GLOBAL WARMING, CLIMATE CHANGE AND SUSTAINABILITY

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Glossary

Carbon dioxide is the principle component in the exhaust from the combustion of fossil fuels and plant material or biomass. It is a heat trapping greenhouse gas.

Greenhouse gases are gases that are in the atmosphere or which are released by human activities that trap heat, leading to global warming and climate change. They include carbon dioxide, methane, nitrous oxide and a number of industrial products and waste gases.

Intergovernmental Panel on Climate Change is a United Nations sponsored organization with a Secretariat in Geneva. It is sponsored by the World Meteorological Organization and the UN Environmental Program. It assembles up to 2000 physical and natural scientists, social scientists, economists, engineers, technology assessment experts and policy scientists to produce a comprehensive assessment of the state of knowledge about climate change its impacts and the opportunities for mitigating and adapting to it.

Kyoto Protocol is the treaty that sets the conditions and procedures that nations are to follow to reduce greenhouse gas emissions during the first commitment period (2008 – 2012). The goal is to have enough nations ratify it by 2002 that it will enter into force.

UN Framework Convention on Climate Change is the international treaty that sets the goal of stabilizing greenhouse gas concentrations in the atmosphere at a level that will avoid damaging the climate system. It establishes priorities for actions, reporting requirements of greenhouse inventories for all nations, and defines the "common but differentiated responsibilities of developed and developing nations.

Summary

The Earth's temperature is approximately 33°C warmer because of the presence of trace gases that trap radiant heat from escaping back into space. All of the natural greenhouse gases are growing in concentration from human activity and additional industrial gases are being added to the atmosphere. The radiative forcing from these added greenhouse gases is now equivalent to an increase by 0.7% in the solar energy reaching the earth's surface. The current rise in global average temperature since 1861 is estimated to be 0.6 ± 0.2°C, and to lie outside the range of normal variance in the climate record for the past 1000 years. The twentieth century and the decade of the 1990s are the warmest during the past millennium. The year 1998 is the warmest single year recorded since records were kept. It was 1.1°C warmer than the average expected temperature extrapolated from the 900 years prior to 1900. Many consequences of global warming and climate change have been measured including lengthened growing seasons in northern latitudes, thinning arctic ice sheets, retreating glaciers, declining coral reefs, rising sea level increased precipitation and droughts, and altered migration patterns of birds and mammals.

Each economic sector is analyzed for its contribution of greenhouse gases. Carbon dioxide from fossil fuel combustion is the most important, but other gases from industry, agriculture and waste management also contribute significantly. Technical opportunities for reducing greenhouse gas emissions and their cost are identified, and policies and treaties designed to reduce greenhouse gases are described.

The implications of the potential changes in climate for human well being are one measure of future sustainability. The mitigation options that are identified for each economic sector suggest ways in which economic and technological choices can improve the likelihood of sustainable development. To the extent that climate changes are irreversible and adversely affect future generations, the less sustainable are those choices and the greater will be the amount of adaptation that will be required.

1. Introduction

1.1 Sustainability and Climate Change

Climate has played a dominant role in shaping human culture and the structure of civilization over the past 12 000 years. As the glaciers of the last ice age retreated, the climate became suitable for the domestication of a small number of plants and animals. The Neolithic revolution marked the birth of agriculture, and the construction of permanent settlements. These settlements in turn either joined together or were conquered to form kingdoms and empires. The ability of ever growing human populations to survive has depended upon a relatively benign climate that has a sufficiently long growing season and adequate precipitation. Likewise, the manner in which appropriate shelter is constructed and most commerce and trade is conducted depends upon a predictable and relatively stable climate. Even since the industrial revolution insulated some aspects of human activity from the vagaries of the weather, climate still plays a significant role the form taken by the infrastructure of cities, power generation and the transport system. If the climate is unstable, highly variable or subject to wild swings in precipitation, drought or storms, people and economies can become vulnerable.

The principle embodied in sustainability is that the current generation should meet its own needs without compromising the ability of future generations to meet theirs. A drastically or irreversibly altered climate system has the potential to compromise the ability of future generations to meet their needs if the climate system changes so that people will find it more difficult to grow food, protect themselves from weather related events, or if they suffer more severe pollution, diseases or pest infestations. Future generations will also be impoverished if there is a significant decline in the number of species or the population of plants and animals that survive under an altered climate system.

An additional equity issue is that the people who are most vulnerable to these changes are those who are poorer, and who depend upon the reliable delivery of ecosystem services to provide goods and services such as food and shelter. While subsistence farmers, fishers and forest dwellers might suffer the greatest consequences of climate change, they will have contributed the least to causing those changes. Adverse climate consequences are likely to more severely affect people in developing countries.

1.2 Climate Science

The earth's climate is determined by the interaction between the radiation received from the sun, and the distribution and transformation of that energy by the atmosphere, oceans, land based (terrestrial) ecosystems and ice and snow. The one constant of climate over millions of years is its variability. The geological record reveals that at various times, the earth has been either warmer or colder, and sometimes wetter or dryer than it is now. The reason for the intense interest in climate and climate change is that there is evidence that human activities are directly and indirectly altering the earth's climate system. This essay will attempt to summarize the state of the knowledge about the earth's climate system, how human activities might be altering it, and the consequences of human induced climate change both for natural systems and human society. This will conclude with a description of the technologies, policies and measures that are proposed and which are being implemented to mitigate climate change, and to adapt to it. These efforts will be discussed in the context of sustainable development.

