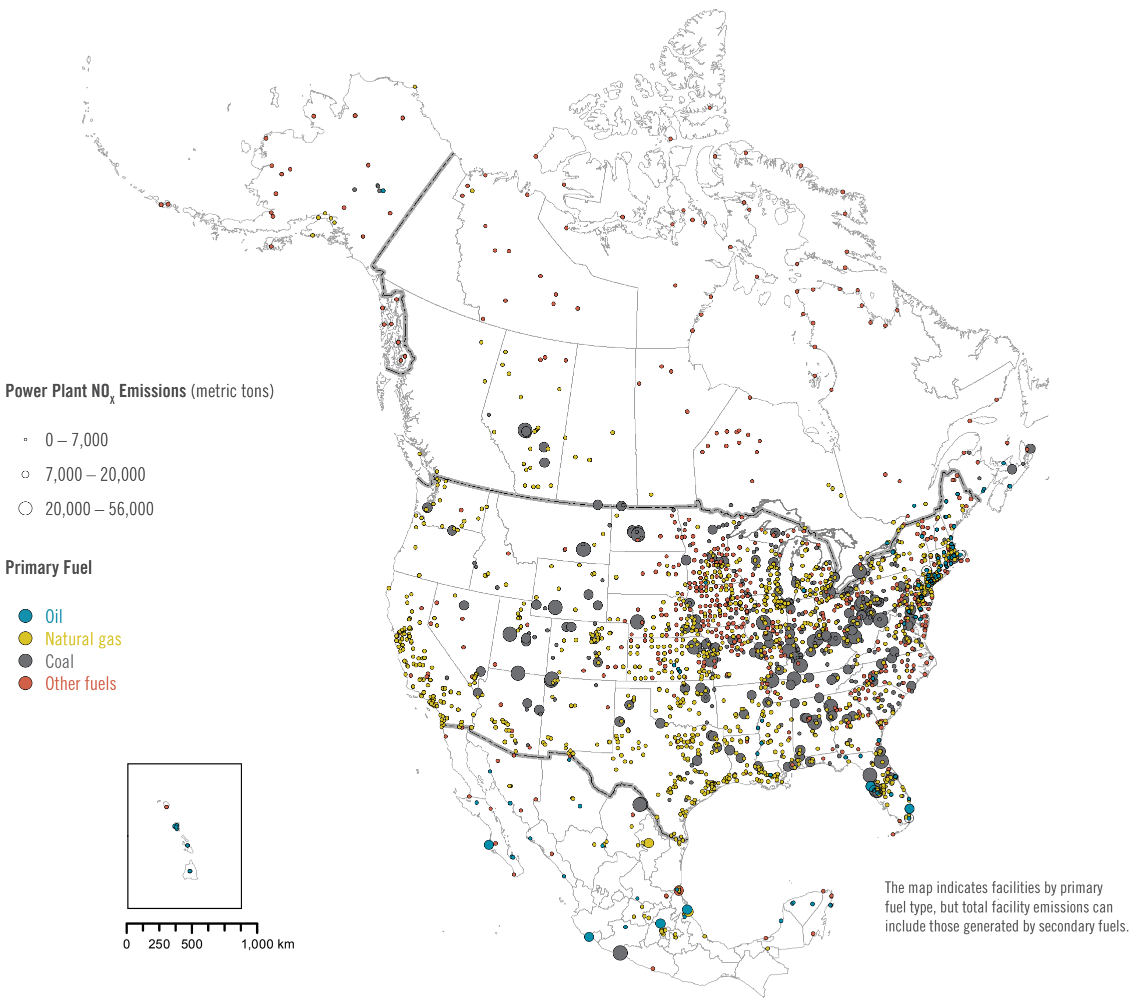


Figure 2.5 Distribution of Power Plant NO_x Emission Sources in North America, 2005



fired power plants, are prominent and are located in Baja California Sur, Colima, Guanajuato and Veracruz.

The largest concentration of NO_X sources in the United States is in the central and eastern areas of the country, with an important concentration in California as well. Coal-fired power plant NO_X emissions hotspots, with emissions in the 20,000 to 56,000 t/year range, can be seen in the states of Arizona, New Mexico, Utah, Wyoming and Montana.

2.3.3 Mercury (Hg) Emissions

Mercury emissions from fossil fuel-based electricity generation in Canada, Mexico and the United States are summarized in **Tables 2.13**, **2.14**, and **2.15** (complete tables can be found at www.cec.org/powerplants).

For 2005, only 25 of the 189 power plants reported Hg emissions data in Canada, for a total of 2,079 kg; and 13 of these plants accounted for 90% of the total reported by Canadian power plants for 2005. Twenty of the 25 reporting facilities were coal-fired. According to the NPRI [41], coal-fired electric power generation was the largest single-remaining man-made source of mercury emissions in Canada in 2005. Therefore, the Canadian Council of Ministers of the Environment (CCME) agreed to set Canada-wide Standards (CWS) for mercury emissions from coal-fired electric power plants, with the goal of reducing mercury emissions from existing plants (a capture of 60% of mercury in combusted coal by 2010) [42], and ensuring that new plants achieve emissions levels based on best available technologies economically achievable, or the equivalent.

Mercury emission rates for these 25 power plants ranged from 0.00146 to 0.0759 kg/GW-h, with the exception of the Grand Lake facility in New Brunswick, which had an emission rate of 0.3225 kg/GW-h for 2005. The emission rate obtained for this plant during the analysis carried out for the development of Canada-wide Standards (CWS) for mercury emissions in October 2003 was 0.2858 kg/GW-h, although there was a mercury mass imbalance of 16% in excess with respect to the mercury input [43]. The high emission rates of this plant were attributed to the use of indigenous coal [42], which had a mercury content of 0.623 mg/kg (dry), whereas the average value of the other coals considered in the study was 0.072 mg/kg [43]. In 2002 this plant was scheduled for retirement by 2010 because of its high emissions of both SO_2 and mercury [44].

The provinces with major power plant Hg emissions were Alberta, followed by Saskatchewan and Ontario, with the three contributing approximately 89% of Canada's total emissions. The top 10 facilities, ranked by Hg emissions, accounted for 82% of the Hg emissions from the 25 Canadian power plants (**Table 2.13**). In Mexico, the main Hg emitters were also coal-fired power stations. Of the total Hg emissions from all 102 Mexican power plants (2,285 kg), 87% were from the country's three coal-fired power plants, and the rest (291 kg) were derived from oil, diesel and natural gas-fired power plants. The mercury emission rates of the three coal-fired power plants ranged from 0.050 to 0.072 kg/GW-h. It is important to note that there was an important difference in the Hg emissions estimation methodology from the 2002 to the 2005 inventories; the emission factor used for the 2002 inventory was 8.59 lb/10^{12} BTU and it was changed to 16.0 lb/10^{12}BTU for 2005. With a recalculated value of the 2002 Hg emissions, a reduction of nearly 7% (in Hg emissions) would be obtained from 2002 to 2005.

The top 10 facilities, ranked by Hg emissions, accounted for 94% of the emissions of that substance from all 102 Mexican power plants in 2005 (**Table 2.14**).

In 2005, 632 of the 2,728 power plants in the United States reported nearly 50,000 kg of Hg. These plants had similar emission rates, of less than 0.250 kg/GW-h (except for five plants whose rates ranged from 0.250–0.796 kg/GW-h). In general, emission rates of less than 1 kg/GW-h are considered normal for such power plants, given the fuels used and amounts of electricity generated. However, four other plants had emission rates ranging from 1.5 to 229 kg/GW-h, and values this high should be regarded with some reservation. Of the 632 plants, 220 accounted for 90% of total Hg emissions, with amounts

Table 2.13 Canada Hg Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	Province	Electricity Generation (MW-h)	Hg (kg)	Hg Emission Rate (kg/GW-h)	Primary Fuel
1	**TransAlta Utilities Corporation** Sundance Thermal Generating Station	Alberta	15,116,034	318	0.021	Coal
2	**SaskPower** Poplar River Power Station	Saskatchewan	3,699,109	281	0.076	Coal
3	**SaskPower** Boundary Dam Power Station	Saskatchewan	6,066,671	281	0.046	Coal
4	**EPCOR Generation** Genesee Thermal Generating Station	Alberta	9,301,772	194	0.021	Coal
5	**Ontario Power Generation** Nanticoke Generating St	Ontario	17,778,061	156	0.009	Coal
6	**TransAlta Utilities Corporation** Keephills Thermal Generating Station	Alberta	5,762,554	110	0.019	Coal
7	**Alberta Power (2000) Ltd.** Battle River Generating	Alberta	5,077,593	105	0.021	Coal
8	**Alberta Power (2000) Ltd.** Sheerness Generating Station	Alberta	5,892,719	95	0.016	Coal
9	**New Brunswick Power Generation Corporation** Grand Lake	New Brunswick	274,085	88	0.323	Coal
10	**SaskPower** Shand Power Station	Saskatchewan	1,664,600	86	0.052	Coal
Total, top 10 plants			70,633,197	1,714		
Total, 25 plants			105,015,358	2,079		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.14 Mexico Hg Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	Hg (kg)	Hg Emission Rate (kg/GW-h)	Primary Fuel
1	CFE CT Pdte. Plutarco Elías Calles (Petacalco)	Guerrero	14,275,114	711	0.050	Coal
2	CFE CT José López Portillo (Río Escondido)	Coahuila	9,357,259	678	0.072	Coal
3	CFE CT Carbón II	Coahuila	8,996,793	605	0.067	Coal
4	CFE CT Pdte. Adolfo López Mateos	Veracruz	10,547,560	36	0.003	Oil
5	CFE CT Gral. Manuel Álvarez Moreno (Manzanillo I)	Colima	8,783,848	33	0.004	Oil
6	CFE CT Francisco Pérez Ríos	Hidalgo	8,741,955	26	0.003	Oil
7	CFE CT Altamira	Tamaulipas	3,776,214	13	0.003	Oil
8	CFE CT José Aceves Pozos	Sinaloa	3,693,831	12	0.003	Oil
9	CFE CT Villa de Reyes	San Luis Potosí	3,243,039	12	0.004	Oil
10	CFE CT Puerto Libertad	Sonora	3,517,521	12	0.003	Oil
Total, top 10 plants			74,933,133	2,140		
Total, 102 plants			180,995,630	2,285		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.15 United States Hg Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	Hg (kg)	Hg Emission Rate (kg/GW-h)	Primary Fuel
1	Monticello	Texas	14,807,478	977	0.06596	Coal
2	James H Miller Jr	Alabama	21,328,867	892	0.04183	Coal
3	Keystone	Pennsylvania	13,488,615	874	0.06477	Coal
4	Scherer	Georgia	24,093,772	718	0.02982	Coal
5	Powerton	Illinois	9,469,508	702	0.07417	Coal
6	Rockport	Indiana	17,942,286	677	0.03774	Coal
7	Bruce Mansfield	Pennsylvania	18,343,905	676	0.03688	Coal
8	PPL Montour	Pennsylvania	10,399,362	645	0.06202	Coal
9	Martin Lake	Texas	18,250,189	639	0.03503	Coal
10	Monroe	Michigan	18,710,600	570	0.03047	Coal
Total, top 10 plants			166,834,582	7,371		
Total, 632 plants			2,213,760,057	49,133		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

ranging from 60 to 977 kg. Coal-fired power plants accounted for 69.5% of the total number of mercury emitting plants, while natural gas and oil power plants accounted for 17.7% and 12.8%, respectively.

The top 10 facilities, ranked by Hg emissions, accounted for 15% of the Hg emissions from the 632 US power plants for which data were available for 2005 (**Table 2.15**).

Figure 2.6 illustrates the contribution to total mercury (Hg) emissions of all the mercury-emitting power plants, by country. It shows that around 35% of the plants in the United States accounted for 90% of its total Hg emissions, while around 5% of the plants in Mexico and nearly 50% of the plants in Canada contributed 90% of each country's Hg emissions.

The geographical distribution of the Hg sources in North America is shown in **Figure 2.7**. The size of the dots represents the scale of emissions and the color represents the type of primary fuel used. In Canada, mercury emissions from power plants appear to occur mainly in the southwest, with the largest Canadian emitters, all coal-fired power plants, in Alberta.

