Appendix M

Understanding and Evaluating Climate Change

Report

Understanding and Evaluating Climate Change

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Acronyms and Abbreviations

AR4	Fourth IPCC Assessment Report
C	Celsius
CCS	CO_2 Capture and Storage
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
F	Fahrenheit
FAR	First IPCC Assessment Report
GHG	Greenhouse Gases
GW/CC	Global Warming/Climate Change
GWP	Global Warming Potential
Halons	Halocarbons containing bromine
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
MW	Megawatt
NCDC	National Climate Data Center
N_2O	Nitrous oxide
NO_x	Nitrates
O_3	Ozone
PFCs	Perfluorocarbons
PPM	Parts Per Million
PM	Particulate Matter
RF	Radiative Forcing
SAR	Second IPCC Assessment Report
SCC	Social Cost of Carbon
SF_6	Sulfur Hexafluoride
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

1. Introduction

Information provided here summarizes current studies by the Intergovernmental Panel on Climate Change (IPCC) and from other peer-reviewed publications. The primary conclusions and projections regarding future climate change are drawn from IPCC. The growing level of international attention to Global Warming/climate Change (GW/CC) has resulted in a high level of ongoing scientific study and analysis. The body of scientific knowledge of the issue is evolving relatively rapidly. The information contained herein may become out-dated quickly, but serves as a "snapshot" of the state-of-knowledge at the time of the analyses conducted under this EIS. The reports referenced herein, and any subsequent reports provided by IPCC or other governmental bodies, should be consulted for more detailed or the most up-to-date information.

1.1 Climate Change Overview

A growing body of evidence indicates that Earth's atmosphere is warming. Records show that surface temperatures have risen about 0.7°C since the early 20th century and that 0.5°C of this increase has occurred since 1978 (National Academies of Sciences [NAS], 2006a summary, U.S. Global Change Research Program [USGRP], 2001). Observed changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend (NAS, 2006a; IPCC, 2001; 2007).

Earth's climate has exhibited variability and has changed over time. The extremes of the 100,000-year ice age cycles and interglacial periods have been well documented. The period of the last 10,000 years has been generally warm and stable. Observations in the 20th century indicate rapid climate change (IPCC, 2001; 2007; NAS, 2006a). The National Academy of Sciences (2006b) recently supported the conclusion that it is likely that the past few decades exhibited higher global mean surface temperatures than during any comparable period of the preceding four centuries. Additionally, 11 years between 1995 and 2006 rank among the 12 warmest years in the instrumentation record (1850 to 2006) for global surface temperature (IPCC, 2007).

1.2 Definitions

In common terms, one can think of "climate" as the "average weather" conditions over some extended period. The IPCC (2001) provides a more rigorous definition of climate as the "statistical description in terms of the mean and variability of relevant parameters over a period of time ranging from months to thousands or millions of years." Parameters measured are most often surface variables such as temperature, precipitation, and wind. Data are typically averaged in 30-year periods as defined by the World Meteorological Organization. "Climate change" is the shift in the average weather, or trend, that a region experiences. Thus, climate change cannot be represented by single annual events nor individual anomalies. That is, a single large flood event or particularly hot summer is not an

indication of climate change, while a series of floods or warm years that statistically change the average precipitation or temperature over time may indicate climate change.

The IPCC (2004) provides the following definition for climate change: Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).

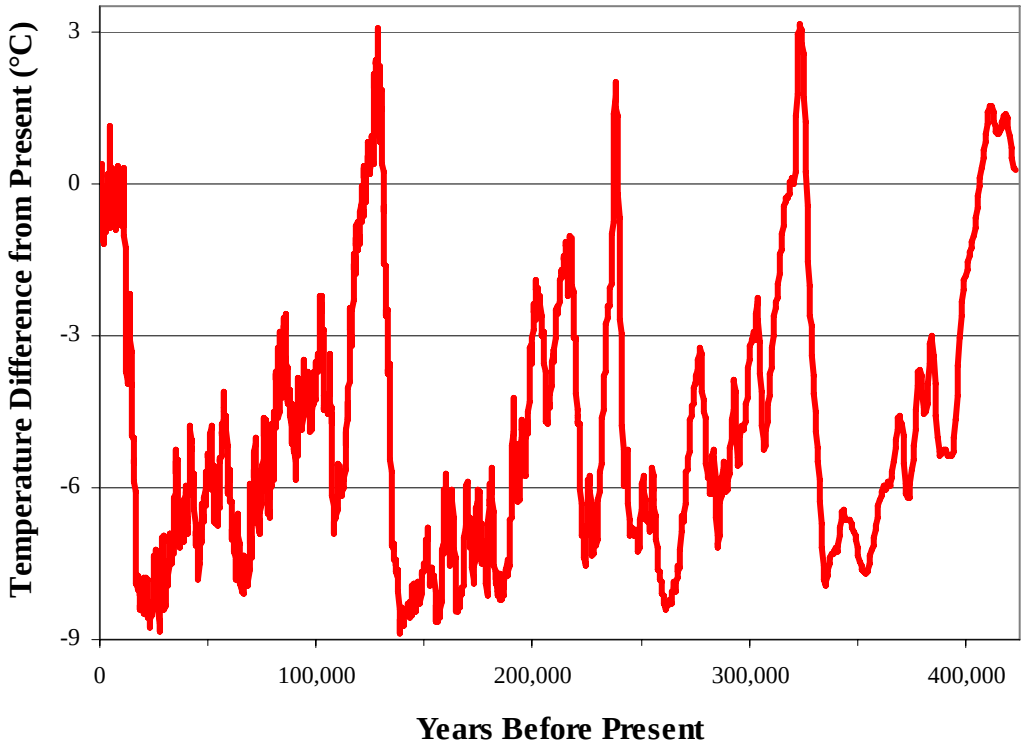
"Climate variability," refers to the deviation from the average climate. For example, an individual year that is drier or hotter than average would indicate variability, but may not indicate a shift in the trend as would be defined as climate change.

1.3 Paleoclimate

Studies of the earth's climate in the past (paleoclimate) provide a context for understanding current and future climate variability. Various "proxy" parameters, such as tree rings, ice cores, sea sediments, and geologic observations, have been studied to provide estimates of the earth's temperature over time. Studies of proxy data have revealed long periods with temperatures both much cooler and much warmer than present day. For example, portions of the Neoproterozoic Era (750 million and 600 million years ago), have been referred to as "snowball earth" periods because much of the Earth was covered by ice. Conversely, several periods within the Phanerozoic Era (the past 600 million years) have been noted as warm periods, including the middle Pliocene (3 million years ago), the Late Paleocene (58 million years ago), the Paleocene-Eocene Thermal Maximum (55 million years ago), the Cretaceous (130 to 65 million years ago), and the Early Jurassic (180 million years ago) (NASA, 2007b).

The recent Pleistocene Epoch (from 1.8 million years to 11,550 years before present) was a period of recurring and widespread glaciations (ice ages, or periods of glacial expansion), with almost one-third of the present land surface area intermittently covered by ice. Warm periods between glaciations are known as interglacial periods. The most recent glaciation reached its peak approximately 20,000 years ago, with a major ice sheet spreading across the North Central United States as far south as Central Illinois (USGS, 1992). This ice age subsided with the onset of the current warm interglacial period, known as the Holocene Epoch. Figure 1 shows a temperature record for the past 420,000 years, reconstructed from ice cores drilled at Vostok Station, located near the center of the East Antarctic ice sheet.

FIGURE 1
Vostok Ice Core Temperatures, Past 420,000 Years



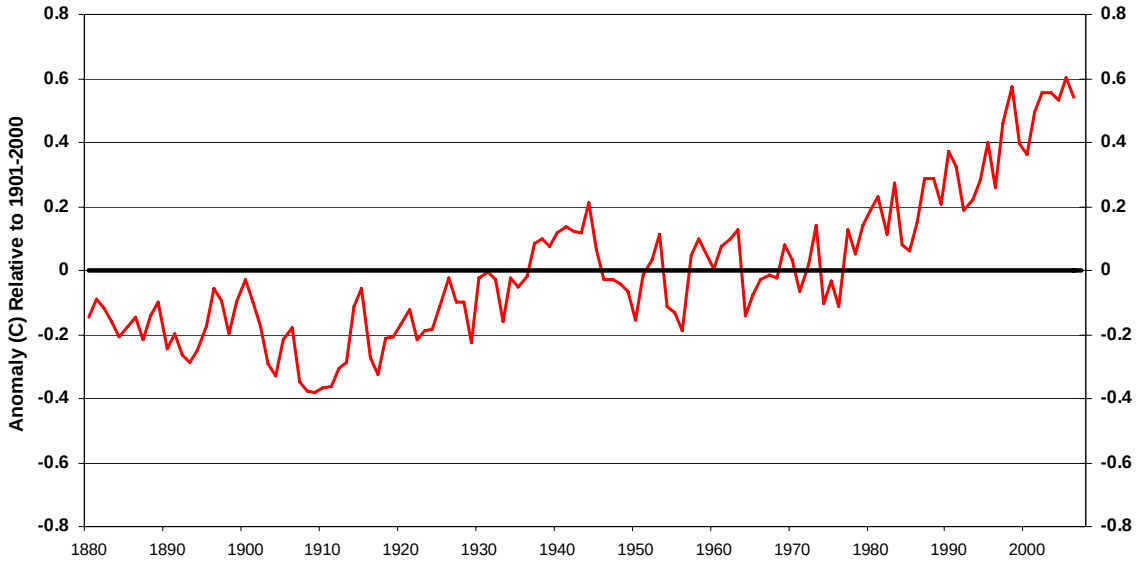
Source: Petit, J.R., et al., 2001

Although warm in comparison with the average climate over the Pleistocene Epoch, the current Holocene Epoch has exhibited periods both warmer and cooler than present day. The Holocene maximum was a period of warm temperatures approximately 3,000 years in duration that occurred 6,000 years before present. A shorter warm period, known as the Medieval warm period, occurred around 1000 AD and lasted for approximately 350 years. After the Medieval warm period, the Little ice age began around 1500 AD and lasted for approximately 300 years. After the Little ice age, both the proxy records and the instrumental temperature records indicate warming starting during the 20th century.

