

PART II OVERVIEW

Energy, Industry, and Waste Management Activities: An Introduction to CO₂ Emissions from Fossil Fuels

Coordinating Lead Author: G. Marland^{1,2}

Contributing Authors: R. J. Andres,³ T. J. Blasing,¹ T. A. Boden,¹ C. T. Broniak,⁴
J. S. Gregg,⁵ L. M. Losey,³ and K. Treanton⁶

¹Environmental Sciences Division, Oak Ridge National Laboratory, ²Ecotechnology Program, Mid Sweden University (Östersund, Sweden), ³Department of Space Studies, University of North Dakota, ⁴Oregon State University, ⁵Department of Geography, University of Maryland, ⁶International Energy Agency (Paris, France)

THE CONTEXT

Fossil fuels (coal, oil, and natural gas) are used primarily for their concentration of chemical energy, energy that is released as heat when the fuels are burned. Fossil fuels are composed primarily of compounds of hydrogen and carbon (C), and when the fuels are burned the hydrogen and carbon oxidize to water and CO₂, and heat is released. If the water and CO₂ are released to the atmosphere, the water will soon fall out as rain or snow. The CO₂, however, will increase the concentration of CO₂ in the atmosphere and join the active cycling of carbon that takes place among the atmosphere, biosphere, and hydrosphere. Since humans began taking advantage of fossil-fuel resources for energy, we have been releasing to the atmosphere, over a very short period of time, carbon that was stored deep in the Earth over millions of years. We have been introducing a large perturbation to the active cycling of carbon.

Estimates of fossil-fuel use globally show that there have been significant emissions of CO₂ dating back at least to 1750, and from North America back at least to 1785. However, this human perturbation of the active carbon cycle is largely a recent process, with the magnitude of the perturbation growing as population grows and demand for energy grows. Over half of the CO₂ released from fossil-fuel burning globally has occurred since 1980 (Fig. 1).

Figure 1. Cumulative global emissions of CO₂ from fossil-fuel combustion and cement manufacture from 1751 to 2002 (data from Marland *et al.*, 2006).

1 Some CO₂ is also released to the atmosphere during the manufacture of cement. Limestone (CaCO₃)
2 is heated to release CO₂ and produce the calcium oxide (CaO) used to manufacture cement. In North
3 America, cement manufacture now releases less than 1% of the mass of CO₂ released by fossil-fuel
4 combustion. However, cement manufacture is the third largest anthropogenic source of CO₂ (after fossil-
5 fuel use and the clearing and oxidation of forests and soils; see Part III of this report). The CO₂ emissions
6 from cement manufacture are often included with the accounting of anthropogenic CO₂ emissions from
7 fossil fuels.

8 Part II of this report addresses the magnitude and pattern of CO₂ emissions from fossil-fuel
9 consumption and cement manufacture in North America. This introductory section addresses some
10 general issues associated with CO₂ emissions and the annual and cumulative magnitude of total
11 emissions. It looks at the temporal and spatial distribution of emissions and some other data likely to be of
12 interest. The following four chapters delve into the sectoral details of emissions so that we can understand
13 the forces that have driven the growth in emissions to date and the possibilities for the magnitude and
14 pattern of emissions in the future. These chapters reveal, for example, that 38% of CO₂ emissions from
15 North America come from enterprises whose primary business is to provide electricity and heat and
16 another 31% come from the transport of passengers and freight. This introduction focuses on the total
17 emissions from the use of fossil fuels and the subsequent chapters provide insight into how these fuels are
18 used and the economic and human factors motivating their use.

20 **Estimating CO₂ Emissions**

21 It is relatively straightforward to estimate the amount of CO₂ released to the atmosphere when fossil
22 fuels are consumed. Because CO₂ is the equilibrium product of oxidizing the carbon in fossil fuels, we
23 need to know only the amount of fuel used and its carbon content. For greater accuracy, we adjust this
24 estimate to take into consideration the small amount of carbon that is left as ash or soot and is not actually
25 oxidized. We also consider the fraction of fossil fuels that is used for things like asphalt, lubricants,
26 waxes, solvents, and plastics and may not be soon converted to CO₂. Some of these long-lived, carbon-
27 containing products will release their contained carbon to the atmosphere as CO₂ during use or during
28 processing of waste. Other products will hold the carbon in use or in landfills for decades or longer. One
29 of the differences among the various estimates of CO₂ emissions is the way they deal with the carbon in
30 these products.

31 Fossil-fuel consumption is often measured in mass or volume units and, in these terms, the carbon
32 content of fossil fuels is quite variable. However, when we measure the amount of fuel consumed in terms
33 of its energy content, we find that for each of the primary fuel types (coal, oil, and natural gas) there is a
34 strong correlation between the energy content and the carbon content. The rate of CO₂ emitted per unit of

1 useful energy released depends on the ratio of hydrogen to carbon and on the details of the organic
2 compounds in the fuels; but, roughly speaking, the numerical conversion from energy released to carbon
3 released as CO₂ is about 25 kg C per 10⁹ joules for coal, 20 kg C per 10⁹ joules for petroleum, and 15 kg
4 C per 10⁹ joules for natural gas. Figure 2 shows details of the correlation between energy content and
5 carbon content for more than 1000 coal samples. Detailed analysis of the data suggests that hard coal
6 contains $25.16 \pm 2.09\%$ kg C per 10⁹ joules of coal (measured on a net heating value basis¹). The value is
7 slightly higher for lignite and brown coal ($26.23 \text{ kg C} \pm 2.33\%$ per 10⁹ joules (also shown in Fig. 2)).
8 Similar correlations exist for all fuels and Table 1 shows some of the coefficients reported by the
9 Intergovernmental Panel on Climate Change (IPCC) for estimating CO₂ emissions. The differences
10 between the values in Table 1 and those in Fig. 1 are small, but they begin to explain how different data
11 compilations can end up with different estimates of CO₂ emissions.

12
13 **Figure 2. The carbon content of coal varies with the heat content, shown here as the net heating**
14 **value.**

15
16 **Table 1. A sample of the coefficients used for estimating CO₂ emissions from the amount of fuel**
17 **burned (from IPCC, 1997).**

18
19 Data on fossil-fuel production, trade, consumption, etc. are generally collected at the level of some
20 political entity, such as a country, and over some time interval, typically a year. Estimates of national,
21 annual fuel consumption can be based on estimates of fuel production and trade, estimates of actual final
22 consumption, data for fuel sales or some other activity that is clearly related to fuel use, or on estimates
23 and models of the activities that consume fuel (such as vehicle miles driven). In the discussion that
24 follows, some estimates of national, annual CO₂ emissions are based on “apparent consumption” (defined
25 as production + imports – exports +/- changes in stocks) while others are based on more direct estimates
26 of fuel consumption. All of the emissions estimates in this chapter are as the mass of carbon released².

