Appendix SIR-2

Climate Change

Dixie National Forest

Oil & Gas Leasing Environmental Impact Statement Climate Change Report

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February 2010

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Acronyms and Abbreviations

AMS	American Meteorological Society
BRAC	Blue Ribbon Advisory Council
C	Celsius
CCS	CO_2 Capture and Storage
CCSP	U.S. Climate Change Science Program
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
CSP	Concentrating Solar Power
DOE	U.S. Department of Energy
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
F	Fahrenheit
GBRM	Great Basin / Rocky Mountain
GHG	Greenhouse Gas
GISS	Goddard Institute for Space Studies
Gt CO_2 -eq	Gigatons of CO_2-equivalent
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
$MMTCO_2$	Million Metric Tons CO_2
N_2O	Nitrous oxide
NMVOC	Non-methane Volatile Organic Compound
NO_x	Nitrogen Oxides
PFCs	Perfluorocarbons
PPM	Parts Per Million
PM	Particulate Matter
PUCN	Public Utility Commission of Nevada
PV	Photovoltaics
RFDS	Reasonably Foreseeable Development Scenario
SF_6	Sulfur Hexafluoride
SO_X	Sulfur Oxides
UNEP	United Nations Environment Programme
USFS	United States Forest Service
WMO	World Meteorological Organization

Introduction

On January 16, 2009, the Deputy Chief of the Forest Service sent a memo to Regional Foresters and Directors containing guidance for considering climate change in land management and project planning. As part of the *Forest Service Strategic Framework for Responding to Climate Change* (USFS 2008), established by the Chief Gail Kimball in a letter to the National Leadership Team on February 15, 2008, two documents were provided in the memo to guide field units on how to treat climate change: *Climate Change Considerations in Project Level NEPA Analysis* and *Climate Change Considerations in Land Management Planning Revisions*. These documents frame two fundamental challenges: how management may influence climate change through greenhouse gas (GHG) emissions, and how climate change may affect National Forests and Grasslands.

This paper is intended to summarize the body of scientific knowledge and professional opinion of global warming/climate change, in order to provide a context for evaluation of global warming effects under the US Forest Service (USFS) action alternatives of the Dixie National Forest Oil and Gas Leasing Environmental Impact Statement (EIS). It is provided as an overview of climate change, associated science, and projected impacts. Potential global effects to resources as a result of climate change, and potential global impacts of continuing anthropogenic contributions of greenhouses gases to climate change, are also summarized. Regional information on effects to resources is also presented, where available.

Information provided here summarizes current studies by the Intergovernmental Panel on Climate Change (IPCC) and other peer-reviewed publications. The growing level of international attention to climate change 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.

1.0 Climate Change Literature Overview

1.1 The Greenhouse Effect (Science / Process)

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).

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).

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 60 degrees F 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.

Several factors affect the amount of the Sun's energy that reaches the Earth, and thus affect the climate of Earth. The Sun itself has a cycle and fluctuates in the amount of energy emitted. The tilt of the Earth's axis controls the amount of the Sun's energy reaching various parts of the Earth at different times of the year, creating seasons on Earth. The elliptical nature of the Earth's orbit around the Sun means that at times the Earth is closer to the Sun, resulting in increased energy levels reaching the Earth. Finally, the composition of the Earth's atmosphere controls how much of the Sun's energy reaches the surface of the Earth, versus energy that is reflected back into space.

The two primary gases in the atmosphere responsible for the greenhouse effect are water vapor and carbon dioxide. 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.

1.2 Historical Study of and Concern for Earth's Climate Change

A major curiosity for scientists in the late 1800s and early 1900s was solving the mystery of prehistoric ice ages. Svante Arrhenius postulated that by cutting in half the amount of CO_2 in the atmosphere, the temperature in Europe could be lowered some 4-5 degrees C. Arvid Hogbom was the first to attempt to calculate the amounts of CO_2 emitted by factories and other industrial sources, and found that human activities were adding CO_2 to the atmosphere at a rate roughly comparable to the natural geochemical processes that emitted or absorbed the gas. Arrhenius figured it would take thousands of years for burning of fossil fuels to contribute enough CO_2 to the atmosphere to result in raising Earth's temperature. Arrhenius' theory was dismissed because it was perceived to over simplify the climate system, and because of faulty experimentation and reasoning used to refute the theory (Weart 2007).

In the early 1900s, the prevailing theory regarding the greenhouse effect and global warming was that the Earth automatically regulated itself in a "balance of nature", specifically that the oceans would absorb any excess of CO_2 in the atmosphere, and if the oceans didn't absorb the excess, biological systems would (Weart 2007).

Guy Stewart Callendar, also interested in solving the mystery of the ice ages and pursued meteorology as a hobby, decided to scientifically investigate popular opinion that a warming trend was underway. Around 1938 he gathered old data on temperatures and atmospheric concentrations of CO_2, and found a warming trend was underway, and the concentration of CO_2 had increased by 10 percent over the previous 100 years. He postulated that the warming trend could be explained by the increase in CO_2. Through the 1940s and into the 1950s the scientific community regarded the old data used by Callendar as untrustworthy, and the idea of the Earth being in a natural balance persisted (Weart 2007).

In 1952 theoretical physicist Lewis D. Kaplan showed that in the upper atmosphere, adding more CO_2 must change the balance of radiation significantly. Building on this, physicist Gilbert N. Plass performed calculations and theorized that human activity would raise the average global temperature at the rate of 1.1 degree C per century (Weart 2007). Plass' calculations were dismissed by the scientific community because, once again, they over simplified the climate system, not taking into account the influence of various components of the system (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).

The 1980s brought a remarkable discovery. 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. 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).

1.3 Global Community Action

1.3.1 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 carbon dioxide 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).

The United Nations General Assembly endorsed the action of the WMO and UNEP to establish the IPCC in 1988. Assessments produced by the IPCC are discussed in the following section.

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 change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

1.3.2 First Assessment Report

“In conjunction with endorsing the IPCC, in 1988 the General Assembly requested as soon as possible a comprehensive review and recommendations with respect to:

- The state of knowledge of the science of climate and climatic change.

- Programs and studies on the social and economic impact of climate change, including global warming.
- Possible response strategies to delay, limit, or mitigate the impact of adverse climate change.
- The identification and possible strengthening of relevant existing international legal instruments having a bearing on climate.
- Elements for inclusion in a possible future international convention on climate." (IPCC 2004).

In 1989, the 44th session of the General Assembly requested the report by the IPCC to be submitted to its 45th Session. Responding to this request, the IPCC adopted its First Assessment Report on August 30, 1990 (IPCC 2004). The report consisted of three components:

- Working Group I: Addressed a broad range of topics including greenhouse gases and aerosols, radiative forcing (defined by UNEP (2008) as the change in the balance between radiation coming into the atmosphere and radiation going out.), processes and modeling, observed climate variations and change, and detection of greenhouse effect in the observations. Key findings included:
    - Experts were certain that emissions from human activities were substantially increasing the atmospheric concentrations of greenhouse gases and that this will enhance the greenhouse effect resulting in additional warming of the Earth's surface.
    - Under business as usual, a predicted rate of increase of the global mean temperature during the 21st century of 0.3 degrees C per decade with an uncertainty range of 0.2 degrees C to 0.5 degrees C;
    - Under business as usual, a predicted increase of the global mean sea level of 6 cm per decade with an uncertainty range of 3 to 10 cm per decade
    - A number of uncertainties were identified, including sources and sinks of greenhouse gases and the role of clouds, oceans and polar ice sheets.
- Working Group II: Summarized the scientific understanding of climate change impacts on impacts to agriculture and forestry, natural terrestrial ecosystems, hydrology and water resources, human settlements, oceans and coastal zones and seasonal snow cover, ice and permafrost.
    - Predicted impacts would be felt most severely in regions already under stress, mainly developing countries
    - Highlighted important uncertainties with regard to timing, magnitude and regional patterns of climate change.
- Working Group III: Defined mitigative and adaptive response options in the areas of energy and industry; agriculture, forestry and other human activities; coastal zone management, emissions scenarios and the implementation of mitigation measures.
    - Presented a flexible and progressive approach comprising of shorter-term mitigation and adaptation measures and proposals for more intensive action over the longer-term.
    - Developed possible elements for inclusion in a framework convention on climate change.

- Presented proposals to promote as rapidly as possible full participation of developing countries (IPCC 2004).

1.3.3 Supplementary Reports

The General Assembly established the Intergovernmental Negotiating Committee in 1990 in order to initiate negotiations of an effective framework convention on climate change. In 1992 the IPCC prepared supplementary reports to meet the need for up-to-date information of the negotiating process. Six tasks addressed by the Supplementary Reports included:

- Assessment of national net greenhouse gas emissions (which eventually became the national greenhouse gas inventories program)
- Predictions of regional distributions of climate change and associated impact studies,
- Energy and industry related issues,
- Agriculture and forestry related issues,
- Vulnerability to sea level rise, and
- Emissions scenarios (IPCC 2004)

1.3.4 United Nations Framework Convention on Climate Change and Conference of the Parties

The United Nations Framework Convention on Climate Change was adopted and opened for signature in June 1992, and entered into force in 1994 (IPCC 2004). "The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases. The convention enjoys near universal membership, with 192 countries having ratified. Under the Convention, governments:

- Gather and share information on greenhouse gas emissions, national policies and best practices
- Launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries
- Cooperate in preparing for adaptation to the impacts of climate change." (UNFCCC 2008)

The Convention defines climate change as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." (IPCC 2004)

1.3.5 Second Assessment Report

The Second IPCC Assessment Report was issued in 1995. The report differed from the First Assessment Report in that it included as a new subject area socioeconomic aspects of climate change. New findings from the Second Assessment include:

<u>Working Group I</u>

- Greenhouse gas concentrations have continued to increase;
- Anthropogenic aerosols tend to produce negative radiative forcing;
- Climate has changed over the past century;

- The balance of evidence suggests a discernible human influence on global climate;
- Climate is expected to continue to change in the future; and
- There are still many uncertainties

Working Group II

- Human induced climate change adds an important new stress;
- Most systems are sensitive to climate change
- Impacts are difficult to quantify, and existing studies are limited in scope;
- Successful adaptation depends on technological advances, institutional arrangements, availability of financing and information exchange;
- Vulnerability increases as adaptive capacity decreases
- Detection will be difficult, and unexpected changes cannot be ruled out
- Further research and monitoring are essential.

Working Group III

- A prudent way to deal with climate change is through a portfolio of actions aimed at mitigation, adaptation, and improvement of knowledge
- Earlier mitigation action may increase flexibility in moving toward stabilization of atmospheric concentrations of greenhouse gases;
- Significant "no-regrets" opportunities are available in most countries and that the risk of aggregate net damage due to climate change, consideration of risk aversion and application of the precautionary principle provide rationales for action beyond no regrets.
- The value of better information about climate processes, their impacts and responses and the need for more research and analysis of economic and social issues related to climate change are highlighted. (IPCC 2004)

Another change between the First and Second reports was the development of the Synthesis Report. The Synthesis Report provided scientific, technical and socioeconomic information that can be used in evaluating whether the projected range of plausible impacts constitutes "dangerous anthropogenic interference with the climate system," and in evaluating adaptation and mitigation options that could be used in progressing towards the ultimate objective of the Convention on Climate Change (IPCC 2004).