1.4 Recent Observations of Climate Change

The earliest records of temperature measured by thermometers are from western Europe beginning in the late 17th and early 18th centuries. The network of temperature collection stations increased over time. By the early 20th century, records were being collected in almost all regions except for polar regions where collections began in the 1940s and 1950s (National Climate Data Center (NCDC), 2007a). As with other periods in the earth's history, the period of instrumental temperature records shows both increases and decreases in global temperature. The changes in global temperature during the period of instrumental record are shown in Figure 2. The term "temperature anomaly" refers to the difference between the observed temperature and the 20th century average temperature.

FIGURE 2
Global Annual Mean Temperature Over Land and Ocean, 1880 to 2007



Source: National Climatic Data Center data, 2007b (accessed January 16, 2008)

As shown in Figure 2, the instrumental global temperature record shows a decreasing temperature trend from 1880 to 1909; an increasing temperature trend from 1910 to 1945; a relatively stable period from 1946 to 1975; and an increasing trend from 1976 to present. The overall trend for the 20th century reflects increasing global temperatures, with current global temperatures approximately 0.6°C above the 20th century average. Over the past century, global surface temperatures have increased at an average rate of approximately 0.05°C per decade, with higher rates of approximately 0.15°C per decade for the periods from 1910 to 1945 and 1976 to 2007 (NCDC, 2007b).

2. Potential Causes of Climate Change

Although climate science is a relatively new field of inquiry, much has been learned in recent years. Several mechanisms have been identified that have the potential to affect the earth's climate. Such mechanisms include, but are not limited to, the following:

- Aerosols
- Solar activity
- Surface albedo
- Variations in the earth's orbit
- Greenhouse gases

Summaries of these mechanisms are provided in the following subsections.

2.1 Aerosols

Aerosols are small particles present in the atmosphere with widely varying size, concentration, and chemical composition. Some aerosols are emitted directly into the atmosphere, while others are generated from chemical reactions between compounds in the atmosphere. Aerosols contain both naturally occurring compounds and those emitted as a result of human activities. Natural aerosols include mineral dust released from the surface, sea salt aerosols, biogenic emissions from the land and oceans, and sulfate and dust aerosols produced by volcanic eruptions (IPCC, 2007d, pp. 135-136, 2007). Human activities such as agricultural burning have also contributed to aerosol concentrations in the earth's atmosphere.

Although the aerosol forcing is not well-understood, aerosols are known to influence the earth's energy balance and resulting climate. The level of scientific understanding for the aerosol forcing is indicated as "medium to low" for the direct effect and "low" for the cloud albedo effect (IPCC, 2007e, Figure SPM.2, 2007). Aerosol particles influence radiative forcing directly through reflection and absorption of solar and infrared radiation in the atmosphere. In climate science, the term "radiative forcing" (expressed in W/m^2) refers to a disturbance in the balance between incoming radiant energy absorbed and outgoing radiant energy. This type of disturbance drives the earth's energy balance and resulting atmospheric temperature toward a new equilibrium (Masters, 1998). Some aerosols cause a positive forcing, while others cause a negative forcing. The direct radiative forcing summed over all aerosol types is believed to be negative. Additionally, aerosols are also believed to cause a negative radiative forcing indirectly through the changes they cause in cloud properties (IPCC, 2007d, p. 136). These indirect effects on clouds include the radiative properties, the amount, and lifetime of the clouds. In its AR4 report, the IPCC denotes the indirect aerosol effects as "cloud albedo effect" and "cloud lifetime effect" as these terms are more descriptive of the microphysical processes that occur (IPCC, 2007d, p. 153).

As mentioned in previous text, aerosols may be either natural or anthropogenic (human-caused) in origin. Volcanic eruptions are an important example of episodic natural aerosol

emissions. Explosive volcanic eruptions can create a short-lived (2 to 3 years) cooling forcing on the climate system through the temporary increases that occur in sulfate aerosol in the stratosphere. The IPCC also notes that the stratosphere is currently free of volcanic aerosol, since the last major eruption was in 1991 (Mount Pinatubo) (IPCC, 2007d, p. 137). Future volcanic eruptions are likely to influence global climate periodically. The degree of climate disruption resulting from these eruptions can be significant. For example, the proxy record indicates a volcano-induced northern hemisphere temperature decrease of 0.81°C in 1601, the year following the eruption of Huaynaputina in Peru (Briffa et al., 1998).

Anthropogenic aerosol emissions originate from a variety of sources (industry, transportation, agriculture, etc.). The IPCC estimates that anthropogenic aerosol emissions provide radiative forcings of -0.5 W/m^2 for the direct effect and -0.7 W/m^2 for the cloud albedo effect; thus, anthropogenic aerosol emissions are believed to exert a cooling influence on the earth's climate. This influence could increase or decrease in the future, depending on future changes in anthropogenic emissions.

2.2 Solar Activity

The sun is the earth's primary source of incoming energy; thus, solar activity is the most significant contributor to the earth's energy balance. The earth's energy balance includes a myriad of factors and is described briefly in the following text.

The magnitude of solar radiation at the outside of the earth's atmosphere is approximately 1,370 Watts per square meter (W/m^2). Averaged over the surface area of the earth, the incoming solar radiation is approximately 342 W/m^2. A portion of this incoming solar energy is reflected back into space by the atmosphere or the surface of the earth. This reflected energy fraction is called the "albedo," and for the earth is estimated to be approximately 31 percent. The remaining 69 percent of the incoming energy is absorbed by the atmosphere or the surface of the earth (Masters, 1998, pp. 464 and 470).

To maintain the earth's energy balance at steady-state conditions (constant temperature), all of the incoming solar energy must be radiated back into space (there is no heat transfer from the earth to space by conduction or convection). Because an object radiates heat at a rate proportional to the object's surface area times absolute temperature to the 4th power, it is possible to back-calculate the temperature (known as the ideal "blackbody temperature") required for the earth to radiate all the absorbed energy from the sun back into space. The earth's effective blackbody temperature is -19°C, a value less than the earth's average surface temperature of approximately 15°C (Masters, 1998, pp. 464 and 465). This 34°C discrepancy between the blackbody temperature and the actual temperature can be explained by the interaction between the outgoing radiation and the earth's atmosphere, a phenomenon known as the "greenhouse effect," as discussed in detail in the greenhouse gas Section 2.5.

Changes in solar energy output result in a forcing on the earth's energy balance and climate system. As discussed in the previous text, the energy balance for the earth is dictated by the amount of radiation received from the sun; thus, small variations in solar output can result in significant radiative forcings on the climate system. For example, solar output is known to follow an 11-year cycle in which solar irradiance varies by 0.1 percent (Dima et al., 2005).

A change in solar irradiance of 0.1 percent would result in a direct solar radiative forcing on the climate system of 0.3 W/m^2. Additional known and unknown feedback mechanisms have the potential to significantly amplify this forcing, and such feedbacks have been suggested by recent research. For example, Scafetta and West (2006) have recently shown that observed feedbacks associated with past changes in solar activity have resulted in radiative forcings greater than those predicted by climate models and that "most of the sun-climate coupling mechanisms are probably still unknown." The magnitude of these solar-associated forcings is such that "the amplitude of the 11-year solar signature on the temperature record seems to be three times larger than theoretical predictions." The conclusions of this research regarding solar-associated feedback mechanisms are consistent with recent findings by Douglass and Clader (2002), Bond, et al. (2001), and Chambers, et al. (1999).

Consistent with the findings of significant climate feedbacks in response to changes in solar activity, recent research suggests that changes in solar irradiance are responsible for a significant portion of the warming observed during the 20th century. For example, Willson and Mordinov have shown that solar irradiance, during times of quiet sunspot activity, has increased by 0.05 percent per decade between 1978 and 2003 (Willson and Mordvinov, 2003). According to Willson and Mordinov, "this trend is important because, if sustained over many decades, it could cause significant climate change" (Willson and Mordvinov, 2003). Beer, et al. (2000) conclude that changes in solar irradiance are responsible for approximately 40 percent of the global warming observed in the last 140 years. Additionally, findings by Scafetta and West suggest the presence of a solar cycle driving the climate of the last millennium, with maximum solar irradiance occurring during the medieval period and at present day (Scafetta and West, 2006). Scafetta and West further estimate that the sun has contributed as much as 45 to 50 percent of the warming observed from 1900 to 2000 (Scafetta and West, 2006). Thus, variations in solar activity are an important factor in the earth's climate (including recent climate change) and continue to be the subject of ongoing climate research.

2.3 Surface Albedo

As discussed in the previous text, the earth's albedo refers to the fraction of incoming solar energy that is reflected back into space by the atmosphere or by the surface of the earth. By reflecting incoming energy, reflective surfaces increase the earth's average albedo and thereby exert a cooling influence on the earth's climate. Conversely, surfaces that tend to absorb energy instead of reflecting it decrease the earth's average albedo and exert a warming influence on climate. The earth's surface albedo constantly changes because of both natural (for example, leaf growth during the springtime) and anthropogenic (for example, agricultural land use) surface influences.

Because natural changes in surface albedo are believed to occur over long timescales, anthropogenic changes are those typically studied with respect to climate change. Two primary types of anthropogenic surface albedo changes are land cover changes and black carbon deposition. Land cover changes, largely resulting from net deforestation, have increased the surface albedo, creating an estimated radiative forcing of minus 0.2 W/m^2, with a medium-low level of scientific understanding. Black carbon aerosol deposited on

snow has reduced the surface albedo, producing an associated radiative forcing of +0.1 W/m^2, with a low level of scientific understanding. Other surface property changes can affect climate through processes that cannot be quantified by radiative forcing, and the level of scientific understanding of these phenomena is very low (IPCC, 2007d, p. 132). Changes in surface albedo are expected to continue to occur in the future, with unknown effects on net radiative forcing.