Climate is defined as a 30 to 40 year average of measurements such as average seasonal and annual temperature, day and night temperatures, daily highs and lows, precipitation averages and variability, drought frequency and intensity, wind velocity and direction, humidity, solar intensity, variability and cloudiness, and storm frequency and intensity. Global climate is the globally averaged set of all climate variables. Climate is therefore a 40 year average of daily weather events, and climate change is the change that takes place in the moving average of weather events and measurements. Global warming only refers to the change in average temperature of the planet. Often the terms global warming and climate change are used interchangeably, but "climate change" is much more comprehensive of all the climate variables.

Understanding the complex planetary processes and their interaction requires the effort of a wide range of scientists from many disciplines. Solar astronomers carefully monitor the intensity of the sun's radiation and its variation. The current average rate at which solar energy strikes the earth is 342 Watts/square meter (W/m^2). It is found that most of the visible light reaches the earth's surface (168 W/m^2); 67 W/m^2 is absorbed directly by the atmosphere, while 77 W/m^2 is reflected by clouds and 30 W/m^2 is reflected from the earth's surface.

As will be explained later, a number of trace gases in the atmosphere are transparent to the sun's visible light, but trap the radiant heat that the earth's surface attempts to emit back into space. The net effect is that instead of being a frozen ball averaging –19°C, earth is a relatively comfortable +14°C. This difference of 33°C arises from the natural greenhouse effect. Human activities appear to have increase the temperature by +0.6 $\pm$ 0.2°C. The French physicist Fourier coined the term "greenhouse effect" in 1827. The transmission of visible light from the sun and the trapping of radiant heat from the earth by gases in the atmosphere occurs in much the same way that the windows of a greenhouse or an automobile cause the interior to become much hotter than the surrounding outside air when it sits in the sun. The analogy is somewhat imperfect since glass also keeps the warm air from mixing with the cooler outside air.

Atmospheric scientists study not only the composition of the atmosphere, but also its circulation that distributes heat by wind and through the evaporation of water, and the melting of snow and ice. Oceanographers identify how oceans store heat and how ocean currents redistribute it throughout the globe. Terrestrial and other ecologists study how plants and soils absorb and emit greenhouse gases, and where industrial and agricultural emissions of greenhouse gases go.

Geologists identify past climate conditions by studying ice cores from glaciers, the ice caps of Antarctica and Greenland, examine ocean and freshwater sediments and coral reefs and compare them with the findings of botanists who study ancient plant samples and currently growing trees. Planetary astronomers compare climate conditions on Earth with the climate and atmospheric composition and conditions of other planets such as Venus, Mars and the moons of Jupiter and Saturn. A consistent model has developed for explaining the general relationship between surface temperatures and the atmospheric composition and distance from the sun for most of these bodies. Finally, climate modelers build complex models of the earth's atmosphere, oceans and land, and utilize information on human population, land use patterns and economic and technological projections to account for past and present climate and project future ones.

Every 5 years since 1990, a group of nearly 2 000 natural and physical scientists, economists, social scientists and technologists assemble under the auspices of the United Nations sponsored Intergovernmental Panel on Climate Change. These scientists spend nearly three years reviewing all of the information on climate change and produce a voluminous report following a public review by others in the scientific community and by governments. The most recent report, *Climate Change 2001*, consists of three volumes that summarize and explain the scientific knowledge of the cause of climate change, its impacts, and the mitigation and adaptation options that are available to address it. The report is 2665 pages long and contains over ten thousand references. Much of the information in this essay utilizes this report and the references in it to assure accurate, up to date information. The IPCC also publishes special reports on forests, global warming scenarios, technologies, policies and measures, equity and sustainable development.

1.3 The Atmosphere

Dry air of the earth's atmosphere is composed of 79% nitrogen, 20% oxygen and 1% argon. Each of these gases is transparent to the sun's visible light, and none absorb radiant heat. Hence they are not heat trapping, greenhouse gases. The principal greenhouse gas is water vapor, followed by carbon dioxide, methane and nitrous oxide. These gases are present in tiny amounts. Water vapor is not uniformly distributed but averages a couple of percent worldwide. Using 1998 data, carbon dioxide is present at a level of 367 parts per million (ppm) or 0.0367%, an increase of 31% above preindustrial levels of 280ppm. Methane is present at much lower levels of 1.7 parts per billion (ppb) which is 2.4 times greater than preindustrial levels of only 0.7 ppb. Nitrous oxide is present at only 0.3 ppb, but this represents an increase of 14% above preindustrial levels. All of these gases occur naturally, but are increasing and changing the composition of the atmosphere because of human activities.

Additional industrial commercial and waste gases that contribute to global warming are perfluorocarbons, chlorofluorocarbons, hydroflurocarbons, sulfur hexafluoride and halons. In addition a number of air pollutants including ozone, particulate soot and other air pollutants contribute to global warming (and cooling) sometimes at levels as low as the parts per trillion.

Each atmospheric gas absorbs radiant heat (infrared radiation) to a different extent, is present at its own unique concentration and hence affects the earth's surface temperature to a different extent. Careful measurements have been made of each greenhouse gas, and two different measures of a substance's ability to trap heat in the atmosphere have been developed. The first is called "radiative forcing" and it is directly proportional to the temperature rise at the earth's surface. The units are watts per square meter just like the sun's intensity. The radiative forcing from human additions of carbon dioxide since the beginning of the industrial revolution is determined to be 1.46 W/m^2. Methane and nitrous oxide additions have provided relative radiative forcings of 0.48 and 0.15 W/m^2. Other gases have individual radiative forcings of less than 0.1 W/m^2. The total radiative forcing of all greenhouse gases added by human activity to the atmosphere is estimated to be 2.43 W/m^2. This should be compared to 342 W/m^2 that reaches the Earth from the sun. Hence, the greenhouse gases added by human activity are equivalent to turning up the sun's power by an extra 0.7%, which is enough to cause the global temperature to rise.