Figure 2.6 Facility Contribution to Power Plant Hg Emissions in Canada, Mexico and the United States

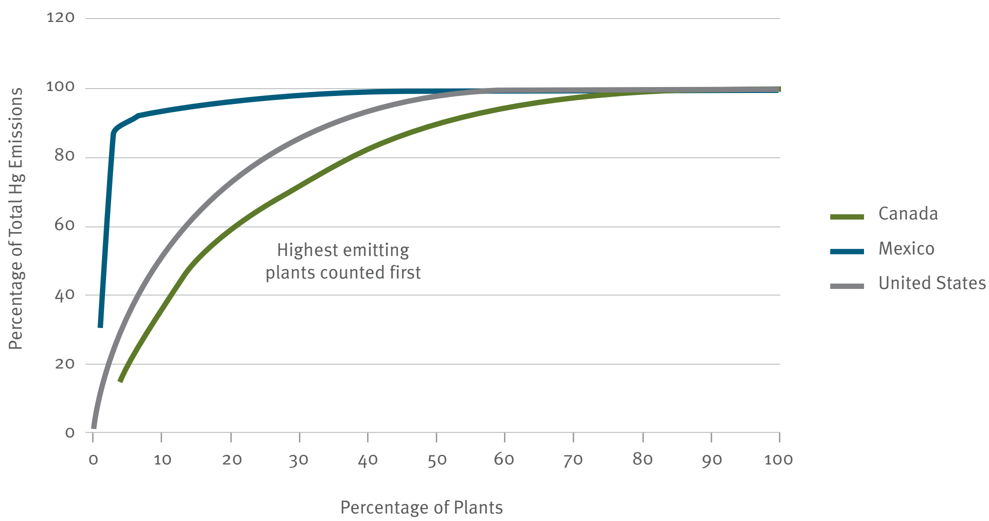
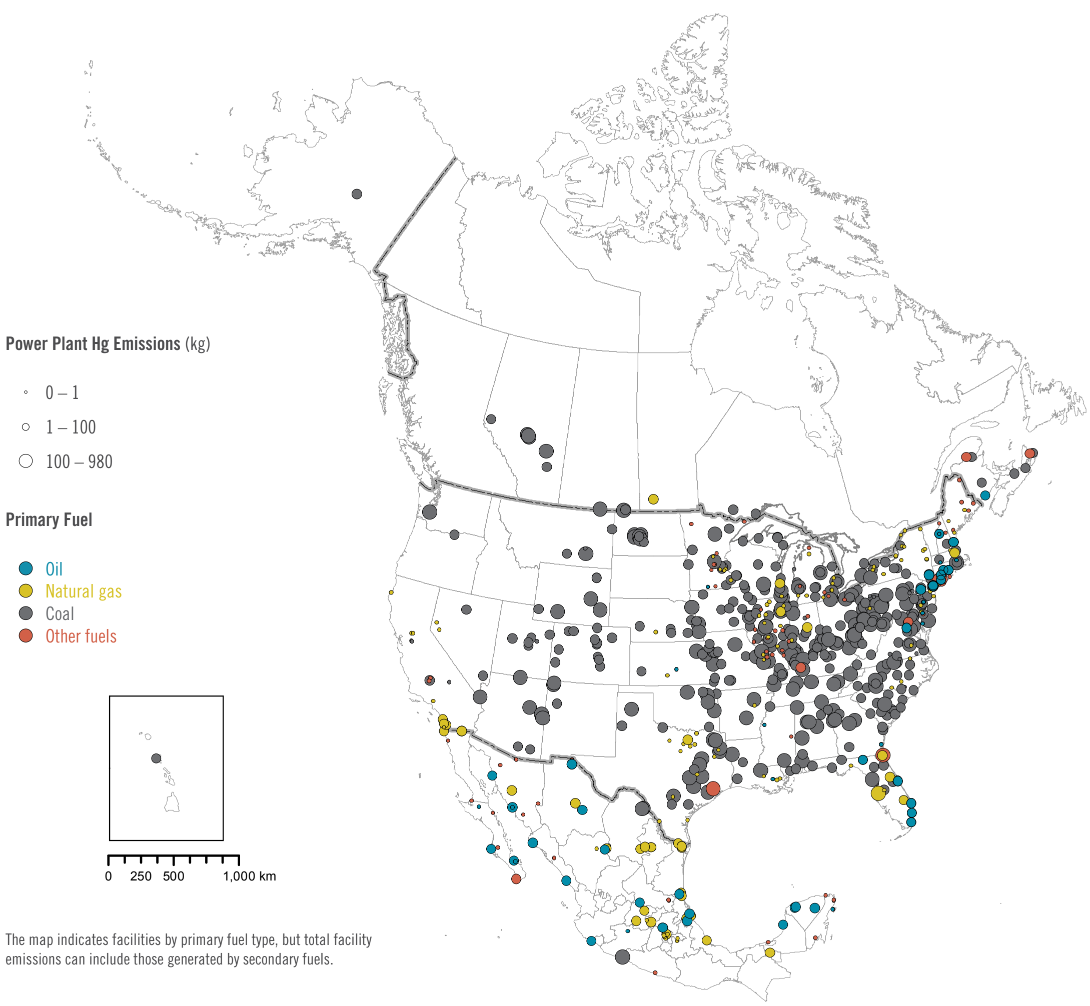


Figure 2.7 Distribution of Power Plant Hg Emission Sources in North America, 2005



The map indicates facilities by primary fuel type, but total facility emissions can include those generated by secondary fuels.

In Mexico, the three major Hg emitters are the coal-fired power stations located in the central-north and central-south regions, whereas there are smaller Hg emissions sources distributed across the whole country—mainly power plants burning oil or other fuels. The largest concentrations of Hg emissions sources in the United States are in the eastern half of the country; and in a fringe crossing the country through the states of Arizona, New Mexico, Utah, Wyoming, Montana and North Dakota. There are only a few Hg emission spots visible in the West.

2.3.4 Particulate Matter Emissions

Available data for this report included only the PM_{10} and $PM_{2.5}$ fractions of the particulate matter emissions from power plants. Emissions of PM_{10} and $PM_{2.5}$ from fossil fuel-based electricity generation are summarized in **Tables 2.16–2.21**, along with other parameters such as electricity generation, emission rates and fuel type. The full tables can be found online at www.cec.org/powerplants. For the United States, particulate matter emissions data presented in these tables have limited coverage as compared to the data for other pollutants (c.f. Section 2.1.3).

In Canada, of the total of 189 power plants, 161 reported PM_{10} emissions and 166 reported $PM_{2.5}$ emissions. For both PM_{10} and $PM_{2.5}$, the ten facilities with the largest emissions accounted for more than 70% of total emissions reported by Canadian power plants for 2005. **Tables 2.16** and **2.17** show the top 10 Canadian facilities ranked by emissions of $PM_{2.5}$ and PM_{10}, respectively. It should be noted that data on electricity generation were not publicly available for at least 50% of the plants. Power plants burning coal accounted for 75% and 61% of PM_{10} and $PM_{2.5}$ emissions, respectively. Plants burning "other fuels" accounted for 10% of PM_{10} and 19% of $PM_{2.5}$ emissions. Natural gas-fired power plants contributed 8% and 12% of PM_{10} and $PM_{2.5}$ emissions, respectively; and oil-fired power plants 6% and 8%, respectively.

In Mexico, emissions estimates of $PM_{2.5}$ and PM_{10} were available for all 102 power plants. The ten plants with the largest emissions accounted for more than 56% and 61% of the total reported emissions of $PM_{2.5}$ and

Table 2.16 Canada $PM_{2.5}$ Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	Province	Electricity Generation (MW-h)	$PM_{2.5}$ (t)	$PM_{2.5}$ Emission Rate (kg/MW-h)	Primary Fuel
1	New Brunswick Power Generation Corporation Dalho	New Brunswick	1,882,452	934	0.50	Other Fuels
2	TransAlta Utilities Corporation Sundance Thermal Generating Station	Alberta	15,116,034	831	0.05	Coal
3	Ontario Power Generation Lambton Generating Stat	Ontario	9,532,953	757	0.08	Coal
4	Ontario Power Generation Nanticoke Generating St	Ontario	17,778,061	666	0.04	Coal
5	NOVA Chemicals Corporation / ATCO Power / EPCOR Joffre	Alberta	1,839,640	497	0.27	Natural Gas
6	Alberta Power (2000) Ltd. Battle River Generating	Alberta	5,077,593	424	0.08	Coal
7	New Brunswick Power Generation Corporation Belle	New Brunswick	3,610,361	353	0.10	Coal
8	Newfoundland and Labrador Hydro Holyrood Thermal	Newfoundland and Labrador	1,355,543	237	0.17	Oil
9	TransAlta Utilities Corporation Keephills Thermal Generating Station	Alberta	5,762,554	231	0.04	Coal
10	SaskPower Poplar River Power Station	Saskatchewan	3,699,109	156	0.04	Coal
Total, top 10 plants			65,654,299*	5,084		
Total, 166 plants			130,047,775	7,208		

* Data on electricity generation were not publicly available for 88 of the 166 Canadian power plants. Due to rounding, totals may vary slightly.
Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.17 Canada PM_{10} Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	Province	Electricity Generation (MW-h)	PM_{10} (t)	PM_{10} Emission Rate (kg/MW-h)	Primary Fuel
1	**Ontario Power Generation** Nanticoke Generating St	Ontario	17,778,061	2,124	0.12	Coal
2	**Ontario Power Generation** Lambton Generating Station	Ontario	9,532,953	2,123	0.22	Coal
3	**TransAlta Utilities Corporation** Sundance Thermal Generating Station	Alberta	15,116,034	1,005	0.07	Coal
4	**New Brunswick Power Generation Corporation** Dalho	New Brunswick	1,882,452	963	0.51	Other Fuels
5	**Alberta Power (2000) Ltd.** Battle River Generating Station	Alberta	5,077,593	651	0.13	Coal
6	**NOVA Chemicals Corporation/ATCO Power/EPCOR** Joffre	Alberta	1,839,640	624	0.34	Natural Gas
7	**EPCOR Generation** Genesee Thermal Generating Station	Alberta	9,301,772	581	0.06	Coal
8	**SaskPower** Poplar River Power Station	Saskatchewan	3,699,109	543	0.15	Coal
9	**TransAlta Utilities Corporation** Keephills Thermal	Alberta	5,762,554	534	0.09	Coal
10	**New Brunswick Power Generation Corporation** Belle	New Brunswick	3,610,361	491	0.14	Coal
Total, top 10 plants			73,600,528*	9,640		
Total, 161 plants			129,195,216	13,448		

* Data on electricity generation were not publicly available for 88 of the 161 Canadian power plants. Due to rounding, totals may vary slightly.
Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.18 Mexico $PM_{2.5}$ Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	$PM_{2.5}$ (t)	$PM_{2.5}$ Emission Rate (kg/MW-h)	Primary Fuel
1	**CFE CT Pdte. Adolfo López Mateos**	Veracruz	10,547,560	6,033	0.572	Oil
2	**CFE CT Gral. Manuel Álvarez Moreno** (Manzanillo I)	Colima	8,783,848	5,561	0.633	Oil
3	CFE CT Francisco Pérez Ríos	Hidalgo	8,741,955	4,241	0.485	Oil
4	CFE CT Altamira	Tamaulipas	3,776,214	2,205	0.584	Oil
5	CFE CT José Aceves Pozos	Sinaloa	3,693,831	2,076	0.562	Oil
6	CFE CT Villa de Reyes	San Luis Potosí	3,243,039	2,069	0.638	Oil
7	CFE CT Puerto Libertad	Sonora	3,517,521	1,990	0.566	Oil
8	**CFE CT José López Portillo** (Río Escondido)	Coahuila	9,357,259	1,460	0.156	Coal
9	CFE CD General Agustín Olachea Avilés	Baja California Sur	488,572	1,419	2.905	Oil
10	CFE CT Guadalupe Victoria	Durango	2,305,169	1,310	0.568	Oil
Total, top 10 plants			54,454,967	36,765		
Total, 102 plants			180,995,630	50,255		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.19 Mexico PM_{10} Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	PM_{10} (t)	PM_{10} Emission Rate (kg/MW-h)	Primary Fuel
1	CFE CT Pdte. Adolfo López Mateos	Veracruz	10,547,560	8,277	0.785	Oil
2	CFE CT Gral. Manuel Álvarez Moreno (Manzanillo I)	Colima	8,783,848	7,630	0.869	Oil
3	CFE CT Francisco Pérez Ríos	Hidalgo	8,741,955	5,804	0.664	Oil
4	CFE CT José López Portillo (Río Escondido)	Coahuila	9,357,259	3,370	0.360	Coal
5	CFE CT Altamira	Tamaulipas	3,776,214	3,026	0.801	Oil
6	CFE CT Carbón II	Coahuila	8,996,793	3,012	0.335	Coal
7	CFE CT José Aceves Pozos	Sinaloa	3,693,831	2,849	0.771	Oil
8	CFE CT Villa de Reyes	San Luis Potosí	3,243,039	2,839	0.875	Oil
9	CFE CT Puerto Libertad	Sonora	3,517,521	2,731	0.776	Oil
10	CFE CD General Agustín Olachea Avilés	Baja California Sur	488,572	1,925	3.939	Oil
Total, top 10 plants			61,146,591	41,461		
Total, 102 plants			180,995,630	67,710		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

PM_{10}, respectively, but as **Tables 2.18** and **2.19** indicate, these plants were not the largest electricity generators. According to the reported data for Mexico, 66.9% of $PM_{2.5}$ was emitted by plants burning heavy (residual) fuel oil, while coal and natural gas-fired power stations contributed 6% and 23.9% of $PM_{2.5}$ emissions, respectively; the remainder corresponded to plants burning "other fuels." For PM_{10}, the contributions of coal and natural gas were 10.3% and 18.6%, respectively; whereas for heavy fuel oil it was 68.0%.