2.4 Variations in the Earth's Orbit

Independent of any variations in solar output, variations in the earth's orbit affect the distribution and intensity of incoming solar radiation and therefore affect the earth's energy balance and resulting climate. The connection between climate and orbital variations were proposed in the 1930s by astronomer Milutin Milankovitch. The effects of the earth's orbital cycles on climate have become known as "Milankovitch oscillations" (Masters, 1998, p. 460). The three primary orbital cycles are as follows:

- Eccentricity—the oscillation in the earth's orbit from elliptical to nearly circular with a period of 100,000 years
- Obliquity—the tilt angle with respect to the earth's orbit, fluctuating from 21.5° to 24.5° with a period of 41,000 years
- Precession—the "wobble" of the earth's spin axis with a period of 23,000 years Masters 1998, p. 460-461)

The historical proxy record reveals that the orbital cycles have impacted the glacial-interglacial cycle during the Pleistocene. The primary glacial-interglacial cycle is approximately 100,000 years, with secondary oscillations with periods of 23,000 and 41,000 years, approximately matching the Milankovitch theory. While these orbital variations only changed the incoming solar energy by about 0.1 percent, the resulting global impacts are thought to be significant enough to trigger major changes in climate (to drive the cycle of ice ages) (Masters, 1998, p. 461-462). The IPCC summarizes this concept by stating that "[r]egular variation in the Earth's orbital parameters has been identified as the pacemaker of climate change on the glacial to interglacial time scale (see Berger, 1988 for a review). These orbital variations, which can be calculated from astronomical laws (Berger, 1978), force climate variations by changing the seasonal and latitudinal distribution of solar radiation (Chapter 6)" (IPCC, 2007d, p. 673).

Although variations in the earth's orbit are not believed to contribute to the warming observed since 1900, these variations have clearly contributed to climate changes in the past and will continue to do so in the distant future. Additionally, the response of the glacial-interglacial cycle to small changes in the amount of solar energy input brought on variations in the earth's orbit reinforces the climate's sensitivity to small changes in the solar forcing.

2.5 Greenhouse Gases

2.5.1 Historic Study of Greenhouse Gases

Joseph Fourier is credited with the discovery in 1824 that gases in the atmosphere might increase the surface temperature of the Earth. Fourier referred to an experiment by M. de Saussure, who exposed a black box to sunlight; he noted that when a thin sheet of glass is put on top of the box, the temperature inside of the box increases. In 1859 John Tyndall identified several gases that could trap heat waves, specifically water vapor and carbon dioxide (CO_2) (Weart, 2007).

During the 1950s, discovery of the radioactive isotope carbon-14 enabled scientists to distinguish fossil carbon in the atmosphere. Measurements of carbon in the atmosphere in conjunction with calculations estimating the carbon being taken up by the oceans led to the realization that although sea water did rapidly absorb CO_2, most of the added gas would promptly evaporate back into the air. By the late 1950s, a few scientists began to warn that greenhouse warming might become a problem, even within the foreseeable future (Weart, 2007).

In the late 1950s and early 1960s, a baseline level of CO_2 measured in the atmosphere of Antarctica and the Mauna Loa volcano in Hawaii established that the level of CO_2 in the atmosphere was rising. The baseline data supported the theory that the oceans were not taking up most industrial emissions. Through the 1960s, interdisciplinary sharing of information resulted in the first reasonably solid estimate of the global temperature change that was likely if the amount of CO_2 in the atmosphere doubled. However, the scientific community continued to persist with the assumption that "…the Earth's geochemistry was dominated by stable mineral processes, operating on a planetary scale over millions of years." (Weart, 2007) The debate continued into the 1970s; the veracity of old data was questioned, and historical temperature shifts could not be tied to CO_2 levels in the atmosphere, casting doubt on theories connecting human activity with CO_2 levels in the atmosphere and possible climactic effects. By the end of the 1970s, however, measurements of CO_2 levels in the atmosphere showed a clear rise, global temperatures began to rise again, and computer models were resulting in agreement on the future warming to be expected from increased CO_2 (Weart, 2007).

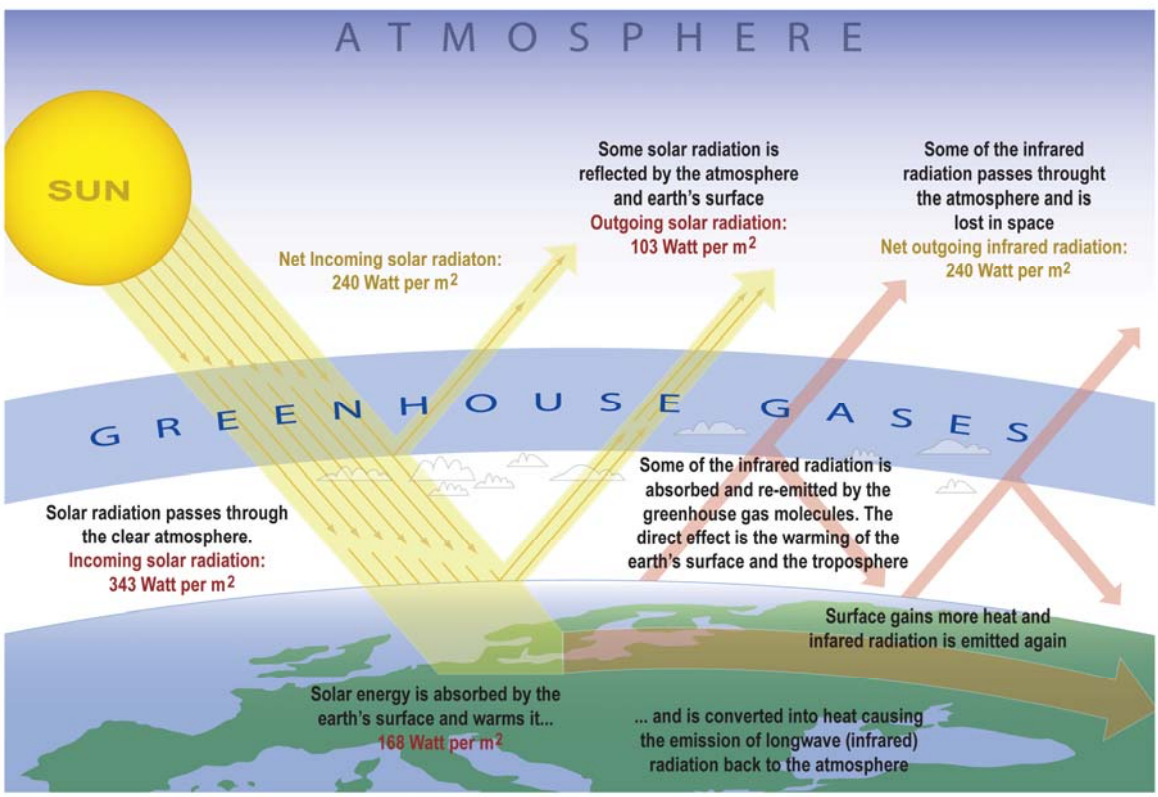
In the 1980s, chemical analysis of air trapped in ice cores drilled from the Greenland and Antarctic ice caps produced a record of temperature variations and provided air samples spanning hundreds of thousands of years. Testing of ice samples from the time of the last ice age showed CO_2 levels in the atmosphere were as much as 50 percent lower than in current warmer times. Researchers working with these and other data found that the level of atmospheric CO_2 had gone up and down in remarkably close step with temperature (see Figure 4 below). The modern air above the ice had reached levels of CO_2 concentrations far above anything seen in the geological era represented in the ice cores. Data from studies of paleontology and water temperatures in ocean basins mirrored trends linking temperature fluctuations with CO_2 concentrations, ultimately affirming computer modeling techniques (Weart, 2007).

2.5.2 The Greenhouse Effect (Science/Process)

The energy from the Sun powers the natural systems on earth. Energy is emitted from the Sun in the form of short wavelengths such as light and other electromagnetic rays. However, shortwave energy is not sensible (sensation of heat). Of the shortwave energy that reaches the Earth's atmosphere from the Sun, approximately one-third is reflected back into space, while the remaining two-thirds reaches the Earth's surface or is absorbed by the Earth's atmosphere. Shortwave energy reaching the earth's surface is either absorbed by the Earth or reflected back into the atmosphere (Le Treut et al., 2007). This process is depicted in Figure 3.

To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum. Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. The Earth's greenhouse effect warms the surface of the planet (Le Treut et al., 2007). Without the natural greenhouse effect, the average temperature at Earth's surface would be approximately 34°C colder. The greenhouse effect creates a climate on Earth that is conducive to life. Therefore, the greenhouse effect is a natural process, upon which life on Earth depends.

FIGURE 3
The Greenhouse Effect (adapted from NAS, 2006a)



The two primary gases in the atmosphere responsible for the greenhouse effect are water vapor and CO_2. Methane, nitrous oxide, ozone and several other gases present in the

atmosphere in small amounts also contribute to the greenhouse effect (Le Treut et al., 2007). Taken together, these are referred to as "greenhouse gases." In addition to reflecting the Sun's energy back into space, greenhouse gases also control the amount of heat radiated by the Earth that is trapped beneath the atmosphere. Fluctuations in greenhouse gases in the atmosphere are partially responsible for variances in the Earth's climate along with other influences. The concentrations of these gases in the atmosphere are affected by complex natural systems that tend to either emit or sequester these gases. Man-made (anthropogenic) influences and emissions also affect the prevalence of these gases in the atmosphere, particularly CO_2 which has been emitted in relatively large and growing quantities since the dawn of the Industrial Revolution when coal and later petroleum were burned for energy.