A second measure that is useful in estimating the future contribution to global warming by added gases is called the Global Warming Potential or GWP. The GWP is the ratio of the climate forcing of one kilogram of a particular gas integrated over time relative to that of a reference gas, which is usually taken to be carbon dioxide. This allows one to put all gases into a common currency of warming, e.g. carbon dioxide equivalents. One of the problems is that each gas has a different average lifetime in the atmosphere so that the relative GWP of gases vary depending upon the time frame chosen. The average lifetime of carbon dioxide is approximately 100 years while that of methane is 12. So one kilogram of methane has 62 times the global warming potential as 1 kilogram of carbon dioxide over twenty years, 23 times over 100, and only 7 times over 500 years. There are also three times as many molecules of methane in a kilogram of methane as there is of carbon dioxide so that burning methane to carbon dioxide reduces the GWP over 100 years by only 8-fold and not 23-fold.

Carbon dioxide is removed from the atmosphere by ocean uptake, by green plants through photosynthesis and trough biogeological processes such as coral reef and marine shell formation. Roughly half of carbon dioxide released today will remain in the atmosphere for a century, and one-quarter may be present several hundred years from now. Some of the synthetic, industrial greenhouse gases have half-lives of hundreds, thousands and in at least one case (carbon tetrafluoride), tens of thousands of years. These long residence times are effectively irreversible changes in the composition of the atmosphere and in climate parameters on the time scale of human generations. This is why some argue that the continued release of greenhouse gases is not sustainable, since it can adversely affect future generations. Even without complete information about the consequences of increasing greenhouse gases for climate change, many invoke the precautionary principle and urge the world to move towards reducing and eliminating them.

1.4 Variability of the Earth's Climate System

Natural variability of the climate system is now well established on many different time scales. This occurs because climate is determined by a variety of causal factors with differing time scales and sometimes random frequency. These climate-influencing factors include:

- variations in solar intensity over time (both short and long term)
- the non-uniform movement of the earth in its orbit around the sun
- the very different rates of atmospheric and ocean circulation
- the rates of appearance and disappearance of ice and snow
- cloud formation and disappearance
- atmospheric particulates and aerosols from fires and volcanoes
- the differential rates of growth of different plant species following disturbances
- biogeochemical cycling of greenhouse gases

Isotopic data from ice cores drilled in Antarctica reveal that most of the past 420 000 years have been 4 to 8°C colder there than at present, with the global average temperature perhaps 5°C cooler. Approximately every 100 to 120 000 years the cold is punctuated by the sudden onset of warming that occurs in about 10 000 years and lasts for approximately an additional 10 000 years before gradual cooling takes place to the previous lows. Five of these interglacial warm periods or "climatic optimal" periods have been identified, and all have approximately the same temperature as the (preindustrial) value of +14°C. It is interesting to note that modern *homo sapien* arrived on the scene just over 100 000 years ago at the peak of the previous interglacial warming, and that the agricultural or Neolithic revolution occurred approximately 12 000 years ago as the earth emerged from the most recent ice age.

Another remarkable finding is that air bubbles trapped at different depths in the Antarctic ice contain the greenhouse gases carbon dioxide and methane. They are found to rise during warm periods, and fall during cooler ones. It is believed that the major driver of the glacial-interglacial cycle is the 120 000 year cycle of the earth's position and orientation relative to the sun which alters the relative amount of solar energy absorbed by the northern and southern hemispheres. As the earth begins to warm slightly from this effect, it is thought that carbon dioxide and methane trapped in the oceans is released like the fizz from a warm can of soda, and additional amounts of these gases are released by increased decomposition rates of organic plant material by bacteria. As the earth warms, more water vapor enters the atmosphere and doubles the effectiveness of greenhouse gas heat trapping. As ice and snow melt, less sunlight is reflected into space causing an even greater warming at high latitudes. After 10 000 years or so, the position of the earth shifts so that it absorbs less solar intensity, and begins to cool slightly. As the greenhouse gases in the atmosphere decline, the cooling effect is further enhanced, and the earth enters a new ice age.

The post ice age period in which human civilization has evolved is known as the Holocene. It has long been assumed that this represented an extended, stable and generally warm climate period. Temperatures were slightly higher than those of today at the beginning of the Holocene, and gradually declined until recently. Measurements from Greenland have shown that the general changes were subject to sudden shifts in temperature on time scales of a decade or century. 1t is believed that these rapid temperature changes occurred as the result of sudden alterations in oceanic and atmospheric circulation.

The period of direct land and ocean instrumental temperature measurements begins in 1861. It shows two periods of global temperature rise from 1910 to 1945 and from 1976 to the present. In between, from 1946 to 1975, there was little change in global average temperature, although some regions cooled while others warmed. The total rise for land based measurements from 1861 to 2000 is estimated by the IPCC to be 0.6°C $\pm$ 0.2°C. The warming rate across the entire earth's surface during the two periods has been 0.15°C per decade. Sea surface temperatures are increasing at about one third that rate, and it has been found that the heat content of the top 300 meters of the ocean has increased significantly during the last half of the twentieth century. The lower atmosphere up to 8 km has also warmed, but at about one-third the land rate. Daily minimum temperatures are rising at 0.2°C per decade, approximately twice the rate of daily maximum temperatures. This has extended the frost-free season in northern areas, and indeed satellite data confirm that total plant growth is increasing at latitudes above 50^{o} N.