1.3.6 Second Conference of the Parties

In 1996 the Second Conference of the Parties recognized and endorsed the Second Assessment Report, and believed the report would provide a scientific basis, and called on parties for the development of a protocol or other legal instrument. The Second Conference noted the following findings:

- The balance of evidence suggests a discernible human influence on global climate. Without mitigation, the global average surface temperature relative to 1990 is projected to increase by about 2 degrees C (between 1 and 3.5 degrees C) by 2100; average sea level is projected to rise by about 50 centimeters (between 15 and 95 centimeters) above present levels by 2100. Stabilization of atmospheric concentrations at twice pre-industrial levels will eventually require global emissions to be less than 50 percent of 1996 levels;

- The projected changes in climate will result in significant, often adverse, impacts on many ecological systems and socioeconomic sectors, including food supply and water resources, and on human health. In some cases, the impacts are potentially irreversible; developing countries and small island countries are typically more vulnerable to climate change;
- Significant reductions in net greenhouse gas emissions are technically possible and economically feasible by utilizing an array of technology policy measures that accelerate technology development, diffusion and transfer; and significant no-regrets opportunities are available in most countries to reduce net greenhouse gas emissions. (IPCC 2004)

1.3.7 Kyoto Protocol

As greenhouse gas emissions continued to rise around the world, the Parties determined that a firm and binding commitment would be needed to reduce emissions. The 1997 Kyoto Protocol shares the objective and institutions of the Convention; however the Protocol commits the parties to stabilize greenhouse gas emissions. The Protocol requires developed countries to reduce their emissions below levels specified for each of them in the Treaty, resulting in a total cut in greenhouse gas emissions of at least 5 percent against the baseline of 1990. The Kyoto Protocol was ratified by 141 nations in February 2005 (IPCC 2004). However, the Treaty places a heavier burden on developed nations, which is why Australia and the United States refused to join. "Bush administration officials said the treaty would hurt the economy and is ineffective and discriminatory because large, rapidly industrializing countries such as China and India escape the limits." (Washington Post 2005)

In 2000 the IPCC released the Special Report on Emissions Scenarios. The new scenarios offered alternative images of how the future might unfold in order to analyze how driving forces may influence future emissions outcomes and assess the associated uncertainties (IPCC 2000).

1.3.8 Third Assessment Report

The Third IPCC Assessment Report was issued in 2001. Key findings included:

<u>Working Group I</u>

- An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.
- Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.
- Confidence in the ability of models to project future climate has increased.
- There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities.
- Human influences will continue to change atmospheric composition throughout the 21st century.
- Global average temperature and sea level are expected to rise under all IPCC Special Report on Emission Scenarios.
- Atmospheric climate change will persist for many centuries.

<u>Working Group II</u>

- Recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems.

- There are preliminary indications that some human systems have been affected by recent increases in floods and droughts.
- Natural systems are vulnerable to climate change, and some will be irreversibly damaged.
- Many human systems are sensitive to climate change and some are vulnerable.
- Projected changes in climate extremes could have major consequences.
- The potential for large scale and possibly irreversible impacts poses risks that have yet to be reliably quantified.
- Adaptation is a necessary strategy at all scales to compliment climate change mitigation efforts.
- Those with the least resources have the least capacity to adapt and are the most vulnerable.
- Adaptation, sustainable development, and enhancement of equity can be mutually reinforcing.

<u>Working Group III</u>

- Alternative development paths can result in very different greenhouse gas emissions.
- Climate change mitigation will both be affected by, and have impacts on, broader socioeconomic policies and trends, such as those relating to development, sustainability and equity.
- Significant progress relevant to greenhouse gas emissions reduction has been made since the Second Assessment Report in 1995 and has been faster than anticipated.
- Forests, agricultural lands, and other terrestrial ecosystems offer significant carbon mitigation potential. Although not necessarily permanent, conservation and sequestration of carbon may allow time for other options to be further developed and implemented.
- Most model results indicate that known technological options could achieve a broad range of atmospheric CO_2 stabilization levels, such as 550ppmv, 450ppmv or below over the next 100 years or more, but implementation would require associated socioeconomic and institutional changes.
- Some sources of greenhouse gas emissions can be limited at no or negative social costs to the extent that policies can exploit no regrets opportunities.
- Emission constraints in Annex I countries have well established, albeit varied “spillover” effects on non-Annex I countries.
- The effectiveness of climate change mitigation can be enhanced when climate policies are integrated with the non-climate objectives of the national and sectoral policy development.

<u>Synthesis Report</u>

The Synthesis Report provided a synthesis and integration of information contained in the Third Assessment Report and previous IPCC Reports. Nine relevant scientific technical and socioeconomic questions were addressed:

- Scientific technical information relevant for the ultimate objective of the UNFCCC (IPCC 2004). The Synthesis Report identified what would become referenced as the five reasons for concern:
    - Risks to unique and threatened systems.
    - Risks associated with extreme weather events.
    - The distribution of impacts.
    - Aggregate impacts.
    - Risks of large-scale, high-impact events (IPCC 2001a).
- Attribution of observed changes in climate and ecological systems since the pre-industrial era.
- The impact of future emissions of greenhouse gases on climate, including changes in variability and extreme events and in ecological and the socioeconomic systems.
- Inertia in the climate, ecological systems and socioeconomic sectors, and the implications for mitigation and adaptation.
- Near and long term implications of stabilizing atmospheric concentrations of greenhouse gases.
- Technologies, policies, and costs of near and long term mitigation.
- Interaction between climate change and other environmental issues and development.
- Robust findings and key uncertainties (IPCC 2004).

1.3.9 Fourth Assessment Report

The Fourth IPCC Assessment Report was developed with an aim to emphasize new findings (IPCC 2004), and was issued in 2007. Key findings included:

Working Group I

- Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.
- The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report, leading to very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming, with radiative forcing.
- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, rising global average sea level, changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and intensity of tropical cyclones.
- Paleoclimate information supports the interpretation that the warmth of the last half century is unusual compared to at least the previous 1,300 years. The last time the Polar

Regions were significantly warmer than present for an extended period (about 125,000 years ago), predictions in polar ice volume led to 4 to 6 meters of sea level rise.

- Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.
- Analysis of climate models together with constraints from observations enables an assessed range to be given for climate sensitivity for the first time and provides increased confidence in the climate system response to radiative forcing.
- For the next two decades a warming of about 0.2 degrees C per decade is projected for a range of Special Report on Emission Scenarios. Even if the concentrations of all greenhouse gases and aerosols has been kept constant at year 2000 levels, a further warming of about 0.1 degrees C per decade would be expected.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.
- Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized (IPCC 2007b).

Working Group II

- With regard to changes in snow, ice and frozen ground (including permafrost), there is high confidence that natural systems are affected.
- Based on growing evidence, there is high confidence that increased and earlier spring runoff is occurring in many glacier and snow-fed rivers, and lakes are warming in many regions.
- There is very high confidence, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including earlier timing of spring events and poleward and upward elevation shifts in ranges in plant and animal species.
- Based on satellite observations since the early 1980s, there is high confidence that there has been a trend in many regions toward earlier ‘greening’ of vegetation in the spring linked to longer thermal growing seasons due to recent warming.
- There is high confidence, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation.
- The uptake of anthropogenic carbon since 1700 has led to the oceans becoming more acidic, with an average decrease in pH of 0.1 units. However the effects of observed ocean acidification on the marine biosphere are as yet undocumented (IPCC 2007c).

Working Group III

- Global greenhouse gas emissions have grown since pre-industrial times, with an increase of 70 percent between 1970and 2004.
- With current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to grow over the next few decades. In order to stabilize the concentration of greenhouse gases in the atmosphere,

emissions would need to peak and decline thereafter. Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels.

- Both bottom-up and top-down studies indicate that there is substantial economic potential for the mitigation of global greenhouse gas emissions over the coming decades, that could offset the projected growth of global emissions or reduce emissions below current levels.
- In 2030 macroeconomic costs for multi-gas mitigation, consistent with emissions trajectories towards stabilization between 445 and 710 parts per million (ppm) CO_2-eq,, are estimated at between a 3 percent decrease of global GDP and a small increase, compared to the baseline. However, regional costs may differ significantly from global averages.
- While studies use different methodologies, in all analyzed world regions near-term health co-benefits from reduced air pollution as a result of actions to reduce greenhouse gas emissions can be substantial and may offset a substantial fraction of mitigation costs.
- New energy infrastructure investments in developing countries, upgrades of energy infrastructure in industrialized countries, and policies that promote energy security, can, in many cases, create opportunities to achieve greenhouse gas emission reductions compared to baseline scenarios.
- Agricultural practices collectively can make a significant contribution at low cost to increasing soil carbon sinks, to greenhouse gas emission reductions, and by contributing biomass feedstocks for energy use.
- Forest-related mitigation activities can considerably reduce emissions from sources and increase CO_2 removals by sinks at low costs, and can be designed to create synergies with adaptation and sustainable development
- Geo-engineering options, such as ocean fertilization to remove CO_2 directly from the atmosphere, or blocking sunlight by bringing material into the upper atmosphere, remain largely speculative and unproven, and with the risk of unknown side-effects.
- Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-greenhouse gas products, technologies and processes.
- There are still relevant gaps in currently available knowledge regarding some aspects of mitigation of climate change, especially in developing countries. Additional research addressing those gaps would further reduce uncertainties and thus facilitate decision-making related to mitigation of climate change (IPCC 2007d).

<u>Synthesis Report</u>

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.
- There is medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.
- Anthropogenic warming over the last three decades has likely had a discernible influence at the global scale on observed changes in many physical and biological systems.

- There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to grow over the next few decades.
- Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of climate change.
- A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There is high confidence that neither adaptation nor mitigation alone can avoid all climate change impacts; however, they can complement each other and together can significantly reduce the risks of climate change.
- Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels. Delayed emission reductions significantly constrain the opportunities to achieve lower stabilization levels and increase the risk of more severe climate change impacts (IPCC 2007e).

1.3.10 Fifteenth Conference of the Parties

The publication of the IPCC Fourth Assessment Report in 2007, containing the most definitive science to date about climate change and its consequences, as well as the 2012 expiration of the Kyoto Protocol, spurred the global community to take definitive steps toward negotiating a new global climate agreement by the end of 2009.The Fifteenth Conference of the Parties is where the Convention hoped to establish a new global climate treaty to replace the Kyoto Protocol. Copenhagen did see a political accord that provides for explicit emission pledges by all the major economies for the first time, including China. However, a treaty with binding commitments was not reached. Key elements of the Copenhagen accord (as described by the Pew Center for Global Climate (PCGCC 2010) include:

- Setting the goal of limiting global temperature increase to 2 degrees Celsius,
- A process for countries to enter their specific mitigation pledges by 13 January 2010,
- Broad terms for the reporting and verification of countries' actions,
- A collective commitment by developing countries for $30 billion in "new and additional" resources in 2010-2012 to help developing countries reduce emissions, preserve forests, and adapt to climate change,
- A goal of mobilizing $100 billion a year by 2020 to address developing country needs,
- Establishment of a Copenhagen Green Climate Fund, a High Level Panel to examine ways of meeting the 2020 finance goal, a new Technology Mechanism, and a mechanism to channel incentives for reduced deforestation.

1.3.11 Fifth Assessment Report

The decision to prepare a Fifth Assessment Report was made by the IPCC at its 28th Session in April 2008. The preparation of the Fifth Assessment Report pursues the overall mandate of the IPCC, which is to prepare comprehensive assessment reports about climate change at regular (5 to 7-year) intervals. Working Group (I-III) structures will remain the same for the Fifth Assessment Report as in past Reports. The Working Group I Report (physical science basis) is to be finalized in 2013, and the Working Group II (impacts, adaptation and vulnerabilities) and Working Group III (mitigation) reports are to be finalized in early 2014.

The most recent IPCC meeting (31st Session; 26-29 October 2009 in Bali, Indonesia) focused on defining the scope of the Fifth Assessment Report, and specifically the decision was made that Article Two of the United Nations Framework Convention on Climate Change would be a major theme (see IPCC 1995).

1.4 Anthropogenic Contributions and Relationship to Climate Change

Human-induced increases in greenhouse gases in the atmosphere increase the radiant heat from Earth that is trapped in the atmosphere, resulting in increased temperatures on Earth. In this way, anthropogenic effects on climate have resulted from humans increasing the levels of carbon dioxide and other greenhouse gases in the atmosphere, resulting in increased temperatures on Earth.