The ability of gases to absorb radiant energy from the earth is the key phenomena of interest in studying the greenhouse effect. Different gases absorb and radiate energy at specific wavelengths. Radiatively active gases that absorb wavelengths longer than 4 microns (long-wavelength radiation emitted by the earth) are called "greenhouse gases." The primary greenhouse gases include water vapor, CO_2, CH_4, N_2O, and O_3 (Masters, 1998, p. 467). Water vapor is the most important greenhouse gas (IPCC, 2007d, p. 115), contributing approximately 90 percent of the total greenhouse heating (U.S. Energy Information Administration, 1994; Ramanathan and Coakley, 1978; Newell and Dopplick, 1979). Because the infrared absorption bands of the various greenhouse gases overlap, the contributions from individual absorbers do not add linearly. For example, CO_2 would be capable of contributing up to 36 percent of greenhouse heating if no other greenhouse gases were present. However, because of the presence of other greenhouse gases with absorption spectra overlapping that of CO_2 (for example, water vapor), only about 12 percent of greenhouse effect heating would be removed if CO_2 were removed from the atmosphere entirely (U.S. Energy Information Administration 1994). Because of the total heating effect of all greenhouse gases, the earth's temperature averages approximately 15°C, instead of the ideal blackbody temperature of minus 19°C.

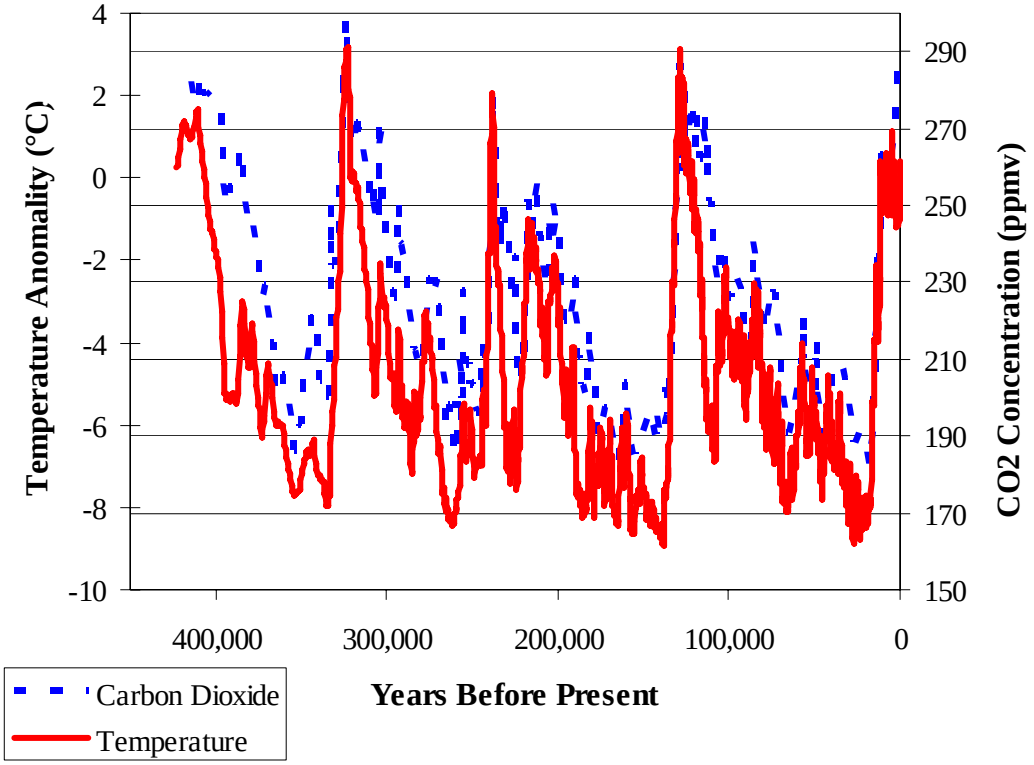
Greenhouse gases are contributed to the atmosphere by both natural and anthropogenic sources. While water vapor is the most important greenhouse gas (IPCC, 2007d, p 115) and contributes the largest portion of greenhouse heating, CO_2 is the most important anthropogenic greenhouse gas (IPCC, 2007e). Natural emissions of CO_2 from the earth's soils, vegetation, and ocean make up the vast majority of CO_2 emissions to the atmosphere. Anthropogenic CO_2 emissions from fossil fuel combustion are also a significant source of CO_2 emissions to the atmosphere, comprising 3 percent of the total global gross emissions of CO_2 (IPCC, 2007d, p. 514-515, Figure 7-3). The net CO_2 fluxes to and from the atmosphere, when averaged over decades or longer, are believed to have been in balance prior to 1750. Concerns have arisen in recent years that anthropogenic CO_2 emissions could contribute to a positive forcing on the earth's climate system, thereby influencing climate.

Fluctuations in greenhouse gas concentrations have occurred throughout the course of the earth's history. A variety of scientific studies have been conducted to evaluate the impacts of changes in CO_2 concentration on the earth's climate. One such study by Rothman (2002) evaluated CO_2 concentrations over the last 500 million years and found that CO_2 levels have generally decreased for the last 175 million years. Prior to that time, CO_2 levels appear to have fluctuated from about two to four times modern levels. The Rothman study concludes that variations in CO_2 levels exhibit "no systematic correspondence with the geologic record

of climatic variations at tectonic time scales." Over the most recent 60 million years, CO_2 concentrations in the atmosphere have typically been higher than present (but decreasing overall), with multiple periods where CO_2 levels were approximately 3 to 10 times present-day levels (IPCC, 2007d, p. 441).

Over the period of record for the Vostok ice cores (approximately the past 420,000 years), CO_2 concentrations and temperature have correlated closely during the last several glacial-interglacial cycles. Figure 4 shows the trends in temperature and CO_2 concentration based on the Vostok ice core data.

FIGURE 4
Temperature and CO_2 Concentration



Source: Petit, J.R., et al., 2001

As shown in Figure 4, temperature and CO_2 concentrations have followed the same trends over the past 420,000 years; however, a statistical analysis of the data indicates that CO_2 did not initiate the changes in temperature trends during this period. Mudelsee (2001) evaluated the CO_2/temperature data from the Vostok ice cores and determined that variations in CO_2 concentration lag behind those of the temperature record by an average of 1,300 years. These findings indicate that during the 420,000 years of the Vostok ice core record, the warming trends began first, followed by increasing CO_2 concentrations an average of 1,300 years later. Variations in the eccentricity of earth's orbit around the sun, with longer periodicities at 400,000 and 100,000 years, also correspond to the cycle of glacial-interglacial periods. However, the variations in the earth's orbit are not believed to contribute to the warming observed since 1900.

3. Anthropogenic Contributions of Greenhouse Gases

Anthropogenic CO_2 emissions have increased from low levels in pre-industrial times (prior to 1750) to approximately 36,000 million tons (36 billion tons) per year at present day (IPCC, 2007e, p 2-3). The majority of anthropogenic CO_2 emitted to the atmosphere, approximately 80 percent, is released by fossil fuel combustion (IPCC, 2007e, p 2-3). The remaining 20 percent originates from anthropogenic land use changes. The main fossil fuel combustion CO_2 emission source categories include electric power generation (35 percent of total anthropogenic CO_2 emissions [International Energy Agency, 2005), transportation (20 percent), other industry (20 percent), and residential (20 percent). Global emissions in all of these fossil fuel categories are currently increasing, and are expected to do so for at least several decades; however, as discussed in the following text, longer term future trends in global CO_2 emissions are uncertain.

Increased CO_2 emissions are associated with commercial, industrial, and population growth; therefore, CO_2 emissions from developing nations such as China and India are increasing rapidly. For example, China is currently constructing the equivalent of two 500-megawatt (MW) coal-fired power plants per week (Katzer et al., 2005). In the developed world, growth in population and industry, along with an aging fleet of existing power plants, dictate the need to construct new electric generating capacity. In the United States, more than 70 coal-fired power plant projects are currently proposed at various stages of development (EPA, 2007b).

Overall, the electric power industry was the single largest contributor to greenhouse gas emissions in 2005, responsible for approximately 33 percent of all greenhouse gas emissions from the U.S. in 2005 (EPA, 2007a). The second and third highest contributors were transportation and industry, emitting 28 percent and 19 percent respectively.

Concentrations of CO_2 in the atmosphere has been the main focus of scientific investigation with regard to anthropogenic effects on Earth's climate, largely because CO_2 is the second highest concentration of greenhouse gas in the atmosphere behind water vapor. However, other atmospheric components lend themselves to anthropogenic forcing including methane, nitrous oxide, and halocarbons. In addition, aerosols are now believed to also play a key role.

3.1 Carbon Dioxide

Testing of the air in bubbles trapped in ice cores has revealed that atmospheric CO_2 levels are 35 percent higher than before the Industrial Revolution (BRAC ND, EPA, 2007a). The atmospheric concentration of CO_2 in 2005 exceeded the natural range over the last 650,000 years (Le Treut et al., 2007). From 1990 to 2005 the U.S. CO_2 emissions increased by 20.3 percent (EPA, 2007a).

Approximately 84 percent of the 2005 greenhouse gas emissions from the United States were CO_2 (EPA, 2007a). The main anthropogenic source of CO_2 in the atmosphere is the consumption of energy from fossil fuels (IPCC, 2001). Other factors include burning of solid waste, trees and wood products, and also as a result of other chemical reactions including production of cement. CO_2 from fossil fuel combustion accounted for 79 percent of CO_2 emissions in 2005. Electricity generators consumed 36 percent of the U.S. energy from fossil fuels and emitted 41 percent of the CO_2 from fossil fuel combustion in 2005. Of the fossil fuel CO_2 emissions in the United States in 2005, approximately 40 percent was from petroleum, 40 percent was from coal, and 20 percent was from natural gas. Approximately 80 percent of electricity generation was produced using coal (EPA, 2007a).