There has been much discussion of whether the recent rise in the instrumental record during the 20th century is simply a return from a "Little Ice Age" that occurred between the 15th and 19th century to conditions of a "Medieval Warming Period" that predated it. A new analysis of surrogate measurements of temperature utilizing data from tree rings, coral reefs and ice cores which extends back 1000 years clearly shows that the temperature rise of the past century for the northern hemisphere lies outside the variability of the period. In fact the current rate of increase, 0.6^{o}C per century, reverses a downward trend of 0.02^{o}C per century over the previous 900 years. The Little Ice Age and Medieval Warming Period now appear to be rather localized North Atlantic climate variations. The statistical analysis shows clearly that there is less than a 5% probability that the recent temperature rise is due to random variability in the climate system.

The IPCC concludes that the 20th century is the warmest in the past 1000 years, and the 1990s are the warmest decade in that period. The year 1998 may have been the warmest single year, 0.7^{o}C above the 40 year average from 1961 to 1990, and nearly 1.1^{o}C warmer than the projected average temperature extrapolated from the previous 900 year trend.

Additional changes in climate parameters such as precipitation, storms and melting of sea ice and glaciers will be discussed in Section 3, Impacts of Climate Change.

2. Human Induced climate change

2.1 Human Activities and Climate Change

By the end of the 19th century, scientists had identified the major greenhouse gases in the atmosphere. In 1897, Svente Arhenius, a distinguished Swedish chemist, carried out the first calculation of the effect of greenhouse gases on the temperature of the earth. His estimate made without a computer or even a good calculator was surprisingly close to what we know today. Arhenius also did a thought experiment in which he recognized that the industrial revolution was moving carbon from under the ground in the form of coal and oil and putting it into the atmosphere as carbon dioxide. What would happen, he asked if human activity were to double the concentration of carbon dioxide in the atmosphere? His answer is about twice the upper limit of the range estimated by the best climate models of 1.5 to 4.5^{o}C. This is called the climate sensitivity. The actual increase in temperature depends upon the amount of greenhouse gas released into the atmosphere. Estimates are that this will amount to approximately a doubling of carbon dioxide equivalent from preindustrial levels sometime before the year 2100.

Systematic measurements begun in 1957 by Charles David Keeling in Hawaii have confirmed that carbon dioxide is indeed increasing along with the increase of fossil fuel consumption. Since that time several monitoring stations at different locations now measure the rate of increase of carbon dioxide and a full range of additional greenhouse gases.

Human activities are influencing climate in several ways. The most direct is through the release of greenhouse gases.

- The greatest share of greenhouse gases comes from the combustion of fossil fuels such as coal, oil and natural gas which release carbon dioxide when burned. Coal releases nearly twice as much carbon dioxide as does natural gas for each unit of heat energy released. Oil lies somewhere in between.
- Land clearance, deforestation and forest fires release carbon dioxide and methane.

- Land use change alters the reflectivity or albedo of the land. Deforestation in the northern forests usually increases reflectivity by replacing dark evergreen trees with more white reflecting snow. In the tropics, less solar energy is absorbed in most cases once forests are removed. Urbanization usually increases the absorption of solar energy. The net effect of land use change is thought to be to off set warming by about -0.2 ± 0.2 W/m^2.
- Combustion of fossil fuels and clearing of land also contribute dust, particulates, soot and aerosol droplets. These either reflect sunlight away from the earth or else absorb radiation. Some aerosols are also believed to increase the amount of cloud cover.
- Agriculture releases carbon dioxide through fossil fuel energy use and from the oxidation of soils. This sector is the major producer of nitrous oxide from the bacterial breakdown of nitrogen fertilizer. Rice culture and livestock are also major producers of methane.
- Industrial processes release a variety of greenhouse gases into the atmosphere either during manufacturing or through the use of products.
- Air pollution that results in ozone and other gases near the earth's surface traps heat, while the depletion of the stratospheric ozone in the upper atmosphere allows more heat to escape to space. The pollution near the earth's surface is the larger effect.
- The waste sector releases large quantities of methane from sewage, animal feedlots and industrial wastewater, and from landfills.

3. Impacts of Climate Change

As temperatures warm, a whole set of climate parameters changes. Many of these have already been observed, and are noted in the following.

- Regional temperatures will rise most significantly in high latitudes. The extension of the growing season has already been noted in northern portions of North America and Eurasia.
- Permafrost is melting in many places.
- Polar sea ice has thinned by 40% in three decades, and the extent has declined by 6% since 1978. The timing of the breakup of sea ice is happening earlier affecting species such as the polar bear.
- The Greenland icecap is thinning significantly in places, while the Antarctic ice sheet remains stable.
- Glaciers are melting and retreating worldwide. Tropical glaciers in places like Mt. Kilmanjaro are unlikely to last more than another two decades.
- The intensity and persistence of El Nino warming events has increased since the mid-1970s.
- Precipitation has increased by between 5 to 10% during the twentieth century, and it is occurring in more concentrated storm events.
- Drought frequency may also have increased in some locations of Asia and Africa.
- There has been an increase in the number of record hot days. Especially high temperature days aggravate air pollution and photochemical smog.
- There has been a small increase in cloud cover over the Northern Hemisphere.
- Sea level has risen at an average rate of 1 to 2 mm per year for the last century as a result of melting ice caps and land glaciers and through the expansion of warmer seawater. A total rise of approximately 15cm is believed to have occurred during the twentieth century. Data suggests that the rate may have increased to over 2 mm per year during the 1990s.
- Animal and bird migration patterns have been altered.
- Coral reefs are suffering both warmer water and rising sea level.
- No increase in tropical storms and other extreme weather events has been verified to date.