In the United States, only 1,182 of the 2,728 plants reported $PM_{2.5}$ and PM_{10} emissions; these plants accounted for 75% of the total electricity generated by all 2,728 power plants. More than 92% of the $PM_{2.5}$ emissions were generated by the 250 largest $PM_{2.5}$ emitters, of which 96.4% burned coal, 2.8% heavy fuel oil and 0.8% natural gas. Likewise, more than 92% of the PM_{10} emissions were released from the 250 largest PM_{10} emitters of which 96.8% burned coal, 2.4% heavy fuel oil and 0.8% natural gas.

The top 10 US facilities, ranked by emissions of $PM_{2.5}$ and PM_{10}, accounted for 16% and 15%, respectively, of the emissions of these pollutants from these 1,182 US power plants **(Tables 2.20** and **2.21).**

Figure 2.8 shows the contribution to $PM_{2.5}$ and PM_{10} emissions of all the plants considered in this report, from the largest to the smallest PM emitters. It can be seen that for the United States and Canada, 20% of the total number of plants in each country accounted for roughly 90% of total PM emissions. For Mexico, 35% of the total number of plants accounted for 90% of total PM emissions.

For Canada, some emission rates were calculated based on estimated electricity generation, and should be regarded with some reservation. In the case of the United States, the majority of plants have low $PM_{2.5}$ emission rates, in the ranges of 0.00–0.05 kg/MW-h, and 0.05–0.10 kg/MW-h. The first range comprises many more natural gas-fired plants than does the second; there is a similar number of oil-fired plants in both ranges; and there are more coal-fired plants in the second range. A similar picture is observed for PM_{10}, except that the predominant range for coal-fired plants is from 0.10 to 0.15 kg/MW-h. For the United States the $PM_{2.5}/PM_{10}$ ratio varies widely, although nearly 70% of the plants have ratios above 0.8.

The geographical distribution of the $PM_{2.5}$ and PM_{10} sources for 2005 is shown in **Figures 2.9** and **2.10**, respectively. As in previous figures, the size of the dots represents the scale of emissions and the color represents the type of primary fuel used. In Canada, the geographic spread of sources emitting particulate matter (both PM_{10} and $PM_{2.5}$) is evident, including plants in the Yukon, the Northwest Territories and Nunavut, although the most important ones are coal-fired power plants in Alberta. Some oil-fired power plants in New Brunswick, Nova Scotia and Newfoundland and Labrador stand out for their PM_{10} emissions, as do some coal-fired power plants in the first two of these provinces. The same plants are important sources of $PM_{2.5}$ except that some of the coal-fired power plants lie in the 0–100 t/year emissions range,

Table 2.20 United States $PM_{2.5}$ Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	$PM_{2.5}$ (t)	$PM_{2.5}$ Emission Rate (kg/MW-h)	Primary Fuel
1	Keystone	Pennsylvania	13,488,615	8,699	0.6449	Coal
2	Bowen	Georgia	22,337,864	8,274	0.3704	Coal
3	Hatfields Ferry Power Station	Pennsylvania	8,672,997	7,477	0.8621	Coal
4	Crist	Florida	5,008,182	7,193	1.4363	Coal
5	Homer City Station	Pennsylvania	13,599,227	7,161	0.5266	Coal
6	PPL Montour	Pennsylvania	10,399,362	6,792	0.6531	Coal
7	Conesville	Ohio	9,716,702	5,700	0.5866	Coal
8	E C Gaston	Alabama	11,273,347	5,684	0.5042	Coal
9	Warrick	Indiana	4,392,558	5,619	1.2791	Coal
10	Mt Storm	West Virginia	10,763,271	5,345	0.4966	Coal
Total, top 10 plants			109,652,125	67,944		
Total, 1,182 plants			2,230,007,077	421,877		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.21 United States PM_{10} Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	PM_{10} (t)	PM_{10} Emission Rate (kg/MW-h)	Primary Fuel
1	Bowen	Georgia	22,337,864	11,016	0.4932	Coal
2	Keystone	Pennsylvania	13,488,615	9,632	0.7141	Coal
3	Hatfields Ferry Power Station	Pennsylvania	8,672,997	9,283	1.0703	Coal
4	Homer City Station	Pennsylvania	13,599,227	8,100	0.5956	Coal
5	Crist	Florida	5,008,182	8,086	1.6146	Coal
6	PPL Montour	Pennsylvania	10,399,362	7,580	0.7289	Coal
7	Warrick	Indiana	4,392,558	7,461	1.6987	Coal
8	E C Gaston	Alabama	11,273,347	6,513	0.5777	Coal
9	Conesville	Ohio	9,716,702	6,086	0.6264	Coal
10	PPL Brunner Island	Pennsylvania	10,167,210	5,675	0.5581	Coal
Total, top 10 plants			109,056,064	79,432		
Total, 1,182 plants			2,230,007,077	514,156		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

whereas the oil-fired power plant emissions tend to be in the 100–1,000 t/year range.

In Mexico, there are power plants burning coal, oil or natural gas distributed across the country that are PM_{10} sources with emissions in the 1,000 to 9,700 t/year range. A similar pattern is observed for $PM_{2.5}$.

Consistent with the geographical distribution of other pollutants (SO_2, NO_X and Hg), there are very large numbers of power plants, mostly coal-fired, emitting particulate matter in the eastern half of the United States. As was the case with Canada and Mexico, the distribution PM_{10} sources in the United States is very similar to the distribution of sources of $PM_{2.5}$.

2.3.5 Greenhouse Gas (GHG) Emissions

Emissions of GHGs from fossil fuel-based electricity generation are summarized in this section, along with other parameters such as electricity generation emission factors and fuel type (sorted by emissions). For this report, only emissions of CO_2, CH_4 and N_2O are taken into account, as these are the main greenhouse gases released by fossil fuel-based

Figure 2.8 Facility Contribution to Power Plant $PM_{2.5}$ and PM_{10} Emissions in Canada, Mexico and the United States

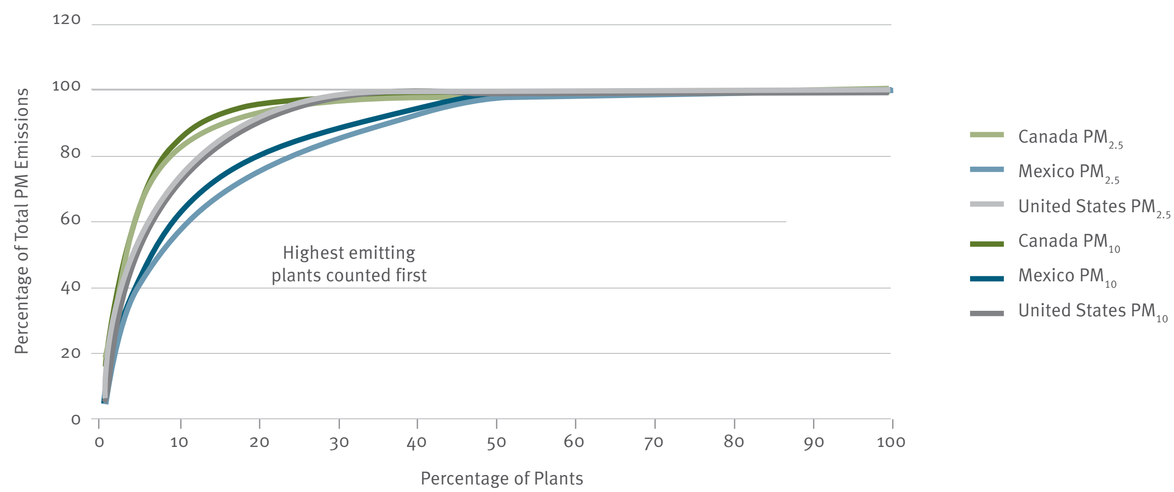


Figure 2.9 Distribution of Power Plant $PM_{2.5}$ Emission Sources in North America, 2005

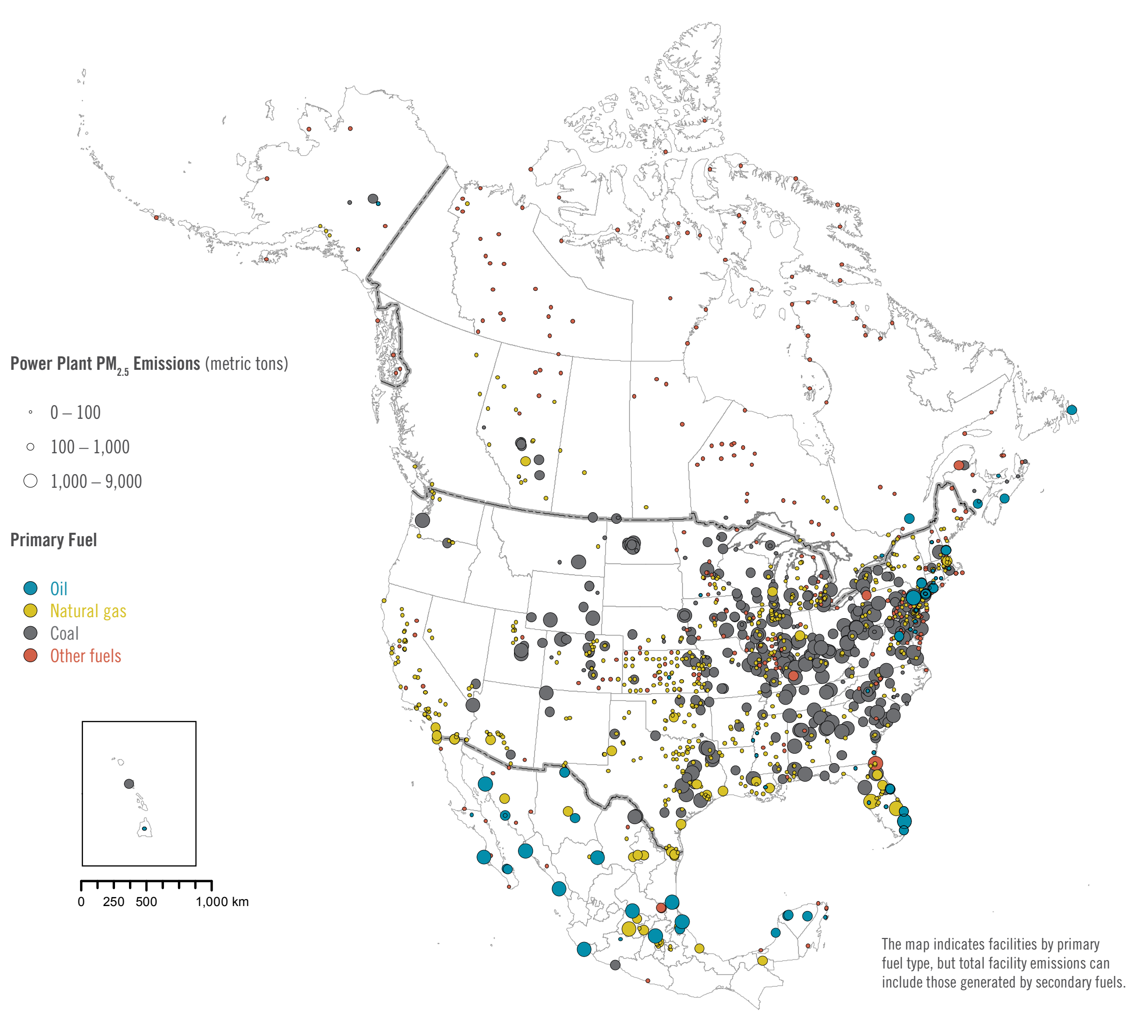
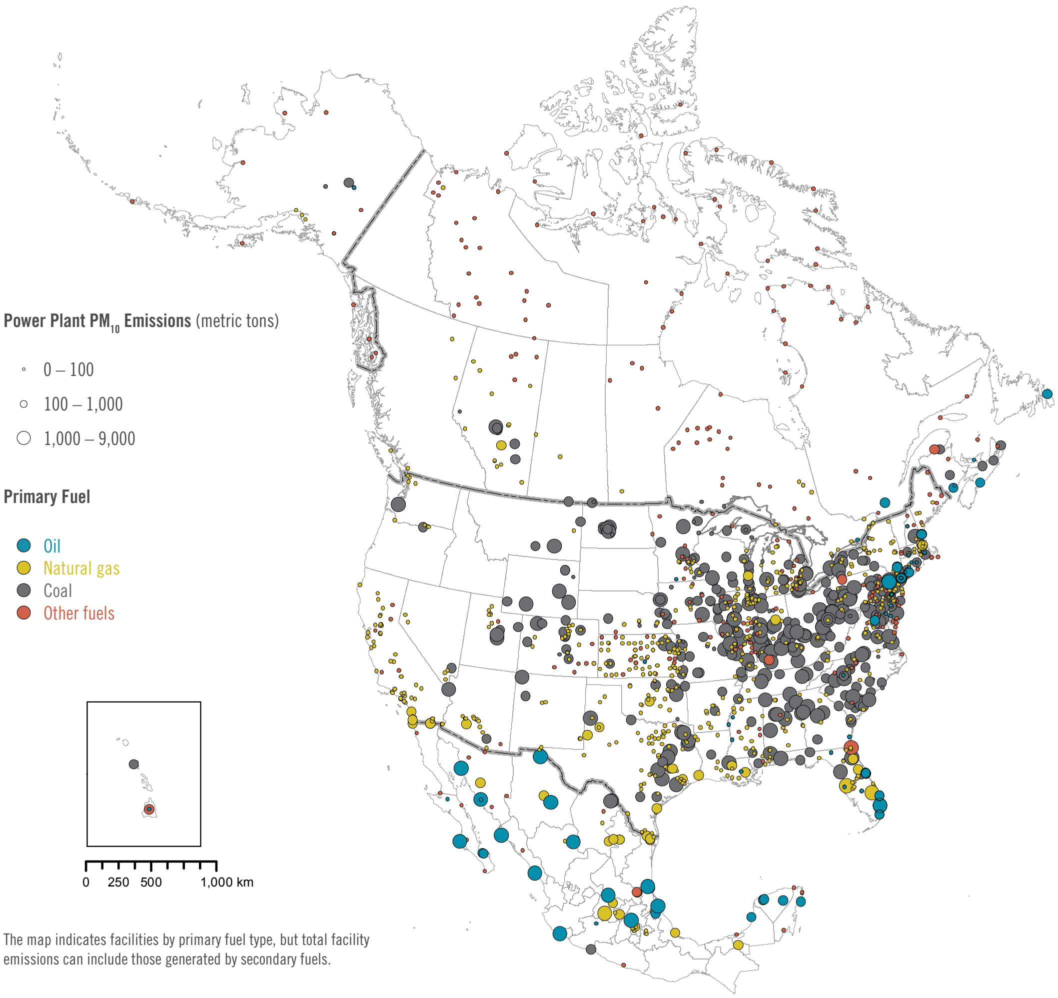