A carbon sink is defined as a place where carbon accumulates and is stored, such as in plants as they accumulate CO_2 during the process of photosynthesis and store it in their tissues as carbohydrates and other organic compounds (Australian Greenhouse Office, 2007). Changes to or reductions in plant cover result in a reduction in the ability of biological processes to remove CO_2 from the atmosphere. This contributes to increasing CO_2 levels in the atmosphere. Thus changes in land use are the other major contributor to CO_2 concentrations in the atmosphere, primarily through deforestation, the effects of fire and grazing on savannahs and grasslands; reductions in peats and wetlands; and conversion of natural vegetation to agriculture (IPCC, 2001a).

3.2 Methane

The global atmospheric concentration of methane is over 140 percent higher than pre-industrial levels. The atmospheric concentration of methane in 2005 exceeded the natural range over the last 650,000 years (Le Treut et al., 2007). Proportionally, methane makes up a much smaller part of greenhouse gases in the atmosphere than CO_2. However, methane is more than 20 times as effective as CO_2 at trapping heat in the atmosphere (IPCC, 2001a; Hofmann, 2004 in EPA, 2007a).

The primary anthropogenic source of methane in the United States in 2005 was landfills. Other anthropogenic sources of methane in the atmosphere include utilization of fossil fuel which includes fugitive emissions plus uncombusted fractions, ruminants (cattle), waste treatment, rice agriculture, biomass burning (IPC, 2001b), and coal mining (EPA, 2007a). In 2005, methane represented 7.5 percent of all U.S. emissions. Methane emissions resulting from generation of electricity from coal-fired power plants represent approximately 0.2 percent of total methane emissions from energy production (EPA, 2007a).

3.3 Nitrous Oxide

Atmospheric concentrations of nitrous oxide are 18 percent higher than pre-industrial levels (Le Treut et al., 2007). While total nitrous oxide emissions are lower than CO_2 emissions, nitrous oxide is approximately 300 times more powerful than CO_2 at trapping heat in the atmosphere.

The primary anthropogenic source of nitrous oxide in the atmosphere is agricultural soils. Nitrous oxide is a primary ingredient in many common fertilizers used in agricultural operations. Other anthropogenic sources include cattle and feedlots, industrial sources (this

would include the energy industry), and biomass burning (IPCC, 2001a). Emissions resulting from coal-fired power plants represented 65 percent of all nitrous oxide emissions from stationary sources, and 17 percent of all nitrous oxide emissions from energy production (EPA, 2007a).

3.4 Halocarbons

Halocarbons are any of various compounds of carbon and one or more halogens (such as chlorine or fluorine). Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons (halocarbons containing bromine) are ozone depleting substances covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. Since implementation of the Montreal Protocol, production of ozone depleting substances is being phased out, and these substances are being replaced by hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), as they do not deplete stratospheric ozone. They are, however, powerful greenhouse gases with high global warming potentials and extremely long atmospheric lifetimes. Emissions resulting from the substitution of ozone depleting substances have been increasing, and are both the largest and fastest growing source of HFC, PFC, and SF_6 emissions (EPA, 2007a).

4. Projections of Future Changes in Climate

4.1 Establishment of the Intergovernmental Panel on Climate Change

Concerns about human impacts on world climate led to efforts to organize and mobilize the scientific community world-wide. The first World Climate Conference organized by the World Meteorological Organization in 1979 called for, "global cooperation to explore the possible future course of global climate and to take this new understanding into account in planning for the future development of human society" (IPCC, 2004).

The Advisory Group on Greenhouse Gases was established by the United Nations Environment Programme (UNEP), World Meteorological Organization (WMO), and International Council for Science as a result of a joint 1985 conference to assess the role of CO_2 and of other greenhouse gases in climate variations and associated impacts. The Advisory Group on Greenhouse Gases was established, "… to ensure periodic assessments of the state of scientific knowledge on climate change and its implications" (IPCC, 2004).

The Intergovernmental Panel on Climate Change (IPCC) by the UNEP was established in concert with the WMO in 1988. The role of the panel is to, "assess on a comprehensive, objective, open and transparent basis the best available scientific technical and socio-economic information on climate change from around the world. The assessments are based on information contained in peer-reviewed literature and, where appropriate documented, in industry literature and traditional practices" (IPCC, 2007a).

4.2 Predicting Climate Change

The IPCC's predictions for future climate change are based primarily on general circulation model (GCM) results. GCMs account for a variety of parameters and interactions within the earth's atmosphere, oceans, and land cover to predict the resulting climate impacts resulting from a given set of input conditions.

GCMs evaluate climate by dividing the earth's atmosphere into discrete grid boxes and numerically solving the fundamental equations describing the conservation of mass, energy, momentum, etc. for each atmospheric grid box, while taking into account the transfer of those quantities between grid boxes. GCMs also consider, often in parameterized form, the physical processes within the boxes, including sources and sinks of these quantities (NASA, 2007a).

Because of the large size of the GCM grid boxes (typically between 250 and 600 kilometers in horizontal resolution), GCM resolution is not typically sufficient to account for small-scale phenomena. Some physical processes, such as those related to clouds, occur at smaller scales and cannot be properly modeled. Instead, their known properties must be averaged over the larger scale in a technique known as parameterization. This is one source of uncertainty in GCM-based simulations of future climate. Other sources of uncertainty relate

to the simulation of various feedback mechanisms. The term "feedback" refers to mechanisms by which a change in one climate parameter can influence other climate parameters. Examples of paired feedback mechanisms include water vapor and warming, clouds and radiation, and ocean circulation and ice and snow albedo. As a result of these uncertainties, different GCMs may simulate different responses to the same forcing because of the ways certain processes and feedbacks are modeled (IPCC, 2007c).

Even considering the uncertainties mentioned in the previous text, GCMs have advanced to a point where model outputs generally reproduce observed features of recent climate and past climate changes (IPCC, 2007d, p. 591).

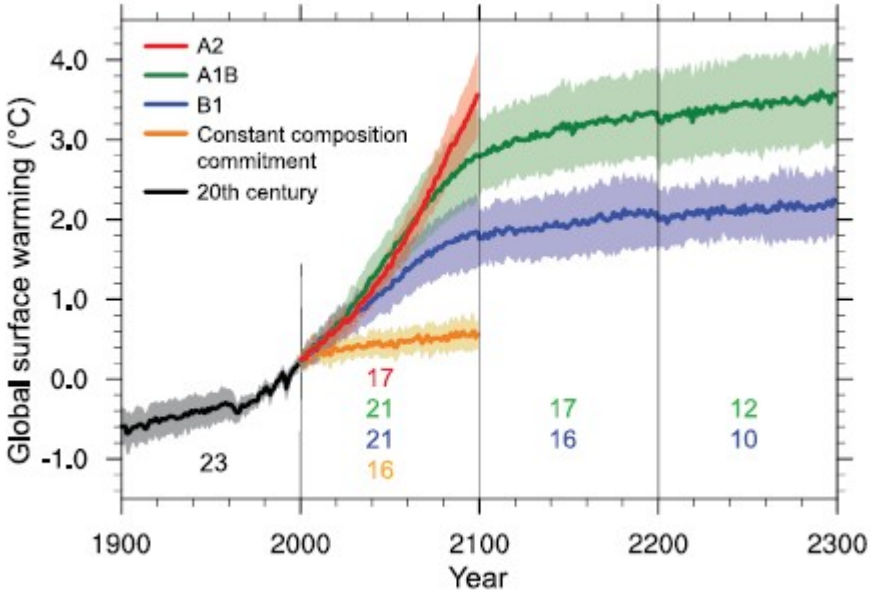
4.3 Summary of IPCC-Reported Predictions for the Effects of Future Climate Change

The IPCC's Working Group I has published its contribution to the IPCC's Fourth Assessment Report (AR4), "The Physical Science Basis." Chapter 10 ("Global Climate Projections") provides predicted climate change impacts for a variety of modeled scenarios. For the 21st century, the IPCC predicts changes to several climate parameters, including temperature, precipitation, ocean acidity, and sea level. The IPCC's predictions for future climate change are summarized in the following subsections. Note that the following climate change impact discussions are not intended to address every conceivable environmental impact of climate change. Rather, the following climate change predictions are presented to summarize the primary climate change impacts noted by the IPCC in the AR4.

4.3.1 Surface Air Temperature

Based on model simulations applied to six different greenhouse gas emission scenarios, the IPCC projected an increase of the globally averaged surface temperature of 1.8 to 4.0°C for the end of the 21st century relative to 1980 to 1999 period. The model projections of temperature changes are illustrated graphically in Figure 5. The various lines represent separate IPCC emission scenarios. A2 represents the rapid population growth scenario; A1B represents the balanced energy scenario; and B1 represents the low emissions intensity scenario.

FIGURE 5
Summary of Predicted Temperatures



Source: IPCC, 2007d, Figure 10.4

4.3.2 Precipitation

Globally, higher temperatures should lead to higher rainfall because a warmer climate will contribute to higher rates of evaporation and a more active hydrologic cycle. However, the spatial distribution of moisture and precipitation changes is complex and drives regionally distinct trends. On a global scale, a poleward shift in storm tracks is projected to continue that trend observed in the last half century (IPCC, 2007; Yin, 2005). As a result, increases in the amount of precipitation are very likely at high latitudes, while decreases are likely in most subtropical land regions (IPCC, 2007). The prediction of changes in precipitation patterns continues to carry great uncertainty, and there remains a lack of consensus for many regions. However, recent scientific opinion appears to support the broad notion that "wet regions get wetter and dry regions get drier" (Held and Soden, 2006; North, personal communication).

Additionally, the intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. In areas where mean precipitation is predicted to decrease, precipitation intensity is projected to increase, with longer periods between rainfall events. A tendency is predicted for drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions (IPCC, 2007d, p. 750).

4.3.3 Sea Level

Mean sea level is expected to rise over the 21st century by 0.18 to 0.59 meter, reflecting the range of modeled scenarios. Thermal expansion (warmer water occupies more space) is the largest component of the projected sea level rise, contributing from 70 to 75 percent of the increase. Melting glaciers, ice caps, and the Greenland Ice Sheet are also projected to contribute positively to sea level. Models indicate that the Antarctic Ice Sheet will receive

increased snowfall without experiencing substantial surface melting, thus gaining mass and thus tending to reduce mean sea level (IPCC, 2007c, p. 750-751). The increases in sea level projected in the Fourth Assessment Report (AR4) are somewhat smaller than those projected in the Third Assessment Report (TAR) (IPCC, 2001; USGRP, 2001), a difference largely related to improved information about uncertainties and contributions.

