Chapter 6. Energy Extraction and Conversion

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KEY FINDINGS

- In recent years, extraction of primary energy sources and their conversion into energy delivery forms (solid, liquid, gas, and electric) in North America released on the order of 2800 Mt CO_2 per year to the atmosphere, approximately 40% of total North American emissions in 2003 and 10% of total global emissions. Electricity generation is responsible for most (90–95%) of North America's energy extraction and conversion emissions.
- Carbon dioxide emissions from energy extraction and conversion in North America are currently rising.
- The principal drivers behind carbon emissions from energy extraction and conversion are (1) the growing appetite for energy services such as comfort, convenience, mobility, and labor productivity, so closely related to economic and social progress, and (2) the market competitiveness of fossil energy sources compared with alternatives.
- Emissions from energy extraction and conversion in North America are projected to increase in the future. Projections vary among the countries, but increases approaching 50% or more appear likely. Projections for the United States., for example, indicate that CO_2 emissions from electricity generation alone will rise to about 3314 Mt CO_2 by 2025, a 45% increase over emissions in 2003, with three-quarters of the increase associated with greater coal use in electric power plants.
- The prospects for major reductions in CO_2 emissions from energy extraction and conversion in North America appear dependent upon the extent, direction, and pace of technological innovation and the likelihood that policy conditions favoring carbon emissions reduction that do not now exist will emerge if concerns about carbon cycle imbalances grow. In these regards, the prospects are brighter in the long term (e.g., more than several decades in the future) than in the near term.
- Research and development priorities for managing carbon emissions from energy extraction and conversion include, on the technology side, clarifying and realizing potentials for carbon capture and sequestration, and, on the policy side, understanding the public acceptability of policy incentives for reducing dependence on energy sources associated with carbon emissions.

INTRODUCTION

A significant component of the North American carbon cycle is the extraction of primary energy sources and their conversion into energy delivery forms (solid, liquid, gas, and electric) because both energy resource extraction and energy conversion activities in North America emphasize fossil fuels and their associated emissions of greenhouse gases. This chapter summarizes the knowledge bases related to energy extraction, energy conversion, and other energy supply activities such as energy movement and energy storage, along with options and measures for managing emissions.

Clearly, this topic overlaps the subject matter of other chapters. For instance, the dividing line between energy conversion and other types of industry is sometimes indistinct, as when industry practices co-generation as an energy-efficiency strategy, and biomass energy extraction/conversion is directly related to agriculture and forestry. In addition, in addressing options and measures, policy alternatives are often directed at both supply and demand responses, i.e., involving not only emission reductions from supply systems but also potential payoffs from efficiency improvements in buildings, industry, and transportation, especially where they reduce the consumption of fossil fuels.

CARBON EMISSIONS INVENTORY

Carbon Emissions from Energy Extraction and Conversion

Carbon emissions from energy extraction (e.g., mining and oil/gas production) and conversion (e.g., electricity generation and refining) are one of the “big three” sectors accounting for most of total emissions from human systems, along with industry and transportation. The largest share of total emissions from energy supply (not including energy end use) are from (a) coal and other fossil fuel use in producing electricity and (b) fossil fuel conversion activities such as oil refining. Other emission sources are less well-defined but generally small, such as methane from reservoirs established partly to support hydropower production (Tremblay *et al*., 2004), or from materials production (e.g., metals production) associated with other renewable or nuclear energy technologies.

Data on emissions from energy supply systems are unevenly available for the countries of North America. Most emission data sets are organized by fuel consumed rather than by consuming sector, and countries differ in sectors identified and the units of measurement. As a result, it seems more appropriate to report inventories by country in whatever forms are available than to try to construct a North American inventory that is consistent across all three major countries (which appears unattainable). Canada and Mexico export energy supplies to the United States; therefore, some emissions from energy *supply* systems in these countries are associated with energy *uses* in the United States.

Canada

Canada is the world's fifth-largest energy producing country, a significant exporter of both natural gas and electricity to the United States. In Alberta, which produces nearly two-thirds of Canada's energy, energy accounts for about one-quarter of the province's economic activity; its oil sands are estimated to have more potential energy value than the remaining oil reserves of Saudi Arabia (DOE, 2004). Although Canada has steadily reduced its energy and carbon intensities since the early 1970s, its overall energy intensity remains high—in part due to its prominence as an energy producer—and total greenhouse gas emissions have grown by 9% since 1990. As of 2003, greenhouse gas emissions in Mt CO_2 equivalents were 134 for electricity and heat generation and 71 for petroleum refining and other fossil fuel production (Environment Canada, 2003).

