

CRS Report for Congress

Greenhouse Gas Emission Drivers: Population, Economic Development and Growth, and Energy Use

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Summary

In the context of climate change and possible responses to the risk associated with it, three variables strongly influence the levels and growth of greenhouse gas emissions: population, income (measured as per capita gross domestic product [GDP]), and intensity of emissions (measured as tons of greenhouse gas emissions per million dollars of GDP).

$$(\text{Population}) \times (\text{per capita GDP}) \times (\text{Intensity}_{ghg}) = \text{Emissions}_{ghg}$$

This is the relationship for a given point in time; over time, any effort to change emissions alters the exponential rates of change of these variables. This means that the rates of change of the three left-hand variables, measured in percentage of annual change, sum to the rate of change of the right-hand variable, emissions.

For most countries, and for the world as a whole, population and per capita GDP are rising faster than intensity is declining, so emissions are rising.

World GHG Intensity, 1990-2000 (annual % change)					
Population		Per Capita GDP		GHG Intensity	GHG Emissions
(1.4)	+	(1.7)	+	(-2.2)	= (1.0)

Note: Numbers do not add precisely because of rounding.

Within this generalization, countries vary widely. During the 1990s, in some countries, including India, Japan, Brazil, Canada, Mexico, South Korea, Indonesia, and South Africa, population growth alone exceeded the decline in intensity. For China, India, Brazil, Mexico, Indonesia, and South Korea, population growth exceeding 1% per year combined with per capita GDP growth that exceeded the intensity improvement each achieved. For the United States, Canada, and Australia, income growth alone exceeded the decline in intensity. Yet several developed countries improved their per capita GDP while decreasing their emissions: Germany, the United Kingdom, France, and Poland; each did so by combining slow population growth (0.4% or less per year) with substantial improvements in intensity (-2.5% or better per year).

Stabilizing greenhouse gas emissions would mean the rate of change equals zero. Globally, with a population growth rate of 1.4% per year and an income growth rate of 1.7% per year, intensity would have to decline at a rate of -3.1% per year to hold emissions at the level of the year that rate of decline went into effect. Within the United States, at the 1990s population growth rate of 1.2% per year and income growth rate of 1.8% per year, intensity would have had to decline at a rate of -3.0% per year to hold emissions level; however, U.S. intensity declined at a rate of -1.6%, leaving emissions to grow at 1.4% per year. President Bush's Climate Change Initiative seeks to increase the rate of intensity decline through 2012 by about -0.4% per year — well short of stabilizing or reducing greenhouse gas emissions.

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Greenhouse Gas Emission Drivers: Population, Economic Growth and Development, and Energy Use

Introduction

The interactions of three variables underlie debates on the issue of climate change and what responses might be justified: the magnitude and rates of change of (1) population growth, (2) incomes, and (3) intensity of greenhouse gas emissions relative to economic activities. This report examines the interrelationships of the variables to explore their implications for policies that address climate change.

Earth is warming and, except for a diminishing but resolute group of doubters, including some credentialed scientists, most experts have concluded that human activities are an important cause of the recent change in climate.¹ The primary cause, in this view, is an increasing concentration of greenhouse gases (GHGs) in the atmosphere. The most important of these gases is carbon dioxide (CO₂), emitted by the combustion of fossil fuels. Both internationally and domestically, initiatives are underway both to better understand climate change and to take steps to slow, stop, and reverse the overall growth in greenhouse gas emissions.²

These initiatives include the following:

- The United Nations Framework Convention on Climate Change (UNFCCC), to which the United States and almost all other nations are Parties. Its stated objective is to stabilize greenhouse gas concentrations in the atmosphere at levels that “would prevent dangerous interference with the climate system.”³ It established the principle that all nations should take action, and that developed nations should take the lead in reducing emissions. It required Parties to prepare national action plans to achieve reductions, with developed countries aiming to reduce year 2000 emissions to 1990 levels. It required preparation of inventories of emissions and

¹ This paper does not explore the underlying science of climate change, nor the question of whether action is justified. See CRS Report RL33849, *Climate Change: Science and Policy Implications*, by Jane Leggett, for more information.

² For a review of international activities, see CRS Report RL33826, *Climate Change: The Kyoto Protocol and International Actions*, by Susan Fletcher. For a review of U.S. activities, see CRS Report RL31931, *Climate Change: Federal Laws and Policies Related to Greenhouse Gas Reductions*, by Brent Yacobucci, and CRS Report RL33846, *Climate Change: Greenhouse Gas Reduction Bills in the 110th Congress*, by Larry Parker.

³ UNFCCC, Article 2, “Objectives.”

annual reports. And it set up a process for the Parties to continue meeting.

- The Kyoto Protocol, to which 169 nations — but *not* the United States — are Parties. Even as the Framework Convention was going into force, it was recognized that most nations would not meet their 2000 aims of holding emissions at 1990 levels. Negotiations through the Conference of Parties ensued, in which the United States participated. These led to the Kyoto Protocol, which called for mandatory reductions in greenhouse gases for the period 2008-2012 by developed nations — but not by developing ones. Whether the reduction goal of the Kyoto Protocol is met, Parties are already discussing post-Kyoto options.
- The Asia-Pacific Partnership on Clean Development and Climate (APP), composed of the United States, China, India, Japan, Australia, and South Korea. The purposes of the Partnership are to create a voluntary, non-legally binding framework for international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging, and longer-term cost-effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation, so as to achieve practical results. It has the goal of meeting “national pollution reduction, energy security and climate change concerns, consistent with the principles of the U.N. Framework Convention on Climate Change (UNFCCC).”⁴

However, these efforts have had to struggle with substantive economic, technical, and political differences among regional, national, and local circumstances. Foremost among these differences is the divide between developed and less-developed nations.⁵ Conflict arises because any pressure to reduce emissions comes up against increases in emissions likely to result from energy use fueling economic development and raising standards of living in developing economies, which contain a large share of the world’s population. Even in many developed nations, efforts to constrain emissions by, for example, conservation, increased energy efficiency, and use of energy sources that emit less or no CO₂, have been outstripped by increases in total energy use associated with population and economic growth. For example, during the 1990s in the United States, the carbon intensity of the economy declined

⁴ Charter for the Asia-Pacific Partnership on Clean Development and Climate (January 12, 2006), “Purposes,” 2.1.1. For additional information, see [<http://www.asiapacificpartnership.org/>].

⁵ See, for example, CRS Report RL32721, *Greenhouse Gas Emissions: Conflicting Situations, Conflicting Perspectives*, by Larry Parker; CRS Report RL32762, *Greenhouse Gases and Economic Development: An Empirical Approach to Defining Goals*, by John Blodgett; and Kevin Baumert and Jonathon Pershing, *Climate Data: Insights and Observations* (World Resources Institute; prepared for the Pew Center on Global Climate Change, December 2004).

at a rate of -1.6% per year, but total emissions increased at the rate of 1.4% per year.⁶ Although some countries have experienced declines in emissions — either through economic contraction⁷ or deliberate policies — the overall trend, both globally and for most individual nations, reflects increasing emissions.

This upward trend in greenhouse gas emissions runs counter to the long-term objectives of these climate change initiatives. This report identifies drivers of the increase in emissions and explores their implications for efforts to reduce emissions. During this exploration, it is useful to bear in mind that although short-term efforts may not achieve emissions reductions that immediately meet goals to prevent dangerous interference with the climate system, such endeavors may nevertheless establish a basis for longer-term efforts that do meet such goals.

Greenhouse Gas Emission Variables

The analysis below, which uses data from the World Resources Institute’s Climate Analysis Indicators Tool (CAIT),⁸ is based on the following relationships:

$$\text{Equation 1. } (\text{Population}) \times (\text{per capita GDP}) \times (\text{Intensity}_{\text{ghg}}) = \text{Emissions}_{\text{ghg}}$$

The CAIT database includes 186 nations with a 2000 population of 6.032 billion, compared with 191 members of the United Nations and with a 2000 world population count of 6.080 billion by the U.S. Census Bureau.⁹ Average income is measured as per capita Gross Domestic Product (GDP), in international dollars of purchasing power parity (\$PPP).¹⁰ (Note that population times per capita GDP equals GDP.) Greenhouse gas intensity is measured as tons of emissions in carbon equivalents¹¹ per million dollars of GDP.

⁶ World Resources Institute, Climate Analysis Indicators Tool, as described below.

⁷ In particular, following the breakup of the former Soviet Union, the economies of various Eastern European and former Soviet republics contracted in the 1990s, such that their emissions declined substantially between 1990 and 2000.

⁸ This database uses a variety of data sources to provide information on greenhouse gas emissions and other relevant indicators. Full documentation, along with caveats, is provided on the WRI website at [<http://cait.wri.org/>].

⁹ See [<http://www.census.gov/ipc/www/worldpop.html>].

¹⁰ GDP-PPP is gross domestic product converted into international dollars using purchasing power parity (PPP) rates. An international dollar has the same purchasing power in the domestic currency as a U.S. dollar has in the United States. The World Bank is the source of CAIT’s PPP data. (World Resources Institute, *CAIT: Indicator Framework Paper*, November 2005, p. 22.)