The sea level rise estimates provided in the previous text do not include possible rapid dynamic changes in ice flow that could contribute to significantly larger increases. These larger values cannot be excluded, but the current understanding is insufficient to assess the likelihood or upper bound on sea level rise (IPCC, 2007).

4.3.4 Ocean Acidity

CO_2 concentrations in the earth's atmosphere are expected to increase over the 21st century. When CO_2 dissolves in water, it can form carbonic acid. Increases in acid concentration tend to result in lower pH; thus, increasing atmospheric CO_2 concentrations lead to increasing acidification (and decreasing pH) of the surface ocean. The IPCC notes modeled ocean pH reductions of between 0.14 and 0.35 pH units in the 21st century (IPCC, 2007c, p. 750).

4.3.5 Climate Variability and Extreme Events

Increased variability in future climate and extreme events are predicted as a result of future climate change. The IPCC reports that temperature extremes, heat waves, and heavy precipitation events are "very likely" to become more frequent, and that future tropical cyclones are "likely" to become more intense (IPCC, 2007e). In its assessment of North America regional climate projections (Christensen et al., 2007), the IPCC reports similar findings of increased prolonged hot spells and increased diurnal temperature range, particularly in summer.

4.3.6 Climate Tipping Points

Some climatologists have postulated the existence of climate "tipping points." A tipping point would occur if an aspect of the climate system were to reach a state such that strong amplifying feedbacks were activated by only moderate additional warming. For example, some scientists have speculated that only moderate additional warming beyond current conditions might induce disintegration of the West Antarctic ice sheet and Arctic sea ice. Amplifying feedbacks could include increased absorption of sunlight as melting exposes darker surfaces and increasing iceberg discharge as the warming ocean melts ice shelves that would otherwise inhibit ice flow (NASA, 2007c). If such accelerated melting were to occur, a range of potential environmental impacts could result, including sea level rise, changes in ocean currents, and impacts to species.

5. Emissions Estimates for and Climate Impacts from Anthropogenic Greenhouse Gas Contributions

5.1 Methodology and Uncertainty

Calculating or measuring greenhouse gas emissions is not a simple task. Smoke stack emission tests are reasonably accurate, but vary over time depending on climate, production and other variables. Emissions from non-point sources, such as motor vehicles, vary based on the octane, additives, catalytic converters, operating temperature and other variables. Data for older point sources may be available for emissions included under National Ambient Air Quality Standards, such as sulfates and nitrates, but not for greenhouse gases, such as nitrous oxide and methane. As an example, in its *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005* (EPA, 2007a), EPA estimates the range of uncertainty in its 2005 data for GHG emissions from "fossil fuel combustion" to be only minus 2 percent to 5 percent for CO_2, but minus 30 percent to 112 percent for methane emissions from stationary combustion and minus 22 percent to 189 percent for nitrous oxide emissions from stationary combustion. Ambient air samples can be affected by uneven mixing, upwind sources, deposition, and other variables.

One of the most widely used methods for estimating emissions is the use of emission factors. Used by EPA, DOE, the IPCC and others, emission factors are based on test data of emissions meeting certain testing quality standards. For example, measured CO_2 emissions from Powder River Basin sub-bituminous coal burned in supercritical steam generating facilities are unitized and averaged, yielding an emission factor that characterizes CO_2 emissions per BTU of heat generated through the combustion process, or each ton of coal burned, or some other unit. This emission factor is then used to predict CO_2 emissions from a proposed generating unit, such as the proposed action, based on the design fuel, generating capacity, and pollution or other control methods that will be used to reduce emissions.

5.2 Quantitative Emissions Analysis

5.2.1 Global

Data available for global emissions of GHGs is based less on measurements, in some countries, and more on estimates. In addition, the most comprehensive data is for CO_2 from the "consumption and flaring of fossil fuels," and does not include CH_4, N_2O, or other gases. Table 1 shows estimated CO_2. emissions for 1995 and 2005 by IPCC region, and percent of the total.

TABLE 1
World CO_2 Emissions from the Consumption and Flaring of Fossil Fuels by IPCC Region (million metric tons of CO_2 (MMT CO_2))

IPCC Region	CO_2 1995 (MMT CO_2)	CO_2 2005 (MMT CO_2)	2005 Percent of Total
North America	6,115.03	6,987.78	24.8
Central & South America	849.88	1,096.16	3.9
Europe	4,272.41	4,674.75	16.6
Eurasia	2,480.82	2,577.82	9.1
Middle East	894.41	1,450.81	5.1
Africa	817.88	1,042.92	3.7
Asia & Oceania	6,559.45	10,362.49	36.8
World Total	**21,989.88**	**28,192.74**	

Source: EIA, 2007d

Table 2 shows direct GHG emissions from generation of electricity by fuel source for 1995 and 2005. The fourth column shows how much electricity was generated using each of the listed fuel sources for 2005. Because the emissions and power data are from different sources, not all of the categories match up. Nevertheless, the data show that, among the major fuel sources, coal produced the largest quantity of CO_2 per megawatt hour, followed by petroleum, natural gas, and geothermal. Nuclear, hydroelectric and wind generation have no GHG emissions, although all sources have associated life cycle impacts.

TABLE 2
GHG Emissions Related to Generation of Electricity (MMT CO_2 Eq.) and Electricity Generation by Fuel Source for 2005 (1,000 megaWatt-hours (MWhr))

Gas/Fuel Type or Source	GHG 1995[1] (MMT CO_2 Eq.)	GHG 2005[1] (MMT CO_2 Eq.)	Power 2005[2] (1,000 MWhr)
CO_2	**1,958.7**	**2,405.8**	**2,513,609**
Fossil Fuel Combustion	1,939.3	2,381.2	
Coal	*1,648.7*	*1,958.4*	2,013,179
Natural Gas	*229.5*	*320.1*	757,974
Petroleum	*60.7*	*102.3*	122,522
Geothermal	*0.3*	*0.4*	
other gases			16,317
Nuclear			781,986
Hydroelectric Conventional			270,321
Other Renewables			87,213
Pumped Storage			-6,558
Other			12,468
Net Generation All Sources			4,055,423
Municipal Solid Waste Combustion	15.7	20.9	

TABLE 2
GHG Emissions Related to Generation of Electricity (MMT CO_2 Eq.) and Electricity Generation by Fuel Source for 2005 (1,000 megaWatt-hours (MWhr))

Gas/Fuel Type or Source	GHG 1995[1] (MMT CO_2 Eq.)	GHG 2005[1] (MMT CO_2 Eq.)	Power 2005[2] (1,000 MWhr)
Limestone & Dolomite Use	3.7	3.7	
CH_4	**0.6**	**0.7**	
Stationary Combustion*	0.6	0.7	
N_2O	**8.5**	**10.0**	
Stationary Combustion*	8.0	9.6	
Municipal Solid Waste Combustion	0.5	0.4	
SF_6	**21.8**	**13.2**	
Electrical Transmission and Distribution	21.8	13.2	
Total Emissions	**1,989.5**	**2,429.8**	

*Includes only stationary combustion emissions related to the generation of electricity
Sources:[1] EPA, 2007a; [2] EIA, 2007c

5.2.2 Global CO_2 Emissions from Fossil Fuels Including Coal Fired Power Plants

The IPCC states that emissions from the burning of fossil fuels is an important component of global anthropogenic GHG emissions. Table 3 summarizes CO_2 emissions from global sources of fossil fuels, including coal fired power plants.

TABLE 3
Contribution of CO_2 Emissions from Coal-Fired Power Plants

CO_2 Emission Sources	CO_2 Emissions (million tons/yr)	Source of Data
Global total from land and ocean	855,592	IPCC AR4 Figure 7.3, p. 515, 2007
Existing global total from fossil fuels	29,085	IPCC Summary for policymakers, p. 2, 2007
Existing global total from coal-fired power plants	7,722	Stern Review on the Economics of Climate Change, Annex 7.b