Mexico

Mexico is one of the largest sources of energy-related greenhouse gas emissions in Latin America, although its per capita emissions are well below the per capita average of industrialized countries. The first large oil-producing nation to ratify the Kyoto Protocol, it has promoted shifts to natural gas use to reduce greenhouse gas emissions. The most recent emission figures are from the country's Second National Communication to the UN United Nations Framework Convention on Climate Change in 2001, which included relatively comprehensive data from 1996 and some data from 1998. In 1998, CO_2 emissions from "energy industries" were 47.3 Mt CO_2; from electricity generation they totaled 101.3 Mt CO_2, and "fugitive" emissions from oil and gas production and distribution were between 1.9 and 2.6 Mt of CH_4, depending on the estimated "emission factor" (Government of Mexico, 2001). An estimate for, say, 2003 might be constructed by increasing these totals in proportion to 1998–2003 gross domestic product growth.

United States

The United States is the largest national emitter of greenhouse gases in the world, and CO_2 emissions associated with electricity generation in 2003 account for 2409 Mt of CO_2, or 41% of a national total of 5870 (EIA, 2004). Emissions from oil refining, natural gas transmission, and other fossil energy supply activities are also substantial, though harder to document because they are grouped with aggregate industrial emissions. Oil refineries are known to be a major source of methane as well as CO_2 emissions; natural gas supply systems emit methane as well. For example, a study of greenhouse gas emissions from a six-county area in southwestern Kansas found that compressor stations for natural gas pipeline systems are a significant source of emissions at that scale (AAG, 2003).

Carbon Sinks Associated with Energy Extraction and Conversion

Generally, energy extraction and conversion are based heavily on mining hydrocarbons from carbon sinks accumulated over millions of years, but carbon sequestration occurs in connection with energy production from biomass during plant growth. Limited strictly to energy sector applications, the total contribution of these sinks to the North American carbon cycle is potentially nontrivial but probably relatively small.

TRENDS AND DRIVERS

Three principal drivers are behind carbon emissions from energy extraction and conversion.

(1) The growing global and national appetite for energy services such as comfort, convenience, mobility, and labor productivity, so closely related to progress with economic and social development and the quality of life (Wilbanks, 1992). Globally, the challenge is to increase total energy *services* (not necessarily *supplies*) over the next half-century by a factor of at least three or four—more rapidly than overall economic growth—while reducing environmental impacts from the associated supply systems (NAS, 1999). Mexico shares this need, while increases in Canada and the United States are likely to be more or less proportional to rates of economic growth.

(2) The market competitiveness of fossil energy sources compared with supply- and demand-side alternatives. In some cases reinforced by policy conditions, production costs of electricity from coal, oil, or natural gas at relatively large scales are currently lower than other sources besides large-scale hydropower, and production costs of liquid and gas fuels are currently far lower than other sources, though rising. These conditions appear likely to continue for some years. In many cases, the most cost-competitive alternative to fossil fuel production and use is not alternative supply sources but from efficiency improvement.

(3) Enhanced future markets for alternative energy supply sources. In the longer run, however, emissions from energy supply systems may—and in fact are likely to—begin to decline as alternative technology options are developed and/or improved. Other possible driving forces for attention to alternatives to fossil fuels, at least in the mid to longer term, include the possibility of shrinking oil and/or gas reserves and changes in attitudes toward energy policy interventions.

Given the power of the first two of these drivers, total carbon emissions from energy extraction and conversion in North America are currently rising (e.g., Figure 6.1). National trends and drivers are as follows.

Figure 6.1. United States CO_2 emissions from electricity generation, 1990–2003, in million metric tons CO_2 (Source: EIA, 2004).

Canada

Canada is the only Annex I country that has ratified the Kyoto Protocol, and it is seeking to meet the Kyoto target of CO_2 emission reduction to 6% below 1990 levels. Of these reductions, 25% are to be through domestic actions and 75% through market mechanisms such as purchases of carbon credits (Government of Canada, 2005). Domestic actions will include a significant reduction in coal consumption. Available projections, however, indicate a total national increase of emissions in CO_2 equivalent of 36.1% by 2020 from 1990 levels (Environment Canada, 2005). Emissions from electricity generation would increase 2000–2020 from about 90 Mt of CO_2 equivalent to about 150, while emissions from fossil fuel production would remain relatively stable at about 100 Mt.