27 The uncertainty in estimates of CO₂ emissions will thus depend on the variability in the chemistry of
28 the fuels, the quality of the data or models of fuel consumption, and on uncertainties in the amount of
29 carbon that is used for non-fuel purposes (such as asphalt and plastics) or is otherwise not burned. For

¹Net heating value (NHV) is the heat release measured when fuel is burned at constant pressure so that the H₂O is released as H₂O vapor. This is distinguished from the gross heating value (GHV), the heat release measured when the fuel is burned at constant volume so that the H₂O is released as liquid H₂O. The difference is essentially the heat of vaporization of the H₂O and is related to the H content of the fuel.

²The C is actually released to the atmosphere as CO₂ and it is accurate to report (as is often done) either the amount of CO₂ emitted or the amount of C in the CO₂. The numbers can be easily converted back and forth using the ratio of the molecular masses, i.e. (mass of C) x (44/12) = (mass of CO₂).

1 countries like the United States—with good data on fuel production, trade, and consumption—the
2 uncertainty in national emissions of CO₂ is on the order of ± 5% or less. In fact, the US Environmental
3 Protection Agency (USEPA, 2005) suggests that their estimates of CO₂ emissions from energy use in the
4 United States are accurate, at the 95% confidence level, within –1 to +6 % and Environment Canada
5 (2005) suggests that their estimates for Canada are within –4 to 0 %. The Mexican National Report
6 (Mexico, 2001) does not provide estimates of uncertainty, but our analyses with the Mexican data suggest
7 that uncertainty is larger than for the United States and Canada. Emissions estimates for these same three
8 countries, as reported by the Carbon Dioxide Information Analysis Center (CDIAC) and the International
9 Energy Agency (IEA) (see the following section), will have larger uncertainty because these groups are
10 making estimates for all countries. Because they work with data from all countries, they use global
11 average values for things like the emissions coefficients, whereas agencies within the individual countries
12 use values that are more specific to the particular country. When national emissions are calculated by
13 consistent methods it is likely that year-to-year changes can be estimated more accurately than would be
14 suggested by the uncertainties of the individual annual values.

15

16 **The Magnitude of National and Regional CO₂ Emissions**

17 Figure 3 shows that from the beginning of the fossil-fuel era (1751 in these graphs) to the end of
18 2002, there were 93.5 Gt C released as CO₂ from fossil-fuel consumption (and cement manufacture) in
19 North America: 84.4 Gt C from the United States, 6.0 from Canada, and 3.1 from Mexico. All three
20 countries of North America are major users of fossil fuels and this 93.5 Gt C was 31.5 % of the global
21 total. Among all countries, the United States, Canada, and Mexico ranked as the first, eighth, and eleventh
22 largest emitters of CO₂ from fossil-fuel consumption, respectively (for 2002) (Marland *et al.*, 2006).
23 Figure 4 shows, for each of these countries and for the sum of the three, the annual total of emissions and
24 the contributions from the different fossil fuels.

25

26 **Figure 3. The cumulative total of CO₂ emissions from fossil-fuel consumption and cement**
27 **manufacture, as a function of time, for the three countries of North America and for the sum of the**
28 **three (from Marland *et al.*, 2006).**

29

30 **Figure 4. Annual emissions of CO₂ from fossil-fuel use by fuel type.**

31

32 The long time series of emissions estimates in Figs. 1, 3, and 4 are from the CDIAC (Marland *et al.*,
33 2006). These estimates are derived from the “apparent consumption” of fuels and are based on data from
34 the UN Statistics Office back to 1950 and on data from a mixture of sources for the earlier years (Andres

1 *et al.*, 1999). There are other published estimates (with shorter time series) of national, annual CO₂
2 emissions. Most notably the IEA (2005) has reported estimates of emissions for many countries for all
3 years back to 1971, and most countries have now provided some estimates of their own emissions as part
4 of their national obligations under the United Nations Framework Convention on Climate Change
5 (UNFCCC, see <http://unfccc.int>). These latter two sets of estimates are based on data on actual fuel
6 consumption and thus are able to provide details as to the sector of the economy where fuel use is taking
7 place³.

8 Comparing the data from multiple sources can give us some insight into the reliability of the
9 estimates generally. These different estimates of CO₂ emissions are not, of course, truly independent
10 because they all rely ultimately on national data on fuel use; but they do represent different manipulations
11 of this primary data and in many countries there are multiple potential sources of energy data. Many
12 developing countries do not collect or do not report all of the data necessary to precisely estimate CO₂
13 emissions and in these cases differences can be introduced by how the various agencies derive the basic
14 data on fuel production and use. Because of the way data are collected, there are statistical differences
15 between “consumption” and “apparent consumption” as defined above.

16 To make comparisons of different estimates of CO₂ emissions we would like to be sure that we are
17 indeed comparing estimates of the same thing. For example emissions from cement manufacture are not
18 available from all of the sources, so they are not included in the comparisons in Table 2. All of the
19 estimates in Table 2, except those from the IEA, include emissions from flaring natural gas at oil
20 production facilities. It is not easy to identify the exact reason the estimates differ, but the differences are
21 generally small. The differences have mostly to do with the statistical difference between consumption
22 and apparent consumption, the way in which correction is made for non-fuel usage of fossil-fuel
23 resources, the conversion from mass or volume to energy units, and/or the way in which estimates of
24 carbon content are derived. Because the national estimates from CDIAC do not include emissions from
25 the non-fuel uses of petroleum products, we expect them to be slightly smaller than the other estimates
26 shown here, all of which do include these emissions⁴. The comparisons in Table 2 reveal one number for
27 which there is a notable relative difference among the multiple sources, emissions from Mexico in 1990.
28 Losey (2004) has suggested, based on other criteria, that there is a problem in the United Nations energy
29 data set with the Mexican natural gas data for the 3 years 1990-1992, and these kinds of analyses result in
30 re-examination of some of the fundamental data.

³The International Energy Agency provides estimates based on both the reference approach (estimates of apparent consumption) and the sectoral approach (estimates of actual consumption) as described by the IPCC (IPCC, 1997). In the comparison here we use the numbers that they believe to be the most accurate, those based on the sectoral approach.

⁴The CDIAC estimate of global total emissions does include estimates of emissions from oxidation from non-fuel use of hydrocarbons.