¹¹ Emissions comprise six greenhouse gases: carbon dioxide, nitrous oxide, methane, perfluorocarbons, hydrofluorocarbons, and sulfur hexafluoride. To aggregate emissions data, figures are typically given in millions of metric tons of carbon equivalents (MMTCE). Thus, global aggregate greenhouse gas emissions for 2000 were 9,125.9 MMTCE, or 9.1 billion tons. In the text, unless otherwise explicitly stated, “tons” of emissions means “metric tons of carbon equivalents.” To convert carbon equivalents to CO₂ equivalents, multiply by 44/12.

Characteristics of Intensity

Intensity can be expressed in many different ways; for example, as CO₂ emitted per million \$PPP, as all six greenhouse gases emitted per million \$PPP, and as CO₂ or greenhouse gases emitted per unit of some activity, such as electricity generated or vehicle miles traveled. Also, measures of intensity can include or exclude emissions or sequestration associated with land use changes.

In this analysis, intensity is identified as greenhouse gas (GHG) intensity (all six greenhouse gases of the UNFCCC) or as CO₂ intensity (referring only to CO₂ emissions from energy use and cement manufacture). In both cases, tonnage of emissions is expressed in carbon equivalents. CAIT has data on all six greenhouse gases only for 1990, 1995, and 2000; analyses referring to other years necessarily include only CO₂.

Unless otherwise specified, land use changes are not included in emissions or intensity data cited in this report.

Using international, purchasing power parity dollars can yield figures different from analyses using other economic measures, such as market exchange rate dollars. Intensity figures in this report, derived using \$PPP, may differ from comparable intensity figures in other studies using other GDP measures.

For the United States, international \$PPP or market exchange rate dollars for GDP should in theory yield consistent figures for intensity. However, for 1990-2000, CAIT data using international dollars yields a decline in intensity for U.S. emissions of all greenhouse gases of -1.6% per year; substituting market exchange rate dollars yields a decline in intensity of -1.8% per year. The Energy Information Administration, using its emissions data and “chained dollars,” calculates a decline in intensity for the same gases over the same period of -1.9% per year.

To ensure consistency, CAIT emissions data and international \$PPP are used throughout this report, unless stated otherwise.

Table 1 provides a snapshot of the **equation 1** variables for the top 20 greenhouse gas emitters in the year 2000, plus for the European Union 25 (those members as of 2004) and for the world. The data reflect the wide range of circumstances faced by any initiative to address GHGs. However, it is the way those variables are changing that illuminates both the seemingly inexorable rise in GHG emissions and the challenge of reducing them. A variable changing at an annual rate of 6.9% doubles in 10 years; at an annual rate of 3%, it doubles in 23 years.

**Table 1. Drivers of Greenhouse Gas Emissions:
Selected Countries, 2000**
(Excludes land use changes)

Country	Population (in 1,000s)	Per Capita GDP (2000 Int'l \$PPP/ person)	Intensity (Tons Cequiv/ million 2000 Int'l \$PPP)	Total GHG Emissions (MMTCE)
United States	282,224	33,970	195.6	1,875.5
China	1,262,645	3,928	273.1	1,354.6
EU-25	439,659	22,916	124.7	1,294.2
Russian Fed	146,303	7,096	503.6	522.8
India	1,015,923	2,415	210.1	515.6
Japan	126,870	26,220	110.9	368.9
Germany	82,210	25,481	132.0	276.6
Brazil	173,858	7,301	182.6	231.8
Canada	30,770	27,289	222.4	186.7
U.K.	59,743	26,332	114.3	179.8
Italy	57,690	24,995	100.7	145.3
Mexico	97,966	9,046	161.9	143.5
S. Korea	47,008	16,172	186.4	141.7
France	58,896	25,698	93.5	141.5
Indonesia	206,265	3,028	220.5	137.7
Australia	19,153	25,417	275.4	134.1
Ukraine	49,176	4,109	651.2	131.6
Iran	63,664	5,827	350.1	129.9
S. Africa	44,000	9,419	275.0	114.0
Spain	40,500	21,765	118.2	104.2
Poland	38,648	10,401	253.1	101.8
WORLD	6,061,723	7,448	207.6	9,201.1

Source: Climate Analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Incorporating growth, **equation 1** becomes

Equation 2. $(Population)e^{k_p t} \times (percapitaGDP)e^{k_g t} \times (Intensity)e^{k_i t} = (Emissions)e^{k_e t}$

in which k_p = population growth rate, k_g = per capita GDP growth rate, k_i = intensity growth rate, and k_e = emissions growth rate; t = time; and e = a constant 2.71828 (the base of natural logarithms).

The exponents of multiplicands are added, so

Equation 3. $(k_p + k_g + k_i) = k_e$

If the sum of the three growth rate variables on the left is positive, emissions are rising; if the sum is negative, emissions are declining; and if the sum is zero, emissions are constant.

Equation 3 makes explicit why there is upward pressure on GHG emissions. For nearly all nations, population is increasing, with developing nations typically having the highest rate. Thus k_p is positive globally and for most nations; it is zero or negative for only a few nations.¹² The economic development of less-developed nations is a global objective acknowledged by the UNFCCC; developed nations also promote economic growth to raise living standards. Thus k_g is increasing globally and for most nations. With k_g and k_p positive, emissions will be rising unless the decline in intensity, k_i , exceeds the growth in population and economic activity, which has seldom been the case. If the goal is to reduce GHG emissions, the larger the *negative* k_i the better.

Table 2 shows the changes in these variables for the 1990s. (The figures in the right-most column are taken from the CAIT database.¹³) As the table shows, global growth rates for population and per capita income outpaced the rate of decline in intensity — so GHG emissions rose; this is also true of the majority of nations, including the United States. Circumstances in several individual countries highlight some important points about GHG emissions and their potential control.

- First, for many nations, population growth is an important contributor to the increase in GHG emissions. For India, Japan,

¹² The rate of population growth has declined in many countries in recent decades, partly as a result of deliberate policies (e.g., birth control programs and, in a few countries, such as China, limits on family size); and partly as a result of education, higher standards of living, and cultural changes. Global population growth is expected to continue at least to mid-century, with projections suggesting a global population of around 9 billion in 2050.

¹³ In principle, these figures could be calculated by adding the three left-hand data columns; in fact, a number of rows do not add due to rounding. The one large discrepancy (China, adding to 3.4 rather than the reported 2.8), probably arises from shortcomings in the underlying reported data (China's GDP numbers are particularly suspect), but either figure would be consistent with the generalizations about trends.

Brazil, Canada, Mexico, South Korea, Indonesia, and South Africa,¹⁴ improvements in intensity were cancelled by increases in population alone.¹⁵

- Second, developing countries, focused on developing their economies, have increasing GHG emissions even when they manage to improve intensity (e.g., China,¹⁶ India,¹⁷ Brazil, Mexico, Indonesia, and South Korea). For these countries, population growth exceeding 1% per year combined with per capita GDP growth overwhelmed whatever intensity improvements they achieved.¹⁸
- Third, lower emissions can be associated with decreasing economic activity. For the Russian Federation and Ukraine, economic contraction following the dissolution of the Soviet Union is the primary cause of decreases in their emissions. (Some fear that the cause and effect of this relationship runs both ways — that policies to reduce emissions will inevitably result in depressed economic activity.)
- Fourth, perhaps alleviating that fear, several developed countries managed to improve per capita GDP (at rates near or better than the United States) while decreasing their GHG emissions; for example, Germany, the United Kingdom, France, and Poland (see also the European Union 25). Each did so by combining slow population growth (0.4% or less) with substantial improvements in intensity (-2.5% per year or better).
- Fifth, in some developed countries, income growth alone exceeded the decline in intensity (e.g., the United States, Canada, and Australia).

Stabilizing emissions would require an accelerated decline in intensity.¹⁹ For global emissions to have remained at 1990 levels during the 1990-2000 period, intensity would have had to decline at the rate of -3.1% per year, rather than at the

¹⁴ For South Africa, both per capita GDP and intensity declined, so the increase in emissions can be attributed to population growth alone.

¹⁵ For Iran and Spain, population and intensity both increased.

¹⁶ The discrepancy between the calculated and CAIT reported emissions for China suggests data shortcomings within the measures of GDP, intensity, and emissions.

¹⁷ For India, the intensity improvement offset only its population increase, so GHG emissions rose at the rate of economic development.

¹⁸ For Iran, GHG emissions rose because population and GDP growth had no offset at all from intensity, which worsened.

¹⁹ Emissions could also be stabilized by declines in population or GDP. However, because U.S. policymakers are unlikely to promote population reduction or GDP contraction, analysis of these options seems unwarranted. In some countries (e.g., China), deliberate efforts to constrain population do occur.

actual -2.2%.²⁰ For the United States, the situation was similar: for emissions in 2000 to have remained at 1990 levels, intensity would have had to decline at the rate of -3.0% per year, rather than the actual -1.6%.²¹ Looking to the future, this relationship holds — absent a declining population or a contracting economy, GHG emissions can be expected to decline only if intensity declines at a rate faster than it did over the last decade of the 20th Century.