Mexico

It has been estimated that total Mexican CO_2 emissions will grow 69% by 2010, although mitigation measures could reduce this rate of growth by nearly half (Pew Center, 2002). Generally, energy sector emissions in Mexico vary in proportion to economic growth (e.g., declining somewhat with a recession in 2001), but such factors as a pressing need for additional electricity supplies, calling for more than doubling production capacity between 1999 and 2008, could increase net emissions while a national strategy to promote greater use of natural gas (along with other policies related in part to concerns about emissions associated with urban air pollution) could reduce emissions compared with a reference case (EIA, 2005b).

United States

The Energy Information Administration (EIA, 2005a) projects that CO_2 emissions from electricity generation in the United States will rise between 2003 and 2025 from about 2286 to about 3314 Mt, a 45% increase, with three-quarters of the increase associated with greater coal use in electric power plants. EIA projects that technology advances could reduce the increase by as much as 7%. Projections of other emissions from energy supply systems appear to be unavailable.

OPTIONS FOR MANAGEMENT OF EMISSIONS FROM ENERGY EXTRACTION AND CONVERSION

Few aspects of the carbon cycle have received more attention in the past several decades than emissions from fossil energy extraction and conversion. As a result, there is a wide array of technology and policy options, many of which have been examined in considerable detail, although there is not a strong consensus on courses of action.

Technology Options

Technology options for reducing energy-supply-related emissions (other than reduced requirements due to end-use efficiency improvements) consist of

- reducing emissions from fossil resource extraction, conversion, and energy production (e.g., for electricity generation, improving the efficiency of existing power plants, or moving toward the use of lower-emission technologies such as coal gasification–combined cycle generation facilities) and
- shifting from fossil energy sources to other energy sources [e.g., energy from the sun (renewable energy) or from the atom (nuclear energy)].

The most comprehensive description of emission-reducing and fuel switching technologies and their potentials is the U.S. Climate Change Technology Program (CCTP) draft *Strategic Plan* (CCTP, 2005), especially Chapters 5 (energy supply) and 6 (capturing and sequestering CO_2)—see also National Laboratory Directors (1997). The CCTP report focuses on five energy supply technology areas: low-emission fossil-based fuels and power, hydrogen as an energy carrier, renewable energy and fuels, nuclear fission, and fusion energy.

There is a widespread consensus that no one of these options, nor one family of options, is a good prospect to stabilize greenhouse gas emissions from energy supply systems, nationally or globally, because each faces daunting constraints (Hoffert *et al*., 2002). Examples include very real limits to effective global "decarbonization" (i.e., reducing the use of carbon-based energy sources as a proportion of total energy supplies), including renewable or other non-fossil sources of energy use at scales that would dramatically change the global carbon balance between now and 2050. One conclusion is that "the disparity between what is needed and what can be done without great compromise may become more acute."

Instead, progress with technologies currently available or likely to be available in the coming decades may depend on adding together smaller "wedges" of contributions by a variety of resource/technology combinations (Pacala and Socolow, 2004), each of which may be feasible if the demands upon it are moderate. If many wedges can be combined, the total effect could approach requirements for even relatively ambitious carbon stabilization goals, at least in the first half of the century, although each wedge would need to be economically competitive with current types of fossil energy sources.

A fundamental question is whether prospects for significant decarbonization depend on the emergence of new technologies, in some cases requiring advances in science. For instance, efforts are being made to develop economically affordable and socially acceptable options for large-scale capture of carbon from fossil fuel streams—with the remaining hydrogen offering a clean energy source—and sequestration of the carbon in the ground or the oceans. This approach is known to be technologically feasible, and recent assessments suggest that it may have considerable promise (e.g., IPCC, 2006). If so, there is at least some chance that fossil energy sources may be used to provide energy services in North America and the world in large quantities in the mid to longer terms without contributing to a carbon cycle imbalance, although the prospects remain speculative at this time.