Overall, the electric power industry was the single largest contributor to greenhouse gas emissions in 2007, responsible for approximately 34 percent of all greenhouse gas emissions from the U.S. in 2005 (EPA 2009a). 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.

On December 7, 2009, the EPA signed two distinct findings regarding greenhouse gases under Section 202(a) of the Clean Air Act as defined by the Supreme Court in 2007 (*Massachusetts v. EPA*, 549 U.S. 497). The first, an "endangerment" finding, determines that greenhouse gases are a threat to human health and welfare. The second, a "cause or contribute" finding, determines that the combined emissions of greenhouse gases from motor vehicles contribute to the greenhouse gas pollution that threatens public health and welfare. At this stage, EPA's findings do not impose any requirements on industry or other entities.

1.4.1 Carbon Dioxide

Testing of the air in bubbles trapped in ice cores has revealed that atmospheric carbon dioxide levels are 36 percent higher than before the Industrial Revolution (EPA 2009a). The atmospheric concentration of carbon dioxide in 2005 exceeded the natural range over the last 650,000 years (Le Treut et al. 2007). From 1990 to 2007 the U.S. CO_2 emissions increased by 20.2 percent (EPA 2009a).

Approximately 85 percent of the 2007 greenhouse gas emissions from the United States were CO_2 (EPA 2009a). The main anthropogenic source of CO_2 in the atmosphere is the consumption of energy from fossil fuels (IPCC 2001b). 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 80 percent of CO_2 emissions in 2005. Electricity generators consumed 36 percent of the U.S. energy from fossil fuels and emitted 42 percent of the CO_2 from fossil fuel combustion in 2007. Of the fossil fuel CO_2 emissions in the United States in 2005, approximately 42 percent was from petroleum, 34 percent was from coal, and 20 percent was from natural gas (EPA 2009a).

A carbon sink is defined as a place where carbon accumulates and is stored, such as in plants as they accumulate carbon dioxide 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 2001b).

1.4.2 Methane

The global atmospheric concentration of methane is over 148 percent higher than pre-industrial levels (EPA 2009a). 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 2001b; Hofmann 2004 in EPA 2009a).

The primary anthropogenic source of methane in the United States in 2007 was enteric fermentation (i.e., cattle ruminants). Other anthropogenic sources of methane in the atmosphere include landfills, natural gas systems, manure management, petroleum systems, waste treatment, and coal mining (EPA 2009a). In 2007, methane represented 8.2 percent of all U.S. emissions (EPA 2009a).

1.4.3 Nitrous Oxide

Atmospheric concentrations of nitrous oxide are 18 percent higher than pre-industrial levels (EPA 2009a). 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 soil management. Nitrous oxide is a primary ingredient in many common fertilizers used in agricultural operations. Other anthropogenic sources include mobile combustion, nitric acid production, manure management, and stationary combustion (EPA 2009a). In 2007, nitrous oxide represented 4.4 percent of all U.S. emissions (EPA 2009a).

1.4.4 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 2009a).

1.4.5 Indirect Greenhouse Gases and Aerosols

There are also several gases that do not have a direct global warming effect but indirectly affect terrestrial and/or solar radiation absorption by influencing the formation or destruction of greenhouse gases, including tropospheric and stratospheric ozone. These gases include carbon monoxide (CO), oxides of nitrogen (NOx), non-CH_4 volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2). Aerosols, which are extremely small particles or liquid droplets, such as those produced by sulfur dioxide (SO_2) or elemental carbon emissions, absorb and emit heat, reflect light and, depending on their properties, can either cool or warm the atmosphere (EPA

2009a). However, an important characteristic of aerosols is that they have short atmospheric lifetimes and for this reason any cooling effect cannot be considered as a long-term offset to the warming influence of greenhouse gases (IPCC 2001b). Indirect greenhouse gases may also react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases (EPA 2009a).

The primary source of aerosols in the atmosphere is dust. Dust may be naturally entrained in the atmosphere from volcanic eruptions or wind erosion of the earth's surface. A significant proportion of this dust may be anthropogenic in that it results from human ground disturbance. Other sources of aerosols include biomass burning and fossil fuels (IPCC 2001b).

Oil and gas activities emit all four indirect greenhouse gases that contribute to the formation of aerosols. In 2007, oil and gas activities emitted 2 percent of all U.S. NOx emissions, 0.5 percent of all U.S. CO emissions, 4 percent of all U.S. NMVOC emissions, and 2 percent of all US SO_2 emissions (EPA 2009a).

1.5 Effects of Anthropogenic Contributions to Climate

1.5.1 Temperature

"Global temperature is a popular metric for summarizing the state of global climate." (Hansen et al. 2006). Measurement of temperatures of nearly all regions of the world was in place by the early 20th century. Temperature measurements for the Polar Regions began in the 1940s and 1950s (NCDC 2008).

The global average surface temperature of the Earth increased about 0.7 degrees C (1.26 degrees F) between the late 1800s and 2000. Most of this warming occurred in the past three decades, during which time the Earth had been warming at a rate of about 0.2 degrees C/decade (0.36 degrees F/decade) (Hansen n.d.).

The highest global surface temperature in more than a century of instrumental data was recorded in the 2005 calendar year in the Goddard Institute for Space Studies (GISS) annual analysis (GISS 2005). Calendar year 2008 was the coolest year since 2000, and the ninth warmest year since 1880, the period of instrumental measurements (GISS 2009). Including 2005 data, total global warming has been 0.6 degrees C in the past three decades and 0.8 degrees C in the past century. After 1975, there has been rapid warming of almost 0.2 degrees C per decade (GISS 2009).

1.5.2 Climate

More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying linked with higher temperature and decreased precipitation has contributed to changes in drought. Changes in sea surface temperatures, wind patterns, and decreased snowpack and snow cover have also been linked to droughts (IPCC 2007a).

1.5.3 El Niño/La Niña

The El Niño phenomenon occurs in the equatorial Pacific Ocean and is characterized by an increase in ocean surface temperature of 0.5 degrees Celsius (0.9 degrees F) or greater than the normal temperature, averaged over a three month period (NOAA 2005). The warmer ocean surface temperatures tend to generate storm clouds, resulting in unusual weather patterns and increased precipitation. These temperature fluctuations also influence mid-latitude westerly winds that flow from the Pacific across the United States. These winds tend to favor the Pacific Southwest during El Niño years.

Conversely, La Niña is characterized by a decrease of at least 0.5 degree Celsius (0.9 degrees F), resulting in a lower than normal sea surface temperature, averaged over a three month period (NOAA 2005). The mid-latitude westerly winds favor the Pacific Northwest during La Niña. The cool water impedes the formation of clouds and tropical thunderstorms, therefore leading to dry conditions.

These phenomena are not caused by global warming. However it has been hypothesized that warmer global sea surface temperatures can enhance the El Niño phenomenon, and El Niños have been more frequent and intense in recent decades.

General affects of El Niño in the American Southwest (WRCC 1998) include:

- The period from October through March tends to be wetter than usual
- Winter temperatures tend to be cooler than normal
- Higher elevation snowpack tends to be deeper
- Spring and summer stream flow is greater
- Likelihood of flooding is increased

La Niña affects on climate in the Southwest are nearly the opposite of El Niño (WRCC 1998).

1.5.4 Tropical Storms

There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones (IPCC 2007a).

In the North Atlantic, for which there are the best records, there has been a clear increase in the number and intensity of tropical storms and major hurricanes. From 1850-1990, the overall average number of tropical storms was about 10, including about 5 hurricanes. Since 1995, the 10-year average has risen dramatically, with the 1997-2006 average at about 14 tropical storms, including about 8 hurricanes. This increase in frequency correlates strongly with the rise in North Atlantic sea surface temperature, and recent peer-reviewed scientific studies link this temperature increase to global warming (PCGCC 2008).

There is an ongoing scientific debate about the link between increased North Atlantic hurricane activity and global warming. The 2007 report of the Intergovernmental Panel on Climate Change rates the probability of such a link as “more likely than not” (PCGCC 2008).

2.0 Potential Environmental Impacts of Climate Change on Resources

The Strategic Plan for the U.S. Climate Change Science Program (www.climatescience.gov or http://www.globalchange.gov; US CCSP 2003) defines uncertainty as:

An expression of the degree to which a value (e.g., the future state of the climate system) is unknown.

Uncertainties can generally be classified into two primary types: value uncertainties and structural uncertainties. Value uncertainties are those that result from the incomplete determination of particular values or results, while structural uncertainties are those from an incomplete understanding of the processes that control particular values or results (Solomon et al. 2007). The Fourth Assessment Report of the IPCC provides uncertainty guidance with a careful distinction between levels of confidence in scientific understanding and the likelihoods of specific results (Solomon et al. 2007). The standard terms used to define levels of confidence as given in the IPCC Uncertainty Guidance note follow:

Confidence Terminology	Degree of Confidence in being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

The standard terms used by IPCC (Solomon et al. 2007) to define the likelihood of an outcome or result where it can be estimated probabilistically are:

Likelihood Terminology	Likelihood of the occurrence/outcome
Virtually certain	Greater than 99% probability
Extremely likely	Greater than 95% probability
Very likely	Greater than 90% probability
Likely	Greater than 66% probability
More likely than not	Greater than 50% probability
About as likely as not	33 to 66% probability
Unlikely	Less than 33% probability
Very unlikely	Less than 10% probability
Extremely unlikely	Less than 5% probability
Exceptionally unlikely	Less than 1% probability

Further discussion and clarification of these standard terms and their uses is available in the 2007 IPCC Technical Summary (Solomon et al. 2007).

2.1 Global

The IPCC predicts global average surface air temperatures to increase by 1.8 to 4.0 degrees C (3.2 to 7.2 degrees F) relative to current conditions over the next century. The greatest temperature increases are expected to take place over land (roughly twice the global average temperature increases) and at high northern latitudes, with less warming over the southern oceans and North Atlantic (Meehl et al. 2007, p.749). Additionally, the IPCC predicts that it is *very likely* that heat waves would be more intense, more frequent, and longer-lasting in a future warmer climate. Decreases in frost days are projected to occur almost everywhere in the middle and high latitudes, with a comparable increase in growing season length (Meehl et al. 2007, p.750).

Precipitation is predicted to generally increase in areas of regional tropical precipitation maxima and over the tropical Pacific in particular, with general decreases in the subtropics, and increases at high latitudes. Globally averaged mean water vapor, evaporation, and precipitation are projected to increase. 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 (Meehl et al. 2007, p. 750).

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 (*high confidence*)
- Increase in number of people suffering from death, disease, and injury from heatwaves, floods, storms, fires, and droughts (*high confidence*)
- Change in the range of some infectious disease vectors (*high confidence*)
- Contraction or expansion of the geographical range of malaria and change in transmission season (*very high confidence*)
- Increase in burden of diarrheal diseases (*medium confidence*)
- Increase in cardio-respiratory morbidity and mortality associated with ground-level ozone (*high confidence*)
- Increase in number of people at risk of dengue (*low confidence*)
- 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 (*high confidence*)

2.2 North America

North America consists of Canada and the United States south of the Arctic Circle. Vulnerability to and impacts of climate change vary significantly from subregion to subregion and sector to sector within North America (IPCC 1997). Therefore climate change projections are discussed qualitatively.

2.2.1 Climate

Large-scale projections indicate a positive temperature change everywhere during the 21st century. This would be greatest over land and in otherwise geographically similar areas; warming is typically greater in arid as opposed to moist regions (Solomon et al. 2007, p.71). The IPCC states that North America is projected to warm between 2 to 10 degrees C (3.6 to 18 degrees F) by 2100, depending on the subregion (Christensen et al. 2007, p.889). Projected increases in Arctic temperatures in northern Alaska and Canada, uncertainties in future emissions, the climate's response to those emissions, and the difficulty of projecting future climate change at the regional level results in the large range in projected warming (EPA 2009b).