Table 2. Rate of Change in Factors Affecting Greenhouse Gas Emissions: Selected Countries, 1990-2000
(Excludes land use changes)

Country	Population (average annual %)	Per Capita GDP (average annual %)	Intensity (average annual %)	Total GHG Emissions (average annual %)
United States	1.2	1.8	-1.6	1.4
China	1.1	9.4	-7.1	2.8
EU-25	0.3	2.1	-2.9	-0.6
Russian Fed	-0.1	-3.5	-0.3	-3.9
India	1.8	3.6	-1.8	3.5
Japan	0.3	1.1	-0.1	1.2
Germany	0.3	1.9	-4.0	-1.8
Brazil	1.5	1.2	-0.5	2.2
Canada	1.0	1.8	-0.9	1.9
U.K.	0.4	1.9	-3.2	-1.0
Italy	0.2	1.3	-0.6	0.9
Mexico	1.6	1.7	-1.4	2.0
S. Korea	0.9	5.1	-0.1	6.0
France	0.4	1.6	-2.5	-0.5
Indonesia	1.5	2.9	-0.9	3.5
Australia	1.2	2.2	-1.4	1.9
Ukraine	-0.5	-7.0	1.3	-6.3
Iran	1.6	2.4	1.1	5.1
S. Africa	2.3	-0.5	-0.2	1.6
Spain	0.4	2.2	0.2	2.8
Poland	0.1	3.0	-4.6	-1.6
WORLD	1.4	1.7	-2.2	1.0

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

²⁰ That is, annual population growth (1.4%) + per capita GDP growth (1.7%) + intensity change (-3.1% [rather than the actual -2.2%]) = 0 emissions growth.

²¹ That is, annual population growth (1.2%) + per capita GDP growth (1.8%) + intensity change (-3.0% [rather than the actual -1.6%]) = 0 emissions growth.

How fast and how far might intensity be driven down? There are two ways to approach this question: one is to examine the sources of emissions and consider how much and how fast they could be curtailed; a second is to assess what level of greenhouse gases can be emitted to the atmosphere without causing “dangerous interference with the climate system” (in the words of the UNFCCC) and to calculate from those emissions what the intensity would have to be over time, taking into account population and income growth.

Sectorial Breakdown of GHG Emissions

Table 3 presents emissions data by economic sector for the top 20 emitting nations (plus the EU-25 and the world). As the table shows, the energy sector is by far the largest contributor of greenhouse gases, accounting for about 75% of total world emissions in 2000; the agricultural sector is second, accounting for about 17%. These two sectors dominate for almost all countries (industrial process emissions rank second for Japan and South Korea).

Table 4 presents a breakdown of the energy sector emissions. Electricity and heat contributes the largest share, accounting for about 42% in 2000, followed by transportation at about 20%, manufacturing at about 17%, other fuel combustion at about 15%, and fugitive emissions at about 6%. Emissions by energy subsector vary considerably among nations; for example, transportation emissions tend to be much higher absolutely and as a percentage of energy sector emissions for developed nations, as compared with developing nations.

**Table 3. GHG Emissions by Sector:
Top 20 Emitters, 1990-2000**
(Excludes land use changes)

Country	Energy ^a		Industrial Processes		Agriculture		Waste (e.g. landfills)		Total	
	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
United States	1,409	1,641	44	58	116.0	121.0	59	51	1,628	1,871
China	689	874	^b 36	^b 103	222	275	34	37	981	1,290
EU-25	1,082	1,059	66	63	146	130	47	38	1,342	1,290
Russian Fed	^c 519	468	^c 8	9	50	27	18	17	^d 596	521
India	182	291	^b 11	^b 19	148	174	20	24	361	509
Japan	279	319	18	27	11	9	2	3	311	358
Germany	277	236	8	10	30	24	10	5	326	275
Brazil	53	88	7	9	112	122	9	11	185	229
Canada	130	161	7	8	14	17	6	7	157	190
U.K.	163	151	12	6	15	14	7	4	196	174
Italy	114	121	9	10	11	11	3	3	137	145
Mexico	87	112	4	6	15	14	10	13	117	144
S. Korea	64	120	6	12	4	4	2	2	76	138
France	101	108	13	8	29	27	4	4	146	147
Indonesia	47	85	2	4	32	34	14	16	95	139
Australia	78	99	2	3	26	28	4	5	111	134
Ukraine	^c 151	85	^c 3	2	13	10	7	8	^d 174	125
Iran	55	104	2	3	15	17	5	6	77	130
S. Africa	72	85	1	3	11	11	2	3	87	101
Spain	58	79	6	8	10	12	2	4	78	103
Poland	102	85	3	4	8	7	5	5	118	101
WORLD	5,146	6,747	289	384	1,425	1,529	371	400	7,232	9,060

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Note: Emissions are given in millions of metric tons of carbon equivalents (MMTCE).

- a. Does not include N₂O for “fugitive emissions.”
- b. CH₄ data not available.
- c. 1992 data for CO₂.
- d. Combines 1990 and 1992 data.

**Table 4. Energy Sector GHG Emissions:
Top 20 Emitters, 1990-2000**
(Excludes land use changes)

Country	Electricity and Heat		Manufacture and Construction		Transportation		Other Fuel Combustion		Fugitive Emissions ^a	
	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
United States	576	733	191	180	389	469	185	196	69	63
China	187	400	262	235	32	60	157	132	51	48
EU-25	410	400	208	180	201	243	230	214	33	22
Russian Fed	^b 302	250	^b 69	59	^b 71	48	^b 72	57	^b 5	53
India	73	152	47	63	22	25	32	40	8	11
Japan	110	126	66	68	57	70	46	55	1	0
Germany	113	97	49	36	44	48	62	50	9	5
Brazil	7	14	16	25	22	34	10	12	1	2
Canada	38	51	24	26	34	41	26	32	9	12
U.K.	67	60	23	18	34	36	32	33	8	5
Italy	39	42	23	22	26	31	23	24	2	2
Mexico	29	46	20	16	24	28	9	10	6	12
S. Korea	18	50	13	23	12	24	20	22	2	1
France	17	18	22	21	32	38	29	30	2	1
Indonesia	15	26	10	20	9	18	10	16	4	5
Australia	38	51	12	14	17	20	5	6	6	7
Ukraine	^b 67	36	^b 52	20	^b 8	5	^b 25	18	^c —	26
Iran	11	22	12	16	11	20	14	27	7	21
S Africa	39	52	19	17	8	10	5	4	2	2
Spain	21	28	12	15	18	25	7	10	1	1
Poland	63	46	13	14	6	7	15	13	6	4
WORLD	1,771	2,805	1,063	1,178	970	1,322	859	998	483	445

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Note: Emissions are given in millions of metric tons of carbon equivalents (MMTCE).

- a. N₂O data not available.
- b. 1992 data for CO₂.
- c. No data reported.

The most revealing aspect of sectorial emissions emerges from **Table 5**, which shows their rates of change,²² including the energy subsectors (shown in italics). The fastest growing sectors are Energy (2.7%/year) and Industrial Processes (2.8%/year). Because Industrial Process emissions²³ are a much smaller share of total emissions than energy, the increase is relatively small in absolute terms; however, the rate of increase is substantial for nations that are industrializing, especially China, India, and South Korea. The largest absolute increase in emissions is driven by the rate of increase for the energy sector. Within that sector, the most rapidly growing subsector is electricity and heat energy, at 4.6% per year, led by developing nations, especially China, India, Brazil, Mexico, South Korea, and Iran. In contrast, for the EU-25, the rate and absolute emissions for the subsector declined slightly; but for the Russian Federation, Ukraine, and Poland, the rate and absolute emissions declined substantially as their economies contracted. The next fastest growing subsector is transportation, at 3.1% a year, with every nation showing a positive rate of growth except the Russian Federation, with its contracting economy during the 1990s (the transportation subsector in Ukraine and Poland is so small that its rate of change was not calculated).

Energy Use as a CO₂ Intensity Driver. The previous section looked at emissions and the rate of change, 1990-2000, for all six greenhouse gases and all sectors of the economy. For the decade, of the six greenhouse gases, CO₂ dominates, accounting for over 70% of the carbon equivalents of global GHG emissions, and nearly 85% of U.S. GHG emissions. Overwhelmingly — not counting land use changes, which are discussed later — the source of that CO₂ is energy use: for world CO₂ emissions, energy use accounts for 96.5%; for the United States, energy use accounts for 99.2%.

Two factors largely determine the intensity of CO₂ emissions of a nation's economy: energy intensity (energy per unit of GDP) and the fuel mix (emissions per unit of energy)²⁴:

$$\text{Equation 4.} \quad \frac{\textit{Energy Use}}{\textit{GDP}} \times \frac{\textit{Emissions}_{co2}}{\textit{Energy Use}} = \frac{\textit{Emissions}_{co2}}{\textit{GDP}}$$

²² Rates of change were not calculated if both the 1990 and 2000 emission levels were below 10 million tons. At low levels, even small changes can yield large rates of change — for example, if emissions went from 2 to 4 million tons between 1990 and 2000, the rate of change would be 6.9% per year, but the actual emissions are too small to meaningfully affect overall totals.

²³ Including CO₂ from cement manufacture, N₂O from Adipic and Nitric Acid production, N₂O and CH₄ from other industrial processes, plus HFCs, PFCs, and SF₆.

²⁴ See Timothy Herzog et al., *Target: Intensity, An Analysis of Greenhouse Gas Intensity Targets* (Washington, DC: World Resources Institute, November 2006), pp. 3-9.