Figure 2.10 Distribution of Power Plant PM_{10} Emission Sources in North America, 2005



The map indicates facilities by primary fuel type, but total facility emissions can include those generated by secondary fuels.

power plants (see Section 3.3.5). **Tables 2.23–2.25** summarize CO_2 data from power plants in each country. Detailed data for emissions of CH_4 and N_2O for each country are available online at www.cec.org/powerplants (**Tables 2.26–2.31**).

As mentioned in the discussion on climate change in Section 2.1, CO_2 is by far the largest GHG emitted by the electricity generation sector in North America. **Table 2.22** summarizes GHG emissions from power stations in the three countries, with emissions of CO_2 accounting for over 99% of total power plant GHG emissions in each country. In terms of equivalent tonnes of CO_2, the emissions of N_2O represent less than 0.5% of the total, with emissions of CH_4 being even less.

In Canada, 72 of the 189 power plants reported emissions of CO_2 to the GHGRP; 14 of these facilities did not report emissions of CH_4 or N_2O. The total emissions of GHG from those 72 plants in units of CO_2-eq were 122 million tonnes. Considering a total estimated generation of 133,764 GW-h from those 72 plants, the national average emission rate was 0.92 t of CO_2-eq/MW-h (or 920 kg/MW-h). CO_2 emissions accounted for 99.1% (121,299,282 t.) of the total reported by Canadian power plants for 2005, while CH_4 emissions equaled 2,465 t and N_2O emissions were 3,501 t. Thus, in terms of both emissions and global warming potential, CO_2 was the most important greenhouse gas emitted by these facilities.

Emissions of CO_2 are strongly dependent on the type of fuel used. Sub-bituminous coals, for instance, have emission factors in the order of 0.1 kg/MJ, heavy fuel oils (No. 6) have emission factors in the order of 0.07kg/MJ, and natural gas has an emission factor in the order of 0.05 kg/MJ (i.e., about half that of coal). Although there are other factors involved in the plant emission rate of CO_2 from different types of fuel, it can generally be said that coal results in more emissions than oil, and oil in more emissions than natural gas.

The ten largest CO_2 emitters (shown in **Table 2.23**) were all coal-based, and accounted for about 69% of total CO_2 emissions reported by Canadian power plants for 2005. Because of the way the generated power was estimated for Canada, the amount of CO_2 emissions was fairly proportional to the power generated. However, it is important to remember that the data on emissions of GHGs represent just over one-third of all Canadian power plants included in this report. Detailed data on CH_4 and N_2O emissions for the 58 reporting facilities are available online at www.cec.org/powerplants.

In Mexico, total GHG emissions from the 102 power plants considered were 118 million tonnes of CO_2-eq. Emissions of CO_2 were 117,737,070 t (or 99.5% of the total), with CH_4 emissions totaling 2,569 t and N_2O emissions, 1,745 t. Detailed data for emissions of CH_4 and N_2O from Mexican power plants are provided at www.cec.org/powerplants.

In Mexico there are only three coal-fired power plants, thus within the ten largest CO_2 emitters most are oil-fired power stations. The ten largest CO_2 emitters accounted for about 57% of the total CO_2 emissions, and are shown in **Table 2.24**. The national average GHG emission rate was estimated to be 0.6538 t CO_2-eq/MW-h (or 653.8 kg CO_2-eq/MW-h).

Table 2.22 Total Emissions and Emission Rates of Major GHGs from Power Plants in North America, 2005

Pollutant	Canada		Mexico		United States		North America
	Emissions Tg of CO_2-eq	Emission Rate t CO_2-eq/MW-h	Emissions Tg of CO_2-eq	Emission Rate t CO_2-eq/MW-h	Emissions Tg of CO_2-eq	Emission Rate t CO_2-eq/MW-h	Emissions Tg of CO_2-eq
CO_2	121.3	0.90681	117.7	0.6505	2419.5	0.81533	2,658.5
CH_4	0.1	0.00046	0.05	0.0003	0.7	0.00024	0.8
N_2O	1.1	0.00954	0.54	0.0030	11.0	0.00370	12.6
TOTAL	122.4	0.91531	118.3	0.65378	2431.2	0.81927	2,671.9

Due to rounding, totals may vary slightly.

Table 2.23 Canada CO_2 Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	Province	Electricity Generation (MW-h)	CO_2 (t)	CO_2 Emission Rate (kg/MW-h)	Primary Fuel
1	**Ontario Power Generation** Nanticoke Generating St	Ontario	17,778,061	17,585,856	989	Coal
2	**TransAlta Utilities Corporation** Sundance Thermal Generating Station	Alberta	15,116,034	15,790,482	1,045	Coal
3	**EPCOR Generation** Genesee Thermal Generating Station	Alberta	9,301,772	8,873,134	954	Coal
4	**Ontario Power Generation** Lambton Generating Station	Ontario	9,532,953	8,694,815	912	Coal
5	**SaskPower** Boundary Dam Power Station	Saskatchewan	6,066,671	6,697,605	1,104	Coal
6	**TransAlta Utilities Corporation** Keephills Thermal Generating Station	Alberta	5,762,554	6,041,060	1,048	Coal
7	**Alberta Power (2000) Ltd.** Sheerness Generating Station	Alberta	5,892,719	5,927,674	1,006	Coal
8	**Alberta Power (2000) Ltd.** Battle River Generating Station	Alberta	5,077,593	5,285,838	1,041	Coal
9	**Nova Scotia Power** Lingan Generating Station	Nova Scotia	4,653,774	4,417,130	949	Coal
10	**SaskPower** Poplar River Power Station	Saskatchewan	3,699,109	4,083,816	1,104	Coal
Total, top 10 plants			82,881,240	83,397,410		
Total, 72 plants			133,764,697	121,299,282		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Table 2.24 Mexico CO_2 Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	CO_2 (t)	CO_2 Emission Rate (kg/MW-h)	Primary Fuel
1	CFE CT Pdte. Plutarco Elías Calles (Petacalco)	Guerrero	14,275,114	15,163,296	1,062	Coal
2	CFE CT José López Portillo (Río Escondido)	Coahuila	9,357,259	10,106,597	1,080	Coal
3	CFE CT Carbón II	Coahuila	8,996,793	9,072,240	1,008	Coal
4	CFE CT Pdte. Adolfo López Mateos	Veracruz	10,547,560	7,971,795	756	Oil
5	CFE CT Gral. Manuel Álvarez Moreno (Manzanillo I)	Colima	8,783,848	7,344,902	836	Oil
6	CFE CT Francisco Pérez Ríos	Hidalgo	8,741,955	6,201,080	709	Oil
7	CFE CT Altamira	Tamaulipas	3,776,214	2,925,631	775	Oil
8	CFE CT José Aceves Pozos	Sinaloa	3,693,831	2,746,102	743	Oil
9	CFE CT Villa de Reyes	San Luis Potosí	3,243,039	2,737,971	844	Oil
10	CFE CT Puerto Libertad	Sonora	3,517,521	2,633,385	749	Oil
Total, top 10 plants			74,933,133	66,902,998		
Total, 102 plants			180,995,630	117,737,070		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

In the United States, all 2,728 power plants included in this report emitted a total of 2,431 million tonnes CO_2-eq of GHG, with 2,718 of them having data for emissions of CH_4 and N_2O. The US facilities' average GHG emission rate was estimated to be 0.82 t CO_2-eq/MW-h (or 820 kg CO_2-eq/MW-h). The large disparity in the total electricity production among the three countries is apparent from the comparison of the amounts of CO_2 emitted. CO_2 emissions from US power plants were 2,419,514,935 t (or 99.5% of total GHG emissions), while emissions of CH_4 were 33,590 t, and emissions of N_2O were 35,428 t (see **Tables 2.28** and **2.31**, online). The sixteen largest emitters of CO_2 in the United States released over 280 million tonnes of CO_2, which is more than the combined CO_2 emissions from power plants in Mexico and Canada.

Regarding the CO_2 emission rate by fuel type, for coal the value is 0.94 t/MW-h (or 940 kg/MW-h), for oil it is 0.74 t/MW-h (740 kg/MW-h), and for natural gas, 0.42 t/MW-h (420 kg/MW-h). In terms of the number of power stations emitting CO_2, natural gas was the predominant fuel used by 50% of the US power stations (with 27% and 22% of the plants burning oil and coal, respectively). However, in terms of electricity generation, coal was used to produce 71% of the total electricity from fossil fuels, followed by natural gas with 25%, and heavy fuel oil with 3.6%. Thus, heavy fuel oil appears as a minor source of CO_2, as compared to coal, natural gas and other fuels.

Table 2.25 shows that the top ten US power plants, ranked by emissions of CO_2, accounted for 8% of all CO_2 emissions by US power plants in 2005.

Figure 2.11 shows the CO_2 emissions contribution of all the plants in North America for which data were available, from the largest to the smallest emitters. It can be seen that 20% of the total number of plants in the United States accounted for roughly 90% of the total CO_2 emissions. For Mexico and Canada, 35% of each country's power plants accounted for 90% of their respective total CO_2 emissions (but readers are reminded that data for CO_2 emissions were available for just over one-third of the Canadian power plants included in this report). As mentioned before, CO_2 emissions are to a large extent proportional to the electricity generated; power plants with the largest generation are also the major emitters of CO_2.

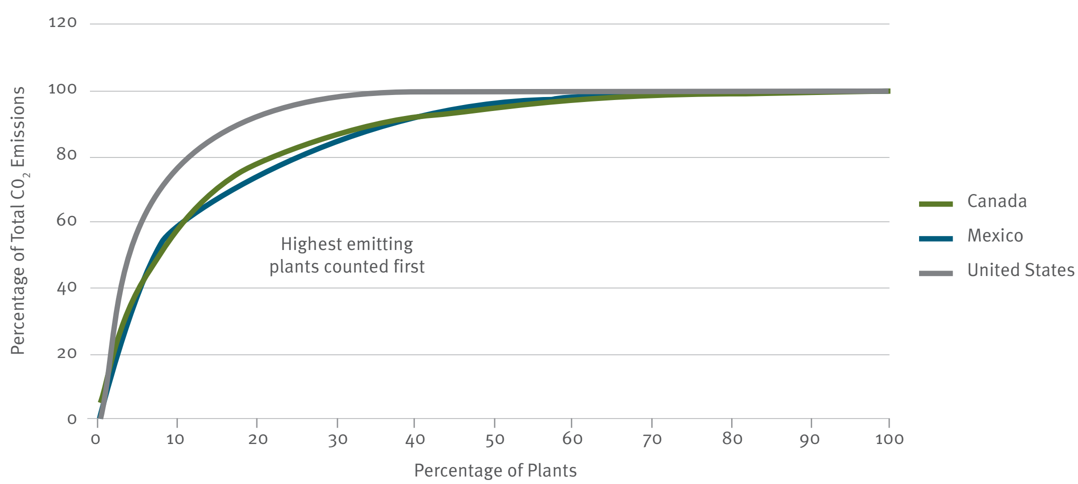
For Canada, some emission rates were calculated based on an estimated electricity generation and should be regarded with some reservation. In the case of the United States, more than 92% of the power stations had a CO_2 emission rate in the range of 200 to 1500 kg/MW-h, while for Mexico about 80% of the power stations were in this range, irrespective of the technology or type of fuel used. A closer examination is needed of the plants with emission rates above this range, with possible reasons being that the data are biased, there were unusual operating episodes, or the power plants were highly inefficient.