1
2 **Table 2. Different estimates (in Mt C) of CO₂ emissions from fossil-fuel consumption for the United**
3 **States, Canada, and Mexico.**

4
5 The IEA (2005, p. 1.4) has systematically compared their estimates with those reported to the
6 UNFCCC by the different countries and they find that the differences for most developed countries are
7 within 5%. The IEA attributes most of the differences to the following:

- 8
- 9 • use of the IPCC Tier 1 method that does not take into account different technologies,
 - 10 • use of energy data that may have come from different “official” sources within a country,
 - 11 • use of average values for net heating value of secondary oil products,
 - 12 • use of average emissions values,
 - 13 • use of incomplete data on non-fuel uses,
 - 14 • different treatment of military emissions, and
 - 15 • a different split between what is identified as emissions from energy and emissions from industrial
16 processes.
- 17

18 **Emissions by Month and/or State**

19 With increasing interest in the details of the global carbon cycle there is increasing interest in
20 knowing emissions at spatial and temporal scales finer than countries and years. For the United States,
21 energy data have been collected for many years at the level of states and months and thus estimates of
22 CO₂ emissions can be made by state or by month. Figure 5 shows the variation in U.S. emissions by
23 month and preliminary analyses by Gurney *et al.* (2005) reveal that proper recognition of this variability
24 can be very important in some exercises to model the details of the global carbon cycle.

25
26 **Figure 5. Emissions of CO₂ from fossil-fuel consumption in the United States, by month.**

27
28 Because of differences in the way energy data are collected and aggregated, it is not obvious that an
29 estimate of emissions from the United States will be identical to the sum of estimates for the 50 U.S.
30 states. Figure 6 shows that estimates of total annual CO₂ emissions are slightly different if we use data
31 directly from the U.S. Department of Energy (DOE) and sum the estimates for the 50 states or if we sum
32 the estimates for the 12 months of a given year, or if we take U.S. energy data as aggregated by the UN
33 Statistics Office and calculate the annual total of CO₂ emissions directly. Again, the state and monthly
34 emissions data are based on estimates of fuel consumption while the national emissions estimates

1 calculated using UN data result from estimates of “apparent consumption.” There is a difference between
2 annual values for consumption and annual values of “apparent consumption” (the IEA calls this
3 difference simply “statistical difference”) that is related to the way statistics are collected and aggregated.
4 There are also differences in the way values for fuel chemistry and non-fuel usage are averaged at
5 different spatial and temporal scales, but the differences in CO₂ estimates are seen to be within the error
6 bounds generally expected.

7
8 **Figure 6. A comparison of three different estimates of national annual emissions of CO₂ from fossil-**
9 **fuel consumption in the United States.**

10
11 Data from DOE permit us to estimate emissions by state or by month (Blasing *et al.*, 2005a and
12 2005b), but they do not permit us to estimate CO₂ emissions for each state by month directly from the
13 published energy data. Nor do we have sufficiently complete data to estimate emissions from Canada and
14 Mexico by month or province. Andres *et al.* (2005), Gregg (2005), and Losey (2004) have shown that we
15 can disaggregate national total emissions by month or by some national subdivision (such as states or
16 provinces) if we have data on some large fraction of fuel use. Because this approach relies on determining
17 the fractional distribution of an otherwise-determined total, it can be done with incomplete data on fuel
18 use. The estimates will, of course, improve as the fraction of the total fuel use is increased. Figure 7 is
19 based on sales data for most fossil fuel commodities and the CDIAC estimates of total national emissions,
20 and shows how the CO₂ emissions from North America vary at a monthly time scale.

21
22 **Figure 7. CO₂ emissions from fossil-fuel consumption in North America, by month.**

23 24 **Emissions by Economic Sector**

25 To understand how CO₂ emissions from fossil-fuel use interact in the global and regional cycling of
26 carbon, it is necessary to know the masses of emissions and their spatial and temporal patterns. We have
27 tried to summarize this information here. To understand the trends and the driving forces behind the
28 growth in fossil-fuel emissions, and the opportunities for controlling emissions, it is necessary to look in
29 detail at how the fuels are used. This is the goal of the next four chapters of this report.

30 Before looking at the details of how energy is used and where CO₂ emissions occur in the economies
31 of North America, however, there are two indices of CO₂ emissions at the national level that provide
32 perspective on the scale and distribution of emissions. These two indices are emissions per capita and
33 emissions per unit of economic activity, the latter generally represented by CO₂ per unit of gross domestic
34 product (GDP). Figure 8 shows the 1950–2002 record of CO₂ emissions per capita for the three countries

1 of North America and, for perspective, includes the same data for the Earth as a whole. Similarly, Table 3
2 shows CO₂ emissions per unit of GDP for the three countries of North America and for the world total.
3 These are, of course, very complex indices and though they provide some insight they say nothing about
4 the details and the distributions within the means. The data on CO₂ per capita for the 50 U.S. states (Fig.
5 9) show that values range over a full order of magnitude, differing in complex ways with the structure of
6 the economies and probably with factors like climate, population density, and access to resources (Blasing
7 *et al.*, 2005b; Neumayer, 2004).

8
9 **Figure 8. Per capita emissions of CO₂ from fossil-fuel consumption (and cement manufacture) in the**
10 **United States, Canada, and Mexico and for the global total of emissions (from Marland *et al.*, 2005).**

11
12 **Table 3. Emissions of CO₂ from fossil-fuel consumption (cement manufacture and gas flaring are not**
13 **included) per unit of GDP for the United States, Canada, and Mexico and for the global total.**

14
15 **Figure 9. Per capita emissions of CO₂ from fossil-fuel consumption for the 50 U.S. states in 2000.**

16
17 Chapters 6 through 9 of this report discuss the patterns and trends of CO₂ emissions by sector and the
18 driving forces behind the trends that are observed. Estimating emissions by sector brings special
19 challenges in defining sectors and assembling the requisite data. Readers will find that there is
20 consistency and coherence within each of the following chapters but will encounter difficulty in
21 aggregating or summing numbers across chapters. Different experts use different sector boundaries,
22 different data sources, different conversion factors, etc. Different analysts will find data for different base
23 years and may treat electricity and biomass fuels differently. Despite these differences in accounting
24 procedures, the four chapters accurately characterize the patterns of emissions and the opportunities for
25 controlling the growth in emissions. They reveal that there are major differences between the countries of
26 North America where, for example, the United States derives 51% of its electricity from coal, Mexico
27 gets 68% from petroleum and natural gas, and Canada gets 58% from hydroelectric stations. Partially as a
28 reflection of this difference, 40% of U.S. CO₂ emissions are from enterprises whose primary business is
29 to generate electricity and heat, while this number is only 31% in Mexico and 23% in Canada (for 2003;
30 from IEA, 2005). Chapter 8 reveals that the sectors are not independent as, for example, a change from
31 fuel burning to electricity in an industrial process will decrease emissions from the industrial sector but
32 increase emissions in the electric power sector. The database of the IEA allows us to summarize CO₂
33 emissions for the three countries according to sectors that closely correspond to the sectoral division of
34 chapters 6 through 9 (Table 4).