Models have calculated likely future changes for these events throughout the twenty-first century, and they continue to change. It is of course impossible to predict future climate change because of uncertainty concerning human behavior. Hence scientists use alternative scenarios of possible combinations of future human population, economic growth and technological choice to illustrate alternative futures. In the most recent IPCC report, high growth and low growth alternatives demonstrate the possible range of climate futures. Depending upon the combination of assumptions about human choices and the range of climate sensitivities, global average temperatures in 2100 could be either 1.5 or nearly 6^{o}C warmer than in 1990. Regional temperatures at high latitudes would be even higher.

4. Technological and Economic Potential to Mitigate and Adapt to Climate Change

4.1 Energy and carbon dioxide

In the following sections, the sources of energy related carbon dioxide will be summarized by sector. It is customary to report only the carbon content of carbon dioxide that represents 12/44 or 27.3% of the mass of carbon dioxide. World total energy use and carbon dioxide has grown rapidly between 1971 and 1995. Energy use increase by 67% to 319 ExaJoules (10^{18} Joules), while carbon dioxide emissions from energy use increased 54% during that period to 5.5 Gigatons C (10^{9}metric tons). The annual average growth rate between 1990 and 1995 was 0.7% for energy and 1.0% for carbon dioxide. In 1995, industrial countries released 49% of carbon dioxide from energy, with an average annual growth rate of 0.6% increase per year. Countries with Economies in Transition (former Soviet Union and Eastern Europe) were well below their peak of 1990 with just 16% of emissions, an increase of just 18% since 1971. Emissions were declining at a rate of 5.1% annually. Developing countries accounted for 35% of emissions with growth rates ranged from 2.0% for Africa to 6.1% for Asia. There is considerable discussion among governments on responsibility for past contributions of greenhouse gases and the future potential for countries where fossil fuel use is growing rapidly.

Known reserves of fossil fuels that could be extracted with current technology at current prices are about 1500 Gt (10^{9} metric tons) of carbon, or 5 times the approximately 300 Gt of carbon released since the beginning of the industrial revolution. Most of this reserve is as coal. Much greater resources of unconventional oil and gas may also be available in the future. Hence, even though conventional oil and gas will peak and then decline in coming decades, there exists abundant fossil fuel that has the potential to release many times the carbon dioxide already added to the atmosphere.

The Climate Change 2001 Report by the IPCC is the principal source of data for this section.

4.1.1 Buildings

Buildings use energy directly for heating and cooling, and indirectly through electricity for lighting, appliances, office equipment, for food storage and preparation, and for motors in elevators, pumps and ventilating systems. Globally, buildings account for 34.4% of energy, and 31.5% of energy related carbon dioxide emissions. The IPCC found many examples of opportunities for substantially reducing the energy use and carbon dioxide emissions from buildings often at net negative cost. For example, new refrigerators use only one-quarter as much electricity ass they did in 1971 in the US. Windows, insulation, heat exchangers and other aspects of the building envelope combined with appropriate siting in an integrated building design have made it possible to lower the heating, cooling and lighting requirements by an average of 40% with demonstrated cases of 60 to 71% for residential and commercial buildings respectively. The cost of achieving a 40% reduction is estimated at $3/GigaJoule ($10^{9}$) saved in the US compared to an average cost for building energy of $14/GJ. Because of the rapid growth of appliance purchases in developing countries, there is an enormous potential to make major savings in electricity use over the coming decades at much lower cost than building additional power plants. For example, China is now the largest producer and consumer of refrigerators and air conditioners.

It is estimated by the IPCC that there could be cost effective savings in the energy sector using available technology that would lower carbon dioxide emissions by 27% by 2010, 31% by 2020 and 52% by 2050. It is concluded that policies will need to be put into place to achieve even these cost-effective goals.

4.1.2 Industry

The industrial sector is the largest user of energy (41%) and releases the largest fraction of energy related carbon dioxide (42.5%) as well as other greenhouse gases. What is unusual in this sector is that for developed countries, energy use has been growing slowly at only 0.9% per year, while carbon dioxide releases from all of the OECD industrial countries combined is 8.6% lower in 1995 than it was in 1971. Developing country emissions amount to only 36.4% of total industrial carbon dioxide releases. Emissions from Countries with Economies in Transition are down form their peak in 1990 by 28%. The major growth has come from developing countries in Asia where industrial carbon dioxide emissions now exceed those of the developed industrial countries. The IPCC estimates that there is the potential to reduce carbon dioxide emissions through energy efficiency gains by 10-20% by 2010, and by twice that amount by 2020. An additional 10% reduction could come from more efficient use of materials including recycling by 2010, and three times that amount by 2020.

Energy required to produce a ton of iron or steel is actually less in some developing countries such as Brazil or Korea than it is the UK or the US, but China and India remain substantially less efficient. Clearly, choosing improved technology can make a major difference as nations industrialize, and as the Economies in Transition reindustrialize. With 75% of its energy being consumed in the industrial sector, it is important that China is improving its energy/GDP intensity by a reported 4% per year. There have even been reports during the latter part of the 1990s that Chinese coal consumption and carbon dioxide emissions had actually declined. Japan remains among the most energy efficient industrial sectors in the world, and industries in countries such as the US, Canada and several European nations have tried to match their levels in specific industries.