Table 2.25 United States CO_2 Emissions, 2005, Ranked by Volume (Top 10 Emitters)

	Plant Name	State	Electricity Generation (MW-h)	CO_2 (t)	CO_2 Emission Rate (kg/MW-h)	Primary Fuel
1	Scherer	Georgia	24,093,772	23,624,208	981	Coal
2	James H Miller Jr	Alabama	21,328,867	20,420,588	957	Coal
3	Bowen	Georgia	22,337,864	20,100,262	900	Coal
4	Gibson	Indiana	22,442,805	19,728,329	879	Coal
5	Martin Lake	Texas	18,250,189	19,589,278	1,073	Coal
6	W A Parish	Texas	19,688,219	18,781,879	954	Coal
7	Navajo	Arizona	17,030,674	17,851,193	1,048	Coal
8	Colstrip	Montana	16,240,783	17,435,515	1,074	Coal
9	General James M Gavin	Ohio	19,142,304	17,093,603	893	Coal
10	Jeffrey Energy Center	Kansas	15,145,728	16,441,720	1,086	Coal
Total, top 10 plants			195,701,205	191,066,576		
Total, 2,728 plants			2,967,510,824	2,419,514,935		

Due to rounding, totals may vary slightly. Note: Total facility emissions may include those generated by both primary and secondary fuels. The full dataset can be accessed at www.cec.org/powerplants.

Figure 2.11 Facility Contribution to Power Plant CO_2 Emissions in Canada, Mexico and the United States



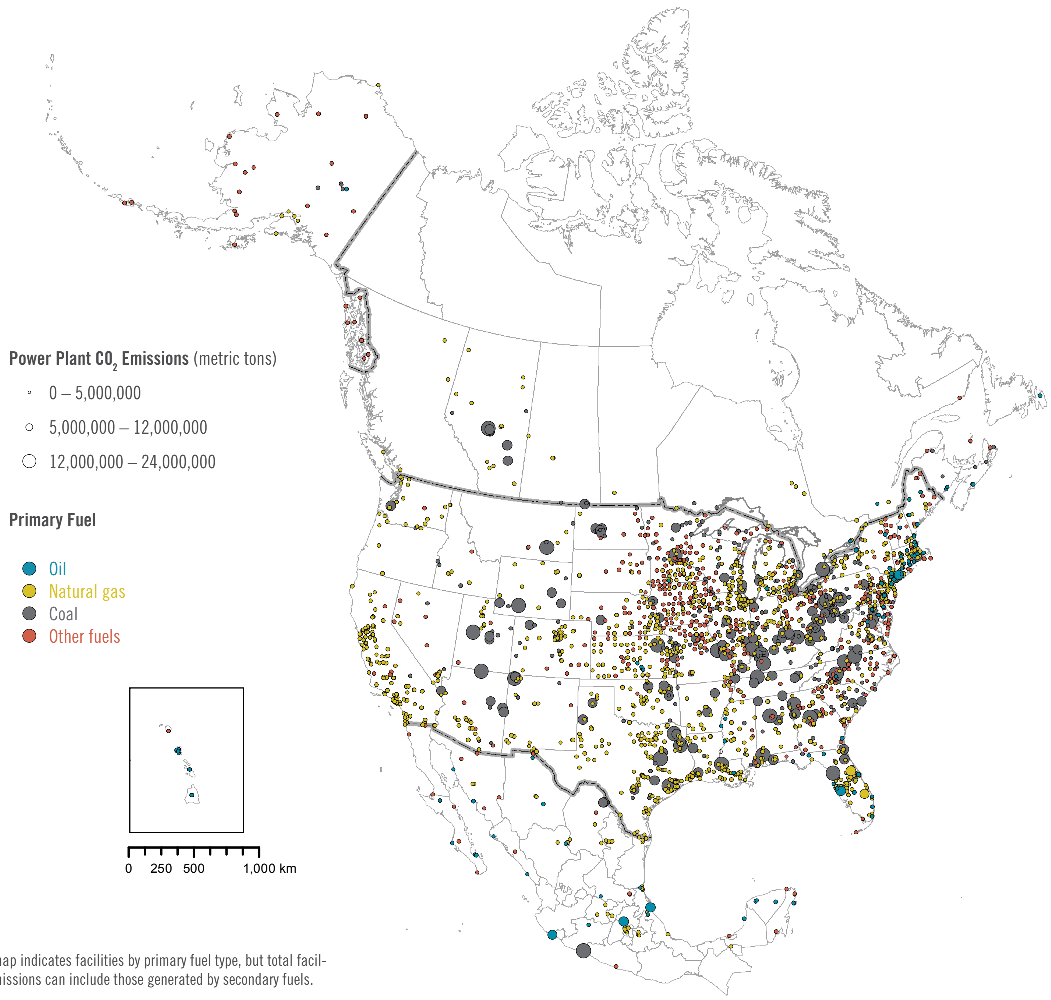
The geographical distribution of the CO_2 sources for 2005 is shown in **Figure 2.12.** The size of the dots represents the magnitude of emissions and the color represents the type of primary fuel used. The two most important CO_2 emitters in Canada were located in the provinces of Ontario and Alberta and were both coal-fired power plants. In contrast, Mexico shows a more uniform distribution across the country, with one isolated spot of very large emissions in Guerrero, on the Pacific Ocean coast. Consistent with the geographical distribution of sources of other pollutants mentioned in this report, there was a very large number of power plants emitting CO_2 in the eastern half of the United States, and also significant concentrations in California (259 plants) and Texas (191 plants). Some coal-fired power stations with large emissions can also be seen in the Midwest states.

2.3.6 Discussion

2.3.6.1 Relationship Between Fuels Used and Pollutants Released

The emissions profiles of the North American power plants analyzed in this report depend on the type and size of facility, electricity generating technology and fuels used. The data for 2005 show that in both Canada and the United States, coal-fired power plants accounted

Figure 2.12 Distribution of Power Plant CO_2 Emission Sources in North America, 2005



The map indicates facilities by primary fuel type, but total facility emissions can include those generated by secondary fuels.

for a majority of the emissions of criteria air contaminants (CACs), SO_2, NO_X, PM_{10}, $PM_{2.5}$. In Mexico, ten facilities accounted for 78 percent of the SO_2 emissions, seven of which were oil-fired power plants. However, the three coal-fired power plants in Mexico dominated emissions of NO_X, and contributed significantly to the emissions of SO_2.

With respect to emissions of particulate matter ($PM_{2.5}$ and PM_{10}), two-thirds of the power plant emissions of $PM_{2.5}$ in Mexico were emitted by the burning of heavy (residual) fuel oil.

Coal-fired power plants in Canada and the United States, along with Mexican oil-fired facilities, showed the largest emissions overall of greenhouse gases (GHGs), particularly CO_2 (although in Canada and Mexico, natural gas-fired power plants were major sources of CH_4, as well as N_2O).

And the data in this report show that mercury (Hg) emissions in the three countries were mainly from the combustion of coal. For Canada and the United States, coal-fired power plants accounted for 98% of all Hg releases from fossil-fuel electricity generating facilities, and in Mexico, they accounted for nearly 88%.

Therefore, these data confirm the findings of other sources referenced in this report that North American fossil fuels power plants are major contributors of emissions of greenhouse gases and other pollutants.

This analysis also reveals that other factors, such as total electricity generation, capacity, age and efficiency of power plants, figure significantly. For instance, many of the top emitting facilities are not necessarily the top generating facilities. Interestingly, the data reveal that the United States has higher per capita emissions of many pollutants than

Canada and Mexico, reflecting the large number of US facilities, many of them coal-fired. However, taking into account the amount of electricity generated by some of these plants, many US facilities actually had lower overall CO_2 emission rates than facilities in the other two countries.

An examination of the five largest power stations in each country, in terms of electricity generation, reveals that except for two plants in Mexico that use heavy fuel oil, all the plants are coal-fired. This is a sign of the strategic value of this fuel, even though in terms of potential pollution generation coal is the "dirtiest" of the fossil fuels. In spite of the difference in economic development levels and energy consumption between the three countries, these top five plants are of similar magnitude. The US plants each had an average capacity of around 3,300 MW; the Canadian plants' average capacity was 2,000 MW; and in Mexico, the average capacity was 1,600 MW. The average plant capacity factors were 0.78, 0.70 and 0.76, respectively.

These data indicate that the top five plants in the United States and Mexico generate electricity during more of the year than the top five in Canada (readers are reminded that in Canada the main source of electricity is hydropower, hence there is no need for fossil-fuel plants to operate at a greater capacity). For these top five plants, the CO_2 emission rates of are all of similar order of magnitude; however, for the other pollutants the emission rates of the plants in Mexico are generally much higher than for those of US plants, indicating the lack of environmental control equipment or poor performance of the Mexican facilities. Plants in Canada, on the other hand, had lower emission rates than plants in the United States, except for NO_X.

2.3.6.2 Sources, Availability and Quality of Emissions Data

Although the emissions inventory data for Canada and Mexico have improved significantly from 2002 to 2005, they are not yet at par with the level of detail of the US data. In the case of Canada, there is an important lack of information regarding the electricity generation of individual plants, along with information about pollution control technologies. In the case of Mexico, the majority of the emissions have been calculated on the basis of AP-42 emission factors, with a small amount of data generated through on-site monitoring—but in no case have methods such as continuous emissions monitoring (CEM) been used.

While the US sources (from the NEI and eGRID) yielded by far the best data, even those are at times inconsistent; and for all three countries, when there appeared to be an inconsistency in the data, no alternative data sources were available for cross-reference and verification purposes.

For instance, as indicated in Section 2.1.3, 105 plants consumed more electricity from the grid than the amount they contributed to it, resulting in a negative figure or zero for annual net electricity generation. Some plants generate the electricity they require for their process and any excess electricity produced may be fed back into the grid, which may result in zero or negative net metering. Nevertheless, certain pollutants are released at all times during electricity generation; therefore, these should be taken into account for the emissions inventory. However, since the eGRID does not provide overall generation data (only net generation), it is not possible to determine the emission rates.

Another example is the exceedingly high emission rates obtained from some eGRID data—as in the case of the very high SO_2 emission rates for a small number of US power plants, with similar cases found in Mexico and Canada. Such discrepancies suggest the need for additional information and supplemental data sources in order to adequately evaluate emissions.

Care should be taken when interpreting the results from this report, since when data were not available for certain parameters, they had to be estimated. The use of emission factors, as well as changes in emissions estimation methodologies, can be important factors when attempting to evaluate changes over time—as in the case of the mercury emissions estimated for Mexico between 2002 and 2005 using different methodologies, with an apparent decrease in calculated emissions over that period.

Coal train
Virginia, United States

3. Fossil fuel power plants: Fundamental Information

3.1 Technologies for Generating Electricity from Fossil Fuels

In general terms, electricity is generated from fossil fuels by burning them in the presence of air. This allows the energy contained in the fuel to be released as heat, resulting in very hot gases. The energy released can then be used in two ways. In internal combustion engines, the hot combustion gases are compressed and then used to directly drive the electric generator and auxiliary equipments [15, 16, 45, 46]. The other method is to use the hot gases to heat water and produce steam at high temperature and pressure. The steam then drives a turbine or generating unit to produce electricity. In this case, combustion is said to be external.

3.1.1 Conventional Steam Generation

Steam turbines, steam electric or thermal generating units are external combustion systems when they use fossil fuels to generate the steam. The thermal efficiency of steam electric units is around 35%, meaning that 35% of the energy of the fuel is transformed into electricity. The remaining 65% of this energy is either lost up the stack (around 10%) or discharged with the condenser cooling water (typically 55%). Fossil-fueled steam-turbine generating units range in size from 1 to more than 1,000 megawatts. Normally, facilities of this type have a useful life that spans several decades, and more efficient steam generating units are being employed only in newer power plants.

3.1.2 Combustion Turbines

Internal combustion units include stationary gas turbines, also known as combustion turbines, and reciprocating internal combustion engines. These units are generally less than 100 megawatts in size and they are considered to be less efficient than steam turbines. However, since the gas turbine generators do not have boilers or a steam supply and condensers, the capital costs are much lower for a gas turbine unit than for a steam electric unit. Gas turbine units have quick startup times, compared with steam-turbine units and, because of their relatively small size, they can be installed in a variety of sites, which make them suitable for generation at peak times when demand exceeds the installed capacity of major power stations or for emergency and reserve power requirements. An important amount of heat is carried away with the exhaust gases that are emitted to the atmosphere from the turbine. Gas turbines are mainly used in the so-called combined cycle plants.

3.1.3 Combined Cycle

Combined-cycle units use a gas turbine to generate electricity in a first stage. The hot exhaust gases from the gas turbine are then used to provide all or a portion of the heat for the boiler that produces steam to drive a steam generator turbine for further electricity generation. This type of arrangement is more efficient than either the combustion turbines or steam generating units separately. The thermal efficiency of a combined cycle is around 50%. These units may have multiple gas turbines driving one steam turbine.

3.1.4 Cogeneration

Cogeneration units, also known as combined heat and power, use heat for electricity generation and for other thermal applications at the site. Cogeneration is the most efficient way to use energy, as it allows the recovery of thermal energy for use in services (for example, space heating) or other industrial processes, such as steam. The thermal efficiency of this process can be as high as 75% in terms of energy utilization.