1
2 **Table 4. Percent of CO₂ emissions by sector for 2003.**
3
4

5 **CONCLUSION**

6 There are a variety of reasons that we want to know the emissions of CO₂ from fossil fuels, there are a
7 variety of ways of coming up with the desired estimates, and there are a variety of ways of using the
8 estimates. By the nature of the process of fossil-fuel combustion, and because of its economic importance,
9 there are reasonably good data over long time intervals that we can use to make reasonably accurate
10 estimates of CO₂ emissions to the atmosphere. In fact, it is the economic importance of fossil-fuel burning
11 that has assured us of both good data on emissions and great challenges in altering the rate of emissions.
12

13 **REFERENCES FOR PART II OVERVIEW**

- 14 **Andres**, R.J., D.J. Fielding, G. Marland, T.A. Boden, N. Kumar, and A.T. Kearney, 1999: Carbon dioxide emissions
15 from fossil-fuel use, 1751–1950. *Tellus*, **51**, 759–765.
- 16 **Andres**, R.J., J.S. Gregg, L.M. Losey, and G. Marland, 2005: *Monthly Resolution Fossil-Fuel-Derived Carbon*
17 *Dioxide Emissions for the Countries of the North American Carbon Program*. Proceedings of the Seventh
18 International Carbon Dioxide Conference, Bloomfield, CO, September, 2005, pp. 157–158.
- 19 **Blasing**, T.J., C.T. Broniak, and G. Marland, 2005a: The annual cycle of fossil-fuel carbon dioxide emissions in the
20 United States. *Tellus*, **57B**, 107–115. Available at <http://cdiac.esd.ornl.gov>
- 21 **Blasing**, T.J., C. Broniak, and G. Marland, 2005b: State-by-state carbon dioxide emissions from fossil-fuel use in
22 the United States 1960–2000. *Mitigation and Adaptation Strategies for Global Change*, **10**, 659–674.
- 23 **Environment Canada**, 2005: *Canada's Greenhouse Gas Inventory: 1990–2003*. National Inventory Report, April
24 15, 2005, Greenhouse Gas Division, Environment Canada.
- 25 **EPA**, 2005: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. EPA 430-R-05-003, United States
26 Environmental Protection Agency, Washington, DC.
- 27 **Gregg**, J.S., 2005: *Improving the Temporal and Spatial Resolution of Carbon Dioxide Emissions Estimates from*
28 *Fossil-Fuel Consumption*. A thesis submitted to the graduate faculty of the University of North Dakota, August,
29 2005, 404 pp. Available at <http://cdiac.esd.ornl.gov>
- 30 **Gurney**, K.R., Y.H. Chen, T. Maki, S.R. Kawa, A. Andrews, and Z. Zhu, 2005: Sensitivity of atmospheric CO₂
31 inversion to seasonal and interannual variations in fossil-fuel emissions. *Journal of Geophysical Research*,
32 **110(D10)**, 10308.
- 33 **IEA**, 2005: *CO₂ Emissions from Fuel Combustion: 1971–2003*. International Energy Agency, OECD/IEA, Paris,
34 France.
- 35 **IPCC** (Intergovernmental Panel on Climate Change), 1997: *Revised 1996 IPCC Guidelines for National*
36 *Greenhouse Gas Inventories (3 Volumes)*. IPCC Technical Support Unit, Bracknell, United Kingdom.

- 1 **Losey, L.M.**, 2004: *Monthly and Seasonal Estimates of Carbon Dioxide Emissions from Fossil Fuel Consumption in*
2 *Canada, Mexico, Brazil, The United Kingdom, France, Spain, Italy, and Poland*. A thesis submitted to the
3 graduate faculty of the University of North Dakota, May, 2004, 328 pp. Available at <http://cdiac.essd.ornl.gov>
- 4 **Marland, G., T. Boden, and R.J. Andres**, 1995: Carbon dioxide emissions from fossil fuel burning: emissions
5 coefficients and the global contribution of eastern European countries. *Időjárás*, **99**, 157–170.
- 6 **Marland, G., T.A. Boden, and R.J. Andres**, 2005: Global, regional, and national CO₂ emissions. In: *Trends: A*
7 *Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National
8 Laboratory, U.S. Department of Energy, Oak Ridge, TN, U.S.A. Available at <http://cdiac.esd.ornl.gov>
- 9 **Mexico**, 2001: *México: Segunda comunicación nacional ante la Convención Marco de las Naciones Unidas sobre*
10 *el cambio climático*. Comité intersecretarial sobre cambio climático, Secretaría de Medio Ambiente y Recursos
11 Naturales (Semarnat), Mexico City, 374 pp.
- 12 **Neumayer, E.**, 2004: National carbon dioxide emissions: geography matters. *Area*, **36(1)**, 33–40.

Table 1. A sample of the coefficients used for estimating CO₂ emissions from the amount of fuel burned (from IPCC, 1997)

Fuel	Emissions coefficient (kg C/10⁹ J net heating value)
Lignite	27.6
Anthracite	26.8
Bituminous coal	25.8
Crude oil	20.0
Residual fuel oil	21.1
Diesel oil	20.2
Jet kerosene	19.5
Gasoline	18.9
Natural gas	15.3

Table 2. Different estimates (in Mt C) of CO₂ emissions from fossil-fuel consumption for the United States, Canada, and Mexico

Country		1990		1998		2002
United States	CDIAC	1305	CDIAC	1501	CDIAC	1580
	IEA	1320	IEA	1497	IEA	1545
	USEPA	1316	USEPA	1478	USEPA	1534
Canada	CDIAC	112	CDIAC	119	CDIAC	139
	IEA	117	IEA	136	IEA	145
	Canada	117	Canada	133	Canada	144
Mexico	CDIAC	99	CDIAC	96	CDIAC	100
	IEA	80	IEA	96	IEA	100
	Mexico	81	Mexico	96	Mexico	NA

Notes:

Many of these data were published in terms of the mass of CO₂, and these data have been multiplied by 12/44 to get the mass of carbon for the comparison here.

Values are from CDIAC (Marland *et al.*, 2005), IEA (2005), USEPA (2005), Canada (Environment Canada, 2005), and Mexico (2001).

All data except CDIAC include oxidation of non-fuel hydrocarbons.

All data except IEA include flaring of gas at oil and gas processing facilities.

1
2
3
4
5
6

**Table 3. Emissions of CO₂ from fossil-fuel consumption
(cement manufacture and gas flaring are not included)
per unit of GDP for the United States, Canada,
and Mexico for the global total**

Country	CO ₂ emissions per unit of GDP ^a		
	Year		
	1990	1998	2002
United States	0.19	0.17	0.15
Canada	0.18	0.18	0.16
Mexico	0.13	0.12	0.11
Global total	0.17	0.15	0.14

7
8
9
10
11
12
13
14
15
16
17
18

^aCO₂ is measured in kg carbon and GDP is reported in 2000 US\$ purchasing power parity (from IEA, 2005).