**Table 5. Rate of Change of GHG Emissions by Sector:
Top 20 Emitters, 1990-2000**
(Excludes land use changes)

Country	Energy	<i>Elec & Heat</i>	<i>Man & Const</i>	<i>Transp</i>	<i>Other Fuel</i>	<i>Fugitive</i>	Ind Proc	Ag	Waste	Total
United States	1.5	2.4	-0.6	1.9	0.6	-0.9	2.8	0.4	-1.5	1.4
China	2.4	7.6	-1.1	6.3	-1.7	-0.6	10.5	2.1	0.8	2.7
EU-25	-0.2	-0.2	-1.4	1.9	-0.7	-4.0	-0.5	-1.2	-2.1	-0.4
Russian Fed	-1.0	-1.9	-1.6	-3.9	-2.3	23.6		-6.2	-0.6	-1.3
India	4.7	7.3	2.9	1.3	2.2	3.2	5.5	1.6	1.8	3.4
Japan	1.3	1.4	0.3	2.0	1.8		4.0	-2.0		1.4
Germany	-1.6	-1.5	-3.1	0.9	-2.2		2.2	-2.2	-6.9	-1.7
Brazil	5.1	6.9	4.5	4.4	1.8			0.9	2.0	2.1
Canada	2.1	2.9	0.8	1.9	2.1	2.9		1.9		1.9
U.K.	-0.8	-1.1	-2.4	0.6	0.3		-6.9	0.7		-1.2
Italy	0.6	0.7	-0.4	1.8	0.4		1.0	0.0		0.6
Mexico	2.5	4.6	-2.2	1.5	1.0			-0.7	2.6	2.1
S. Korea	6.3	10.2	5.7	6.9	1.0		6.9			6.0
France	0.7	0.6	0.5	1.7	0.3		-4.9	-0.7		0.1
Indonesia	5.9	5.5	6.9	6.9	4.7			0.6	1.3	3.8
Australia	2.4	2.9	1.5	1.6	1.8			0.7		1.9
Ukraine	-5.8	-6.2	-9.6			^a —		-2.6		-3.3
Iran	6.4	6.9	2.9	6.0	6.6	11.0		1.2		5.2
S. Africa	1.7	2.9	-1.1	2.2	-2.2			0.0		1.5
Spain	3.1	2.9	2.2	3.3				1.8		2.8
Poland	-1.8	-3.1	0.7		-1.4					-1.6
WORLD	2.7	4.6	1.0	3.1	1.5	-0.8	2.8	0.7	0.8	2.2

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Note: Average Annual percentage per year. (Not calculated if tonnage for both years <10.)

a. Not calculated; no data for 1990 or 1992.

Table 6 presents data on energy sector CO₂ emissions for 2003. The first data column represents energy intensity of the economy, measured in 1,000 tons of oil equivalent (toe) per million \$PPP. The smaller the number, the more efficiently energy is used to support economic activity in that country. Italy, Spain, the United Kingdom, and Japan are the most efficient; the Ukraine and the Russian Federation are the least efficient. In general, the higher the number in column one, the more least-cost options that nation should be able to find for reducing energy use without adversely affecting the overall economy. Improvements could come, for example, from upgrading boilers, substituting gas-combined cycle electricity generation, improving the efficiency of the electricity grid, or upping the efficiency of the vehicle fleet.

The second data column in the table reflects the fuel mix of energy use, measured as tons of carbon (C) per 1,000 tons of oil equivalent. The lower the number, the less CO₂ being emitted by the energy used. Higher numbers would generally reflect a higher proportion of coal combusted in the electricity-generating, manufacturing, and heating sectors and a low transportation fleet fuel economy; lower numbers would generally reflect a higher proportion of hydropower, renewables, or nuclear power in the electricity, manufacturing, and heating sector, and a high transportation fleet fuel economy. Again, in many cases, the higher the number, the more least-cost options for lowering CO₂ emissions without adversely affecting the overall economy, for example by substituting natural gas for coal or renewables for oil.

The third data column contains each nation's intensity of carbon emissions for the energy sector; it is the product of the first and second data columns. (Note that this intensity number is for CO₂ emissions only, and is thus different from *greenhouse gas intensity*, which includes CO₂ plus five other gases.) The higher the number, the less efficiently the economy is using carbon-emitting energy. The last column in the table provides data on total CO₂ emissions from energy use.²⁵

Another question is the relationship between new economic growth and emissions, which are often influenced by the degree of industrialization and the prices and availability of different fuels. **Table 7** compares this by providing information on the rates of change of factors affecting CO₂ emissions from energy use. The first three data columns parallel the first three in **Table 6**, giving the rates of change during 1990-2003. In terms of CO₂ emissions, negative numbers mean that over time a nation is getting more economic activity for less energy (first data column) and more energy for less CO₂ (second data column). As Table 7 shows, there are wide variations among nations. For example, China's economy made rapid progress in using energy more efficiently (energy intensity of -6.5% per year), even though the energy it used actually produced more CO₂ per unit of energy (+0.8% per year). A number of countries, including the EU-25, improved efficiency and reduced emissions per unit of energy used. The third data column, which should be the sum of the first two, is negative if, overall, the country is producing more economic activity for the CO₂

²⁵ As given, the emissions data are taken from CAIT tables, but in principle could be calculated by multiplying the intensity (column 4) times GDP; because of inconsistent data, the calculations in some cases diverge from the reported emissions, though the general magnitudes and the relative positions of nations are right.

emitted. The fourth and fifth columns in Table 7 give the rates of change of the nations' GDPs and total CO₂ emissions from energy use. A nation's rate of change of CO₂ intensity can be negative, but if GDP is growing faster than CO₂ intensity is declining, emissions will rise (the last column).²⁶

**Table 6. CO₂ Emissions Intensity of the Energy Sector:
Top 20 Emitters, 2003**
(Excludes land use changes)

Country	Energy Intensity (1,000 toe / million 2000 \$PPP)	CO ₂ Intensity of Energy Sector (Tons C / 1,000 toe)	CO ₂ Intensity of Economy (Tons C / million 2,000 \$PPP)	Total CO ₂ Emissions from Energy Use (MMTCE)
United States	0.22	690	153	1,570
China	0.22	870	192	1,015
EU-25	0.16	630	101	1,062
Russian Fed	0.52	670	350	417
India	0.19	570	108	287
Japan	0.15	660	102	328
Germany	0.16	680	112	234
Brazil	0.17	400	68	106
Canada	0.29	570	166	152
U.K.	0.14	650	92	148
Italy	0.12	710	87	124
Mexico	0.18	680	122	102
S. Korea	0.24	650	154	122
France	0.17	400	68	106
Indonesia	0.23	590	137	89
Australia	0.21	830	172	95
Ukraine	0.53	660	353	81
Iran	0.31	750	233	99
S. Africa	0.26	880	226	87
Spain	0.14	670	96	86
Poland	0.22	910	197	80
WORLD	0.22	670	145	6,636

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007). CRS calculations.

²⁶ In principle, the sum of the first two data columns should equal the third data column, and the fifth column should be the sum of the third and fourth columns; however, because of data inconsistencies, the calculated numbers may not exactly correspond to the CAIT reported numbers. China is an example of a substantial discrepancy. Nevertheless, the general relationships hold.

Table 7. Rate of Change in Factors Affecting CO₂ Emissions from Energy Use: Top 20 Emitters, 1990-2003

(Excludes land use changes)

Country	Energy Intensity	Carbon Intensity of Energy Used	CO ₂ Intensity of Energy Sector	GDP	Total CO ₂ Emissions of Energy Use
United States	-1.6	0.0	-1.6	2.9	1.3
China	-6.5	0.8	-5.2	10.2	3.9
EU-25	-1.2	-0.9	-2.0	2.2	0.2
Russ Fed ^a	-1.7	-0.3	-2.1	0.0	-2.0
India	-2.3	1.2	-1.0	5.5	3.2
Japan	0.1	-0.2	-0.2	1.1	1.3
Germany	-2.0	-0.8	-2.8	1.8	-0.9
Brazil	0.5	0.4	0.9	2.4	3.5
Canada	-1.0	0.1	0.8	2.7	1.9
U.K.	-1.4	-1.0	-2.4	2.1	-0.2
Italy	0.2	-0.4	-0.2	1.4	1.0
Mexico	-0.7	0.0	-0.7	2.7	1.9
S. Korea	0.6	-1.1	-0.5	5.7	5.4
France	-0.5	-1.1	-1.6	1.9	0.7
Indonesia	-0.1	1.4	1.3	4.2	5.9
Australia	-1.4	0.0	-1.4	3.4	2.3
Ukraine ^a	-0.8	-1.2	-2.0	-3.6	-5.5
Iran	1.0	-0.1	0.8	4.4	5.7
S. Africa	-0.2	0.0	-0.2	2.2	1.7
Spain	0.4	0.0	0.4	2.7	3.2
Poland	-3.5	-0.6	-3.9	3.0	-1.3
WORLD	-1.6	-0.1	-1.7	3.2	2.9

Source: Climate Analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007). CRS calculations.

Note: Average Annual percentage.

a. 1992-2003 trend.

The carbon intensity of energy use — that is, the consequences of fuel mix — is especially notable in looking at the energy mix of electricity generation, as discussed in the next section.