According to IPCC (Solomon et al. 2007, p.75), a robust pattern of increased subpolar and decreased subtropical precipitation dominates the projected precipitation pattern for the 21st century over North America with nearly all models projecting increased precipitation over most of northern North America with most of the continental U.S. in a more uncertain transition zone that moves north and south following the seasons.

During the 21st century, cities in North America that currently experience heatwaves are expected to be further challenged by an increased number, intensity, and duration of heatwaves (IPCC 2007c).

2.2.2 Water Resources

Evaluating the impacts of climate change on water resources is difficult; water availability, quality, and streamflow are sensitive to changes in temperature and precipitation; however water resources are also impacted by factors such as increased demand due to population growth, changes in the economy, new technologies, changes in watershed characteristics, and water management (EPA 2009b). In the U.S., water resources are strictly managed and water supply is scarce in some regions of the country.

According to IPCC (Christensen et al. 2007), a general increase in precipitation over most of the North American continent is projected, except in the most southwesterly region. In the western region, modest changes in annual precipitation are projected with an increase in winter precipitation and a decrease in summer. Further, it is projected that a decrease in snow depth could result from delayed autumn snowfall and earlier spring snowmelt.

2.2.3 Ecosystem

Changes in precipitation amounts and patterns can affect background soil erosion rates and soil moisture. The retreat of snow and ice cover, subsequent earlier spring snowmelt, and earlier reduction in soil moisture are important in the discussion of warming continental climates (Christensen et al. 2007).

Climate change is likely to alter the geographic distribution of North American forests (EPA 2009b). Further, effects on forests are likely to include changes in forest health and productivity. Factors affecting forest health include temperature, rainfall (amount and seasonal distribution), atmospheric levels of CO_2 and other greenhouse gases, extreme weather events, insect outbreaks, and fire. In turn these effects to forest health can alter timber production, outdoor recreation activities, water quality, wildlife, and rates of carbon storage (EPA 2009b). Land use, especially when dependant on natural resources, may be restricted or altered by climate change impacts.

2.2.4 Socioeconomics and Health

Generally, agriculture in the U.S. is projected to benefit from warming temperatures; however there will be strong regional affects with some areas losing productivity (EPA 2009b). Changes in water supply and soil moisture could make it less feasible to continue crop production in certain regions. Increased potential for extreme weather events such as droughts, floods, and heat waves will pose challenges to farmers.

The general health affects described in Section 2.1 would be applicable to North America, but developed countries such as the U.S. should be able to minimize impacts of disease through existing disease prevention and control methods (EPA 1998). As noted in Confalonieri et al. (2007), based on data from the U.S., occupations most at risk of heatstroke include construction and agriculture/forestry/fishing work.

2.3 Regional (Southwest / Arid West / Rocky Mountains)

The project area is located in south central Utah. In available regional data regarding climate change, this area falls into discussions of the many regional descriptions, including the southwest U.S. (Nevada, Utah, Colorado, New Mexico, Arizona, southeastern California), the arid west (mainly Arizona, New Mexico, Nevada, and Utah), the intermountain west (mainly Idaho, Utah, and Nevada), the Colorado Plateau (parts of Colorado, Utah, Arizona, and New Mexico), and the Great Basin/Rocky Mountains (western and northern Utah, most of Nevada, Idaho, and Wyoming, and parts of Oregon, Montana, Colorado, and New Mexico). The IPCC climate modeling in *Regional Climate Projections* (Christensen et al. 2007) was done at a continental scale but the maps produced in that work can be evaluated for regional predictions. Two region-specific studies are available: *Preparing for A Changing Climate: The Potential Consequences of Climate Variability and Change, Southwest* (Sprigg and Hinkley 2000) and *Preparing for A Changing Climate: The Potential Consequences of Climate Variability and Change, Rocky Mountain/Great Basin Regional Climate-Change Assessment* (Wagner 2003). These reports, and any subsequent region-specific report, should be consulted for more detailed information such as scenarios, methodology, and modeling. The following is a summary of potential impacts of climate change on environmental resources of the project area obtained from these reports.

2.3.1 Climate

The climate of the regions named above can be generalized as hot and dry at the low elevations to cool and moist at the high elevations. The southwest region of the U.S., which includes southern Utah, is unique in that it is under the influence of a subtropical ridge of high pressure associated with the thermal contrast between land and adjacent ocean, and as a result is very arid for most of the year.

The IPCC continental-scale modeling conducted for North America indicates warmer temperatures and generally less precipitation in the southwest U.S. on an annual basis (Christensen et al. 2007, p.850, p.887-888). For the western U.S., the IPCC modeling suggests modest changes in average annual precipitation ranging from slightly less than normal in the south to slightly greater than normal in the north. Change in winter precipitation is predicted to be variable with more winter precipitation in the northern part of the western U.S. and less in the Southwest. Summer precipitation is predicted to be less throughout the West. However, it is also noted that the continental-scale regions encompass a broad range of climates and are too large to be used as a basis for conveying quantitative regional climate change information.

The IPCC projection of less warming over the ocean than the land, and amplification and northward displacement of the subtropical anticyclone is likely to cause a decrease in annual precipitation in the southwestern U.S. (Christensen et al. 2007). According to the *Fourth Assessment Report* of the IPCC (Christensen et al. 2007), the following general climate change projections were made for the southwest U.S.:

- Seasonally, warming is *likely* to be largest in summer.
- Maximum summer temperatures are *likely* to increase more than the average summer temperature.

- Annual mean precipitation is *likely* to decrease.
- Snow season length and snow depth are *very likely* to decrease.

Wagner et al. (2003) reviewed the work of a number of climatologists, evaluated 20th century climate records for trends, and conducted two large computer models with the assumption that CO_2 concentrations would double in the 21st century to predict climate change effects in the Great Basin/Rocky Mountain (GBRM) region. They noted that use of global-scale models cannot be expected to project climate changes at localized areas with highly variable climates and great topographic variation like the GBRM area. Their modeling results showed year-round increases in temperature with the greatest increases occurring in winter. They also showed that annual precipitation was predicted to increase with the greatest increase occurring in winter.

2.3.2 Water Resources

According to the IPCC *Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report* (IPCC 2007e, p.8), there is *high confidence* that by mid-century annual river runoff and water availability are projected to decrease in some dry regions in the mid-latitudes and tropics and that many semi-arid areas (i.e. southwestern United States) would experience an overall decrease in water resources due to climate change.

In most of the regions named above, stream flow largely results from spring and summer snowmelt in the mountains. Large quantities of water accumulate as snow during the historically typical winter at high mountain elevations and this water is stored as snowpack from early fall until summer. Gradual and prolonged spring and summer melting of the snowpack and movement of this water as surface streams out of the high elevations supports agricultural and urban uses of surface water. This pattern of runoff and use is supported by current water management regulations and practices including reservoirs that store spring runoff for use later in the year. In addition to surface water uses, riverbeds and mountain front alluvial fan areas are major groundwater recharge sites. The melting snow in the mountain ranges of the West provides prolonged springtime stream flows to mountain front recharge areas that recharge groundwater resources in the intervening valleys.

Changes in climate that result in overall warming of temperatures, particularly winter temperatures, can impact the hydrologic pattern described above by causing more precipitation to fall as rain instead of snow and increasing evaporation which reduces the availability of surface water and increases the summer demand for irrigation water. Increased temperatures and decreased overall precipitation would decrease the annual replenishment of surface water resources and decrease groundwater recharge. Increased temperatures combined with increased annual precipitation can still result in overall decreased water availability if less water is stored as snow and more winter precipitation occurs as rain. Under these conditions, surface water normally available later in the season from snowmelt would not be available without changes in water management practices. Lenart (2006) reviewed research by a number of hydrologists working in the western U.S. that showed the importance of prolonged stream flows from melting snowpack for groundwater recharge along the mountain fronts of the West and Southwest. The overall conclusion was that changing winter precipitation from snow to rain and reducing snowpack volume by retreating snowlines has the potential to decrease the amount of prolonged stream flow and groundwater recharge.

Udall and Bates (2007) reviewed five studies on the topics of snow water equivalent (SWE), streamflow, temperature and precipitation trends, and the proportion of rain vs. snowfall in the western states published between 2004 and 2006. The five studies were consistent in their findings of widespread warming in the West and declining snowpacks in milder climates (e.g., Pacific Northwest). Findings for the Intermountain West, however, showed few consistent, statistically significant trends. Although the Intermountain West has warmed considerably, low mean winter temperatures and increases in precipitation have protected snowpack from losses, as of 2000 (studies were done prior to the drought of 2000-2004; Udall and Bates 2007).

Wagner et al (2003) evaluated three scenarios of potential climate change effects on water availability in the GBRM area: 1) increased temperature and uniformly increased precipitation, 2) increased temperature with increased precipitation in the north and no precipitation increase in the south, and 3) increased temperature with no change or a decrease in precipitation throughout the region. Under the first scenario, they predicted a 50 to 100 percent increase in water resources which would support more urban and agricultural use but reduced snowpacks would require significant changes in water management regulations and practices, mitigation of flooding problems, and changes in reservoir capacities. Under the second scenario the conditions in the northern portion of the region would be the same as the first scenario but the southern area would experience exacerbation of the current water scarcity in that area. With the third scenario they predicted overall xerification of the region and decline in water resources forcing more conservation measures and transfer of water rights from agricultural uses to urban. Due to scarcity of water in the GBRM region, and because it is already fully appropriated, any climate change affecting water availability could have social, economic, and ecological affects, either positive or negative (Wagner 2003).

In a simulation of the impacts of several 'business-as-usual' climate scenarios on the hydrology of the Colorado River Basin, Christensen et al. (2004) showed, using a water management model, that average total basin storage would be reduced by 7 percent under a control climate (1995 GHG levels) and reduced by up to 40 percent in 2098 under a 'business-as-usual' scenario. The authors also discuss the high sensitivity of reservoir system performance under future climate warming due to its current 'fragile equilibrium' with current system demands (Christensen et al. 2004).

By contrast, studies sponsored by the USDA Agricultural Research Service on the rate at which water filters through the vadose zone found elevated temperature and CO_2 concentrations increased the rate of groundwater recharge (USDA 2007).

2.3.3 Ecosystem

Changes in precipitation amounts and patterns (i.e., extreme weather events, flooding) can affect soil erosion rates and soil moisture. Projected increases in temperature would increase evaporation and shorten the snow season in the mountains, causing earlier spring runoff and reduced summer stream flow. Wetland habitat essential for migrating and breeding birds and fish could become reduced or degraded. Cold water aquatic species indigenous to western streams could be affected by warming temperatures as the southern limits of the species range would be forced to contract northward (Wagner 2003). Trout habitat in particular could be affected directly; some simulations predict a 50 percent reduction in Rocky Mountain trout habitat by the end of the century (NRDC 2008). The most recent Global Change Research Program Report states that about 90 percent of bull trout are projected to be lost due to warming in the coming decades (USGCRP 2009). In general, available wildlife habitat and populations could be reduced as a result of elevational and geographic contractions due to warming temperatures. Conversely, some animal populations could benefit from the warmer temperatures, including those that hibernate, which would have a longer activity period, and avian multiple-clutch species (Wagner 2003).

Changes in climate patterns such as drought, temperature, frost occurrence and duration, snow cover (or lack thereof), soil moisture, and fire occurrence and intensity can affect plant species in different ways depending on species tolerances (DeGomez and Lenart 2006). These factors directly influence seedling survival, plant growth, and seed/fruit production; therefore changes in these factors due to climate change could alter the composition of plant communities within the western U.S. Reductions in plant cover combined with intense rainfall events can cause soil erosion resulting in declines in vegetation system capacity and lags in recovery after drought (Sprigg and Hinkley 2000).