Table 4. Percentage of CO₂ emissions by sector for 2003

Sector	United States	Canada	Mexico	North America
Energy extraction and conversion ^a	46.2	36.2	47.7	45.4
Transportation ^b	31.3	27.7	30.3	31.0
Industry ^c	11.2	16.8	13.6	11.8
Buildings ^d	11.3	19.3	8.4	11.8

19
20
21
22
23
24

^aThe sum of three IEA categories, “public electricity and heat production,” “unallocated autoproducers,” and “other energy industries.” (IEA, 2005).

^bIEA category “transport.” (IEA, 2005).

^cIEA category “manufacturing industries and construction.” (IEA, 2005).

^dIEA category “other sectors.” (IEA, 2005).

1

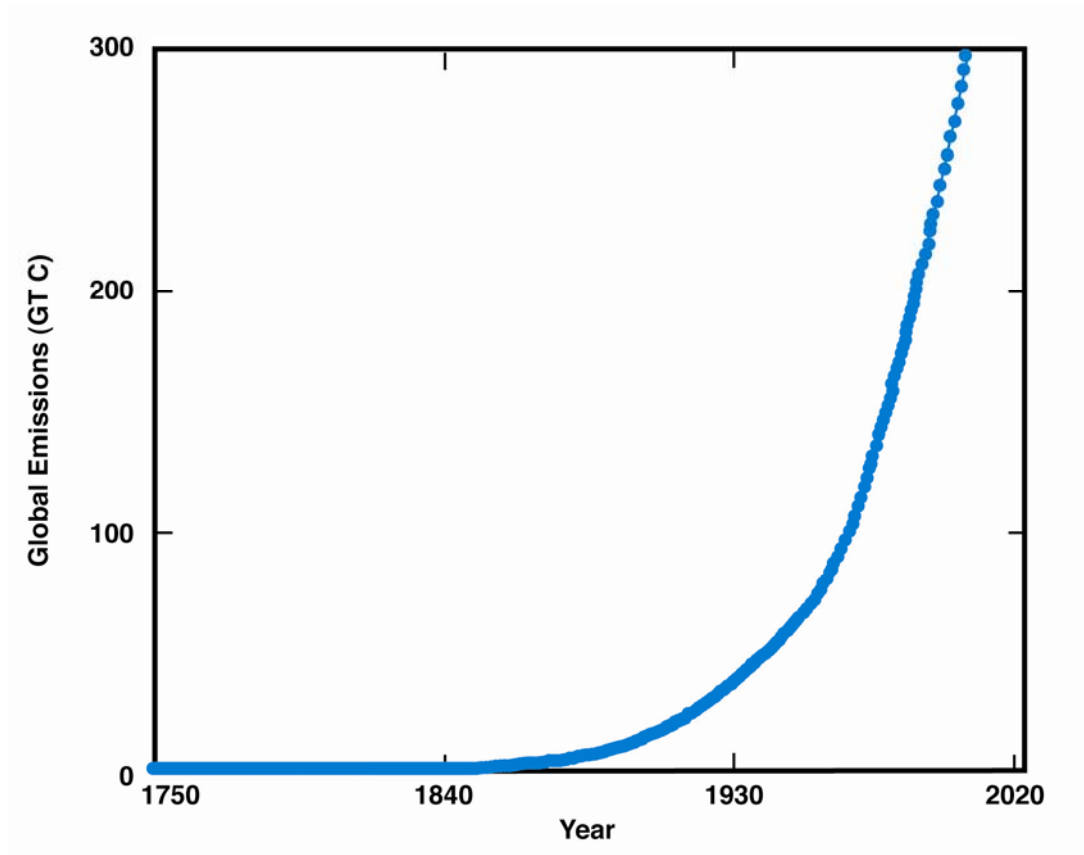


Fig. 1. Cumulative global emissions of CO₂ from fossil-fuel combustion and cement manufacture from 1751 to 2002 (data from Marland *et al.*, 2006).

2

1

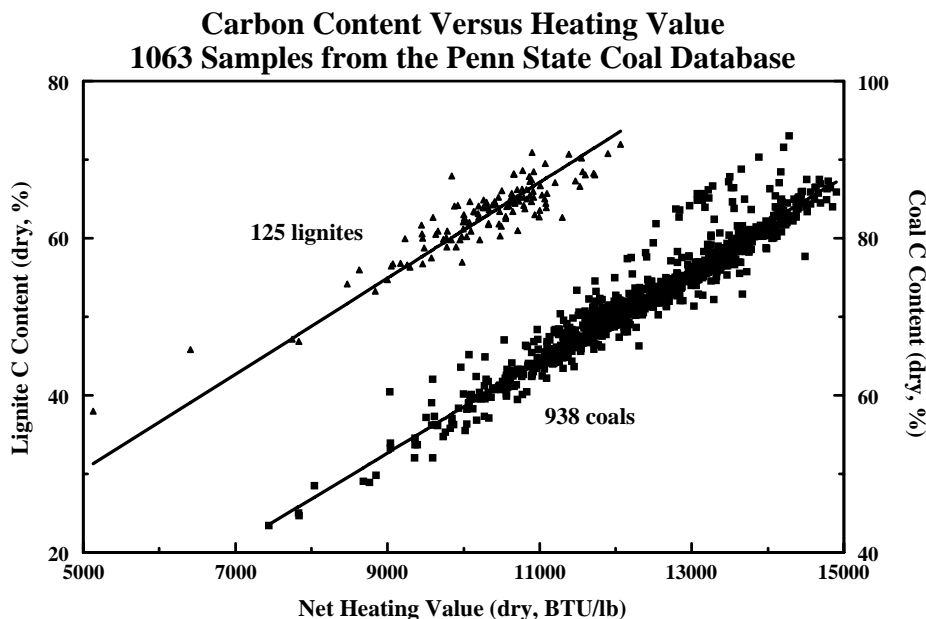


Fig. 2. The carbon content of coal varies with the heat content, shown here as the net heating value. To make them easier to distinguish, data for lignites and brown coals are shown on the left axis, while data for hard coals are offset by 20% and shown on the right axis. Heating value is plotted in the units at which it was originally reported, Btu/lb, where 1 Btu/lb = 2324 J/kg (from Marland *et al.*, 1995).