4.1.3 Transportation

The transport sector consumes just 21.6% of global primary energy, and produces 22.0% of fossil fuel carbon dioxide. It is, however, the fastest growing sector with annual growth in carbon dioxide emissions of 2.4% per year. The world automobile fleet has been growing at a rate of 4.5% per year, and now exceeds 600 million light vehicles. Unfortunately the gains in efficiency that characterized the 1980s and early 1990s have begun to reverse themselves.

On the technology side, two Japanese manufacturers have had hybrid gasoline electric cars on the market since 1997, some 5 years earlier than was anticipated by the IPCC report of 1996. These vehicles essentially double fuel economy relative to similar, gasoline powered cars and provide a clean air bonus as well without sacrificing performance. Several additional manufacturers plan to introduce hybrid vehicles by 2003. Fuel cell technology has also moved rapidly forward several manufacturers have announced the introduction of fuel cell powered vehicles by 2005, some 10-20 years earlier than was anticipated only a few years ago. These innovations are currently expensive, and it remains to be seen if the price targets can be met. In addition to new engines, there is the potential for major weight reduction with alternative materials. A prototype composite vehicle using a fuel cell has achieved fuel economy of 2.5 liters per 100km

(100 miles per gallon), but the cost of a production model is uncertain. It is estimated by IPCC that the potential for emission reductions from the transport sector is in the range of 10-30% by 2010 with reductions of twice that amount being possible by 2020.

The major problem is that the amount of vehicle kilometers traveled continues to rise and outpace any technological gains in efficiency. A similar problem affects air transport as well. European governments have kept fuel prices high through taxes on fuel and have negotiated a voluntary, improved fuel economy standard with manufacturers. By contrast, in the United States, the trend is towards lager, less fuel-efficient vehicles and the exploitation of loopholes that undermine the legal fuel economy standards imposed by law.

The use of vehicle fuels derived from biomass also could reduce net carbon dioxide emissions substantially. Brazil has shown the way with its extensive ethanol from sugar cane industry that is now the most efficient in the world. The use of domestically produced biomass also reduces balance of payments problems for developing countries as well. In addition to improving technological performance, it is necessary to address alternative transport systems that build upon more effective land use planning.

4.1.4 Electric Power Production

The electric power sector is heavily dependent upon coal, and is responsible for 2.1 GtC/year, which is 38.2% of global energy and 37.5% of global carbon dioxide energy related emissions. The emissions from this sector are incorporated into the buildings, industrial, transport and agricultural sectors in calculating their contributions.

In many ways, electric power offers the largest range of possible technological options for reducing greenhouse gases. However, because of the rapid growth in electricity, emission reduction potential is estimated to be just 3 to 9% by 2010 and possibly 2 to 4 times that by 2020.

Efficient gas turbines have now become the fossil fuel technology choice since they achieve over 50% conversion efficiencies from heat to electricity. Work is proceeding on coal gasification that could make use of this technology in an integrated fashion. Emissions from all fossil fuel power plants could be reduced by recovering a portion of the one-half to three-quarters of the heat that is simply dumped into the environment through cogeneration. Fuel cells and microturbines promise a revolution of highly efficient distributed power systems that could revolutionize electric power generation by providing both electricity and heat onsite with significant reduction in transmission and distribution losses.

Renewable energy also holds significant promise. On a percentage basis, wind turbines represent the fastest growing energy source growing at a rate of over 25% per year for the last half of the 1990s; it presently accounts for about 20 GW of power or 0.1% of installed electric capacity world wide. The distribution is very uneven with Denmark now meeting 15% of its electric needs. Germany is the leader with one-third of the world's total wind power, and the U.S. and Spain following at about the same installed capacity as Denmark. India leads the developing countries because of Danish foreign assistance and investment. The potential for wind is particularly great in North America, in Africa and in Russia and other Economies in Transition, and substantially exceeds the total current use of electricity worldwide. The direct conversion of solar energy to electricity still represents a small fraction of annually added energy, but promising innovations such as solar roof tiles could enhance distributed roof top power systems. Burning or even better gasifying biomass would also substantially reduce net carbon dioxide to the atmosphere since the carbon is returned to growing plants on a sustained basis. Geothermal systems also make significant contributions in Central America, the Philippines, the U.S. and in Iceland. Hydropower continues to grow in many developing countries including China, India and Brazil, but few major projects are under development elsewhere.

A major effort has begun to explore the use of the hydrogen from fossil fuels and biomass for fuel cells and gas turbines. The carbon dioxide produced when hydrogen is removed could be sequestered in depleted oil and gas fields, injected into underground aquifers or possibly injected into the deep ocean. This sequestration option would greatly extend the use of fossil fuels without adding to the atmospheric loading of carbon dioxide. The economic and technical feasibility is currently being studied.

4.2 Agriculture carbon dioxide, nitrous oxide and methane

Agriculture is responsible for only about 4% of energy related carbon dioxide. Economies in Transition are the heaviest users of fossil fuels in agriculture followed by the developing countries of East Asia, and then the industrial nations. Other developing countries use very little fossil fuels. Rapid growth rates of 10% or greater in China and in Latin America are offset by declines of 5% in Economies in Transition for an annual global growth rate in carbon dioxide of only 0.6%. Agriculture is, however, responsible for approximately 20% of global warming because of heavy emissions of methane from rice farming, livestock and animal waste. Nitrous oxide is released from agricultural lands by bacterial denitrification of nitrogen fertilizer and the decomposition of animal waste, and accounts for 65 – 80% of total human emissions of this gas. It is technically feasible to lower emissions of methane and nitrous oxide from the agriculture sector by 10 – 12% in 2010, and by roughly twice that amount by 2020.