3.2 Fossil Fuels Used to Generate Electricity

The choice of which technology to use and the type of power plant to build depends on many factors, such as purpose of the plant, capacity required and fuel availability. The fuel is one of the most important elements to consider also in terms of air pollutant emissions. **Table 3.1** shows the most common fuels used, by type of power plant.

Table 3.1 Fuels used by Type of Power Plant

Type of plant	Fuel
Steam	Residual Fuel Oil/Coal/Natural Gas
Combined Cycle	Natural Gas
Turbine	Natural Gas/Diesel
Dual	Coal/Heavy (Residual) Fuel Oil
Internal Combustion	Diesel
Nuclear	Uranium

In **Figure 3.1** the relative proportion of pollutants emitted during the combustion of fossil fuels is shown. In this figure, coal has been taken as a reference; therefore, for each pollutant, emissions from coal are given a value of 100%. Natural gas is said to be the "cleanest" of the three types of fossil fuels, due to the significantly lower emissions generated before the post-combustion control equipment. Emissions of NO_X are highly dependent on firing configuration, type of burners, flame temperature and to some extent on the nitrogen content of the fuel, although NO_X is formed even when the fuel contains no nitrogen.

In addition to the pollutants shown in **Figure 3.1**, there are other pollutants emitted by fossil fuel power stations, such as organic compounds that include volatile organic compounds (VOCs), semi-volatile organic compounds, and condensable organic compounds. There are also emissions of some metallic compounds (of which mercury is the only one considered in this report); other greenhouse gases besides CO_2, such as methane and nitrous oxide; and some halogenated compounds.

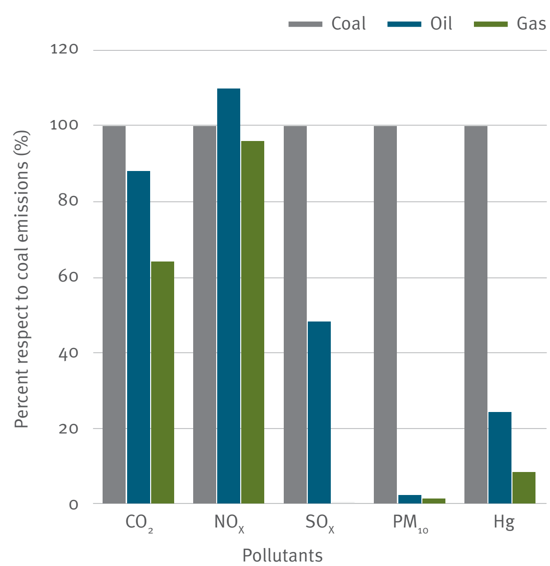
3.2.1 Coal

Coal is the most widely used fossil fuel for electricity generation; its composition is a complex combination of organic compounds and inorganic, mineral matter. Coal is fossilized plant material preserved by burial in sediments and changed by geological forces that compact and condense it into a carbon-rich rock. It has been suggested that coal formation may date back to Precambrian times but most of the coal was originally laid down as organic material during the carboniferous period, 286 million to 360 million years ago, when the earth's climate was warmer and wetter. Coal is considered a non-renewable energy source since it takes so long to form [16, 47, 48].

Coal is classified by type based on its stage of formation. This classification consists of five categories: peat, lignite, sub-bituminous, bituminous and anthracite (see **Figure 3.2**). Younger coals, such as lignite and sub-bituminous coals, are easier to burn because they contain a larger amount of volatile compounds that evolve as gases when the coal is heated. In contrast, older coals are more difficult to burn as they are made almost entirely of solid carbon. However, anthracite was preferred in the past instead of bituminous because it burns cleaner, producing less smoke and leaving less ash—and is more efficient in terms of units of heat produced per unit of weight.

Emissions from coal combustion strongly depend on the rank and composition of the coal. Pollutants emitted from coal combustion include greenhouse gases (mainly CO_2), particulate matter (including ash and unburned carbon resulting from incomplete

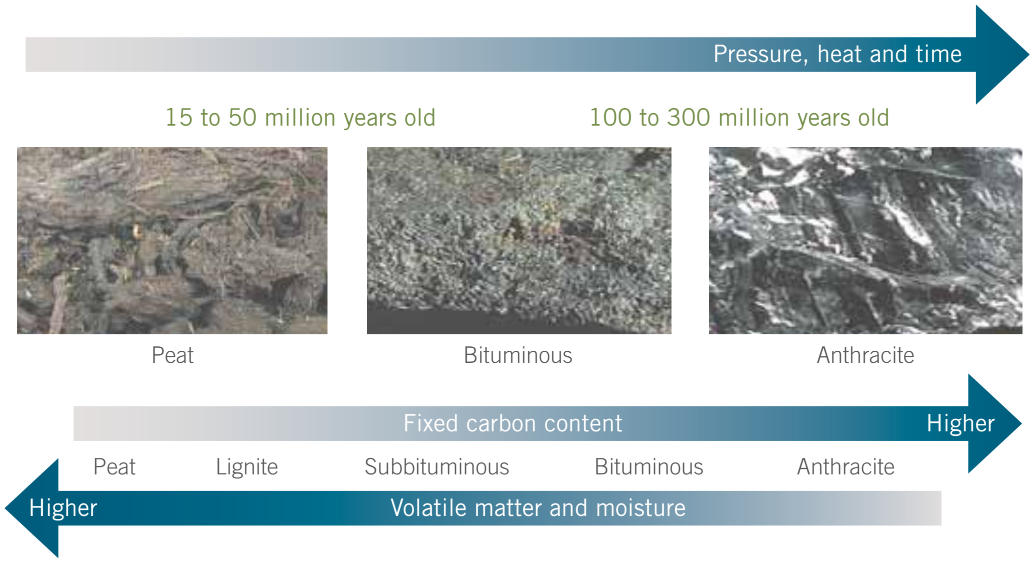
Figure 3.1 Relative Emissions of Pollutants Generated during Fossil Fuel Power Generation



ASSUMPTIONS: Fuels used are sub-bituminous coal, low sulfur No. 6 heavy fuel oil, or natural gas. Uncontrolled emissions from large wall-fired power stations (>100MBtu/hr). Data from AP-42, Chapter 1, Sections 1 (9/98), 3 (9/98) and 4 (7/98). Coal emissions are taken as reference.

Figure 3.2 Natural Transition of Coal through Time

Coal is a solid fossil fuel. It is a sedimentary rock, composed mainly of carbon, hydrogen and oxygen. It is formed from vegetation, which has been consolidated, mainly, between other strata and altered through time by thecombination of pressure and heat over millions of years.



combustion), nitrogen oxides and sulfur oxides. Other emissions from coal power stations are carbon monoxide, unburned hydrocarbon compounds, some carcinogens like dioxins and furans, and trace metals (e.g., lead and mercury).

3.2.2 Fuel Oil

Fuel oil is derived from crude petroleum and is the most widely used liquid fuel for power generation. Distillate and heavy fuel oils are the two major categories of this type of fuel. Fuel oils are classified by grade numbers, with No. 1 and No. 2 being distillate fuel oils and No. 5 and No. 6 being heavy (residual) fuel oils (such as are preheated and fired in power plants). The Mexican oil, called "combustóleo" has similar characteristics to heavy fuel oil No.6 [46–48].

Distillate fuel oils contain less than 0.3 % sulfur (by weight), are more volatile and less viscous than residual oils and have negligible nitrogen and ash contents. Distillate fuel oils are commonly used in domestic and small commercial applications and include kerosene and diesel. On the other hand, heavy fuel oils are highly viscous and may need heating for easy handling and proper use in combustion. Heavy fuel oils contain important amounts of ash, sulfur and nitrogen and are mainly used in industrial and large commercial applications.

Due to differences in composition and combustion characteristics, distillate and heavy oils result in different emissions upon combustion. For example, particulate matter emissions from distillate oils are lower than from heavy fuel oils. On the other hand, No. 6 fuel oil generally has a higher sulfur content, and because the emissions of sulfur oxides are directly related to the sulfur content of the oil, emissions from No. 6 fuel oil are more polluting than those from distillate oils.

Other pollutants generated during combustion of fuel oils are nitrogen oxides, carbon monoxide, greenhouse gases, volatile compounds (like unburned hydrocarbons) and toxic trace metals.

3.2.3 Natural Gas

After coal and oil, natural gas is the third type of fuel most widely used for electricity generation. The main component of natural gas is methane (85–90%); it also contains propane, ethane, butane, some inert gases such as nitrogen, helium and carbon dioxide, and trace amounts of other gases. Natural gas is the most rapidly growing energy source in the world, and is considered to be the cleanest fossil fuel. Most of the air pollutant emissions from natural gas combustion processes are nitrogen oxides and greenhouse gases (mainly CO_2). Other emissions are small amounts of particulate matter, sulfur oxides, and trace amounts of metals. When natural gas is burned, it produces only half as much CO_2 as an equivalent amount of coal (in thermal energy terms); therefore, if this cleaner fuel were substituted for coal, a reduction in emissions could be achieved. However, this is sometimes economically and/or strategically infeasible [46–48].

3.3 Pollutant Emissions

As mentioned earlier, depending on the fuels used, pollutants generated from power plants can include: sulfur dioxide (SO_2), nitrogen oxides (NO_X), mercury (Hg), particulate matter (including PM_{10} and $PM_{2.5}$) and greenhouse gases such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). Other compounds such as volatile organic compounds (VOCs) and trace metals are also emitted as air pollutants. In order to provide an idea of the order of magnitude of the amount of pollutants emitted during the generation of electricity, **Table 3.2** shows average emission rates of CO_2, SO_2 and NO_X from electricity generation units using different fossil fuels. Particulate emission rates vary widely, particularly for oil and coal, depending strongly on the amount of ash produced after burning. In the following sections brief descriptions of the pollutants covered in this report are given.

Table 3.2 Typical Emission Rates from Different Fuels [49]

Pollutant	Emission rates (kg/MW-h)		
	Coal	Oil	Gas
CO_2	1,021.04	759.09	515.29
SO_2	5.90	5.45	0.05
NO_X	2.72	1.82	0.77

Most air pollutants are generated during combustion, regardless of which type of fuel is burned. However, the amount and characteristics of each pollutant strongly depend on the fuel. For instance, particulate matter generated from coal combustion results in particles of larger size, and containing greater amounts of organic and elemental carbon, than particulate matter generated from fuel oils. Some metallic elements that are toxic pollutants, such as lead and mercury, are emitted from coal combustion, while oil combustion results in emissions of vanadium as well as lead, but almost no mercury. Natural gas is the cleanest of all the fossil fuels, resulting mainly in emissions of NO_X, CO_2 and very small amounts of other pollutants.

Table 3.3 shows the main health and environmental effects of some of the pollutants emitted by power plants.

3.3.1 Sulfur Oxides

The main sources of sulfur compounds in air are anthropogenic, with sulfur dioxide (SO_2) the predominant form. Emissions of sulfur oxides are mainly generated during combustion as the sulfur contained in the fuels is oxidized; therefore, sulfur oxides emissions are almost exclusively dependent on the sulfur content of the fuel and not on boiler size, burner design, or fuel grade. In combustion systems, approximately 95% of the sulfur present in the fuel is converted to sulfur dioxide (SO_2), between 1 to 5% is further oxidized to sulfur trioxide (SO_3), and 1 to 3% is emitted as sulfate particulates.

As SO_2 is a colorless, corrosive gas, it has a very harmful effect on plants, animals and humans and even on the physical environment. In air it can be further oxidized to SO_3, which reacts with water vapor to

Table 3.3 Principal Health and Environmental Effects of the Main Pollutants Emitted by Power Plants

<table>
<tr><th>Nitrogen oxides</th><th>Sulfur dioxide</th><th>Mercury</th><th>Carbon dioxide</th></tr>
<tr><td>Component in ground-level ozone and smog</td><td>Major precursor of fine particulate soot</td><td>Humans are affected primarily by eating contaminated fish</td><td rowspan="5">Contributes to global warming and climate change</td></tr>
<tr><td colspan="2">Contributes to death, serious respiratory illness and aggravates existing cardiovascular disease</td><td>Disruption of the nervous system, damage to brain functions, DNA and chromosomal damage, allergic reactions, negative reproductive effects</td></tr>
<tr><td colspan="2">Reacts to acidify surface water, killing fish and other biota, including trees and soil organisms</td><td>Mercury ingestion in animals can damage kidneys, intestines, DNA alteration</td></tr>
<tr><td colspan="2">Speeds weathering of monuments, buildings, metal structures</td><td>Loons, eagles, otters, mink, kingfishers and ospreys are fish-eaters and are seriously affected by mercury exposure through the food web</td></tr>
<tr><td colspan="2">Contributes to visual impairment (regional haze)</td><td></td></tr>
</table>

form sulfuric acid (H_2SO_4), one major component of acid rain. Also, the sulfate anion ($SO_4^{=}$) can be inhaled by humans into the lungs where it is very detrimental. In addition, sulfate particles contribute to impairment of visibility and affect the Earth's albedo, or global radiation balance, which in turn, has an effect on climate [46–48].