2
3

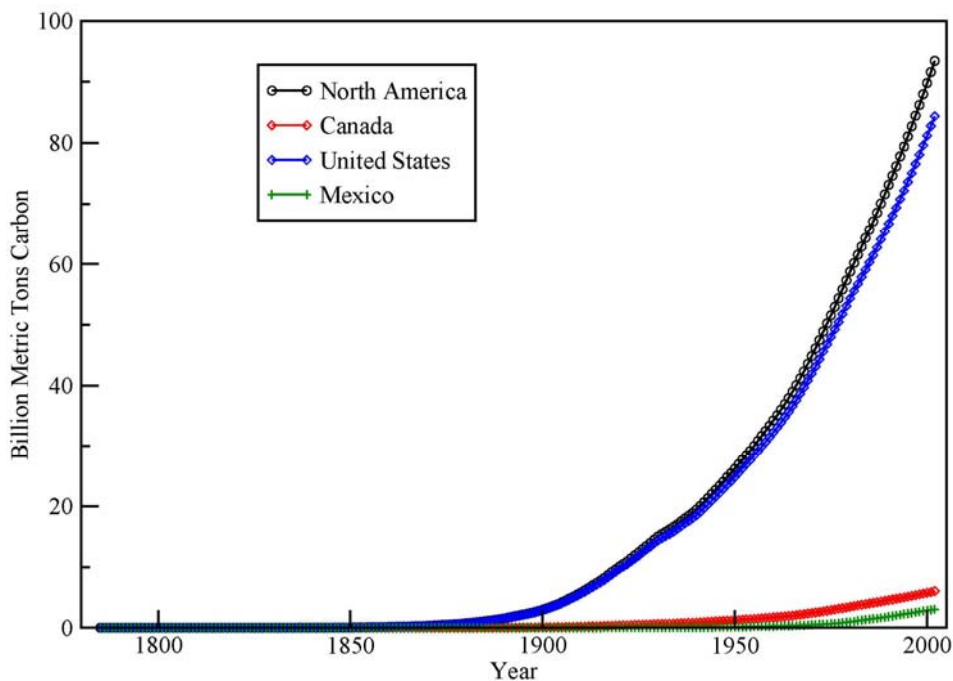
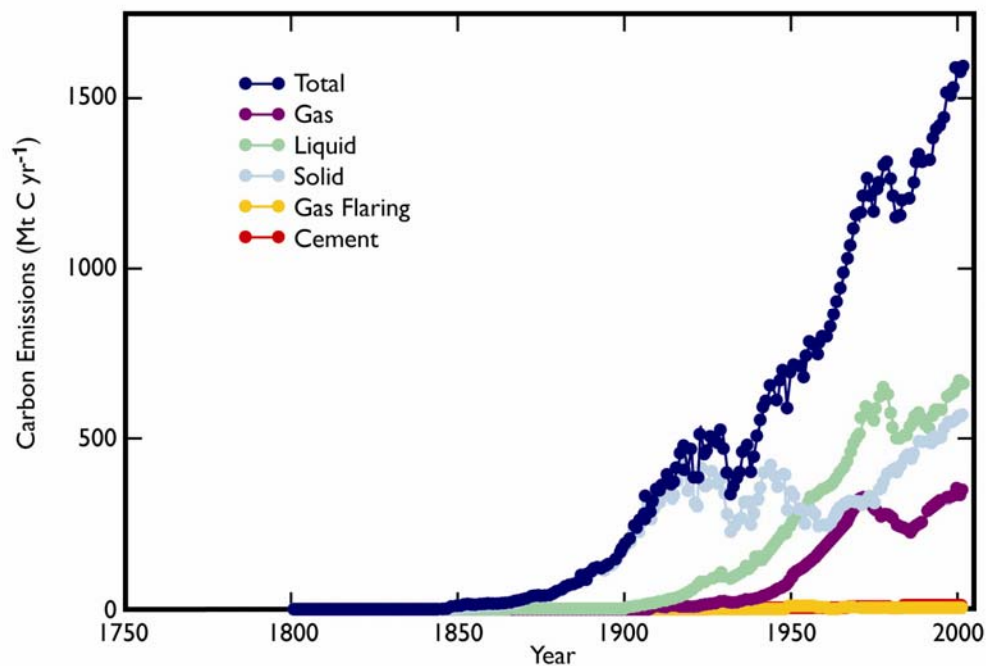


Fig. 3. The cumulative total of CO₂ emissions from fossil-fuel consumption and cement manufacture, as a function of time, for the three countries of North America and for the sum of the three (from Marland *et al.*, 2006).

1

(A) United States



(B) Canada

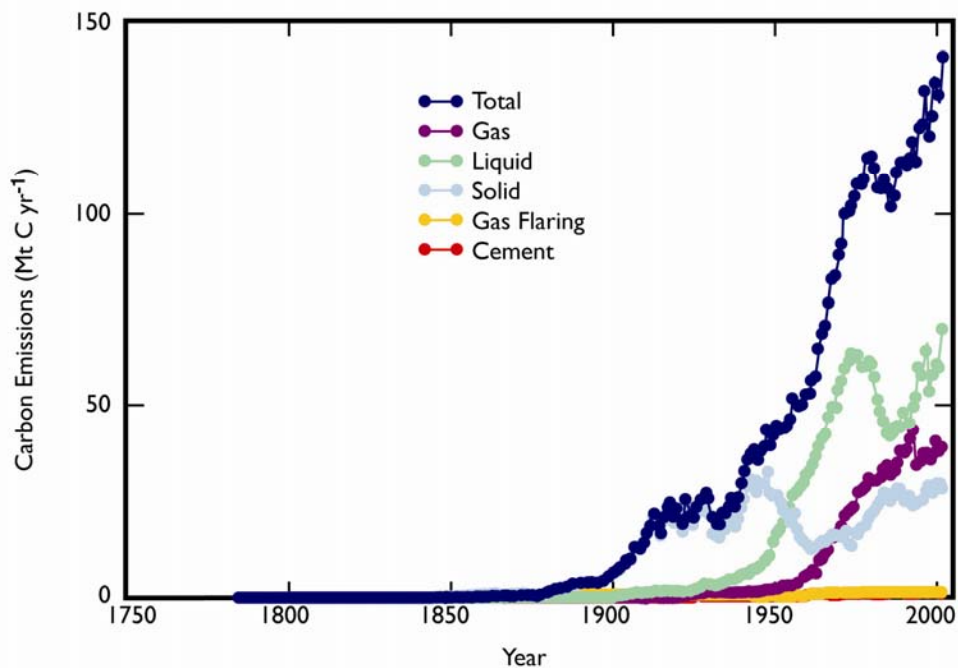
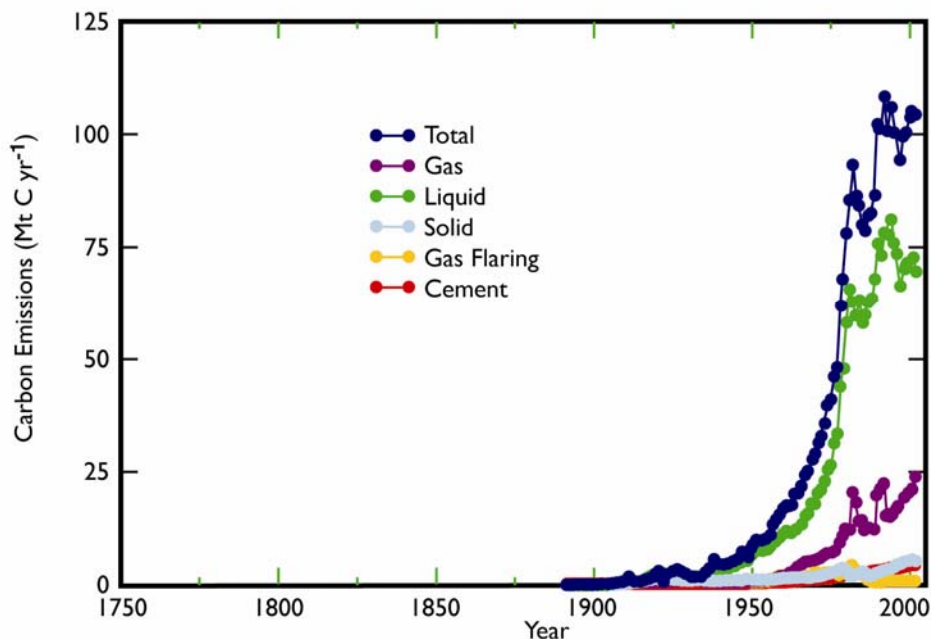