Carbon Intensity of Electricity Generation. Variations among countries of the carbon intensity of energy use (see **Table 6**) are strongly affected by the carbon intensity of electricity generation, which accounts for about one-third of world CO₂ emissions (not counting land use changes and forestry practices). Differences among countries are marked, as depicted in **Table 8**.

Choices among generating technologies are the primary driver of disparities among countries in the carbon intensity of their electricity generation. In general, countries with high numbers generate a substantial proportion of their electricity by burning coal, and countries with low numbers generate large quantities of electricity by nuclear facilities, hydropower, or other renewables. For example, Poland, with a carbon intensity of electricity production of 280, generates about 96% of its electricity by combusting coal; while France, with a carbon intensity of electricity production of 12.5, generates about 77% of its electricity by nuclear power, about 13% by hydropower, and 6% by coal. The United States, with a carbon intensity of electricity production of 152.9, generates about 20% of its electricity by nuclear power, about 7% by hydropower, and about 52% by combusting coal.

Although a nation's electricity-generating technologies are obviously affected by its resource endowments in terms of hydropower and fossil fuels, choices can be made, as exemplified by France. In 1980, France's electricity was generated 27% by hydropower, 24% by nuclear, 27% by coal, and 19% by oil. By 1990, with electricity production up over 60%, nuclear had risen to a 75% share, whereas coal and oil had fallen to 8% and 2% shares, respectively.²⁷ Not only did nuclear power account for all the growth in electricity generation during the period, but it displaced half the coal-fired and more than three-quarters of the oil-fired electricity generation. In 1990, the electricity produced by nuclear power exceeded France's total amount of electricity generated 10 years earlier.

France's transition to nuclear power meant that its CO₂ intensity (i.e., CO₂ emissions/GDP) declined between 1980 and 1990 at a rate of -5.0% per year, and CO₂ emissions declined at a rate of -2.4% per year. Thus, between 1980 and 1990, France's total CO₂ emissions declined by 22% — at the same time its GDP was growing by 30.9% (+2.7% per year).²⁸ Thus **equation 3** yields a negative growth in emissions (numbers do not add precisely, due to rounding):

²⁷ International Energy Agency, *Electricity Information 2002* (OECD, 2002), p. II.285.

²⁸ Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

France: CO ₂ Intensity, 1980-1990			
Population	+	Per Capita GDP	CO ₂ Intensity
(0.5)		(2.2)	(-5.0)
		+	=
			CO ₂ Emissions
			(-2.4)

During the 1990s, the United Kingdom made a major shift from coal to natural gas in the generation of its electricity. In 1990, the United Kingdom's electricity was generated 21% by nuclear, 1% by natural gas, and 65% by coal. In 2000, with electricity generation up 17%, nuclear's share was 23%, whereas coal's share had dropped to 33% and natural gas's share had risen to 39%.²⁹ Because natural gas produces less total CO₂ per kilowatt hour than coal (at a ratio of about 0.6 to 1 on a Btu basis³⁰), CO₂ intensity in the United Kingdom declined between 1990 and 2000 at a rate of -2.6% per year, and CO₂ emissions declined at a rate of -0.4% per year. Thus, between 1990 and 2000, total CO₂ emissions in the United Kingdom declined by 3.6% — at the same time its GDP was growing by 25% (+2.3% per year).³¹ Thus **equation 3** yields a negative growth in emissions (numbers do not add precisely, due to rounding):

United Kingdom: CO ₂ Intensity, 1990-2000			
Population	+	Per Capita GDP	CO ₂ Intensity
(0.4)		(1.9)	(-2.6)
		+	=
			CO ₂ Emissions
			(-0.4)

The examples of France and the United Kingdom show that for a period of time, at least, greenhouse gas intensity improvements can be sufficient to absorb growth in population and economic activity, so that actual emissions decline. The examples also show that the introduction of new technology can cause sudden shifts in emission rates.

The United States has also had periods when its CO₂ emissions declined. From 1977-1986, U.S. CO₂ intensity declined at a rate of -3.7% per year and emissions declined at a rate of -0.7% per year. But since 1987, the intensity rate has been about -1.8% per year, not enough to compensate for population and per capita GDP growth, so emissions have risen at 1.2% per year. Over the longer term, therefore, emissions have risen: in terms of **equation 3**, U.S. CO₂ emissions for 1975-2003 are as follows (numbers do not add precisely, due to rounding):

United States: CO ₂ Intensity, 1975-2003			
Population	+	Per Capita GDP	CO ₂ Intensity
(1.1)		(2.1)	(-2.2)
		+	=
			CO ₂ Emissions
			(0.9)

²⁹ International Energy Agency, *Electricity Information 2002* (OECD, 2002), p. II.683.

³⁰ If gas combined-cycle technology is considered, the ratio could be 0.4 or 0.5 to 1.

³¹ Climate Analysis Indicators Tool (CAIT), version 4.0. (Washington, DC: World Resources Institute, 2007). In terms of all six greenhouse gases, between 1990 and 2000, the United Kingdom's greenhouse gas intensity declined at an annual rate of -3.2%.

**Table 8. Carbon Intensity of Electricity Generation:
Top 20 Emitters, 2003**

Country	Intensity (gC/kWh)
United States	152.9
China	192.9
EU-25	105.1
Russ Fed	150.9
India	222.0
Japan	87.4
Germany	139.3
Brazil	16.4
Canada	59.3
U.K.	113.7
Italy	127.0
Mexico	142.3
S. Korea	101.5
France	12.5
Indonesia	132.8
Australia	245.8
Ukraine	138.7
Iran	131.1
S. Africa	210.9
Spain	85.3
Poland	280.0
WORLD	134.8

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Carbon Intensity of Travel. The carbon intensity variation of electricity generation among nations recurs in the transportation sector, one of the fast-growing sources of emissions (see **Table 5**). Data are limited, however, making inter-country comparisons of the carbon intensity of passenger miles or of ton-miles difficult. For the United States, data are available for comparisons among some modes of transportation.

Studies indicate that nations vary considerably in the energy efficiency and greenhouse gas emissions intensity of their transport sectors. For example, one effort

examining vehicle miles, published by the Pew Center on Global Climate Change, shows substantial variations among several nations, with the United States being the highest emitter per vehicle³² (**Figure 1**). To some extent, these variations reflect differing geographic, cultural, and infrastructure circumstances among the nations; however, as with the carbon intensity of electricity generation, a substantial cause of the variations is deliberate policies, such as fuel efficiency standards, emission standards, fuel taxes, and choices of investments in transportation infrastructure.

For the United States, the Bureau of Transportation Statistics provides data on the energy intensity of passenger modes (**Table 9**).

**Table 9. Energy Intensity of Passenger Modes:
United States, 1970-2000**
(Btus per passenger-mile)

Passenger Modes	1970	1980	1990	2000	2004
Air, certified carrier					
Domestic	10,185	5,742	4,932	3,883	3,297
International	10,986	4,339	4,546	3,833	3,428
Highway					
Passenger car	4,841	4,348	3,811	3,589	3,527
Pickup, SUV, minivan	6,810	5,709	4,539	4,509	4,452
Motorcycle	2,500	2,125	2,227	2,273	1,968
Transit motor bus	—	2,742	3,723	4,147	^a 3,496
Amtrak	—	2,148	2,066	2,134	—

Source: Bureau of Transportation Statistics: [http://www.bts.gov/publications/national_transportation_statistics/html/table_04_20.html].

a. Preliminary 2003 data.

Two important points emerge from **Table 9**. First, transportation efficiency for several modes has improved over time. Air traffic gained efficiency in the transition to jets and larger aircraft. Vehicular passenger miles have gained efficiency, but at a slowing pace. On the other hand, transit motor bus efficiency per passenger mile has worsened over time. Second, the choice of transportation mode, which can be affected by infrastructure investments and other public policies,³³ substantively affects passenger-mile efficiency. Amtrak — and, by extension, commuter rail — is considerably more efficient than any of the other choices, except motorcycles.

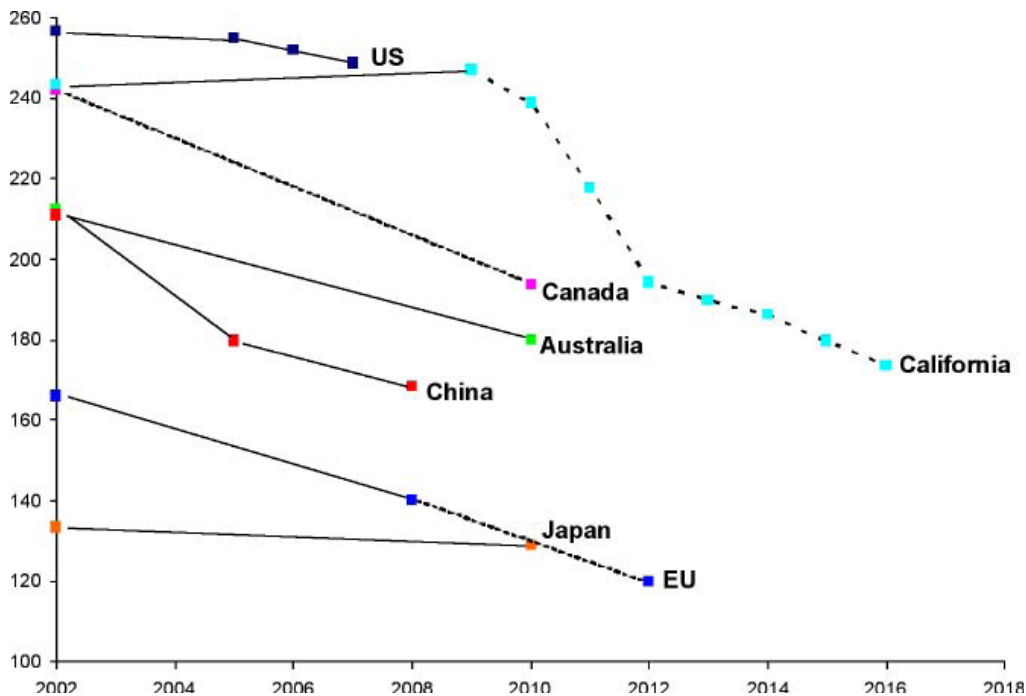
³² Feng An and Amanda Sauer, “Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards Around the World,” Pew Center on Global Climate Change (December 2004).