The use of biogas (methane) from anaerobic manure and crop residue decomposition has long been practiced in India and China for on-farm fuel production. More recently, this technique has been introduced into Europe and North America as a substitute for natural gas, and to assist in the management of animal waste and crop residues. Significant additional quantities of both methane and carbon dioxide are associated with the rapid rates of deforestation and land use change to produce new agricultural lands in developing countries. An unknown amount of soil carbon is also oxidized to carbon dioxide especially from peat soils when they are exposed to air. Non-tilling methods and other land management techniques can simultaneously reduce these sources of greenhouse gases and lower emissions from energy use.

Agriculture can also produce energy crops such as wood or sugar that can be burned directly, or else gasified or liquefied. Brazil has been at the forefront in converting sugar into ethanol for transport fuel with the production of 10 units of energy for each unit of fossil fuel input. For U.S. corn production of ethanol for fuel, the conversion efficiency is only about 1.5. Brazilian industry representatives have realized that sugar constitutes only about one-third of the energy value of sugar cane and efforts are being made to gasify the rest of the plant to run gas turbines for electric power generation. Energy plantations can often utilize land that is unproductive for agricultural crops. The burning of biomass releases about as much carbon dioxide per unit of energy as does coal, but if energy crops are grown sustainably, the growing fuel crop absorbs as much carbon dioxide while growing as it will release when burned.

4.3 Industrial gases

Industrial gases with significant global warming potential are released either during the manufacturing process or during the use of a product. The chemical industry has traditionally released significant quantities of nitrous oxide during the manufacture of nylon and nitric acid, but new processes have in some cases reduced these emissions by over 90%. A number of

Hydrofluorocarbons are emitted as waste products during chemical production, but these are now being captured. One company, DuPont, has announced that it will reduce its global warming potential by 65% by eliminating the release of most industrial greenhouse gases. The aluminum industry releases quantities of very long lived (50,000 years) perfluorocarbons, which are powerful greenhouse gases, during the conversion of bauxite to aluminum. New processes have been able to eliminate over 90% of these emissions, and a number of companies have volunteered to implement them. Sulfur hexafluoride has the highest GWP of any gas. It is used in electric switching equipment, in magnesium production and in a number of consumer products. Improved management and recovery of this material and its elimination from consumer products can reduce its emissions substantially. Similarly, recovery of hydrofluorocarbons from refrigerators and air conditioning systems as is now done with chlorofluorocarbons can significantly reduce their release to the atmosphere. The technical potential to eliminate nearly 60% of current industrial gas releases is possible in both 2010 and 2020.

Carbon dioxide is also an industrial gas from the reduction of iron ore to iron, in the production of ammonia from natural gas and in the manufacture of cement. Alternative manufacturing technologies or else physical sequestration of the carbon dioxide would be required to eliminate these sources, which amount to 5 to 10% of greenhouse gases.

4.4 Gases from waste

Municipal waste is a significant source of methane accounting for an estimated 7 – 8% of global emissions from landfills alone. Methane from wastewater treatment adds another few percent. As much as 80% of these emissions can be removed and burned as a fuel at net negative cost. In Europe and Japan, most waste is disposed of by incineration with heat recovery or electric power generation. Another source of carbon dioxide that might be considered waste comes from the flaring of unwanted natural gas in the production of petroleum, and in underground and surface coal and peat fires. Methane from coalmines is also a significant global warming gas that is released from both surface and deep mining of coal. The recovery of this coal bed methane has recently proven to be cost effective, reduces the risk of mine explosions and in some regions is now a significant natural gas substitute.

5. Policy Options

5.1 International Treaties

Because climate change is a global problem, the nations of the world have seen fit to create international agreements to address it. The first of these is the United Nations Framework Convention on Climate Change (UNFCCC), which was signed by 156 national heads of state and government in Rio de Janeiro in June of 1992. This represented the largest gathering of the world's political leaders in history, and the largest number of nations to sign an international agreement at a single time. By March of 1993, enough national parliaments had ratified the treaty for it to enter into force. This is a remarkably rapid process of adoption. Today 186 nations are parties to the UNFCCC agreement.

Article 2 of the Convention states the objective of the treaty as follows:

> *"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be*

achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

This treaty is primarily about goals and establishing procedures for decisions, keeping inventories of greenhouse gases, and establishing responsibilities. Nations have "common, but differentiated responsibilities." This means that all nations should strive to lower their greenhouse gas emissions, but that industrial nations are expected to be the first to take action stabilizing and then lowering their emissions; they should assist developing countries in lowering theirs. No specific requirements for action by countries to reduce the emission of greenhouse gases are included in the treaty.

The parties to the Framework Convention met for the first time in March of 1994, where they agreed that the procedural actions under the Convention were insufficient to meet the objective of stabilizing greenhouse gas concentrations at levels that would prevent harm to the climate system. Diplomats embarked on a negotiating process that resulted in the Kyoto Protocol in December 1997. The agreement was incomplete in terms of details, but it set targets and timetables for industrial nations, and proposed several innovative options for complying with the agreement.