Fig. 4A and 4B. Annual emissions of CO₂ from fossil-fuel use by fuel type.

Figure 4A is for the United States, Figure 4B is for Canada, Figure 4C is for Mexico, and Figure 4D is for the sum of the three. Note that in order to illustrate the contributions of the different fuels, the four plots are not to the same vertical scale (from Marland *et al.*, 2006).

1
2

(C) Mexico



(D) Sum of United States, Canada, and Mexico

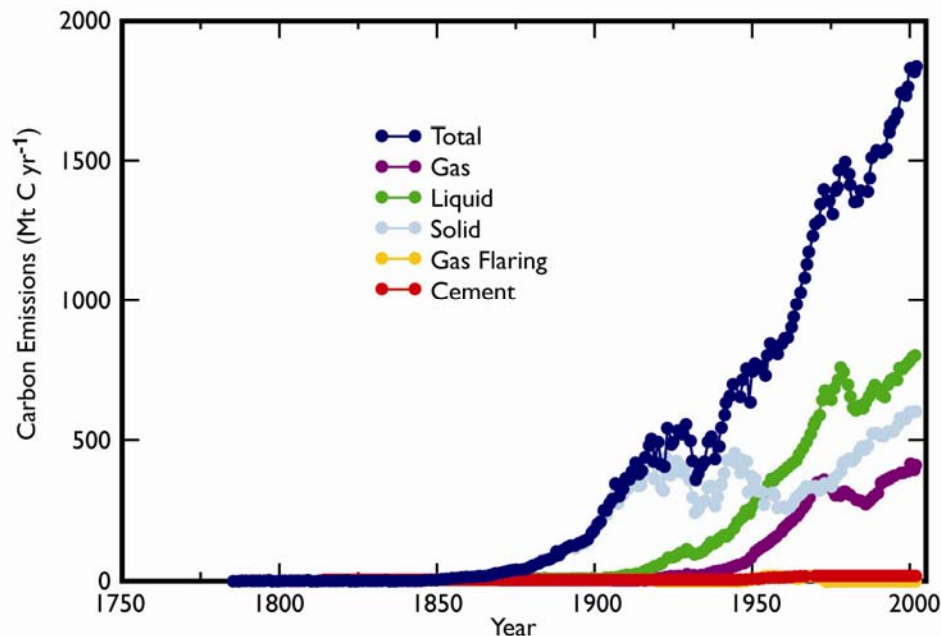


Fig. 4C and 4D. Annual emissions of CO₂ from fossil-fuel use by fuel type.

Figure 4A is for the United States, Figure 4B is for Canada, Figure 4C is for Mexico, and Figure 4D is for the sum of the three. Note that in order to illustrate the contributions of the different fuels, the four plots are not to the same vertical scale (from Marland *et al.*, 2006).

3

1

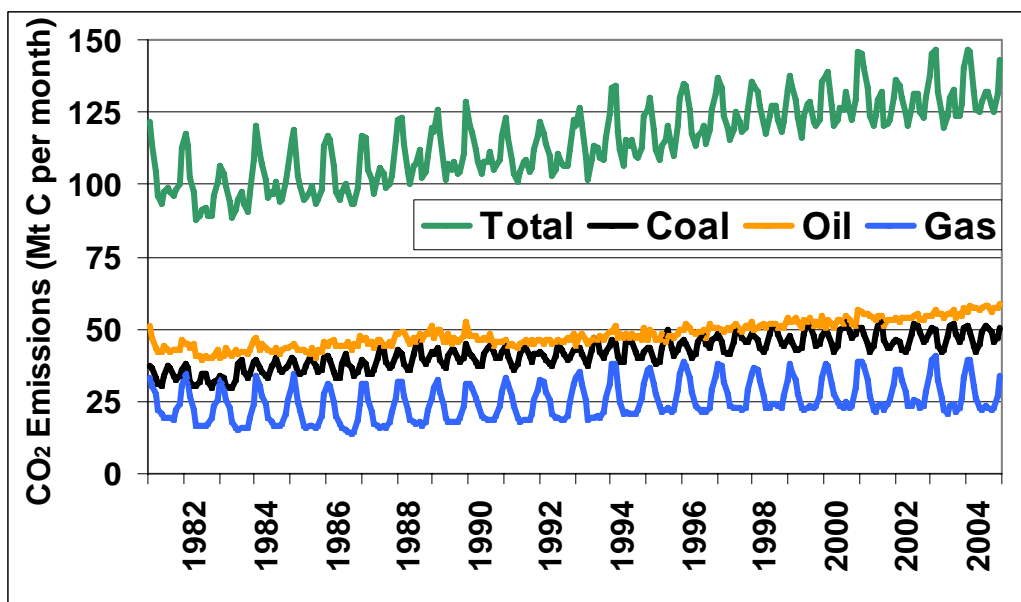


Fig. 5. Emissions of CO₂ from fossil-fuel consumption in the United States, by month. Emissions from cement manufacturing are not included (from Blasing *et al.*, 2005a).