³³ For example, the London “congestion tax” is intended to shift commuters out of passenger cars and onto public transit.

Moreover, within the highway mode, efficiency varies significantly: in 2000, passenger cars were 25% more efficient on average than pickups, SUVs, and minivans.

All in all, it appears that policy choices can affect the energy intensity of travel, and thus opportunities for improvement exist. Because there is clearly a limit on greenhouse gas emission reductions to be achieved by heightened efficiencies in the transportation sector, interest turns to alternative fuels that do not generate greenhouse gases, including renewables and hydrogen. Brazil has made considerable progress in substituting ethanol for gasoline (40% by volume); however, the U.S. promotion of ethanol is still a minute proportion of gasoline consumption (3.6% by volume in 2006), and there are questions about the net impact of ethanol use on CO₂ emissions.³⁴ Hydrogen remains a distant possibility.

Figure 1. Comparison of Fuel Economy and GHG Emission Standards Normalized by NEDC-converted g CO₂/km



Source: Feng An and Amanda Sauer, “Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards Around the World,” Pew Center on Global Climate Change (December 2004), p. 26.

Note: Dotted lines denote proposed standards.

³⁴ See CRS Report RL33928, *Ethanol and Biofuels: Agriculture, Infrastructure, and Market Constraints Related to Expanded Production*, by Brent D. Yacobucci and Randy Schnepf.

Effects of Land Use on Intensity. Although land use changes can affect emissions and intensity, they have been excluded from most analyses in this report because the data are limited and less robust than most of the emissions data, and because for most nations, taking it into account changes little. However, as **Table 10** shows, substantial effects result from logging and clearing forests in a few nations: Indonesia, Brazil, and (to a lesser extent) Mexico. The greenhouse gas intensity for each of these countries is much higher when land use changes are included. Yet these countries' emissions attributable to land use changes (almost all CO₂) are much smaller in 2000 than they were in 1990, and the rates of intensity in all three countries decreased over the decade.

Even though land use changes may have a small effect on emissions for most countries, including it in analyses can identify those situations where it is important and for which interventions might pay large dividends in terms of curtailing greenhouse gas emissions or sequestering CO₂.

**Table 10. Land Use Changes:
Impact on Emissions and Intensity**

Country	Intensity 2000 (excluding land use) tCeq/million \$PPP	Intensity 2000 (including land use) tCeq/million \$PPP	Annual % change, Intensity 1990-2000 (excluding land use)	Annual % change, Intensity 1990-2000 (including land use)
United States	195.6	184.2	-1.6	-1.5
China	273.1	270.5	-7.1	-7.7
EU-25	124.7	124.1	-2.5	-2.5
Russ Fed	503.6	517.9	-0.3	-0.2
India	210.1	205.7	-1.8	-1.8
Japan	110.9	111.2	-0.1	-0.2
Germany	132.0	132.0	-4.0	-4.0
Brazil	182.6	477.7	-0.5	-4.3
Canada	222.4	243.3	-0.9	-1.3
U.K.	114.3	114.0	-3.2	-3.2
Italy	100.7	100.2	-0.6	-0.6
Mexico	161.9	191.7	-1.4	-2.4
S. Korea	186.4	186.8	-0.1	-0.2
France	93.5	92.4	-2.5	-2.5
Indonesia	220.5	1,340.4	-0.9	-2.3
Australia	275.4	277.8	-1.4	-1.6
Ukraine	651.2	651.2	1.3	1.3
Iran	350.1	356.1	1.1	0.9
S. Africa	275.0	276.1	-0.2	-0.2
Spain	118.2	115.6	0.2	0.2
Poland	253.1	251.9	-4.6	-4.6
WORLD	207.6	254.5	-2.2	-2.4

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Cumulative Emissions. Greenhouse gas emissions are long-lived in the atmosphere, so their effect cumulates over time. A justification for developed nations taking the lead on reducing emissions, while giving developing ones the opportunity to increase emissions from activities that are necessary for economic development, is not just that developed nations are wealthier but also that they account for the bulk of cumulative emissions affecting climate. Data to assess cumulative emissions are limited. In general, data are available only for CO₂ and are calculated from fuel use estimates; land use changes over long time spans are important, but data are scanty or unavailable. CAIT provides figures for CO₂ emissions only from 1850, not including land use changes (**Table 11**).

Because climate-forcing depends on the cumulative emissions, not current emissions, it is easy to see from **Table 11** why developing nations feel that developed ones should take the lead. Given CAIT data, the United States and the European Union-25 account for well over half the cumulative CO₂ emissions from energy use since 1850.

The data on cumulative emissions and on including or excluding land use changes (see **Table 10**) highlight why individual nations are so differently affected by proposals to reduce greenhouse gas emissions. Setting a baseline year for determining a nation's emissions means that countries that developed early could do so with no restrictions on the use of fuels and other resources regardless of their potential impact on climate, while those nations just now undergoing development might face restrictions. The emissions of already developed nations are embedded in their baselines. Similarly, whether certain activities such as land use changes are included or not affects what is in the baseline. The greenhouse gas emissions of Brazil and Indonesia, for example, increase markedly when emissions from land use changes of the last few decades are counted; but comparable land use changes in many other countries (e.g., the United States) happened in earlier centuries, and the resulting emissions count only toward cumulation, not against any current baseline.

**Table 11. Cumulative CO₂ Emissions from Energy:
Top 20 Emitters, 1850-2003**
(Excludes Land Use Changes)

Country	Cumulative Emissions (MMTCE)	Percentage of World	Rank in World
United States	86,992	29.0	1
China	23,284	7.8	4
EU-25	78,265	26.3	2
Russ Fed	24,100	8.1	3
India	6,645	2.2	9
Japan	12,336	4.1	7
Germany	21,424	7.2	5
Brazil	2,403	0.8	21
Canada	6,380	2.1	11
U.K.	18,381	6.2	6
Italy	4,759	1.6	13
Mexico	3,016	1.0	16
S. Korea	2,320	0.8	23
France	8,564	2.9	8
Indonesia	1,616	0.5	26
Australia	3,178	1.1	15
Ukraine	6,414	2.2	10
Iran	1,958	0.7	24
S. Africa	3,491	1.2	14
Spain	2,676	0.9	19
Poland	6,059	2.0	12
WORLD	297,955	100.0	—

Source: Climate analysis Indicators Tool (CAIT), version 4.0 (Washington, DC: World Resources Institute, 2007).

Interactions of the Variables

Numerous subtle and indirect interactions occur among population, income, intensity, energy use, and emissions. These interactions affect policy choices concerning climate change because of their implications for other important social policy initiatives and objectives — most importantly, policies to promote income growth. These interactions also make difficult the projection of trends over time.

Economic development and growing incomes interact with population growth in two ways. First, birth rates tend to decline as incomes rise,³⁵ reducing one of the upward pressures on emissions. Most high-income nations have annual birth rates of 0.5% or lower, compared with developing nations with birth rates that in some cases exceed 2% per year. Second, the economic opportunity that many developed nations offer means they may have relatively high immigration rates, so their population growth is higher than their birth rate.³⁶ Overall, most demographers expect the rate of population growth to slow, although world population is projected to exceed 9 billion in 2050, with most of the increase in the developing world.³⁷

Economic development and energy use are closely intertwined. The substitution of fossil fuel energy for human and animal power has been an important driver of the industrial revolution and consequent higher incomes. Indeed, for many, industrialization is synonymous with economic development. Yet at some point in development, the growth in incomes becomes at least partially detached from energy use, as energy costs lead to attention to energy efficiencies and as economies shift toward post-industrial services. Public policies can affect the relationship between economic development and growth and energy use in many ways, including taxation, infrastructure development, and research and development. The UNFCCC assumes that developing nations will inevitably have to exploit more energy as they give priority to reducing poverty. One of the elements of the climate change debate is how to decouple that economic development-energy use link — or indeed, whether it can be done. Another element being debated is whether and at what point depressing energy use would necessarily depress economic activity.