3.3.2 Nitrogen Oxides

The most important anthropogenic sources of nitrogen oxides are combustion processes. Nitrogen oxides can be formed in combustion processes from the nitrogen contained in the fuel or from the nitrogen that is part of the air. In most of the external fossil fuel combustion systems, around 95% of the nitrogen oxides emitted are in the form of nitrogen monoxide (NO), whereas the remaining 5% is in the form of nitrogen dioxide (NO_2). The NO emitted oxidizes further in the atmosphere to NO_2. The term NO_X refers to the sum of nitric oxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2. NO_2 is a highly reactive gas whose color gives the peculiar tone of reddish-brown to photochemical smog. Also, these oxides react with water to produce nitric acid (HNO_3), which, together with sulfuric acid, results in acid rain. Another harmful effect of nitrogen oxides is the atmospheric deposition of nitrogen as nitrates and nitrites derived from NO_X, which leads to eutrophication of inland waters and coastal seas [46–48].

3.3.3 Mercury

Mercury is a known persistent, bioaccumulative and toxic (PBT) trace metal that occurs naturally in coal at very low concentrations. The combustion of coal is considered the major anthropogenic source of this pollutant to the atmosphere. According to data from the UNEP [51], combustion of coal in power plants, industrial boilers, residential boilers, heaters and stoves contributed with around 888 tonnes (46%) to the total global anthropogenic emissions in 2005. Coal-fired power plants are one of the most important sources of mercury due to the large quantity of coal used for electricity generation. For example, about one-half of the anthropogenic mercury emissions in 2005 in the United States came from these plants, approximately 52.4 t/year [52].

Most of the mercury in the atmosphere is in the form of elemental mercury vapor; however, in water, soil, sediments, or biota it is found in both organic and inorganic forms. Elemental mercury vapor is relatively insoluble and nonreactive, which is why it can remain aloft, carried by air currents over vast distances for very long periods—up to a couple of years—before it is finally deposited on land or in surface waters. Once mercury is deposited, microbes can convert it into an organic form (methylmercury) that can be absorbed by other organisms and accumulated as it passes through food webs. Mercury has a variety of important ecological and human health impacts. For example, mercury pollution is the most common cause of impairment of rivers and lakes in the United States, and many US states have issued warnings about eating fish from those water bodies. Ingestion of mercury from eating contaminated fish can lead to impaired neurological development in fetuses, infants and children. In adults it can cause neurological damage [53]. The United States National Institutes of Health (NIH) estimates that one woman in 12 in the United States has more mercury in her blood than the amount considered safe by the Environmental Protection Agency. According to NIH estimates, health impairment due to mercury cause nearly US$9 billion annually in higher medical costs and lost productivity in the workforce [47, 54].

3.3.4 Particulate Matter

Particulate matter (PM) consists of a wide range of materials in solid or liquid phase that range in size from less than 1 nanometer up to one hundred micrometers and can have complex chemical composition. Some of the components include nitrates, sulfates, metals, organic compounds, soil, pollen, soot, etc. Particulate matter (PM) is measured using a variety of size metrics, of which the most common are PM_{10} and $PM_{2.5}$. Both are measures of the mass of particles with an aerodynamic diameter of less than 10 or 2.5 micrometers, respectively. There are a large number of sources of particulate matter, with stationary combustion (e.g., non-mobile sources, such as power plants) being one of the major contributors, along with road transportation. Among the stationary, fuel combustion sources are industrial sector activities like iron and steel manufacturing, the residential sector heating and power stations. Emissions of PM from the combustion of solid fuels (like coal) are, in general, larger in diameter than those originating from the combustion of liquid fuels, and the latter are coarser than particles generated from gas combustion. But in general, particles produced by combustion are smaller in diameter than 1 micrometer.

Some environmental impacts of particulate matter emissions are reduction in visibility, acid rain, and damage and stain on materials (statues and monuments). Deposition of particulate matter can also contribute to the acidification of lakes and rivers, change the nutrient balance of water bodies and soil, and affect forests and farm crops [55].

Particulate matter can cause severe health problems in humans, especially the particles whose diameter is smaller than 10 micrometers, since they can be inhaled deeply into the lungs and even be absorbed into the bloodstream. The most common health effects of particulate matter are respiratory symptoms such irritation of the air passages, coughing, difficulty in breathing, decreased lung function, asthma, chronic bronchitis and premature death [55].

3.3.5 Greenhouse Gases

Greenhouse gases (GHGs) are those gases that trap heat in the atmosphere; this allows an average temperature on Earth of approximately 15°C. Without this natural "greenhouse effect," the average ambient temperature would be about 33°C lower than it is now, making most life as we know it today impossible. But since the Industrial Revolution, human activities have added significant amounts of greenhouse gases to the atmosphere, enhancing the natural greenhouse effect. This is causing an increase in the global average temperature, resulting in severe effects on the climate.

Some of these gases, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are emitted to the atmosphere from both natural and anthropogenic processes, while other greenhouse gases, such as chlorofluorocarbons (usually known as CFCs), stem exclusively from industrial activities. The principal greenhouse gases released from human activities, particularly from fossil fuel combustion, are carbon dioxide, methane, and nitrous oxide.

GHG emissions, regardless of the gas concerned, are commonly reported in terms of equivalent emissions of carbon dioxide. This measure is used to compare the ability of each GHG to trap heat (Global Warming Potential, or GWP) in the atmosphere relative to that of CO_2, which is taken as a reference gas. The carbon dioxide equivalent for a gas is derived by multiplying the amount of gas emitted by its GWP.

Brief descriptions of the principal GHGs are given below:

Carbon dioxide (CO_2) is a nontoxic and innocuous gas. The steady increase in CO_2 concentration in the atmosphere that is of concern for its effects on climate change is mostly due to human activities. It has been estimated that global atmospheric concentrations of CO_2 in 2005 were 35% higher than the values observed before the Industrial Revolution. The main source of this gas is the burning of fossil fuels, (of which electric power sources contribute between 17 and 40% of total CO_2 emissions); other sources are forest and grass fires, and combustion processes in producing material for cement [48, 56–58].

Methane (CH_4) remains in the atmosphere for 9 to 15 years and is 21 times more effective in trapping heat in the atmosphere than carbon dioxide. Like carbon dioxide, methane is emitted to the atmosphere from diverse natural and anthropogenic sources. Natural sources include wetlands, termites, oceans, wildfires, etc., while anthropogenic sources are mainly combustion of fossil fuels, enteric fermentation, landfills, natural gas systems, fossil fuel production, rice cultivation, biomass burning, and waste handling. It is estimated that natural sources contribute approximately 37% of the total methane emitted into the air every year; therefore, anthropogenic sources are the principal sources of its release to the atmosphere.

Nitrous oxide (N_2O) is a colorless gas with a slightly sweet odor and it is about 310 times more effective in trapping heat in the atmosphere than carbon dioxide. As with carbon dioxide and methane, nitrous oxide is also emitted from natural and human-related sources, but contrary to the situation with the two other gases, natural sources of this gas contribute approximately 64% of the total inputs to the atmosphere.

3.4 Pollution Control Technologies

Increasing concern about the effects of air pollutant emissions has led to stricter regulations on air pollutant emissions and the installation of pollution control and prevention equipment in order to reduce the amount of contaminants released to the atmosphere. The following section provides a brief overview of the pollution control equipment used by electric power stations, according to the fuel consumed.

3.4.1 Coal

Among all the fossil fuels used for power generation, coal requires the most extensive infrastructure for processing, handling, storage, loading and unloading operations (all these facilities generate important environmental impacts). Coal firing requires the use of crushers, pulverizers, ash handling equipment, soot blowers, and dust and emissions control equipment.

The most widely used particle controls used for coal combustion are multiple cyclones, electrostatic precipitators, fabric filters and Venturi scrubbers. Various techniques are employed to reduce SO_2 emissions from coal-fired plants: physical coal cleaning, chemical coal cleaning, switching to lower-sulfur coals and flue gas desulfurization. Some methods for controlling nitrogen oxides are reducing the peak temperatures in the combustion zone or the gas residence time in the high-temperature zone, the installation of low-NO_X burners, selective catalytic reduction, and selective non-catalytic reduction.

At some plants in Canada and the United States, devices are used to inject activated carbon or add sorbent to coal specifically to control mercury emissions. Other methods, such as flue gas desulfurization and particulate control, also help to reduce mercury emissions. It has been reported that mercury emissions reductions of 29%, 39% and 45% can be obtained from electrostatic precipitators, baghouses and flue gas desulfurization, respectively [45, 46, 48, 50].

3.4.2 Heavy Fuel Oil

Although the uncontrolled air pollutant emissions from oil-fired power stations are substantially lower than those from coal-fired boilers, some emission controls are still required for large oil-fired boilers to meet emissions standards. Control devices similar to those used for coal-fired power plants are used for oil-fired power stations. Mechanical collectors, electrostatic precipitators and fabric filters control particulate matter emissions. Wet scrubbing and spray dryers are common techniques used for reducing SO_2 emissions. Due to the low amount of nitrogen present in fuel oils, the techniques for reducing emissions of nitrogen oxides are mainly controls on combustion (for example, flue gas recirculation, staged combustion, etc,); however, post-combustion NO_X control techniques are also applied, such as selective non-catalytic reduction and selective catalytic reduction [45, 46, 48, 50].

3.4.3 Natural Gas

Most of the environmental control techniques used in natural gas-fired boilers are for NO_X control or abatement and are similar to those described for coal-fired power plants. These include flue gas recirculation, staged combustion, low-NO_X burners, selective catalytic reduction and selective non-catalytic reduction [45, 46, 48, 50].

Navajo Generating Station
Page, Arizona, United States

4. For More Complete Information

The full data sets used for this report will be found on the CEC website for this project, www.cec.org/powerplants, in the following tables (the numbers below refer to the tables in this report, which are excerpts of the complete tables, and list only the top 10 facilities in each category).

Table 2.7 Canada SO_2 Emissions, 2005, Ranked by Volume

Table 2.8 Mexico SO_2 Emissions, 2005, Ranked by Volume

Table 2.9 United States SO_2 Emissions, 2005, Ranked by Volume

Table 2.10 Canada NO_X Emissions, 2005, Ranked by Volume

Table 2.11 Mexico NO_X Emissions, 2005, Ranked by Volume

Table 2.12 United States NO_X Emissions, 2005, Ranked by Volume

Table 2.13 Canada Hg Emissions, 2005, Ranked by Volume

Table 2.14 Mexico Hg Emissions, 2005, Ranked by Volume

Table 2.15 United States Hg Emissions, 2005, Ranked by Volume

Table 2.16 Canada $PM_{2.5}$ Emissions, 2005, Ranked by Volume

Table 2.17 Canada PM_{10} Emissions, 2005, Ranked by Volume

Table 2.18 Mexico $PM_{2.5}$ Emissions, 2005, Ranked by Volume

Table 2.19 Mexico PM_{10} Emissions, 2005, Ranked by Volume

Table 2.20 United States $PM_{2.5}$ Emissions, 2005, Ranked by Volume

Table 2.21 United States PM_{10} Emissions, 2005, Ranked by Volume

Table 2.23 Canada CO_2 Emissions, 2005, Ranked by Volume

Table 2.24 Mexico CO_2 Emissions, 2005, Ranked by Volume

Table 2.25 United States CO_2 Emissions, 2005, Ranked by Volume

The following tables appear only on the website and in their complete form:

Table 2.26 Canada CH_4 Emissions, 2005, Ranked by Volume

Table 2.27 Mexico CH_4 Emissions, 2005, Ranked by Volume

Table 2.28 United States CH_4 Emissions, 2005, Ranked by Volume

Table 2.29 Canada N_2O Emissions, 2005, Ranked by Volume

Table 2.30 Mexico N_2O Emissions, 2005, Ranked by Volume

Table 2.31 United States N_2O Emissions, 2005, Ranked by Volume


Ontario Power Generation
Nanticoke Generating Station
Nanticoke, Ontario, Canada

Annex. Information Sources and Methodology for Estimating Electricity Generation Data of Canadian Power Plants

Saskatchewan

For the Saskpower plants that use lignite as fuel, the estimated electricity generation corresponds (within 1.5%) to the overall net generation reported by the company [1]. Heating values used for the calculation were the national averages by type of fuel [2].

Newfoundland and Labrador

The electricity generation values for the Province of Newfoundland and Labrador [2] were matched to the generation of the only coal-fired plant in that province.

Nova Scotia

Emission rates for the Nova Scotia Power (NSP) coal-fired power plants were obtained from the NSP web site [3]. The Nova Scotia Power emission rates are disclosed under the Carbon Disclosure Project, an international, independent, not-for-profit organization that maintains a database of climate change information. The total generation derived from these emission rates and the NPRI data for CO_2 emissions agreed to within 2.7% with the total generation reported for the corresponding technology in that province [2]. The three NSP combustion turbine generating stations were considered together since a single datum was found for CO_2 emissions from the three facilities [3]. The corresponding electricity generation for these three facilities was found to be negligible in comparison with the generation from this type of technology reported for that province [2].