Increases in temperature can reduce water availability to forests through increasing evaporation rates, and further reductions in precipitation can cause increased susceptibility of forests to wildfire (DeGomez and Lenart 2006). The lengthening of the frost-free season can also impact the development and survival rates of insects, which can in turn change the frequency of insect outbreaks and effects on forests and vegetation.

Increases in temperature and precipitation could result in subalpine forest moving upward into alpine tundra, pinyon-juniper extending out into the shrub steppe, and the area of shrub-steppe declining (Wagner 2003). Marked changes in community composition would be probable.

2.3.4 Socioeconomics and Health

Natural-resource based economic activities are particularly sensitive to natural variations in temperature and precipitation. Livestock ranching, agriculture, and tourism/recreation are some of the major land uses in rural areas of the West. Agriculture and farm productivity are highly sensitive to weather extremes (droughts, floods, severe storms) and climate variability. Under drier or drought conditions, ranchers could face higher costs in supplemental feed, water hauling, and cattle relocation (Sprigg and Hinkley 2000). In addition, increases in carbon dioxide are reducing the quality of forage such that more acreage is needed to provide animals with the same nutritional value (US GCRP 2009). Conversely, increases in precipitation could increase yields benefiting agriculture and socio-economic stability (Wagner 2003). Recreation and tourism dependant on natural resources could be positively or negatively impacted by climate change depending on the impact to the specific resource. For example, decreased stream flow could negatively impact fishing and other water sports; decreased snowpack and early snowmelt could negatively impact the ski industry; warmer temperatures and longer warm seasons could positively impact sightseeing, hiking, and other outdoor activities.

Incidence of diseases such as Hantavirus and valley fever has been linked to weather and precipitation patterns. Sequences of rain-drought-rain can produce outbreaks of Hantavirus and cases of valley fever are reported to increase in unusually wet seasons (Sprigg and Hinkley 2000).

2.4 Utah

The Blue Ribbon Advisory Council (BRAC) on Climate Change was organized by Governor Jon M. Huntsman, Jr. on August 25, 2006, to provide a forum where government, industry, environment, and community representatives could identify proactive measures that Utah might take to mitigate the impacts of GHG. The following is taken largely from a Scientific Consensus Report (BRAC 2007: Appendix A), as part of the BRAC report, that summarizes present scientific understanding of climate change and its potential impacts on Utah and the western United States. The Scientific Consensus Report was prepared by scientists from the University of Utah, Utah State University, Brigham Young University, and the U.S. Department of Agriculture, and emphasizes the consensus view of the national and international scientific community with discussion of confidence and uncertainty as defined by the BRAC (BRAC 2007: Appendix A).

2.4.1 Climate

In Utah, the average temperature during the past decade was higher than observed during any comparable period of the past century, and roughly 2º F higher than the 100-year average. Utah is projected to warm more than average for the entire globe and more than coastal regions of the contiguous United States. The expected consequences of this warming are fewer frost days, longer growing seasons, and more heat waves (BRAC 2007: Appendix A).

2.4.2 Water Resources

Most of Utah's water resources originate in mountainous areas above 6,500 feet in elevation, which cover about 19 percent of the state (BRAC 2007). The primary source of this water is snowpack, which releases months of stored precipitation in about 4 to 8 weeks during spring and summer, as described in Section 2.3.2. Clear and robust long-term snowpack declines have yet to emerge in Utah's mountains, as they have in low-elevation mountains in other states (i.e., in the Pacific Northwest and California). In addition, recent temperature increases in Utah appear to have had little impact on snowpack in the high mountains of the Intermountain West. Streamflows in Utah and the Intermountain West also do not show clear trends over the past 50 years. Dai et al. (2009), who studied flow history of 925 of the world's largest rivers, including the Colorado River in southern Utah, pointed out that flow data included changes induced by human activities, such as the withdrawal of stream water and building dams (Dai et al. 2009). High water usage in Utah and its effect on flow data thus complicates the relationship that can be deduced between flow and climate change. Regardless, studies of precipitation and runoff over the past several centuries and climate model projections for the next century indicate that ongoing GHG emissions at or above current levels will likely result in a decline in Utah's mountain snowpack, thus the threat of severe and prolonged episodic drought in Utah is real (BRAC 2007). If temperatures increase as projected, it is likely that a greater fraction of precipitation will fall as rain instead of snow, the length of seasonal snow accumulation will decrease, and snowpack loss due to evaporation will increase, as predicted for the region (Section 2.3.2).

Precipitation in Utah during the 20th century was unusually high, but also fluctuates dramatically, further complicating the identification of long term trends. Using geologic records and tree rings, Woodhouse and others (Woodhouse and Lukas 2006; Woodhouse et al. 2006) have reconstructed river flow and precipitation in the Colorado River Basin for the last several centuries. Their estimates show that sustained droughts are a defining feature of the upper Colorado River Basin, which has experienced far more prolonged and severe drought than observed during the comparatively wet 20th century. The drought of 1999-2004 was a severe event, but there have been even longer and more severe droughts in the past, such as in the 16th century (BRAC 2007). However, if average precipitation remains similar to that of the 20th century, changes in snowpack will result in a declining water supply. Current climate models project a decline in summer precipitation across all of Utah (BRAC 2007).

2.4.3 Ecosystem

Forests are generally adapted to recent climatic conditions and variability (see Hamrick 2004), but the rate of temperature change expected during the next century will greatly exceed that produced naturally over the past several thousand years. Apart from other human-related factors such as forest management practices and land-use changes, future climate change is likely to contribute to drier conditions in Utah forests as well as increased wildfire intensity, more insect outbreaks and reduced forest health.

Droughts in Utah have exacerbated declining forest health across the state, and consequently Utah's forests have become more susceptible to intense wildfire, insects, and disease (UDNR 2003). The ecological impacts of wildfires as well as forest pests and diseases are expected to rise with climate warming, with extended periods of high fire risk and large increases in area burned (IPCC 2007b; USGCRP 2009). A study of historical spruce beetle outbreaks on the Markagunt Plateau revealed that small-scale disturbances have been the norm over the past century, and that large-scale outbreaks occurring in recent history (in the early 1990s, in this study) are an unprecedented phenomenon (DeRose and Long 2007).

The Forest Service also reports that rising levels of atmospheric carbon dioxide could help the spread of invasive weeds such as Canada thistle, yellow starthistle, leafy spurge, spotted knapweed, field bindweed, and perennial sowthistle (Ziska 2003).

Utah soils are expected to dry more rapidly due to increasing temperatures, which will likely increase soil vulnerability to wind erosion. This will increase dust transport during high wind events, particularly from salt flats and dry lake beds such as Sevier Lake. Dust deposited on mountain snowpack also accelerates spring snowmelt (BRAC 2007).

2.4.4 Socioeconomics and Health

The population of the Intermountain West (eight states including Utah) is projected to increase by 65 percent from 2000 to 2030, representing one-third of all U.S. population growth (USGCRP 2009). Between 2000 and 2005, Utah was among the five fasted growing states in the U.S. (US GCRP 2008). Projections of decreased snowpack and earlier spring melting suggest lower stream flows in the future, particularly during the high-demand period of summer (USGCRP 2008). There is a high likelihood that water shortages will limit power plant electricity production in many regions, and constraints in production by 2025 are projected in ten states including Utah (USGCRP 2009).

Poor air quality in Utah is currently and has been a historic problem (data at UDAQ 2009), and as forest fires increase in frequency, severity, distribution, and duration, so may their associated adverse pulmonary effects (USGCRP 2008).

As discussed in Section 2.3.4, climate warming impacts on agriculture may be both adverse and beneficial. Based solely on climate change, per-acre crop yields in Utah will likely increase on irrigated fields provided: (1) water remains available for irrigation, and (2) temperatures do not increase beyond crop tolerance levels. Pasture yields and livestock forage will likely decline on non-irrigated fields. Climate change may also have indirect effects on crop yields through changes in the distribution and population of insects and animals, which affects pollination and crop damage.

3.0 Emissions Estimates for Anthropogenic Greenhouse Gas Emissions

This section provides a quantitative analysis of projected GHG emissions that could occur as a result of the connected actions associated with a leasing decision and the Reasonable Foreseeable Development Scenario (RFDS; i.e., hypothetical oil and gas activities projected for the next 30 years). In addition to the quantitative analysis it describes some of the uncertainties inherent in calculating these quantities, and demonstrates the additional difficulties caused by the lack of a universally sanctioned methodology for determining emissions and the atmosphere's sensitivity to GHG emissions. Despite these uncertainties, the quantitative analysis puts the project in perspective compared with other areal and temporal scales.

3.1 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 (NAAQS), 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: 1990-2007* (EPA 2009a), the Environmental Protection Agency (EPA) estimates the range of uncertainty in its 2007 data for GHG emissions from "fossil fuel combustion" to be only -2 percent to 5 percent for CO_2, but -34 percent to 128 percent for "stationary combustion" of methane and -24 percent to 187 percent for "stationary combustion" of nitrous oxide. 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, Department of Energy (DOE), the IPCC and others, emission factors are based on test data of emissions meeting certain testing quality standards. Emission factors represent the average emission rate for a given source, and are generally expressed as a mass or volume of emissions per source type or measure of activity related to the source (API 2009). Published emission factors (by regulators) are based on the "average" fuel carbon content (when measuring CO_2) or the average equipment characteristics (when measuring CH_4 or N_2O). Equipment manufacturer emission factors are based on engine type, air/fuel ratios and fuel type (when measuring CO_2) or are closely related to equipment characteristics (in the case of CH_4 and N_2O; API 2009). Emission factors are source-specific and thus are summed, according to the rate of activity (i.e., consumption) for each, to calculate the total emissions of a proposed action or set of actions.

In addition to the uncertainties inherent in estimates of emissions to the atmosphere from anthropogenic sources, including both greenhouse gases and aerosols, there is the additional uncertainty of how the earth's climate will react to "radiative forcing," or "global mean change in energy balance imposed over time by changes in atmospheric composition and other influences such as land use" (Schwartz et al. 2007a). The current uncertainty estimate by the IPCC (2007b) has been criticized by Schwartz et al. (2007a) for not accounting for the full range of radiative forcing; however, see responses by IPCC (Forster et al. 2007) and Schwartz et al. (2007b). Oppenheimer et al. (2007) also criticize the IPCC for excluding in their uncertainty calculation the so-called "wild cards" of climate change, or highly tentative but potentially catastrophic events (e.g., melting of West Antarctic ice sheets). However, the IPCC estimate in the Fourth Assessment Report makes use of clearly defined levels of confidence in scientific understanding and the likelihoods of specific results in their predictions, such that processes which have limited data or poor predictability would not be included (Le Treut et al. 2007).

A protocol for determining greenhouse gas emissions and their effect has been developed by the World Resources Institute and the World Business Council for Sustainable Development,. The "GHG Protocol for Project Accounting" (GHG Protocol Initiative 2005) has a companion, 17-page protocol titled "GHG Protocol guidance on uncertainty assessment in GHG inventories and calculating statistical parameter uncertainty." (GHG Protocol Initiative 2003)

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 or the possibilities of catastrophic events. This is not to say that there is no value in attempting to quantify the emissions and their effects, but rather a caution against drawing definite conclusions from indefinite data and science. In addition, uncertainty estimates are conservative due to the use of only well-established science.

3.2 Quantitative Analysis

At the national and world levels the most recent available data are for 2007, so 2007 data are shown for most tables. Where available, methane and nitrous oxide emissions are shown as CO_2 equivalent, but in most cases, only CO_2 is available in published data. In all cases, units and sources are provided.

3.2.1 Dixie NF Oil and Gas Activities: Greenhouse Gas Emission Profile

This section contains an estimate of the yearly greenhouse gas emissions that could result from connected actions to the leasing decision and the RFDS, under any of the Dixie National Forest Oil and Gas Leasing EIS action alternatives. Annual emissions estimates for these predicted oil and gas activities are described in **Appendix SIR-2A**. This section contains a summary of the assumptions and methods used to arrive at these estimates.