Income and emissions are related in another way, as well. In general, low-income people in developing nations focus their efforts on survival, whereas nations and individuals with higher incomes are likely to have more time and money to attend to environmental needs and amenities. Thus, while richer nations consume more goods and services, including energy, per capita, they also have generally been the most aggressive in addressing pollution and other environmental insults. This empirical relationship is known as the Environmental Kuznets Curve. However, its applicability to CO₂ emissions has been questioned,³⁸ and to the degree that it does exist for such pollutants as sulfur dioxide, it reflects policy choices to constrain emissions.

³⁵ This is not a simple cause and effect, but reflects evolutionary changes in areas such as education, cultural expectations, women's rights, access to birth control, and health care — all of which may be affected by social policy.

³⁶ For the United States, in 2005, the annual rate of population increase from the birth rate was 0.6%, whereas, counting migration, the population growth rate was 0.9%. See [<http://www.census.gov/cgi-bin/ipc/idbsum.pl?cty=US>].

³⁷ See [<http://www.un.org/News/Press/docs//2007/pop952.doc.htm>].

³⁸ The entire March issue of the *Journal of Environment & Development*, vol. 14 (2005) is devoted to this topic; see especially Joseph E. Aldy, "An Environmental Kuznets Curve Analysis of U.S. State-Level Carbon Dioxide Emissions," pp. 48-72. Also, William R. Moomaw and Gregory C. Unruh, "Are Environmental Kuznets Curves Misleading Us? The Case of CO₂ Emissions," in *Environment & Development Economics* (Cambridge University Press, 1997), pp. 451-463.

These interactions have both short-run and long-run implications. For most nations most of the time, the combination of population growth and per capita GDP growth has more than offset forces tending to depress emissions, so emissions have increased. Overall, the most critical interaction is the one between per capita GDP growth and resource uses, especially energy, but also including cement manufacture, agricultural practices, waste disposal, and the consumption and release of certain chemicals.

Changes in Intensity To Meet Climate Stabilization Goals

What might be required to “prevent dangerous interference with the climate system” remains debatable. The answer actually depends on the concentration of greenhouse gases in the atmosphere, not the level of emissions at a given point in time. Ultimate goals, then, are typically expressed in terms of what concentration would be required to keep global warming below a certain amount with a certain probability.³⁹ Models are then used to assess what emission reductions would be required to keep concentrations below the target level.

Developed nations that have agreed to the Kyoto Protocol have interim, 2008-2012 greenhouse gas reduction targets, based on reducing emissions from 1990 (or adjusted) baselines. The United States, while it does not have an emissions reduction target, does have an initiative introduced by the Bush Administration focused on an intensity reduction target. Various bills introduced into the 110th Congress specify emission reduction targets.

U.S. Greenhouse Gas Intensity: Trends and Targets. Analyzing and projecting the values and the rates of change for the variables population, income, intensity, and emissions depend on the baseline, the time period in question, and assumptions about changes over time. For the purpose of analyzing U.S. targets for greenhouse gas emissions, one could assume the following “business as usual” projection: from the baseline year of 2000, population grows at the annual rate of +0.9% for 2000-2010 and +0.8% for 2011-2025,⁴⁰ per capita income grows at an annual rate of +2.1% (the 1975-2003 rate), and intensity declines at the annual rate of -1.6% (the 1990-2000 rate for GHG).

President George W. Bush’s Climate Change Initiative, announced February 14, 2002, focused on increasing the rate of intensity decline.⁴¹ Observing that the Energy Information Agency was projecting that total U.S. greenhouse gas intensity would decline between 2002 and 2012 by -14%, President Bush said that his initiative would seek to increase that to -18%. The baseline rate of decline for this period is approximately -1.5% per year, while the objective would be to achieve a rate of

³⁹ See, for example, M.G.J. den Elzen and M. Meishausen, “Meeting the EU 2°C climate target: global and regional emission implications,” Report 728001031/2005, Netherlands Environmental Assessment Agency.

⁴⁰ U.S. Census Bureau, “IDB Summary Demographic Data for United States,” [<http://www.census.gov/cgi-bin/ipc/idbsum.pl?cty=US>]

⁴¹ See [<http://www.whitehouse.gov/news/releases/2002/02/climatechange.html>].

approximately -1.9%. With the assumptions of population and income growth presented above, this would leave total greenhouse gas emissions increasing at about 1.0% per year ($0.8 + 2.1 - 1.9 = 1.0$).

An interim target to reducing greenhouse gas emissions would be to stabilize them. Because the sum of the assumed rates of population growth and per capita GDP growth equals 2.9% per year after 2010, a decline in the intensity rate of -2.9% would be necessary to stabilize total greenhouse emissions at the emissions level of the year that rate of decline went into effect, compared with the recent annual rate of intensity decline of about -1.6% for the United States.

Now consider the goal, contained in a number of pending bills in Congress, of returning U.S. greenhouse gas emissions to their 1990 level of 1,631 MMTCE. Because it would take time to implement policies and programs to reduce intensity, one could assume that current trends continue through 2009 and that greenhouse intensity is then brought down; what rate of intensity decline would be necessary to achieve the 1990 goal by 2020? This is the typical first-stage emissions limit established by a number of bills that include economy-wide caps (e.g., S. 280, S. 309, S. 485, and H.R. 620). The answer is, it would take a rate of intensity decline of -5.4% per year⁴² (compared with the recent -1.6% per year), beginning in 2010, to reach the level of 1,644 in 2020, slightly over the target. At that point, intensity would be at 95.6 MMTCE/million\$PPP, compared with a level of 93.5 for France in 2000.

Over the longer term, S. 485, for example, requires that beginning in 2021, emissions economy-wide be reduced 2.5% annually from the previous year's level, and that beginning in 2031, emissions economy-wide be reduced 3.5% annually from the previous year's level. Assuming the "business as usual" rates of growth for population and income, the 2021-2030 annual reduction target means that intensity would be declining at a rate of -5.4% per year, equivalent to the decline required to achieve the bill's first-stage goal of reducing U.S. greenhouse gas emissions in 2020 to 1990 levels. The 2031-2050 annual reduction target means that intensity would be declining at a rate of -6.4% per year.

S. 309 sets a 2050 cap on economy-wide greenhouse gas emissions of 326 MMTCE (20% of 1990 emissions). Again assuming population and per capita GDP grow from 2010 to 2050 at the average annual rates of 0.8% and 2.1%, respectively, then given the emission rate at the cap, U.S. greenhouse gas intensity in 2050 would be 8.0 MMTCE/million\$PPP. Or, in terms of rate of change, assuming current trends until 2010, intensity would have to decline over the next 40 years, at an average rate of about -7.6% per year.⁴³

⁴² Achieving this could include, besides direct reductions in emissions, offsets from reductions made and paid for in other countries, as well as reductions from land use changes and sequestration.

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To give perspective to rates of intensity decline, consider an illustrative scenario in which, for each of the 10 years 2016-2025, two 1,000-megawatt nuclear electrical generating facilities go into service (or equivalent generating capacity based on renewables), replacing existing coal-fired facilities. Each plant would displace approximately 6 million tons of carbon per year; when all 20 coal-supplanting plants were in service in 2025, they would be displacing 120 million tons of carbon per year. All else equal, displacing this much carbon would accelerate the rate of decline in intensity for 2016-2025 by about -0.4% per year, so that in 2025, intensity would be approximately 125.5, compared with the business-as-usual intensity of 130.7.

This example, which lowers emissions and intensity only incrementally, shows that large declines in intensity would require multiple initiatives. To meet the goal of reducing economy-wide emissions to 20% of 1990 levels by 2050 implies some mix of making tremendous gains in energy efficiency, shifting to energy sources that emit virtually no CO₂, and developing the capacity to capture and sequester enormous amounts of CO₂.

Global Greenhouse Gas Intensity. As has been noted, world greenhouse gas intensity has been declining, but not at a rate sufficient to prevent rising GHG emissions (numbers do not add precisely, due to rounding):

World GHG Intensity, 1990-2000					
Population		Per Capita GDP ⁴⁴		GHG Intensity	GHG Emissions
(1.4)	+	(1.7)	+	(-2.2)	= (1.0)

An in-depth analysis of policies and programs for reducing global greenhouse gas emissions is far beyond the scope of this report. But if greenhouse gases are to be reduced, the imperative to reduce intensity is clear. Simply put, more people at higher standards of living means more goods and services, especially energy — to cook, heat and cool homes, to manufacture goods, to transport people and goods, etc.

To decouple those increases in the numbers of consumers and their consumption from increases in greenhouse gas emitting energy uses implies policies fostering greater efficiency in using energy and/or use of non-greenhouse gas-emitting forms of energy, such as renewables or nuclear. But greater efficiency ultimately reaches limits from the laws of physics; alternative fuels run into the facts that, in most places, coal is the least expensive fuel for generating electricity and heat, and oil is the least expensive fuel for powering transport.

Beyond the energy sector, moreover, there are many other areas where policies may affect GHG emissions. Land use and agricultural and forestry policies can have direct implications for emissions, and could reduce intensity. The non-CO₂ gases, many of which pose particularly long-term climate implications, offer cost-effective

⁴⁴ Economic contractions of several newly independent nations following the breakup of the former Soviet Union depressed global GDP, so this rate will likely rise in subsequent decades.

opportunities for reductions from certain industrial processes, landfills, and fuel production.