New Brunswick

In the province of New Brunswick, NB Power Generation Corporation operated 5 steam power plants in 2005: Dalhousie, Belledune, Grand Lake, Courtenay Bay, and Coleson Cove. In addition, there were three combustion turbine plants (Ste Rose, Millibank, Grand Manan) for which information was not available from the NPRI nor the GHGRP. However, according to the 2005 NB Power (NBP) annual report [4], the first two belong to the Environmental Management Systems (EMS) of Belledune, and the last one belongs to the EMS of Coleson Cove, so it is possible that emissions from these combustion turbine plants are reported as part of those larger power plants. Courtenay Bay Generating Station (CBGS) had three units, but in 2002 Irving Paper Ltd assumed responsibility for the operation of Unit 2 (NPRI ID No. 8003). Units 1 and 3 were still the responsibility of NBP (NPRI ID No. 1706) but NBP did not operate CBGS in 2005 [4]. Emissions of CO_2 were reported to the GHGRP for CBGS unit 2, under NAICS code 221330, even though the facility was registered for the NPRI with a NAICS code 221112.

The emissions of CO_2 obtained from the GHGRP for the five steam power plants were consistent with the overall system fossil fuel generation emission rates [5] and the total electricity generation reported by Statistics Canada [2]. The estimated electricity generation for each individual plant based on the CO_2 emissions was also consistent with the overall generation reported by Statistics Canada [2]. One additional combustion turbine plant, the Bayside Power Plant (then owned by Irving Oil Power L.P.), accounted for the electricity generation reported by Statistics Canada [2] for this technology. It has a combined cycle natural gas turbine [6] with an estimated net thermal efficiency of 51.6%. Efficiencies of this order and even higher have been reported for this type of technology [7, 8, 9].

Ontario

Ontario Power Generation (OPG) owned and operated 6 fossil-fueled power plants with steam turbine generators in 2005. The Lakeview Power Station operated only during the first third of the year, after which it was shut down permanently [10]. The electricity generation of this power plant was estimated on the basis of its CO_2 emissions and an assumed thermal efficiency typical of coal power plants [11]. For the remaining five plants, the net generation was obtained from an OPG public report [12]. The Fort Frances plant, owned by Abitibi Consolidated Inc., also operated during 2005. Its generation was estimated from its reported CO_2 emissions using an efficiency [rating] similar to the other steam generating power plant in Ontario, the EPCOR Tunis power plant. The generation for the Tunis plant was estimated from the Ontario EPCOR operations total generation [13], which was then apportioned to each plant of the Ontario operations according to the installed capacity of each plant.

The total generation during 2005 from the steam generating fossil-fueled plants in Ontario considered in this report differed by 3.2% from the figure indicated in the Statistics Canada report [2]. However, combustion turbine generating plants in the province consisted of two types, single and combined cycle, therefore different thermal efficiencies were assigned to them in order to estimate the generation from CO_2 emissions. There were also some plants that had units of both types, that is, steam and combustion turbines, but it was not possible to estimate the generation for each type, as CO_2 emissions are reported for the whole plant. Therefore, the value estimated for the total generation from steam turbines is slightly smaller than the value reported by Statistics Canada [2]. The difference between the total estimated and reported generation is less than 0.1%.

Québec

Emissions of CO_2 from two plants in Quebec, Tracy and Cap-aux-Meules, were reported in the GHGRP. The former is a 600 MW steam generating heavy fuel oil-fired plant dating back to the 1960s [14, 15]. In 2005, this was only operated when the system was at peak demand. Old, low-efficiency steam plants are generally used for peaking [16]. The Cap-aux-Meules plant is one of the province's diesel-fueled internal combustion plants. Hydro Quebec published the total generation for its four main fossil fuel generating plants as well as their corresponding CO_2 emissions [17, 18]. It was possible to determine the combined generation for Tracy and the other three plants, Bécancour, La Citière and Cadillac. These three are light fuel oil-fired, using combustion turbines, and are also used for peaking. Therefore, it was reasonable to treat them as a unit.

The total emissions from these four power plants can be expressed as:

$$E_T = r_1 G_1 + r_2 G_2$$

where

E is the CO_2 emissions (Mg)

r is the CO_2 emission rate (Mg/MW-h)

G is generation in MW-h

the subscript 1 refers to Tracy, the subscript 2 refers to the three combustion turbine plants together, and the subscript T refers to the total of the 4 plants considered.

Obviously,

$$G_T = G_1 + G_2$$

and

$$E_T = E_1 + E_2$$

where

$$E_1 = r_1 G_1$$

and

$$E_2 = r_2 G_2$$

Accordingly, the generation from Tracy can be determined as a function of the total generation, the total CO_2 emissions of the four plants and those from Tracy (all of which are known) along with the emission rate of Tracy.

$$G_1 = \frac{K}{1+K} G_T$$

where

$$K = \frac{r_2}{r_1} \frac{E_1}{E_2}$$

and the following relation holds between the emission rates

$$r_2 = \frac{r_1 E_2}{r_1 G_T - E_1}$$

The emission rate at Tracy (r_1) was estimated using the following relationship:

$$r_1 = \frac{F}{\eta H}$$

Where F is the CO_2 emission factor for steam generating plants using heavy fuel oil, assumed 3.124 kg/L [19]; H is the net heat content of heavy fuel oil, assumed 36,813.47 kJ/L [20]; and h, the thermal efficiency, assumed 28%. This efficiency value was chosen considering the lowest limit of the range of efficiencies observed for this type of plants. In 2000 there were already concerns about the high emission rates and low efficiency of this plant [15]. Also, since the plant was operated at low capacity factors, the efficiency could have been reduced even further [15, 21].

By following the above procedure, all the reported values for both generation and emissions are made consistent.

In 2005, Hydro Quebec operated one steam generating plant (Tracy), three light fuel oil combustion turbine plants (Bécancour, La Citière and Cadillac) and 24 diesel-fueled internal combustion plants for a total of 1595 MW of installed capacity [18]. The internal combustion plants provided off-grid base-load electricity, mainly in the northern regions. The total electricity generated by these 24 plants in 2005 was 277.1 GW-h [22, 23], although the plant at Cap-aux-Meules generated nearly 65% of the total. This plant also reported emissions of CO_2 to the GHGRP.

The Boralex generating station at Kinsey Falls was registered in the GHGRP under NAICS code 221112 ("fossil fuel electric power generation"), whereas in the NPRI it was registered under NAICS code 221119 ("other electric power generation"). Since emissions of CO_2 exceeded the threshold value for reporting and the plant used natural gas, it was included in this report with the NAICS code for fossil fuel electricity generation. The generation of the Kingsey Falls plant was estimated on the base of its CO_2 emissions.

Alberta

Generation data for Alberta were obtained from ATCO Power [24] for its plants in that province, and from the Alberta Electric System Operator (AESO)'s web page [25]. Generation data for some of the plants indicated in the table were not publicly available and the value was therefore estimated on the basis of the CO_2 emissions and efficiencies of similar plants.

British Columbia

There are inconsistent values reported for British Columbia. For example, the Burrard Thermal Generating Station is a conventional natural gas-fired generating station that generated 456 GW-h [26]. The heat rate of this plant for years 1999 and 2000, based on generation and energy input reported in a cost benefit evaluation of the plant made in 2001 [27], was found to be approximately 10,000 Btu/kW-h, which is standard for this type of plant. Using this heat rate, the quoted generation, and either typical CO_2 emission factors [28] or the reported CO_2 emission intensity [27], a CO_2 emission of between 239.4 and 244.8 kt of CO_2 is obtained. The value reported to the GHGRP for the CO_2 emissions from Burrard in 2005 is only 68.1. This value is obviously inconsistent with the generation reported by BC Hydro. From an analysis of the CO_2 emissions reported to the GHGRP and the generation reported by BC Hydro, it is clear that the data inconsistency spans several years. It seems that the GHG values reported by BC Hydro are adjusted by overall GHG reduction actions [29].

The generation of the other steam turbine plant, Duke Energy Gas Transmission–McMahon Cogeneration Plant, that operated in BC in 2005 was obtained by adjusting the thermal efficiency so that the total generation from steam turbine plants matched the value found reported [2]. Finally, the two combustion turbine plants considered were probably those with the highest generation among the plants in BC using this technology. A number of internal combustion plants operated in BC during 2005 for back-up or peak supply purposes, but these were not considered here, as no information was available. The total relative difference for each technology was less than 1%.

Estimation Methods

Natural Gas

According to Section 1.4 of AP-42 [30], emissions of CO_2 from combustion of natural gas can be estimated, irrespectively of the technology, assuming a 100% conversion of the carbon in the fuel into CO_2, using the following emission factor:

$$F = 3.67\gamma CD$$

Where, F is the emission factor (lb/10^6 scf); g is the conversion of carbon in the fuel into CO_2; C is the carbon content of the fuel (0.76) and D is the density of the fuel (4.2 x 10^4 lb/10^6 scf).

The CO_2 emission factor for natural gas combustion is:

$$F = 1.171\text{x}10^5 \text{ lb}/10^6 \text{ scf}$$

The natural gas consumption can be estimated from the CO_2 emissions using the following relationship:

$$Q = \frac{E_{CO2}}{F}$$

Where, E_{CO2} is the CO_2 emissions (lb); Q is the natural gas consumption (millions of scf); F is the emission factor (lb/10^6 scf). If emission factors are on a volume basis (lb/10^6 scf) , to convert them to an energy basis (lb/MMBtu), they have to be divided by the heating value of the fuel (1,020 MMBtu/10^6 scf for natural gas according to AP-42, Chapter 1, Section 4).

Generation can be estimated multiplying the fuel consumption by the heating value of the fuel (H) and considering the thermal efficiency (η):

$$G = QH\eta$$

In terms of the commonly used units for the quantities involved, and introducing the corresponding conversion factors, the following formula is obtained:

$$G = \frac{E_{CO2}}{0.45359} \frac{1020}{1.171\text{x}10^5} \left(\frac{1055.056}{3.6}\right)\eta$$

Where G is given in MW-h, E_{CO2} is in tonnes and η is dimensionless.

Fuel Oil

According to Section 1.3 of AP-42, emissions of CO_2 from combustion of petroleum liquids can be estimated, irrespectively of the technology, assuming a 99% conversion of the carbon in the fuel into CO_2, using the following emission factors:

Fuel Type	%C	Density	Emission Factor	
		lb/gal	lb/10^3 gal	kg/m^3
No. 1 (kerosene)	86.25	6.88	21,500	2,580
No. 2 (diesel)	87.25	7.05	22,300	2,676
Low S No. 6	87.26	7.88	25,000	3,000
High S No. 6	85.14	7.88	24,400	2,928

The consumption of fuel oil can be estimated from the CO_2 emissions using the following formula:

$$Q = \frac{1000E_{CO2}}{F}$$

Where, E_{CO2} is the CO_2 emissions (tonnes); Q is the fuel oil consumption (m^3); and F is the emission factor (kg/m^3), taken from the preceding table.

The generation in MW-h is then estimated from the following relationship:

$$G = \frac{E_{CO2}}{F} \frac{H\eta}{3.6}$$

Where H is the heating value in MJ/m^3 and η is the thermal efficiency (dimensionless). Heating values were different for each Canadian province [2].

Solid Fuels

The consumption of solid fuels for electricity generation can be estimated from the CO_2 emissions using the following formula:

$$Q = \frac{1000E_{CO2}}{F}$$

Where, E_{CO2} is the CO_2 emissions (tonnes); Q is the solid fuel consumption (tonnes); and F is the emission factor (kg/tonne).

Electric generation in MW-h from solid fuels can be estimated from the following relationship:

$$G = \frac{E_{CO2}}{F} \frac{H\eta}{3.6}$$

Where H is the heating value in MJ/tonne and η is the thermal efficiency (dimensionless). Heating values were different for each Canadian province, although national values were considered [2].

Sub-bituminous and Bituminous Coals

According to Section 1.1 of AP-42, emissions of CO_2 from combustion of sub-bituminous and bituminous coals for electricity generation can be estimated, irrespectively of the technology, assuming a 99% conversion of the carbon in the fuel into CO_2, using the following emission factors:

Fuel Type	%C	Density	Emission Factor	
			lb/ton coal	kg/tonne
Sub-bituminous	66.3	72.6	4810	2405
High Volatile Bituminous	75.9	72.6	5510	2755
Medium Volatile Bituminous	83.2	72.6	6040	3020
Low Volatile Bituminous	86.1	72.6	6250	3125

Lignite

According to Section 1.7 of AP-42, emissions of CO_2 from combustion of sub-bituminous and bituminous coals for electricity generation can be estimated, irrespectively of the technology, assuming a 99% conversion of the carbon in the fuel into CO_2, using the following emission factors:

Fuel Type	%C	Conversion	Emission Factor	
			lb/ton coal	kg/Mg
Lignite	63.36	72.6	72.6 x C = 4600	2300

If the %C value is not known, a default CO_2 emission factor value of 4600 lb/ton may be used.

Coke

Emissions of CO_2 from coke combustion for electricity generation can be estimated using an emission factor of 102.12 kg/MMBtu. [31]. To convert to a mass basis, this value has to be multiplied by a heating value of 27.965 MMBtu/tonne [32].

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