2

1

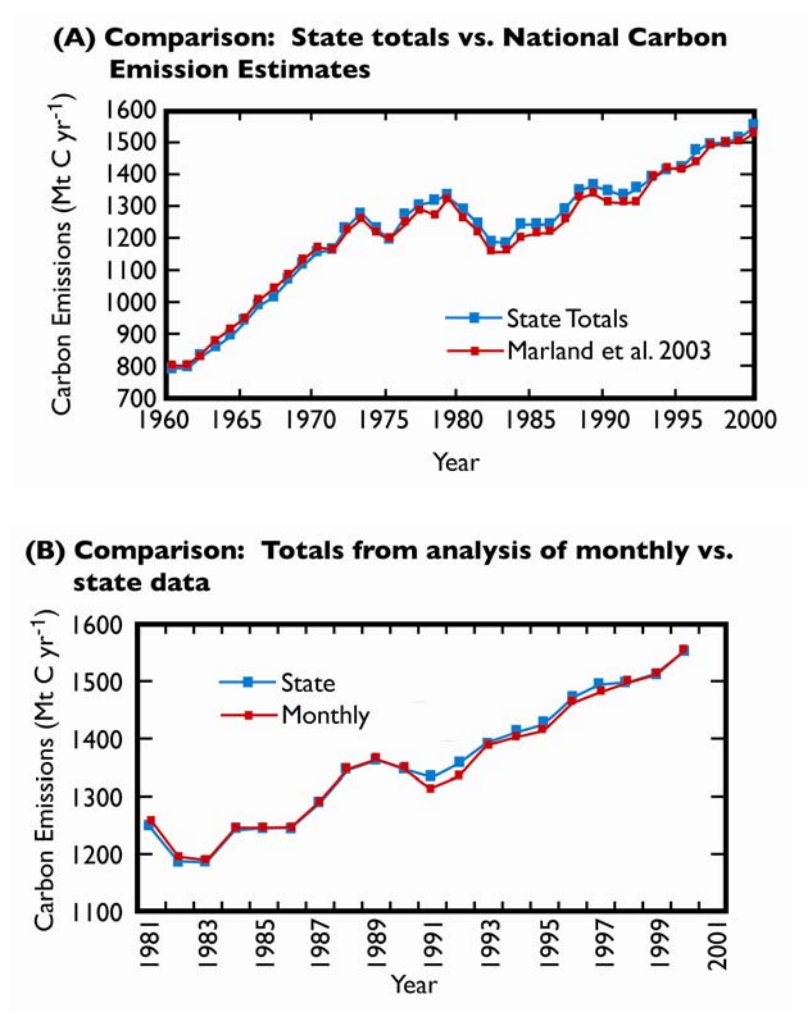


Fig. 6. A comparison of three different estimates of national annual emissions of CO₂ from fossil-fuel consumption in the United States. (6A) Estimates from U.S. Department of Energy data on fuel consumption by state (blue squares) vs. estimates based on UN Statistics Office data on apparent fuel consumption for the full United States (red squares) from Marland *et al.* (2003). (6B) Estimates based on DOE data on fuel consumption in the 50 U.S. states (blue squares) vs. estimates based on national fuel consumption for each of the 12 months (red squares). The state and monthly data include estimates of oxidation of non-fuel hydrocarbon products; the UN-based estimates do not (from Blasing *et al.*, 2005b).

2

3

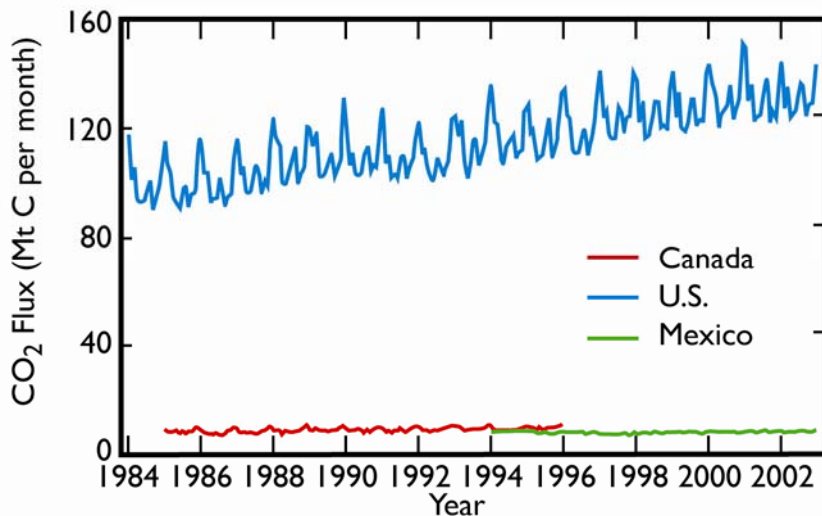


Fig. 7. CO₂ emissions from fossil-fuel consumption in North America, by month. Monthly values are shown where estimates are justified by the availability of monthly data on fuel consumption or sales (from Andres *et al.*, 2005).

1
2
3
4

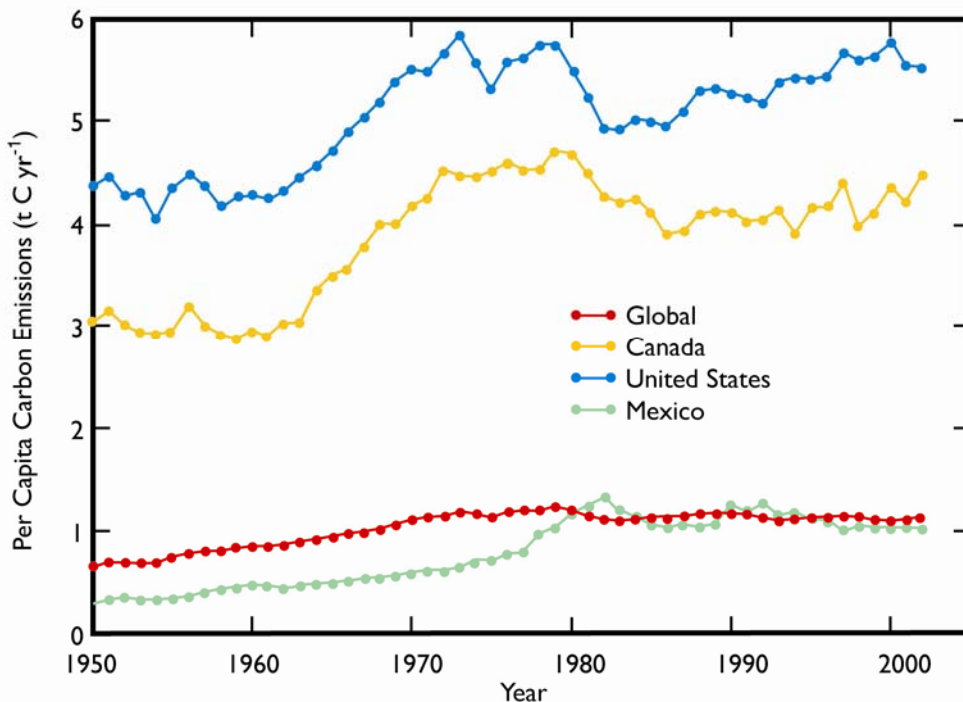


Fig. 8. Per capita emissions of CO₂ from fossil-fuel consumption (and cement manufacture) in the United States, Canada, and Mexico and for the global total of emissions (from Marland *et al.*, 2005).

5

1



Fig. 9. Per capita emissions of CO₂ from fossil-fuel consumption for the 50 U.S. states in 2000. To demonstrate the range, values have been rounded to whole numbers of metric tons carbon per capita. A large portion of the range for extreme values is related to the occurrence of coal resources and inter-state transfers of electricity (from Blasing *et al.*, 2005b).

2