The specific oil and gas activities predicted in the RFDS that could contribute to GHG emissions are listed below:

- Exploration drilling
- Production operations- drilling and pumping
- Transportation of crude oil from field to refinery
- Refining of crude oil into final product
- Transportation of final product to end user
- End use of product

Emissions from seismic exploration are not analyzed due to the relatively small contribution of these emissions to the total, and because seismic exploration could occur outside of the action alternatives. Transportation of rigs to and from the exploration and production sites (unknown distances), as well as average daily traffic related to exploration and production activities (discussed in Section 4.10.3 of the EIS), were not included in emission calculations. Including emissions from refining, transportation of refined product, and product end use is a conservative impact estimate because these emissions may occur regardless of the product source in order to satisfy current and future market conditions, and it could be argued that these actions are not necessarily related to oil and gas production on the Dixie National Forest.

Total emissions estimates for each predicted oil and gas activity (i.e., connected action) are summarized in **Table 3.2-1**. Emissions are reported in metric tons of Carbon Dioxide Equivalent (CO_{2e}) which is the standard unit of measure established by the EPA for GHG emissions. Non-CO_2 gases were converted to CO_{2e} by multiplying by the Global Warming Potential for each gas.

Table 3.2-1 Estimated Emissions for Connected Actions to Leasing (Metric Tons)

Oil and Gas Activity	CO_{2e}
Exploration	9,993
Production	43,443
Transportation of Crude	2,161
Refining	21,019
Transportation of Refined	868
Product End Use (off-site)	268,312
TOTAL	**345,796**

The general calculation method used to determine the emissions (i.e., emission rate) from each individual activity (source) was the following:

Emission factor * Rate of Use = Emission Rate (metric tons of CO_2 per year)

Detailed calculations and assumptions are described for each predicted oil and gas activity in **Appendix SIR-2A**. The general approach and assumptions made for each connected action are summarized below.

Exploration

Exploratory drilling is predicted to occur at unspecified locations in the Forest as part of the RFDS. GHG emissions estimates were developed utilizing the impacts of a single diesel fueled drill rig operation that will be able to drill and complete three exploratory wells per year. Each well was assumed to take approximately 90 days to drill and assumed 24 hour per day operation. In addition to direct drill rig emissions, a conservative assumption was made that natural gas encountered during drilling would be flared at the drill site. GHG flare emissions were calculated assuming a flare combustion efficiency of 98 percent, and the 2 percent of non-combusted natural gas was estimated to be composed of 90 percent methane. The emissions from this non-combusted portion were also reported.

Emissions were calculated utilizing emission factors from the Mandatory Greenhouse Gas Reporting final rule, 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1.

Production

The estimate of production GHG emissions sought to predict maximum potential GHG emissions and therefore assumed that a full 20-well production field was already in place for the production emissions scenario (a theoretical 20-well production field is used in other analyses for the EIS). The theoretical production field was comprised of 20 active oil well pumps fueled by diesel fuel. Emissions for natural gas and electric-fueled well pumps were also developed, but diesel was utilized during this analysis as it produced the highest GHG emissions per barrel of oil developed. For conservatism, the field was assumed to contain 20 heater/treater apparatus (one for each well location), a central natural gas fired compressor, two natural gas dehydrators, and a single production flare. The field also included ongoing drilling operations for either exploration or additional production well development. In addition to combustion GHG emissions during the production phase, fugitive methane emissions from production equipment were also estimated.

The emission factors inherent to the calculations were sourced from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1.

Transportation of Crude

It is assumed that a likely destination for the crude oil would be a refinery in the Salt Lake City area. The RFDS predicts that the oil field would produce about 2,000 barrels per day of crude oil. A 365 day per year production would yield an estimated 730,000 bbl annually. The distances from several random points on the Dixie National Forest (the location of a predicted well is unknown) to the nearest Salt Lake City refinery were calculated, and the numerical average of these distances was 300 miles. A total of 2,491 trips per year by a “heavy-duty vehicle” were estimated (see **Appendix SIR-2A**). The primary GHG emissions resulting from transport of crude oil to the refinery is CO_2. In addition to the GHG emissions caused by mobile combustion during transport, fugitive methane emissions from loading and unloading tanker trucks as well as tanker truck vents were estimated.

Transportation emission factors were taken from the World Resources Institute GHG Protocol tool for mobile combustion.

Refining

Emissions were estimated based on a crude oil life cycle case study published in the Oil and Gas Journal.

An average emission factor from five crude oil life cycle case studies was used to estimate refining emissions.

Transportation of Refined Product

After the crude oil is refined into a final product, it is assumed to be transported via tanker truck to terminals for final distribution and end use. The average one-way distance from the representative Salt Lake City refinery to the end user is assumed to be 150 miles. The majority of the product is assumed to be gasoline, distillate (diesel) fuel, jet fuel and residual fuel oil that would be transported to market in tanker trucks. Assuming a lead tank truck with pull trailer configuration with an average capacity of 13,400 gallons equates to a total of 2,066 trips per year by a “heavy-duty vehicle.”

Transportation emission factors were taken from the World Resources Institute GHG Protocol tool for mobile combustion.

Product End Use

Product end use is the largest contributor to the Dixie National Forest oil and gas predicted activities emissions (>75 percent of total; see **Table 3.2-1**). Product end use also assumes a demand for refined oil and gas products, which would be independent of any Dixie National Forest oil and gas production. However, product end use must be taken into account in the emission scenario because the demand does exist, due to the need for these fuels and the relatively low price of refined oil and gas products compared to alternative fuels currently available. It can reasonably be assumed, therefore, that if the Dixie National Forest were to discover and produce oil and gas products, they would be used.

For the analysis of product end use, only CO_2 emissions estimates are included because N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion or oxidation emissions of the subject products.

The following product mix was assumed:

- 49.2% motor gasoline
- 24.9% distillate fuel
- 7.8% jet fuel
- 5.1% residual fuel oil
- 3.3% liquid petroleum gas
- 3.2% still gas
- 6.5% other, mostly unfinished oil and coke (not burned)

The end use emission calculations utilized 40 CFR Part 86 equation MM-1 and emission factors from Table MM-1.

3.2.2 Baseline Condition

No new leasing decisions and no new oil and gas leasing are currently occurring on the Dixie National Forest. Due to the current demand for refined oil and gas products, it is reasonable to assume that under the current management scenario (i.e., no new leasing) an approximation of the emission scenario described in Section 3.2.1 would occur in another location off the Dixie National Forest, as oil and gas resources are produced for refinement and use.

This section describes the GHG emissions and sinks associated with baseline conditions and management activities on the Dixie National Forest. These conditions and activities would also occur regardless of any leasing, thus the following carbon emissions scenario is independent of the leasing decision.

Estimates of carbon stock (sequestration) and carbon emissions on the Dixie National Forest have not been calculated. However, some estimates have been made for other National Forests in the west, and the EPA has estimated carbon output from "forest ecosystems" in the U.S. and as well as from forest fires. These data are presented below to provide a rough approximation of the Dixie National Forest carbon stock, and GHG emissions from Dixie National Forest operations and forest fires under normal (i.e., baseline) management.

Forest Carbon Stock Estimates

Estimates of carbon sequestration or carbon sinks have not been prepared for the Dixie National Forest. Such estimates have been prepared by the EPA for forest ecosystems in the U.S. (EPA 2008a) and are discussed in a document released by the USFS Northern Research Station (NRS 2009). These estimates include the overall carbon stock balance of carbon sequestered in forest media, wood products in use, and wood in solid waste disposal facilities. These estimates are shown in **Table 3.2-2**.

Table 3.2-2 Carbon Stocks in the U.S. Forest and Harvested Wood Pools (Million Metric Tons)

Carbon Pool	1990	1995	2000	2005	2006	2007
Forest	**40,106**	**40,810**	**41,535**	**42,308**	**42,481**	**42,654**
Above Ground Biomass	14,547	14,955	41,535	42,308	42,481	42,654
Below Ground Biomass	2,896	2,974	3,063	3,167	3,189	3,211
Dead Wood	2,453	2,515	2,592	2,664	2,679	2,695
Litter	4,557	4,641	4,680	4,738	4,753	4,769
Soil Organic Carbon	15,652	15,725	15,795	15,817	15,826	15,835
Harvested Wood	**1,862**	**2,033**	**2,193**	**2,332**	**2,362**	**2,392**
Products in Use	1,231	1,311	1,382	1,436	1,448	1,461
Solid Waste	631	722	810	896	913	931
Total Carbon Stock	**41,968**	**42,843**	**43,728**	**44,640**	**44,843**	**43,376**

When the carbon stock information is combined with the estimated GHG emissions from forest ecosystems, EPA (2008a) estimated the amount of CO_2 that is sequestered annually in the U.S., as shown in **Table 3.2-3**.

Table 3.2-3 Net Annual Changes in U.S. Carbon Stocks (Metric Tons CO_2/year)

Carbon Pool	1990	1995	2000	2005	2006
Forest	(489.1)	(540.5)	(436.8)	(635.1)	(635.1)
Harvested Wood	(132.6)	(119.4)	(113.9)	(108.5)	(110.0)
Total Net Flux	(621.7)	(659.9)	(550.7)	(697.3)	(698.7)

It is assumed that the overall carbon stock balance for the Dixie National Forest follows the national trend described by the EPA, in that carbon is being sequestered in both the Forest ecosystem and harvested wood obtained from the Forest, and that this is resulting in a net sequestration of CO_2 on an annual basis.

GHG Emissions from Forest Operations

The Dixie National Forest has not conducted a Forest-specific estimate of GHG emissions from normal forest management activities. In July 2009 the USFS published its first estimates of GHG emissions for six national forests in the Greater Yellowstone Area (USFS 2009). The inventory only addressed anthropogenic emissions during fiscal year 2007 from the six National Forests, and did not include carbon sequestration or carbon sinks. The inventory estimated GHG emissions generated by Forest Service activities in Fiscal Year 2007 on the following six National Forests in the Greater Yellowstone Area: Bridger-Teton, Beaverhead-Deerlodge, Caribou-Targhee, Custer, Gallatin, and Shoshone. The results of the inventory are shown in **Table 3.2-4**.

Table 3.2-4 Fiscal Year 2007 Emissions by Source Category for Each Greater Yellowstone Area Forest (Metric Tons CO_{2e})

Source	Beaverhead-Deerlodge	Bridger-Teton	Caribou-Targhee	Custer	Gallatin	Shoshone
Mobile Sources	526	1,050	1,270	170	772	797
Purchased Electricity	457	558	326	128	275	170
Stationary Sources	322	287	247	69	218	123
Employee Commuting	13	164	245	39	184	91
Business Air Travel	13	22	28	11	21	11
Total	1,332	2,080	2,117	417	1,469	1,190

Although the Dixie National Forest has not conducted a greenhouse gas emissions inventory of its own operations, it is likely within the range included in the emissions estimates for the six national forests in the Greater Yellowstone Area.

GHG Emissions from Forest Fires

A significant amount of GHG is emitted from forest fires. EPA (2008b) estimated GHG emissions from forest fires in the U.S., at shown in **Table 3.2-5**.