What can be expected from technology options over the next quarter to half a century is a matter of debate, partly because the pace of technology development and use depends heavily on policy conditions Chapter 3 in the CCTP draft *Strategic Plan* (2005) shows three advanced technology scenarios drawn from work by the Pacific Northwest National Laboratory, varying according to carbon constraints. Potential contributions to global emission reduction by energy supply technology initiatives between 2000 and 2100 range from about 25 Gt C equivalent to nearly 350 Gt, which illustrates uncertainties related to both science and policy issues. Carbon capture and storage, along with terrestrial sequestration, could add between about 100 and 325 Gt. It has been suggested, however, that significantly decarbonizing energy systems by 2050 could require massive efforts on a par with the Manhattan project or the Apollo space program (Hoffert *et al.*, 2002).

Estimated costs of potential technology alternatives for reducing greenhouse gas emissions from energy supply systems are summarized after the following summary of policy options because estimates are generally based on assumptions about policy interventions.

Policy Options

Policy options for carbon emission reduction from energy supply systems revolve around either *incentives* or regulatory *requirements* for such reductions. Generally, interventions may be aimed at (a) shaping technology choice and use or (b) shaping technology development and supply. Many of the policy options are aimed at encouraging end-use efficiency improvement as well as supply-side emission reduction.

Options for intervening to change the relative attractiveness of available energy supply technology alternatives include appealing to voluntary action (e.g., improved consumer information, “green power”), a variety of regulatory actions (e.g., mandated purchase policies such as energy portfolio standards), carbon emission rights trading (where emission reduction would have market value), technology/product standards, production tax credits for non-fossil energy production, tax credits for alternative energy use, and carbon emission taxation or ceilings. Options for changing the relative attractiveness of investing in carbon-emission-reducing technology development and dissemination include tax credits for certain kinds of energy R&D, public-private sector R&D cost sharing, and electric utility restructuring. For a more comprehensive listing and discussion, see Chapter 6 in IPCC (2002).

In some cases, perceptions that policies and market conditions of the future will be more favorable to emission reduction than at present are motivating private industry to consider investments in technologies whose market competitiveness would grow in such a future

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Most estimates of the impacts of energy policy options on greenhouse gas emissions do not differentiate the contributions from energy supply systems from the rest of the energy economy [e.g., Interlaboratory Working Group (IWG), 1997; IWG, 2000; IPCC, 2001; National Commission on Energy Policy, 2004; also see OTA, 1991, and NAS, 1992]. For instance the IWG (1997) considered effects of $25 and $50 per ton carbon emission permits on both energy supply and use, while IWG considered fifty policy/technology options (IWG, 2000; also see IPCC, 2001), most of which would affect both energy supply and energy use decisions.

Estimated Costs of Implementation

Estimating the costs of emission reduction associated with the implementation of various technology and policy options for energy supply and conversion systems is complicated by several realities. First, many estimates are aggregated for the United States or the world as a whole, without separate estimates for the energy extraction and conversion sector. Second, estimates differ in the scenarios considered, the modeling approaches adopted, and the units of measure that are used.

More specifically, estimates of costs of emission reduction vary widely according to assumptions about such issues as how welfare is measured, ancillary benefits, and effects in stimulating technological innovation. According to IWG (2000), benefits of emission reduction would be comparable to costs, and the National Commission on Energy Policy (2004) estimates that their recommended policy initiatives would be, on the whole, revenue-neutral with respect to the federal budget. Other participants in energy policymaking, however, are convinced that truly significant carbon emission reductions would have substantial economic impacts (GAO, 2004).

Globally, IPCC (2001) projected that global CO_2 emissions from energy supply and conversion could be reduced in 2020 by 350 to 700 Mt C equivalents per year, based on options that could be adopted through the use of generally accepted policies, generally at a positive direct cost of less than U.S.$100 per t C equivalents. It estimated that the cost of emission reducing technologies for power generation, compared with coal-fired power, range from 3 to 8 cents/kWh, except for more expensive photovoltaic and solar thermal technologies. According to the IPCC report, based on DOE/EIA analyses in 2000, advanced coal generation technologies such as integrated gasification combined cycle technology would cost between 3 and 4 cents/kWh in the United States without CO_2 capture. CO_2 capture would raise costs to between 5 and 7 cents. Nuclear energy costs would rise 5 to 6 cents/kWh. Solar energy options would rise from 3 to 5 cents for wind power, 4 to 8 cents for biomass, and 9 to 25 cents for photovoltaics and thermal solar. Within the United States, the report estimated that the cost of emission reduction per metric ton of carbon emissions reduced would range from –$170 to +$880, depending on the technology used. Marginal abatement costs for the total United States economy, in 1990 U.S. dollars per metric ton carbon, were estimated by a variety of models compared by the Energy Modeling Forum at $76 to $410 with no emission trading, $14 to $224 with Annex I trading, and $5 to $123 with global trading.