- Industrial nations as a group must lower their emissions of greenhouse gas emissions by 5.2% below 1990 levels by the "first commitment period" 2008-2012. Different goals were set for groups of nations, e.g. Japan must reduce by 6%, the U.S. by 7%, and the European Union by 8%. Russia may remain at 1990 levels, and a few nations could increase their emissions.
- Reductions could be achieved by any combination of six gases, carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride using global warming potentials to determine equivalencies among them.
- Reductions were net reductions that could be achieved in part by planting biological sinks that could absorb carbon dioxide from the atmosphere.
- Industrial nations could reduce their emissions domestically through energy efficiency improvements, by fuel switching to lower carbon intensive fuels or biomass, utilize renewable energy or nuclear power.
- Industrial nations could meet their target by trading emission permits among themselves in order to minimize costs.
- Industrial nations could join together to achieve reductions through "joint implementation."
- Industrial nations could receive credit for building low greenhouse gas projects in developing countries under the "Clean Development Mechanism."

Unfortunately, it was unclear as to what the operating rules for these "Kyoto Mechanisms" would be. In 1998, the Parties met in Buenos Aires, and decided they needed two more years to negotiate. In November 2000, the Parties met in The Hague, and failed to reach agreement. It appeared that the Kyoto Protocol might have to be abandoned. Instead of terminating the meeting, the organizers suspended it, and agreed to reconvene in Bonn, Germany in July 2001. By this time there had been a change in the government of the United States, and the new administration announced that it was withdrawing from the Kyoto process. At the very last possible moment, the other 178 countries reached agreement on many of the outstanding disagreements. Additional negotiation to complete the operational provisions continued in Marrakech, Morocco. The Kyoto Protocol appears to still be in tact, but it appears increasingly unlikely that the reduction targets set for the industrial countries will be met within the timeframe of the Protocol.

5.2 National Actions

Even as diplomats work to achieve an agreement on the Kyoto Protocol, individual governments have been taking unilateral action to improve energy efficiency and lower greenhouse gas emissions. Many European countries and Japan have stringent performance standards for buildings that substantially lower energy use. European auto manufacturers have agreed with governments to a voluntary increase in fuel efficiency. Even though the United States has withdrawn form the negotiations, the National government supports numerous programs to reduce energy use through improved lighting, appliance and building standards. Sub nationally, individual states in the U.S. and provinces in Canada have agreed to ambitious greenhouse gas reduction targets regardless of what their national government does.

5.3 The Role of Civil Society

Non-governmental organizations, municipal governments institutions, universities and corporations have individually and collectively made commitments to lower greenhouse gases and have taken action to do so. The International Council of Local Environmental Initiatives (ICLEI) is a decentralized coalition of over 350 city, town and county governments in North America and in Europe. Their best known effort has been a highly successful local climate initiative begun in 1988 that has brought about major reductions in greenhouse gas emissions through local governmental actions. Another NGO, Clean Air-Cool Planet has cooperated with ICLEI, and worked with companies, universities, schools and religious groups to achieve real reductions in emissions. A growing number of colleges and universities including all of the public universities in New Jersey and Pennsylvania, the University of Colorado, Tufts University and others have taken actions to reduce their emissions and/or to meet the Kyoto target. These and other NGOs that work to improve energy efficiency and reduce greenhouse gases are listed in the bibliography.

Many corporations have pledged to reduce greenhouse gases. The large energy firm, BP Amoco, has pledged to reduce its carbon dioxide emissions 10% below 1990 levels by 2010. The company has introduced an internal emissions trading system to lower costs. Shell and other companies have also made commitments including many of the large companies associated with the Pew Center on Climate Change that develops policy strategies for addressing climate change. DuPont has committed to keeping its fossil fuel carbon emissions steady at 1990 levels until 2010, and to purchase 10% of its energy from renewable source by then. This is in addition to lowering their total greenhouse gas emissions by 65% by reducing industrial waste gas releases. The pulp and paper industry has made a major transition to the use of biowaste to fuel over half of its electricity and heat production in parts of Europe and North America.

6. Conclusions

Human activities have been shown to be altering the earth’s atmospheric composition and the climate. Warming by $0.6^{o}C$ during the past 140 years lies outside the bounds of normal fluctuations. Many other indicators from melting sea ice and glaciers, shifting vegetation patterns, to altered precipitation patterns and rising sea level have been identified and measured.

Nations are attempting to negotiate treaties that would address this problem in a comprehensive manner that would avoid giving some nations unfair economic advantage. This task is proving difficult, but several innovative strategies have emerged. Even though the Kyoto Protocol that requires specific reduction by nations is yet to enter into force, several national governments, many subnational governments as well as corporations, institutions and individuals have already taken action to reduce greenhouse gas emissions without waiting for an agreement. The Kyoto Protocol of the UN Framework Convention on Climate Change is currently the major international effort to begin the reduction of greenhouse gas releases. Some have argued that with its innovative provisions for international cooperation, the Protocol could be a "Blueprint for Sustainable Development." The Kyoto mechanisms of emissions trading will assist developed industrial countries to lower costs of emissions reductions through innovative technology development, joint implementation will encourage Economies in Transition to reindustrialize sustainably, and the Clean Development Mechanism can help developing countries achieve their goal of sustainable development while reducing greenhouse gas emissions. While some skeptics argue that we should wait to determine whether climate change will be a very serious problem before acting, others are pushing for a much more comprehensive, long-term approach.

Climate Change clearly poses a major challenge to our ability to design a sustainable future, but the issue is engaging the best efforts of scientists, economists, government officials and ordinary people.

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