2. WHAT CAUSES CLIMATE CHANGE?

From draft of Chapter 10, Energy Economics and the Environment (3d. Ed., 2010) (Prof. Joel B. Eisen)

a. THE GREENHOUSE EFFECT

The "greenhouse effect" is one of the most well-established theories in the atmospheric sciences. It is the name given to the process that occurs when GHGs accumulate in the atmosphere and trap heat at the surface of the earth, thus contributing to increases in temperature levels. Jean-Baptiste-Joseph Fourier hypothesized its existence in the 1820s, *see* Gale E. Christianson, Greenhouse: The 200-Year Story of Global Warming 11-12 (1999), and the Swedish chemist Svante Arrhenius was awarded the Nobel prize for his calculations of the greenhouse effect as early as 1903. *Id.* at 105-115.

In addition to CO_2, other greenhouse gases include N_2O, SO_2, chlorofluorocarbons (CFCs) and tropospheric ozone. Methane, the chemical name for natural gas, is itself a powerful greenhouse gas that on a molecule for molecule basis has ten times the heat retention power of carbon dioxide. Christianson, *supra,* at 219-221.

Energy from the sun enables life to exist on the planet. The net effect of the GHG accumulation is that the earth's atmosphere acts as a blanket to retain the sun's heat and maintain the earth's average surface temperature of about 15°C. This heat retention is principally due to the action of the particles and gases that give rise to the greenhouse effect. Carbon dioxide and certain other gases preferentially allow sunlight to filter through to the surface of the planet relative to the amount of radiant energy that the atmosphere allows to escape back up through the atmosphere to space. A certain amount of greenhouse gas is needed to keep a planet at a habitable temperature; the earth would be much colder in the absence of any greenhouse warming. But when the amount of GHGs increases, there is an increase in the planet's temperature because more heat is trapped.

The unchallenged facts about the greenhouse effect include three key propositions: (1) atmospheric levels of GHGs are increasing because of human activities; (2) GHGs absorb and re-radiate infrared radiation in a way that heats the planet; and (3) atmospheric changes are long-lasting, because the major GHGs remain in the atmosphere for periods ranging from a decade to centuries, and the climate itself has considerable inertia, mainly because of the high heat capacity of the world ocean. J.D. Mahlman, Uncertainties in Projections of Human-Caused Climate Warming, 278 Science 1416, 1419 (Nov. 21, 1997).

b. CLIMATE SCIENCE AND THE IPCC

The growing recognition in the 1970s and 1980s of the possibility that increases in GHGs were triggering climate change came at the time that high-powered computer modeling was beginning to be widely used. In various parts of the world, global climate models began to be developed by academic and governmental institutions. These institutions realized that there was a need for international cooperation if the scientific research was to proceed efficiently.
Much of global warming science has been developed by the International Panel on Climate Change ("IPCC"), established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. *See* http://www.ipcc.ch/. The IPCC includes thousands of scientists from around the world, representing the model builders and other academic and governmental agencies with expertise in climate science.

The IPCC was directed to prepare a report every five years that would indicate the consensus of the views of the expert community about the extent of climate change that was likely to take place, and its causes. The IPCC reports are based on sophisticated computer climate models that seek to replicate the forces that affect climate on a global basis and distinguish between natural and anthropogenic influences on climate. The models are updated and recalibrated through a constant process of comparing modeled and observed spatial and temporal patterns of climate change. In the United States, some prominent models are located at the National Center for Atmospheric Research, the Lawrence Livermore Laboratory, the Goddard Institute for Space Studies, and the Geophysical Fluid Dynamics Laboratory. Other models are operated by institutions in other countries.

In November 2007, the Fourth Assessment Report of the IPCC ("IPCC AR4") stated much more definitively than even the IPCC's own past reports that the planet is warming, human-generated emissions are the cause, and reductions in the growth of GHG emissions must start now to mitigate global climate disruptions.

Intergovernmental Panel on Climate Change
Climate Change 2007: Synthesis Report (IPCC 2007)

This underlying report represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

1.1 Observations of climate change

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the TAR (Figure 1.1). The linear warming trend over the 50 years from 1956 to 2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years from 1906 to 2005.

The temperature increase is widespread over the globe and is greater at higher northern latitudes. Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed faster than the oceans. Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000m and that the ocean has been taking up over 80% of the heat being added to the climate system. New analyses of balloonborne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature.

Increases in sea level are consistent with warming. Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8] mm per year from 1993 to 2003. Whether this faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer term trend is unclear. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice caps contributing about 28% and losses from the polar ice sheets contributing the remainder. From 1993 to 2003 the sum of these climate contributions is consistent within uncertainties with the total sea level rise that is directly observed.

Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15%. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C.

At continental, regional and ocean basin scales, numerous long term changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has *likely* increased since the 1970s.

Some extreme weather events have changed in frequency and/ or intensity over the last 50 years:

_ It is *very likely* that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent.

_ It is *likely* that heat waves have become more frequent over most land areas.

_ It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas.

_ It is *likely* that the incidence of extreme high sea level has increased at a broad range of sites worldwide since 1975.

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long term trends in tropical cyclone activity. Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years.

2.1 Emissions of long-lived GHGs

The radiative forcing of the climate system is dominated by the long-lived GHGs, and this section considers those whose emissions are covered by the UNFCCC.

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004.

Carbon dioxide (CO2) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004. The rate of growth of CO2-eq emissions was much higher during the recent 10-year period of 1995-2004 (0.92 GtCO2-eq per year) than during the previous period of 1970-1994 (0.43 GtCO2-eq per year). The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate.

2.2 Drivers of climate change

Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The atmospheric concentrations of CO_2 and CH_4 in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture.

The global atmospheric concentration of CO_2 increased from a pre-industrial value of about 280ppm to 379ppm in 2005. The annual CO_2 concentration growth rate was larger during the last 10 years (1995-2005 average: 1.9ppm per year) than it has been since the beginning of continuous direct atmospheric measurements (1960-2005 average: 1.4ppm per year), although there is year-to-year variability in growth rates.

There is *very high confidence* that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m2.

The combined radiative forcing due to increases in CO_2, CH_4 and N_2O is +2.3 [+2.1 to +2.5] W/m2, and its rate of increase during the industrial era is *very likely* to have been unprecedented in more than 10,000 years (Figures 2.3 and 2.4). The CO_2 radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years.

3. IMPACTS OF CLIMATE CHANGE

There is little dispute that the increased atmospheric concentration of GHGs is largely attributable to human activities like the burning of fossil fuels. How much of an impact will that have? The aspect of climate change that captures most public attention is the idea that there will be "global warming." "Climate sensitivity," the long-term temperature change that will result from a doubling of atmospheric CO_2 concentrations, is a common measure of the severity of the global warming threat. The scientific literature as of 2006, as summarized in IPCC AR4, implied that the most likely estimate of climate sensitivity was 3°C. That is, every time atmospheric CO_2 doubles — from today's 385 ppm to 770 ppm CO_2, for example — the global average annual temperature would increase by 3°C. IPCC AR4 viewed it as "likely" that the true value fell between 2.0°C and 4.5°C; in IPCC usage, this means there is a one in six chance that climate sensitivity is actually above 4.5°C.

Concern about future warming of the planet has led to a good deal of work to predict its likely effects. One obvious category of direct effects is changes in crop yields and the range or numbers of pests that affect plants, or diseases that threaten animals or human health. Water supplies throughout the world may be affected by changes in the probability of catastrophic episodes of drought and flooding if climate warming alters the number and character of destructive storms. The effect on natural ecosystems, such as tropical forests, has also been a matter of concern.