Similarly, the National Commission on Energy Policy (2004) considered costs associated with a tradable emission permit system that would reduce United States national greenhouse gas emission growth from 44% to 33% from 2002 to 2025, a reduction of 760 Mt CO_2 in 2025 compared with a reference case. The cost would be a roughly 5% increase in total end-use expenditures compared with the reference case. Electricity prices would rise by 5.4% for residential users, 6.2% for commercial users, and 7.6% for industrial users.

The IWG (2000) estimated that a domestic carbon trading system with a $25/t C permit price would reduce emissions by 13% compared with a reference case, or 230 Mt CO_2, while a $50 price would reduce emissions by 17 to 19%, or 306 to 332 Mt CO_2. Both cases assume a doubling of United States government appropriations for cost-shared clean energy research, design, and development.

For carbon capture and sequestration, IPCC (2006) concluded that this option could contribute 15 to 55% to global mitigation between now and 2100 if technologies develop as projected in relatively optimistic scenarios and very large-scale geological carbon sequestration is publicly acceptable. Under these assumptions, the cost is projected at $30 to $70/t CO_2. With less optimistic assumptions, the cost could rise to above $200/t.

Net costs to the consumer, however, are balanced in some analyses by benefits from advanced technologies which are developed and deployed on an accelerated schedule due to policy interventions and changing public preferences. The U.S. Climate Change Technology Program (2005; see page 3-19 in that report) illustrates how costs of achieving different stabilization levels can conceivably be reduced substantially by the use of advanced technologies, and IWG (2000) estimates that net end-user costs of energy can actually be reduced by a domestic carbon trading system if it accelerates the market penetration of more energy-efficient technologies.

In many cases, however, discussions of the promise of technology options are not associated with cost estimates. Economic costs of energy are not one of the drivers of the IPCC SRES scenarios, and such references as Hoffert *et al.* (2002) and Pacala and Socolow (2004) are concerned with technological potentials and constraints as a limiting condition on market behavior rather than with comparative costs and benefits of particular technology options at the margin.

Summary

In terms of prospects for major emission reductions from energy extraction and conversion in North America, the key issues appear to be the extent, direction, and pace of technological innovation and the likelihood that policy conditions favoring carbon emissions reduction that do not now exist will emerge if concerns about carbon cycle imbalances grow. In these regards, the prospects are brighter in the long term (e.g., more than several decades in the future) than in the near term. History suggests that technology solutions are usually easier to implement than policy solutions, but it is possible that observed impacts of carbon cycle imbalances might change the political calculus for policy interventions in the future.

RESEARCH AND DEVELOPMENT NEEDS

If it is possible that truly effective management of carbon emissions from energy supply and conversion systems cannot be realized with the current portfolio of technology alternatives under current policy conditions, then research and development needs and opportunities deserve expanded attention and support (e.g., National Commission on Energy Policy, 2004). If so, the priorities include:

Technology. Several objectives seem to be especially relevant to carbon management potentials:

- clarifying and realizing potentials for carbon capture and sequestration;
- clarifying and realizing potentials of affordable renewable energy systems at a relatively large scale;
- addressing social concerns about the nuclear energy fuel cycle, especially in an era of concern about terrorism;
- improving estimates of economic costs and emission reduction benefits of a range of energy; technologies across a range of economic, technological, and policy scenarios; and
- “Blue Sky” research to develop new technology options and families, such as innovative approaches for energy from the sun and from biomass, including possible applications of nanoscience (Caldeira *et al*,. 2005; Lewis, 2005).

Policy. Research and development can also be applied to policy options in order to enlarge their knowledge bases and explore their implications. For instance, research priorities might include learning more about:

- the public acceptability of policy incentives for reducing dependence on energy sources associated with carbon emissions,

- other incentives for the energy industry to increase its support for pathways not limited to fossil fuels,
- approaches toward a more distributed electric power supply enterprise in which certain renewable (and hydrogen) energy options might be more attractive, and
- transitions from one energy system/infrastructure to another.