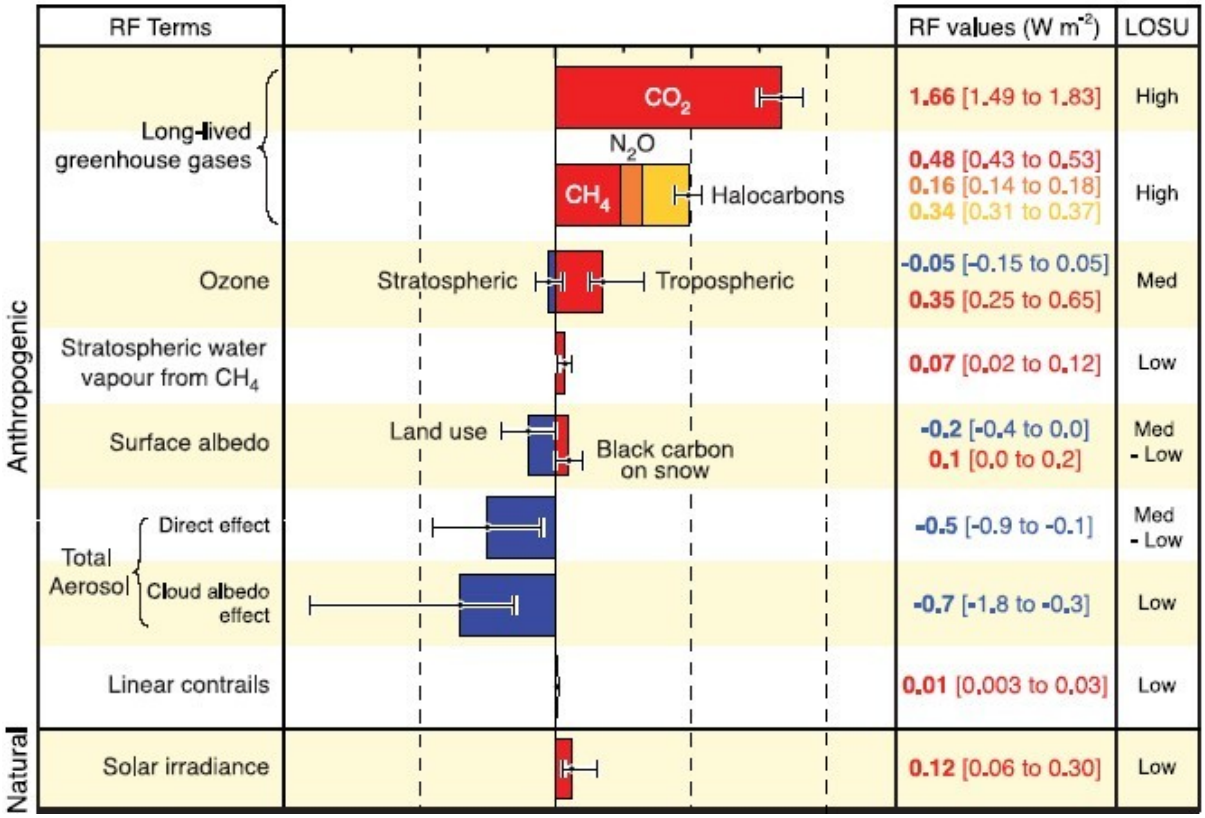
According to the IPCC, the range of uncertainty in the global CO_2 emissions from fossil fuel combustion and cement production is ±1,212 million tons per year of CO_2 (IPCC, 2007d, p. 516). Thus, the CO_2 emissions increases from a single plant (for example, 12 million tons per year), or even the emissions increases resulting from several new plants considered together, are well within the range of uncertainty in the IPCC's estimates.

5.3 Climate Impacts from Anthropologic Greenhouse Gas Emissions

5.3.1 Global

The IPCC states that, "[m]ost of the observed increase in global average temperatures since the mid-20th century is very likely because of the observed increase in anthropogenic greenhouse gas concentrations" (IPCC, 2007d, p 2-3). Further, the IPCC concludes that "[i]t is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica" (IPCC, 2007d, p 2-3).

FIGURE 6
Radiative Forcing on Climate Between 1750 and 2005



Source: IPCC, 2007d, Figure SPM.2

As reflected in Figure 6, the combined radiative forcing resulting from all known factors since 1750 is 1.84 Watts per square meter (W/m^2). Anthropogenic CO_2 emissions are the largest component of this estimated forcing, estimated at 1.66 W/m^2. It should be noted that the level of scientific understanding (LOSU) for the various forcings in Figure 6 ranges from low to high. There is a high LOSU for the greenhouse gas forcings because these forcings are well established based on theoretical and laboratory study. The LOSU for some other significant forcings (for example, cloud albedo effect) is currently low; thus, the magnitudes of several of the forcings would be expected to change in future IPCC assessment reports as the state of the science progresses. The margins of uncertainty in Figure 6 should be noted as

well. In many cases, the range of uncertainty is wide, again reflecting the potential for more refined estimates in future IPCC assessment reports.

To summarize, quantification and estimation of greenhouse gas emissions and their effect is influenced by uncertainty encountered and compounded at multiple levels, from measurement of emissions to predicting the long-term effects of future emissions.

5.3.2 Single source

Individual sources of CO_2 (for example, a factory, power plant or other industrial process that emits CO_2) have an extremely small contribution to the global collection of CO_2 emissions (both natural and anthropogenic). Emissions from individual sources fall well within the margins of uncertainty associated with general circulation model (GCM) predictions of climate parameters. It is not possible to predict the potential climate impacts that might result from an individual CO_2 emission source. Thus, GCM predictions of future changes in climate would not be affected by the presence or absence of any individual source of CO_2 emissions.

The concept that climate impacts cannot be attributed to an individual CO_2 emissions source is reinforced by a Special Rule published by the U.S. Fish & Wildlife Service in connection with listing the polar bear as a threatened species under the Endangered Species Act (ESA):

> There is currently no way to determine how the emissions from a specific project under consultation both influence climate change and then subsequently affect specific listed species or critical habitat, including polar bears. As we now understand them, the best scientific data currently available does not draw a causal connection between GHG emissions resulting from a specific Federal action and effects on listed species or critical habitat by climate change, nor are there sufficient data to establish the required causal connection to the level of reasonable certainty between an action's resulting emissions and effect on species or critical habitat. (Special Rule, 50 CFR Part 17, Endangered and Threatened Wildlife and Plants; Special Rule for the Polar Bear (Ursus maritimus) Throughout Its Range, 73 Fed. Reg. 28306, 28313 (May 15, 2008))

6. Potential Impacts of Greenhouse Gas Emission Sources

6.1 Direct Impacts

Emitting CO_2 into the atmosphere is not itself an adverse environmental impact. It is the increased concentration of CO_2 in the atmosphere, potentially resulting in global climate change and the associated consequences of climate change, that may result in environmental effects (for example, sea level rise, loss of snowpack, severe weather events). Although it is possible to generally estimate a project's incremental contribution of CO_2 into the atmosphere, it is not possible to determine whether or how an individual project's relatively small incremental emissions contribution might translate into physical effects on the environment. Given the complex interactions between various global and regional-scale physical, chemical, atmospheric, terrestrial, and aquatic systems that may result in the physical expressions of global climate change, it is not possible to discern whether the presence or absence of CO_2 emitted by a given project would result in any altered conditions. See Section 5.2.2 of the previous text for additional details.

6.2 Cumulative Impacts

Greenhouse gas emissions are appropriately considered a cumulative impacts issue, and the construction and operation of any new CO_2 source, including the proposed Station, would comprise an incremental increase (albeit relatively small) to cumulative GHG emissions, unless the increase were offset by reductions from other sources, such as the retirement of older, less efficient plants. Absent policy changes or changes in market forces, if there is a continuing trend over the next several decades of an increased number of fossil fuel-fired power plants in the U.S. and around the globe, these plants would continue to be a relatively major contributor to the cumulative anthropogenic emissions pool, absent offsets, capture and sequestration, etc. This anthropogenic CO_2 emissions pool would contribute to the total global emissions pool (which also includes natural sources), potentially resulting in a net positive radiative forcing on climate, which could contribute to the current observed and predicted climate change impacts discussed in the previous text.

6.2.1 Social Cost of CO_2 Emissions

Various economists have endeavored to quantify the economic costs to society resulting from climate change. These economic estimates assume that climate change impacts are caused by anthropogenic emissions of greenhouse gases (specified as CO_2). The "social cost of carbon" (SCC), also referred to as the "marginal damage cost," serves as a cost metric for the climate-related cost of CO_2 emissions and is estimated as the net present value of future climate impacts assumed to result from the emission of one ton of CO_2 today.

In its Second Assessment Report (IPCC, 1995), the IPCC reported a wide range of published SCC values, from $1 to $31 per ton of CO_2. Additional studies have been published subsequently, but this cost range remains representative of the SCC values typically reported in the literature. For example, based on an evaluation of 28 published studies, economist and IPCC author Richard Tol concluded that the marginal damage costs of CO_2 emissions are not likely to exceed $12 per ton of CO_2 ($50 per metric ton of carbon) and would likely be substantially smaller (Tol, 2005). This report identified that for some economic scenarios, the estimated SCC is a negative value (meaning that emitting CO_2 represents a benefit to society) and in other cases that the SCC may exceed the range identified in the Second Assessment Report.

The Stern Review on the Economics of Climate Change was published in October 2006 (Stern, 2006). In this report, economist Nicholas Stern suggests that the SCC is on the order of $77 per ton of CO_2 ($85 per metric ton of CO_2, or $311 per metric ton of carbon) for a scenario with no future CO_2 emissions limitations. This value is significantly higher than the typical range of values in the SCC literature as discussed in previous text. For additional discussion of the Stern Review and its methodologies, refer to Tol (2006) and Nordhaus (2007).

More recently, William Nordhaus, Sterling Professor of Economics at Yale University, reported that for a scenario with no future CO_2 emissions limitations (the highest cost scenario), the SCC value is estimated at $7 per ton of CO_2 ($30 per metric ton of carbon) (Nordhaus, 2007).

The wide range of SCC values estimated by the various sources indicates a degree of uncertainty behind these economic estimates; however, the $12 per ton of CO_2 ($50 per metric ton of carbon) SCC estimate provided by Tol (2005) takes into account 28 published studies and is considered a conservative value representative of the body of peer-reviewed SCC literature (Tol states that the cost would likely be less).

6.2.2 Effect on Climate Tipping Points

Although the threshold conditions that would be required to trigger a tipping point in the climate system are not known, some climatologists are concerned that increasing atmospheric concentrations of CO_2 in the future could move the climate system toward a tipping point. Therefore, the collection of current and future anthropogenic activities that contribute to the global pool of CO_2 emissions (including coal-fired power plants) could move the climate system toward a tipping point if the postulated tipping points exist. However, given the current level of understanding of the climate system and uncertainties surrounding the rate of growth in global CO_2 emissions (refer to "Trends in Anthropogenic CO_2 Emissions" in the previous text), it is not possible to determine whether the addition of a single emissions source (or even a group of emissions sources considered together) would cause or contribute to a climate tipping point being triggered.

7. Potential Environmental Impacts of Climate Change

Changes in climate affect ecosystems on a local and regional scale. The IPCC's Working Group II has published its contribution to the IPCC's Fourth Assessment Report (AR4), "Impacts, Adaptation and Vulnerability." This IPCC report indicates that climate change is currently impacting natural resources and is predicted to cause additional impacts in the future. The following subsections provide a brief summary of the climate change impacts on resources discussed by the IPCC.

The following text summarizes the current observed effects of climate change, as well as the predicted future effects of climate change based on information from the IPCC.