Table 3.2-5 GHG Emissions from Forest Fires in the U.S. (Million Metric Tons)

GHG	1990	1995	2000	2003	2004	2005	2006
CO_2	48.8	51.3	207.2	95.4	75.5	134.3	267.9
CH_4	4.5	4.7	19.0	8.7	6.9	12.3	24.6
N_2O	0.5	0.5	1.9	0.9	0.7	1.2	2.5

In California, Bonnicksen (2008) used the Forest Carbon and Emissions Model to estimate GHG emissions from forest fires (Bonnicksen 2008). Bonnicksen studied four California wild fires that burned a total of 144,825 acres and were found to have released about 9.5 million tons of GHG emissions from combustion, or about 63 tons per acre. This was based on a tree density of about 273 trees per acre. It was calculated that this GHG emission rate would have been lowered to about 12 tons per acre for a tree density of about 60 trees per acre. However, GHG emissions from eventual decay of wood and plant materials caused by the fires was calculated to be roughly three times that of combustion alone, increasing the total GHG emissions from the fires to about 38 million tons over the next 50 to 100 years. This is because forests emit more GHG when they decay than when they burn because large quantities of biomass remain in the forest after combustion. The total GHG emissions from these four fires was calculated to be roughly equivalent to about seven million cars driving in California for one year.

The Dixie National Forest has experienced forest fires in the past and will continue to do so in the future. The extent and severity of wildfires on the Forest cannot be predicted, and neither can the GHG emissions from these events. However, GHG emission estimates that have been made nationally and in other states have shown that forest fires are significant sources of GHG emissions, and forest fires on the Dixie National Forest would also produce large quantities of GHG emissions.

3.2.3 Greenhouse Emissions in Utah and Regionally

This section presents GHG emissions data for the State of Utah and regionally as a means of putting estimated emissions from connected actions to the leasing decision in context. Where available, data include both GHGs from all major sources (electricity generation, transportation, agriculture, industry, and landfills).

Utah

The largest source of GHG emissions in Utah is electric power generation (CCS 2007). Over 90 percent of electric power emissions in Utah are from burning coal (**Table 3.2-6**). The largest (coal-fired) power plant and producer of CO_2 emissions in Utah is Intermountain [i.e., Intermountain Power Project in Delta, Utah] (EIA 2009; EPA 2008b). Intermountain accounts for about 40 percent of Utah's GHG emissions on a production basis (EPA 2008b). The top producer of electricity in Utah is PacifiCorp, an electric power company, which produced 80 percent of total electricity generated in Utah in 2007 (22,353,159 megawatt hours; EIA 2009). **Table 3.2-6** shows CO_2 emissions from the Utah electric power industry by fuel source for 2007. Note that these estimates may differ slightly from the U.S. Inventory data (i.e., 38.44 vs. 37.09 for Electric Power in **Table 3.2-7**) due to methodological differences, including scope of coverage, underlying data, and assumptions (see EPA 2009c).

Table 3.2-6 Utah Electric Power Industry CO_2 Emissions by Fuel Source

Fuel Source	2007 CO_2 ($MMTCO_2$)	2007 Percent of Total
Coal	35.10	91
Petroleum	0.03	<0.1
Natural Gas	3.30	9
Geothermal	0.004	<0.1
Total	**38.44**	**100**

Source: (EIA 2009)

Table 3.2-7 shows CO_2 emissions from fossil fuel combustion in all consumption sectors for Utah, given in million metric tons of CO_2 ($MMTCO_2$) by sector (EPA 2009c). Note that this table does not show all greenhouse gas emissions, only CO_2, which EPA estimates to "represent 80 percent of total U.S. greenhouse gas emissions" (EPA 2009a).

Table 3.2-7 Emissions from Fossil Fuel Combustion by Consumption Sector for Utah

Sector	1995 ($MMTCO_2$)	2000 ($MMTCO_2$)	2007 ($MMTCO_2$)	2007 Percent of Total
Commercial	1.41	2.05	2.22	3
Industrial	3.06	10.30	8.03	12
Residential	1.33	3.28	3.61	5
Transportation	11.42	15.63	18.28	26
Electric Power	18.19	32.51	37.09	54
Total	**35.40**	**63.78**	**69.23**	**100**

Source: (EPA 2009c)

Based on EPA's estimate that CO_2 emissions represent 80 percent of greenhouse gas emissions, it can be estimated that total greenhouse gas emissions for 2007 in Utah were 86.5 million metric tons GHG (69.2 MMT CO_2 ÷ 0.80 = 86.5 MMT). Note that this is not CO_2 equivalent, which cannot be determined without knowing the relative proportions of the non-CO_2 gases, which vary not only by fuel type but the specific source of the fuel (e.g. subituminous coal from different states).

Region

In the atmosphere, pollutants can accumulate in stationary air masses, then move with the air mass to another location. The American Meteorological Society (AMS) defines "regional air pollution" as follows:

> Pollutants that have been emitted from all sources in a region and have had time to mix, diffuse from their peak concentration, and undergo physical, chemical, and photochemical reactions. The size of a region is indeterminate, but usually incorporates one or more cities, and is on the order of 100 to 10 000 km2. (AMS 2008)

An air mass is a "widespread body of air, the properties of which can be identified as 1) having been established while that air was situated over a particular region of the earth's surface, and 2) undergoing specific modifications while in transit away from the source of origin. (AMS 2008) Air masses relatively homogeneous horizontally, particularly with respect to temperature and humidity. Vertically, temperature and moisture variations are approximately the same over the horizontal extent of the air mass.

Air masses form through prolonged contact with a relatively uniform region, such as an ocean or flat land area; these are classified as marine or continental air masses (Whiteman 2000). Regional air masses are also classified as tropical or polar, among others. Whiteman notes "in the United States, the topography is too varied (for air masses to form). Instead, the midlatitudes are a region where clashing air masses meet." (Whiteman 2000) In Utah, those air masses are most often either continental tropical (summer only; from Mexico) or continental polar (from the Northwest Territory in Canada) (Whiteman 2000).

Utah is part of several "regions," including the Great Basin, the Rocky Mountains, and the Colorado Plateau. For the purposes of analysis in this section, the following states will be compared and defined as the "seven-state region": Utah, Nevada, Idaho, Wyoming, Colorado, New Mexico, and Arizona. These states share many climatic, ecological, and population attributes.

Table 3.2-8 shows 2007 emissions from fossil fuel combustion by sector for the seven-state region described above, as well as their regional total CO_2 emissions. The table also shows population (2008 estimate) and per capita CO_2 emissions from fossil fuel combustion from these data. The data show that Utah, at 25.3 metric tons per capita, has the third highest emission per capita of CO_2 from combustion of fossil fuel in the region. The national per capita rate was 19.2 metric tons for 2008 (see **Table 3.2-14** below). As of 2005, Utah's gross CO_2 emissions are rising at a faster rate than those of the nation (EPA 2008b). By 2020, Utah's gross CO_2 emissions are projected to climb to 96.1 MMt CO_2, which is 95 percent above 1990 levels (53.8 MMt CO_2 in 1990, EPA 2009c; gross emissions=69.2 MMt CO_2 in 2007; **Table 3.2-8**).

Table 3.2-8 Regional CO_2 Emissions from Fossil Fuel Combustion 2007

2007 CO_2 Emissions (MMT)								
Sector	**Utah**	**NV**	**ID**	**WY**	**CO**	**NM**	**AZ**	**Region**
Commercial	2.2	1.7	1.0	0.8	3.8	1.5	2.1	13.2
Industrial	8.0	2.8	3.4	11.0	13.1	8.6	4.9	51.9
Residential	3.6	2.3	1.6	0.9	7.7	2.2	2.3	20.7
Transportation	18.3	18.1	9.5	8.8	31.1	15.4	37.5	138.7
Electric Power	37.1	16.6	0.7	43.1	42.4	30.8	54.7	225.4
Total	**69.2**	**41.6**	**16.3**	**64.6**	**98.1**	**58.6**	**101.5**	**449.9**
% of Region	15	9	4	14	22	13	23	100
Population (2008 est)	2,736,424	2,600,167	1,523,816	532,668	4,939,456	1,984,356	6,500,180	20,817,067
CO_2 Emission per Capita	25.3 metric tons	16.0 metric tons	10.7 metric tons	121.2 metric tons	19.9 metric tons	29.5 metric tons	15.6 metric tons	21.6 metric tons

Source: EPA 2009c; U.S. Census Bureau 2009

3.2.4 United States

The EPA tracks GHG emissions in the U.S. by source sector (e.g., industrial, land use, electricity generation, etc), fuel source (e.g., coal, natural gas, geothermal, petroleum, etc), and economic sector (e.g., residential, transportation, commercial, agriculture, etc). Data are further refined by the emissions (e.g., carbon dioxide, methane, nitrous oxide, etc) and their CO_2 equivalent. With so many GHG emission sources nationally, from cows to tailpipes to electric power generators, no single source is likely to represent a significant percentage of national emissions. Nevertheless, in the context of NEPA and disclosure of potential impacts, GHG emissions for the U.S. are provided here in several ways. **Table 3.2-9** shows GHG emissions (in CO_2 equivalent) by economic sectors for 1995, 2000, and 2007. **Table 3.2-10** shows total U.S. emissions in 1995, 2000, and 2007 by gas and source and by CO_2 equivalent; only the largest sources/sinks are shown for each gas. Note that, for CO_2, "Land Use, Land-Use Change, and Forestry" represents a sink rather than a source, and is therefore in parentheses.

Table 3.2-9 U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_{2e})

Implied Sectors	1995 (MMT CO_{2e})	2000 (MMT CO_{2e})	2007 (MMT CO_{2e})
Electric Power Industry	1,989.0	2,329.3	2,445.1
Transportation	1,685.2	1,919.7	1,995.2
Industry*	1,524.5	1,467.5	1,386.3
Agriculture	453.7	470.2	502.8
Commercial	401.0	388.2	407.6
Residential	368.8	386.0	355.3
U.S. Territories	41.1	47.3	57.7
Total Emissions	**6,463.3**	**7.008.2**	**7,150.1**
Land Use, Land-Use Change, and Forestry (Sink)	(851.0)	(717.5)	(1,062.6)
Net Emissions (Sources and Sinks)	**5,612.3**	**6,290.7**	**6,087.5**

Source: EPA 2009a; *includes Natural Gas Systems and Petroleum Systems.

Table 3.2-10 U.S. Greenhouse Gas Emissions and Sinks (MMT CO_{2e})

Gas/Source	1995 (MMT CO_{2e})	2000 (MMT CO_{2e})	2007 (MMT CO_{2e})
CO_2	**5,407.9**	**5,955.2**	**6,103.4**
Fossil Fuel Combustion	5,013.9	5,561.5	5,735.8
Non-Energy Use of Fuels	137.5	144.5	133.9
Cement Manufacture	36.8	41.2	44.5
Iron and Steel Production and Metallurgical Coke Production	103.1	95.1	77.4
Natural Gas Systems*	33.8	29.4	28.7
Petroleum Systems*	0.3	0.3	0.3
Land Use, Land-Use Change, and Forestry (Sink)	(851.0)	(717.5)	(1,062.6)
CH_4	**615.8**	**591.1**	**585.3**
Landfills	144.3	122.3	132.9
Enteric Fermentation	143.6	134.4	139.0
Natural Gas Systems	132.6	130.8	104.7
Coal Mining	67.1	60.5	57.6
Manure Management	34.5	37.9	44.0
Petroleum Systems	32.0	30.3	28.8
N_2O	**334.1**	**329.2**	**311.9**
Agricultural Soil Management	202.3	204.5	207.9
Mobile Combustion	53.7	52.8	30.1
Nitric Acid Production	22.3	21.9	21.7
Stationary Combustion	13.3	14.5	14.7
Manure Management	12.9	14.0	14.7
HFCs, PFCs, and SF_6	**105.5**	**132.8**	**149.5**
Substitution of Ozone Depleting Substances	28.5	71.2	108.3
HCFC-22 Production	33.0	28.6	17.0
Electrical Transmission and Distribution	21.6	15.1	12.7
Total Emissions	**6,463.3**	**7.008.2**	**7,150.1**
Net Emissions (Sources and Sinks)	**5,612.3**	**6,290.7**	**6,087.5**

Source: EPA 2009a; *Combusted CO_2 emissions from Natural Gas and Petroleum Systems are accounted for in the Fossil Fuels Combustion source category.