In these ways, technology and policy advances might be combined with multiple wedges of available technology to transform the capacity to manage carbon emissions from energy supply systems, if that is a high priority for North America.

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THE CARBON MITIGATION INITIATIVE AT PRINCETON

In September 2000, British Petroleum and Ford Motor Company established a partnership with the Princeton Environmental Institute to explore pathways for capturing and sequestering a large fraction of the carbon emissions from fossil fuels, with $20 million in industry funding over a ten-year period. This program assesses the potential of low-carbon energy technologies, studies the feasibility of long-term underground carbon storage, considers impacts of carbon dioxide on the carbon cycle, and analyzes possible pathways for carbon mitigation.

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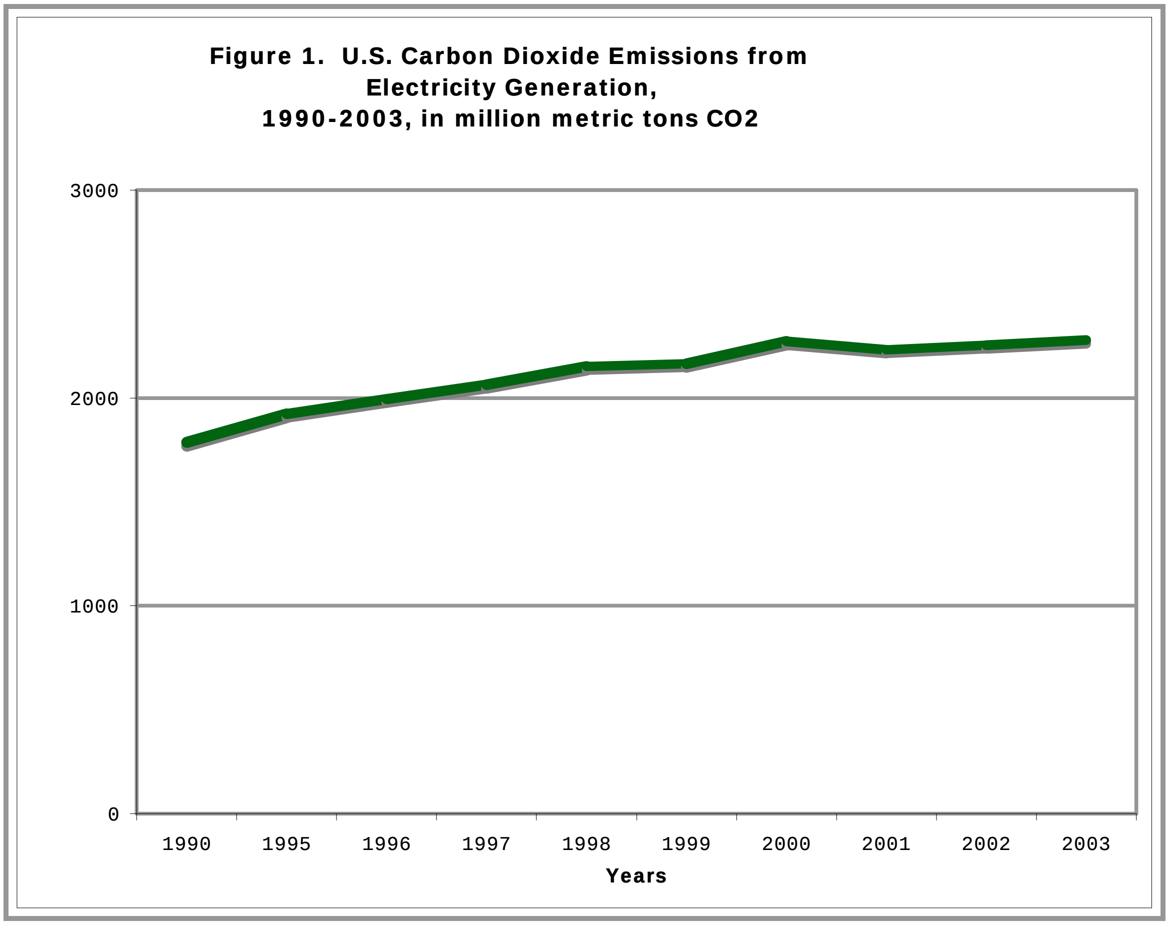

Figure 6.1. United States CO_2 emissions from electricity generation, 1990–2003, in million metric tons CO_2 (Source: EIA, 2004).