7.1.1 Current Observed Impacts of CC/GW on Resources

Wide-ranging observations suggest that natural systems are being affected by regional climate changes. Examples of such regional climate change effects include the following *(*IPCC, 2007d, p. 1-2*)*:

- Enlargement and increased numbers of glacial lakes resulting from temperature increases
- Increasing ground instability in permafrost regions
- Earlier timing of spring events, such as leaf unfolding, bird migration and egg laying
- Poleward and upward shifts in ranges in plant and animal species
- A trend towards earlier "greening" of vegetation in the spring linked to longer thermal growing seasons
- Shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans
- Increases in algal and zooplankton abundance in high-latitude and high-altitude lakes
- Range changes and earlier migrations of fish in rivers
- Effects to biological systems, such as earlier timing of spring events (for example, leaf-unfolding, bird migration, and egg-laying) and poleward and upward shifts in ranges in plant and animal species (IPCC, 2007e).

7.1.2 Projected Future Impacts on Resources

Additional climate-related impacts on natural resources are predicted for the future. The impacts primarily reflect projected changes in precipitation, temperature, sea level, and concentrations of atmospheric CO_2. The magnitude and timing of impacts will vary with the

amount and timing of climate change and, in some cases, the capacity to adapt. Examples of such predicted impacts include the following (IPCC, 2007d, p. 2-8):

- By mid-century, annual average river runoff and water availability are projected to increase by 10 to 40 percent at high latitudes and in some wet tropical areas, and decrease by 10 to 30 percent over some dry regions at middle latitudes and in the dry tropics.
- Drought-affected areas will likely increase in extent. Heavy precipitation events, which are very likely to increase in frequency, will augment flood risk.
- In the course of the century, water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in regions supplied by melt water from major mountain ranges.
- Crop productivity is projected to increase slightly at middle to high latitudes for local mean temperature increases of up to 1 to 3°C depending on the crop, and then decrease beyond that in some regions.
- At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C).
- Coasts are projected to be exposed to increasing risks, including coastal erosion, because of climate change and sea level rise.
- Coastal wetlands including salt marshes and mangroves are projected to be negatively affected by sea level rise, especially where they are constrained on their landward side, or starved of sediment.
- The balance of positive and negative health impacts will vary from one location to another, and will alter over time as temperatures continue to rise. Critically important will be factors that directly shape the health of populations such as education, health care, public health prevention and infrastructure and economic development.
- Increased risk of extinction to plant and animal species for warming scenarios exceeding 1.5°C, along with major changes in ecosystem structure and function. Negative impacts on marine shell forming organisms (for example, corals) and their dependent species because of progressive acidification of oceans (IPCC, 2007e).

7.1.3 Human Health

According to the IPCC Fourth Assessment Report (Confalonieri et al., 2007), climate change related exposures of importance to human health include:

- Increase in malnutrition and consequent disorders, including those relating to child growth and development
- Increase in number of people suffering from death, disease, and injury from heat waves, floods, storms, fires, and droughts
- Change in the range of some infectious disease vectors

- Contraction or expansion of the geographical range of malaria and change in transmission season
- Increase in burden of diseases resulting in diarrhea
- Increase in cardio-respiratory morbidity and mortality associated with ground-level ozone
- Increase in number of people at risk of dengue
- Some health benefits including fewer deaths from cold, although it is expected that this will be outweighed by negative effects of rising temperatures worldwide, especially in developing countries

8. Global, National and Regional Actions and Possible Mitigation Measures

8.1 Global, National, and Regional Actions

Various national and international conventions, panels, commissions, and scientific or strategically focused entities have been formed to suggest protocols, policies, and goals aimed at reducing greenhouse gas emissions. International treaties and state legislation has been enacted to deal with global climate change. The Kyoto Protocol, an international treaty designed by the United Nations Framework Convention on Climate Change (UNFCC) to secure a global commitment to the reduction of greenhouse gases is perhaps the most well-known initiative. More than 160 countries have signed the treaty to demonstrate their commitment to reduce emissions of greenhouse gases or to engage in emissions trading.

The United States was not a signatory to the treaty and has approached the reduction of greenhouse gas emissions at the federal level on a voluntary basis thus far. However, the U.S. has established a goal of reducing greenhouse gas intensity in the American economy by 18 percent during the period of 2000 to 2012(EPA, 2007). In addition, there have been many actions taken by individual cities, counties, and states to set greenhouse gas policies, plans, and goals. Many states have set greenhouse gas emission targets and established greenhouse gas emission reduction action plans.

With the Kyoto Protocol set to expire after 2012, the United Nations Framework Convention on Climate Change (UNFCCC) convened the United Nations Climate Change Conference (the Conference) in Bali, Indonesia, on December 3, 2007. The Conference included representatives from more than 180 countries (including the United States) and ultimately resulted in a decision to adopt the Bali Action Plan, which sets forth a new negotiating process to be concluded by 2009 that will lead to a post-2012 international agreement on climate change (UNFCCC, 2007).

Currently in the United States, there is no federal requirement that greenhouse gases be regulated through New Source Review (NSR) permitting for individual stationary sources. No federal guidance has as been provided, and no emissions thresholds of concern have been established. However, in the recent *Massachusetts v. EPA* decision, the United States Supreme Court determined that CO_2 meets the definition of an "air pollutant" under the Clean Air Act and that "EPA has the statutory authority to regulate the emission of such gases from new motor vehicles." (U.S. Supreme Court, 2007, p. 30) Although the Court did not conclude that CO_2 was subject to regulation under the Clean Air Act, it directed EPA to make a finding as to whether such regulation is warranted. The Court held that, on remand, EPA must make a determination as to whether greenhouse gas emissions "cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare …." (U.S. Supreme Court, 2007, pp. 30-32, Clean Air Act §202(a)(1)). It is only if EPA makes "a finding of endangerment [that] the Clean Air Act requires the agency to regulate emissions of the deleterious pollutant from new motor vehicles." U.S. Supreme

Court, 2007, p. 30) An endangerment finding on CO_2 would require EPA to initiate a rulemaking process for regulating CO_2 emissions from new motor vehicles. After such regulations were final, CO_2 would be considered a regulated pollutant under the Clean Air Act, and EPA would be required to initiate a rulemaking process to address CO_2 emissions from stationary sources under Title I of the Clean Air Act.

Independent of any action by EPA, Congress could pass legislation regulating CO_2 emissions from stationary sources. Several such legislative proposals have been drafted, such as the Lieberman-Warner *Climate Stewardship and Innovation Act of 2005(S.2191)*, the Waxman *Safe Climate Act of 2007*, or the Kerry-Snowe *Global Warming Reduction Act*. Climate legislation ultimately passed by Congress may take the form of a "cap-and-trade" program that would establish a national cap on greenhouse gas emissions, a carbon tax that would apply to sources of energy that emit CO_2, or other similar measures.

Regionally in the United States, individual states or groups of states have enacted policies or legislation to reduce CO_2 emissions. For example, the California Public Utilities Commission has adopted an interim Greenhouse Gas (GHG) Emissions Performance Standard that requires all new long-term commitments for baseload generation to serve California consumers be with power plants that have emissions no greater than a combined cycle gas turbine plant (California Public Utilities Commission, 2007). As an additional example, ten northeastern states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont) have cooperated to create the Regional Greenhouse Gas Initiative (RGGI), a mandatory cap-and-trade program intended to reduce greenhouse gas emissions from the region. Nevada has not enacted any legislation to regulate or reduce carbon emissions.

8.2 Mitigation Measures

The concept of mitigation measures to address global warming has evolved since they were first discussed in the IPCC's First Assessment Report (FAR). The FAR dealt with available cost-effective response measures in terms of mitigation, mainly in the form of carbon taxes without much concern for equity issues. For the IPCC's Second Assessment Report (SAR), the socio-institutional context was emphasized as well as the issues of equity, development and sustainability. In the IPCC's Third Assessment Report (TAR), the concept of mitigative capacity was introduced, and the focus of attention was shifted to sustainability concerns (Rogner et al., 2007).

Most scenarios project that the supply of primary energy will continue to be dominated by fossil fuels until at least the middle of the century (IPCC, 2005a). Within the energy sector, reductions in CO_2 emissions can be accomplished through increased use of nuclear and renewable energy sources, through increased efficiency of existing sources, and through implementation of new technology to existing sources (carbon capture, etc.).

CO_2 capture and storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere (IPCC, 2005a). A detailed discussion of CCS is provided in Appendix E of this FEIS.

Although not yet feasible on a large scale for power plants, capture of CO_2 may someday be applied to large carbon point sources including coal-, gas- or biomass-fired electric power-generation or cogeneration facilities, major energy-using industries, synthetic fuel plants, natural gas fields and chemical facilities for producing hydrogen, ammonia, cement and coke. Potential storage methods include injection into underground geological formations, in the deep ocean or industrial fixation as inorganic carbonates. Application of CCS for biomass sources could result in the net removal of CO_2 from the atmosphere. Storage capacity in oil and gas fields, saline formations and coal beds is considered to be large but currently uncertain. Clarification of the nature and scope of long-term environmental consequences of ocean storage requires further research. Concerns around geological storage include rapid release of CO_2 as a consequence of seismic activity, the impact of old and poorly sealed well bores, and impacts to ground water resources. Overall capacity estimates for CCS are still under debate. In absence of explicit government policies requiring CCS, it is unlikely to be deployed on a large scale by 2030. (Sims et al., 2007). CCS in underground geological formations is a new technology with potential to make an important contribution to mitigation by 2030. Technical, economic and regulatory developments will affect the actual contribution (IPCC, 2007d).

Despite anticipated reductions in emissions from expanded use of nuclear and renewable energy sources, increased efficiency, and increased use of sustainable design, the global energy supply will continue to be dominated by fossil fuels for several decades to come. To reduce the resultant GHG emissions will require a transition to zero- and low-carbon technologies, which will require policy intervention on an international scale (Sims et al., 2007).

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