Perhaps most importantly, at the global scale, the possibility exists for identifying and exploiting the least-expensive opportunities for reducing greenhouse gases, thereby increasing the efficiency with which economies use greenhouse gas-emitting technologies. This depends, however, on global instruments for accounting for and verifying such reductions. Reaching practical agreements on international mechanisms (e.g., for a carbon tax or a cap-and-trade system to obtain economic efficiencies among nations in reducing emissions) requires divergent national goals to be focused on what is, ultimately, a global issue. The global nature of climate change challenges national sovereignty. The UNFCCC, the Kyoto Protocol, and the Asia-Pacific Partnerships are efforts in multilateral approaches to reducing emissions, but their individual and complementary successes remain to be seen.

Conclusion

In the end, the interactions of the variables, population, income, and intensity of emissions (**equation 1**), together with the inexorable force of compounding growth rates over time (**equation 2**), are inescapable conditions determining both the risks of climate change and the costs, benefits, and tradeoffs of options for responding. If climate change poses a genuine risk to the well-being of mankind, the nations of the world, individually and collectively, face two fundamental challenges: adopting and implementing policies and encouraging the development and use of technologies that emit lower levels of greenhouse gases, and maintaining a sufficiently high rate of intensity decline over the long term to ensure declining emissions.

In 1992, Congress enacted the Energy Policy Act of 1992 (EPACT, P.L. 102-486), which contained provisions to implement the United Nations Framework Convention on Climate Change (UNFCCC), which had been signed earlier in the year.⁴⁵ The UNFCCC's objective to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" was echoed in EPACT, which called for a National Energy Policy Plan to "include a least-cost energy strategy ... designed to achieve [among other goals] ... the stabilization and eventual reduction in the generation of greenhouse gases...."⁴⁶

In ratifying the UNFCCC, the United States agreed to several principles for achieving this objective, including the following:

- "[D]eveloped country Parties should take the lead in combating climate change and the adverse effects thereof."⁴⁷

⁴⁵ The United States signed the UNFCCC on June 12, 1992, and ratified it on October 15, 1992. The UNFCCC entered into force on March 21, 1994.

⁴⁶ Section 1602(a)

⁴⁷ UNFCCC, article 3.

- “Parties should take precautionary measures to anticipate, prevent or minimized the causes of climate change and mitigate its adverse effects.”⁴⁸
- “Parties have a right to, and should, promote sustainable development....” Climate change policies should take “into account that economic development is essential for adopting measures to address climate change.”⁴⁹

The UNFCCC’s linking of sustainable development and climate change mitigation reflects the perceived need to decouple economic development and growth from non-sustainable, greenhouse gas-emitting energy technologies.

As this report suggests —

- An expanding population in many parts of the developing world is an important driver for economic growth. As affirmed in the UNFCCC, climate change policies are to take “into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty.”⁵⁰
- Economic development may reduce population pressure in the long-term but creates increasing demand for resources that, employing current technologies, contribute to greenhouse gas emissions. Although economies become more efficient over time, those efficiencies have yet to overcome the combination of expanding population and growing economies without the intervention of governments.
- Satisfying the energy needs of dynamic economies is increasing the demand for coal and other fossil fuels for economic and other reasons. Coal is abundant, available locally, and is relatively inexpensive. To meet the massive reductions in greenhouse gas emissions in the long term required by various stabilization scenarios would require either the development of a commercially available technology to reduce substantively, or to capture and sequester, the emissions of CO₂ from coal and other fossil fuels or a substantial restructuring of many countries’ economies. The UNFCCC recognizes the “special difficulties of those countries, especially developing countries, whose economies are particularly dependent on fossil fuel production, use and exportation, as a consequence of action taken on limiting greenhouse gas emissions.”⁵¹

⁴⁸ Ibid.

⁴⁹ Ibid.

⁵⁰ UNFCCC, Preamble.

⁵¹ UNFCCC, Preamble.

Breaking the current dynamic of increasing populations and economic growth pushing up greenhouse emissions would depend on developing “sustainable” alternatives — both in improving the efficiency of energy use and in moving the fuel mix toward less greenhouse gas-emitting alternatives. In the UNFCCC, developed nations committed to taking the initiative by “adopt[ing] national policies and tak[ing] corresponding measures on the mitigation of climate change ... [that] will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention”⁵² Such development paths are critical not only for any domestic program, but also participation by developing countries in any global greenhouse gas stabilization program may be at least partially dependent on the availability and cost of such technologies.

As stated by the UNFCCC,

The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties.⁵³

The focus of the Asia-Pacific Partnership on Clean Development and Climate on technology development and its transfer among nations represents an important component of the United States’ response to this principle. It remains to be seen how it will relate to the UNFCCC, the Kyoto Protocol, or other cooperative agreements. Fostering technological change depends on two driving factors: exploiting new technological opportunities (technology-push) and market demand (market-pull).⁵⁴

Currently, U.S. policy is oriented primarily to the technology-push part of the equation, with a focus on research and development (R&D). In contrast, the European Union is complementing its research and development efforts by constructing a multi-phased, increasingly more stringent market-pull for greenhouse gas-reducing technologies and approaches, including taxes and regulatory requirements overlain by the European Trading System.⁵⁵

The market-pull side focuses on market interventions to create demand, which poses questions of —

- Whether, how, and to what extent to use price signals to change behaviors and to stimulate innovation of technologies that increase energy efficiency or that emit less greenhouse gases. Direct taxes on

⁵² UNFCCC, article 4(2)(a).

⁵³ UNFCCC, article 4(7).

⁵⁴ L. Clarke, J. Weyant, and A. Birky, “On the Sources of Technological Change: Assessing the Evidence,” *Energy Economics*, vol. 28 (2006), pp. 579-595.

⁵⁵ See CRS Report RL33581, *Climate Change: The European Union’s Emissions Trading System (EU-ETS)*, by Larry Parker.

energy or on greenhouse gases could be one approach, whereas the concept of shifting taxes from incomes to consumption would be a broader one.

- Whether, how, and to what extent to use regulatory actions to change behaviors and to require technologies that increase energy efficiency or emit less greenhouse gases. A direct regulatory effort would be a renewable power standard for electricity-generating facilities, which requires some specified portion of electric power to be generated by renewables, such as water power, solar, or wind (whether nuclear power might count is an open question). Heretofore, especially in the United States, regulatory efforts curtailing greenhouse gas emissions commonly originated in response to other objectives, such as reducing health-damaging air pollutants or enhancing energy security by fostering substitutes for imported oil. In these cases, reductions in greenhouse gases were coincidental (“no regrets”); further co-reduction opportunities remain (e.g., methane from landfills). However, the objective of reducing greenhouse gases as the primary object of regulations is increasingly coming to the fore, especially in some states.⁵⁶

The technology-push side focuses on research and development. It raises questions as to what R&D programs should be supported at what levels:

- Over the short- to mid-term, how can existing technologies be made more sustainable? How can energy (and other resources) be used more efficiently? What alternatives can be pursued?
- What are the relative federal and private roles in selecting and financing R&D of specific technologies?
- Perhaps most important for the longer run, what breakthrough research should be pursued? Over the past 100 years, a number of technological changes have occurred (e.g., in nuclear power, computing, and communications) that demonstrate the low success rate of predicting technological and societal changes far into the future. At present, at least two technological breakthrough possibilities can be discerned: fusion power, which conceivably could wean economies from fossil fuels, and sequestration,⁵⁷ which could capture and store carbon dioxide — and perhaps even remove excess from the atmosphere. Other breakthroughs are surely possible — including serendipitous discoveries that cannot be conceived of now.

⁵⁶ See CRS Report RL33812, *Climate Change: Action by States To Address Greenhouse Gas Emissions*, by Jonathan L. Ramseur.

⁵⁷ See CRS Report RL33801, *Direct Carbon Sequestration: Capturing and Storing CO₂*, by Peter Folger.

If the ultimate, 50-year target for reducing greenhouse gas emissions is as aggressive as 80% below 1990 levels, as in some proposals, then fundamentally at issue is whether the risks of climate change can be addressed only by incremental “muddling through” — or some extraordinary, aggressive effort is needed. Certainly, there are many opportunities for incremental and iterative policies to reduce greenhouse gases, to conserve energy, to find alternative energy sources, to make vehicles more energy efficient, to enhance carbon sequestration through afforestation and refined cropping practices, to deter deforestation and land use changes that increase CO₂ emissions, and so on. The incremental nature of such a response provides flexibility, while a time frame of decades offers hope of unpredictable breakthroughs — or the discovery that climate change is not so threatening as some fear.

Conversely, given the drivers for increasing emissions — population growth and economic development and growth — it is hard to see how incremental changes affecting intensity will achieve the rate of intensity decline sufficient to reduce emissions to the proposed levels, even over decades.⁵⁸ From this perspective, an intense, aggressive pursuit of breakthroughs — a sort of climate change Manhattan project, or Apollo man-on-the-moon effort — even with high costs and high risks of failure, has to be weighed against the costs and risks of failing to prevent potentially dangerous interference with the climate system.

⁵⁸ However, some pollution control efforts have had dramatic successes: lead has been essentially eliminated as an air pollutant; regulated auto emissions have been reduced by over 90% from unregulated levels; between 1990 and 2005, sulfur dioxide emissions from acid rain program sources dropped by about 35%; and electricity generated rose about 30%.