Non-combustion CO_2 and CH_4 emissions for Natural Gas Systems (as shown in **Table 3.2-10**) are generally process-related, with normal operations (e.g., from natural gas engines and turbine uncombusted exhaust), routine maintenance (i.e., from pipelines, equipment, and wells during maintenance), and system upsets (e.g., from pressure surge relief systems and accidents) being the primary contributors (EPA 2009a). Emissions from the four major stages of Natural Gas Systems are shown in **Table 3.2-11**.

Non-combustion CO_2 emissions for Petroleum Systems (as shown in **Table 3.2-10**) are primarily associated with crude oil production and are negligible in the transportation and refining operations. Non-combustion CH_4 emissions are associated with all three activities, during which CH_4 emissions are released as fugitive emissions, vented emissions, and emissions from operational upsets (EPA 2009a). Emissions from the three major stages of Petroleum Systems are shown in **Table 3.2-11**.

Table 3.2-11 U.S. GHG Emissions Related to Natural Gas Systems, and Petroleum Systems

Gas/Source	GHG 1995 (MMT CO_{2e})	GHG 2000 (MMT CO_{2e})	GHG 2007 (MMT CO_{2e})
CO_2	5,407.9	5,955.2	6,103.4
Natural Gas Systems	**33.8**	**29.4**	**28.7**
Field Production	9.1	6.0	7.4
Processing	24.6	23.3	21.2
Transmission and Storage	0.1	0.1	0.1
Distribution	--	--	--
Petroleum Systems	**0.3**	**0.3**	**0.3**
Production Field Operations	0.3	0.3	0.3
Crude Oil Transportation	**--**	**--**	**--**
Refining	**--**	**--**	**--**
CH_4	615.8	591.1	585.3
Natural Gas Systems	**132.6**	**130.8**	**104.7**
Field Production	38.7	40.3	22.4
Processing	15.1	14.5	12.3
Transmission and Storage	46.4	44.6	40.4
Distribution	32.4	31.4	29.6
Petroleum Systems	**32.0**	**30.3**	**28.8**
Production Field Operations	31.3	29.6	28.1
Crude Oil Transportation	0.1	0.1	0.1
Refining	0.5	0.6	0.6

Source: EPA 2009a

Indirect greenhouse gases do not have a direct global warming effect, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or in the case of SO_2, the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases (EPA 2009a). Oil and gas activities are among the energy sources that contribute indirect GHG emissions to the atmosphere; these amounts are listed in **Table 3.2-12**.

Table 3.2-12 Indirect U.S. GHG Emissions Related to Oil and Gas Activities

Gas/Source	GHG 1995 (MMT)	GHG 2000 (MMT)	GHG 2007 (MMT)
NO_X	**21.07**	**19.00**	**14.25**
Oil and gas activities	0.1	0.11	0.31
CO	**109.03**	**92.78**	**63.88**
Oil and gas activities	0.32	0.15	0.32
NMVOCs	**19.52**	**15.23**	**13.75**
Oil and gas activities	0.58	0.39	0.53
SO_2	**16.89**	**14.83**	**11.73**
Oil and gas activities	0.34	0.29	0.21

Source: EPA 2009a

3.2.5 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 3.2-13** shows estimated CO_2 emissions for 1995, 2000, 2005, and 2008 by IPCC region, and percent of the total. **Table 3.2-14** shows similar information for the ten highest consuming countries and the ten highest per capita consuming countries. The tables were derived from Energy Information Administration data (EIA 2010).

Table 3.2-13 World CO_2 Emissions from the Consumption and Flaring of Fossil Fuels by IPCC Region (MMT CO_2)

IPCC Region	CO_2 1995 (MMT CO_2)	CO_2 2000 (MMT CO_2)	CO_2 2005 (MMT CO_2)	CO_2 2008 (MMT CO_2)	2008 Percent of Total
North America	6,158.5	6,823.1	7,028.8	6,852.3	23
Central & South America	858.2	992.6	1,110.3	1,247.8	4
Europe	4,323.5	4,476.1	4,693.1	4,662.0	15
Eurasia	2,474.3	2,332.8	2,506.3	2,651.9	9
Middle East	901.5	1,094.2	1,448.0	1,678.4	6
Africa	827.0	891.7	1,056.0	1,108.3	4
Asia & Oceania	6,675.5	7,266.2	10,628.6	12,176.6	40
World Total	**22,218.5**	**23,876.6**	**28,471.0**	**30,377.3**	**100**

Source: EIA 2010

Table 3.2-14 World CO_2 Emissions from the Consumption and Flaring of Fossil Fuels by Largest Consuming Countries and Largest Per Capita Consuming Countries

IPCC Region	CO_2 1995 (MMT CO_2)	CO_2 2000 (MMT CO_2)	CO_2 2008 (MMT CO_2)	2008 (Metric Tons CO_2 Per Capita)
TEN LARGEST CONSUMING COUNTRIES				
China	2,885.42	2,871.53	6,533.55	4.91
United States	5,325.90	5,863.81	5,832.82	19.18
Russia	1,607.09	1,560.42	1,729.38	12.29
India	876.39	1,009.76	1,494.88	1.31
Japan	1,118.96	1,205.07	1,214.19	9.54
Germany	894.27	857.98	828.76	10.06
Canada	509.94	574.78	573.50	17.27
United Kingdom	561.79	561.66	571.80	9.38

IPCC Region	CO_2 1995 (MMT CO_2)	CO_2 2000 (MMT CO_2)	CO_2 2008 (MMT CO_2)	2008 (Metric Tons CO_2 Per Capita)
Korea, South	382.48	440.29	542.09	11.21
Iran	262.25	320.67	511.12	7.76
TEN LARGEST PER CAPITA CONSUMING COUNTRIES				
Gibraltar	3.24	7.30	4.64	161.57
Virgin Islands, U.S.	8.56	9.85	13.89	126.49
Qatar	30.31	34.70	61.14	74.13
Netherlands Antilles	11.41	11.62	12.29	54.55
Bahrain	15.88	20.26	31.08	43.21
United Arab Emirates	100.94	115.72	199.20	43.10
Trinidad & Tobago	22.63	27.51	50.48	41.00
Singapore	82.97	107.64	159.48	34.61
Kuwait	39.99	59.50	82.10	31.60
Brunei	3.52	3.79	10.40	27.28
World Total	**22,284.01**	**24,010.66**	**30,377.31**	**4.54**

Source: EIA 2010

3.2.6 Summary

Table 3.2-15 summarizes the information in **Sections 3.2.1** through **3.2.5**, showing total CO_2 emissions for the Dixie National Forest Oil and Gas Activities, Utah, the seven-state region in **Section 3.2.3**, the United States, and the World. Data are for CO_2 emissions only and have the same caveats and conditions as described for the tables (above) from which they are derived.

Table 3.2-15 Summary Table

IPCC Region	CO_2 1995 (MMT CO_2)	CO_2 2000 (MMT CO_2)	CO_2 2007 (MMT CO_2)
Dixie NF Oil and Gas Activities	--	--	0.35 (Predicted)
Utah	35.40	63.78	69.23
Region (7-state)	--	--	449.9
United States	5,323.97	5,860.38	5,902.75
World Total	**22,284.01**	**24,010.66**	**30,377.31 (2008)**

4.0 Impacts Analysis

4.1 Connected Actions on Global Warming

The following summarizes Dixie National Forest oil and gas activities emissions, assuming all connected actions to the leasing decision were to occur, as related to U.S. and Global emissions.

4.1.1 Connected Actions GHG Emissions Compared to Existing US and Global emissions

Without taking carbon sinks (Section 3.2.2) into account, CO_2 emissions from predicted oil and gas activities on the Dixie National Forest (i.e., connected actions to leasing) would increase U.S. and world CO_2 emissions. At the national and global scales, this would be a negligible impact. On a state scale, CO_2 emissions from connected actions on the Dixie would constitute a minor increase in CO_2 emissions for Utah in 2007. Because the increases reported here are so small, the difference between CO_{2e} and CO_2 is overlooked. It should also be noted that the GHG emission estimate for connected actions has included emissions from refining, transportation of refined product, and product end use. This is a conservative impact estimate because it could be argued that the emissions from the refinery and later activities are not connected actions to potential Dixie National Forest oil and gas production and may occur regardless of the product source in order to satisfy current and future market conditions.

4.1.2 Effects of Connected Actions on Foreseeable Impacts of Climate Change

Section 2.0, above, describes the potential effects of climate change on Utah, the U.S., and the world, with emphasis on resources. The GHG emission impacts from predicted Dixie National Forest oil and gas activities (connected actions) would incrementally contribute a relatively small amount to the total volume of GHG released to the atmosphere and consequently could be responsible for an increment of the predicted effects of climate change. The incremental impact from connected actions would be negligible to minor and its duration and would likely be long term.

4.2 Effects of Climate Change on the Dixie NF and the Cumulative Effects Area

The potential direct, indirect, and cumulative effects of the connected actions on the environmental resources of the Forest and cumulative effects area are described in the Oil and Gas Leasing EIS. These effects are predicted based on information describing past and existing baseline conditions. These baseline conditions have, to some degree, already been affected by climate change and thus these past and current climate change effects are already included in the impact analysis of the EIS. Future climate change has the potential to further impact many of the same environmental resources in ways that are described in **Section 2.0**. It is difficult to predict with any certainty the cumulative effects of future climate change along with the environmental impacts already described in the EIS.

5.0 Foreseeable Future Responses

The concept of responses to address global warming has evolved since they were first discussed in the First Assessment Report. This report 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 Second Assessment Report, the socio-institutional context was emphasized as well as the issues of equity, development and sustainability. In the Third Assessment Report, the concept of mitigative capacity was introduced, and the focus of attention was shifted to sustainability concerns (Rogner et al. 2007).

The discussion of foreseeable future "responses" to climate change herein will focus on Fourth Assessment Report. The report summarizes the information contained in previous IPCC reports – including the IPCC special reports on Carbon Dioxide Capture and Storage, on Safeguarding the Ozone Layer and on the Global Climate System published since the Third Assessment Report – and assesses the scientific literature published since 2000 (Rogner et al. 2007).

The main anthropogenic source of CO_2 in the atmosphere is the consumption of energy from fossil fuels (IPCC 2001b). Electricity generation and transportation accounted for the vast majority of CO_2 emissions from fossil fuel combustion in 2005 (EPA 2007a). In order to reduce carbon in the atmosphere, meaningful reductions of greenhouse gas emissions will have to be made in these sectors. For this reason, this section will focus on responses to climate change for these two segments of the economy. Brief explanations of responses related to residential and commercial buildings, industry, agriculture, forestry, waste management, and sustainable development will be included as well.

The Third Assessment Report indicates that no single technology option will provide all of the emission reductions needed to achieve stabilization, but a portfolio of responses will be needed (IPCC 2005a).

5.1 Electric Energy Supply

Most scenarios project that the supply of primary electric 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.).

5.1.1 Nuclear Energy

In 2005, 16 percent of the world total electricity supply was generated by nuclear power. Total life-cycle greenhouse gas emissions per unit of electricity are similar to those for renewable energy sources. Proposed and existing fossil fuel power plants could be partly replaced by nuclear power plants to provide electricity and heat. Since the nuclear plant and fuel system consumes only small quantities of fossil fuels in the fuel cycle, net CO_2 emissions could be lowered significantly. The IPCC estimates that 18 percent of total global power generation capacity could come from existing nuclear power plants as well as new plants displacing proposed new coal, gas and oil plants in proportion to their current share of the baseline (Sims et al. 2007). Increased use of nuclear energy at this rate would result in approximately 1.88 Gt CO_2-eq/yr reduction in emissions.

5.1.2 Renewable Energy

Renewable energy accounted for over 15 percent of the world primary energy supply in 2004, including traditional biomass (7 to 8 percent), large hydroelectric (5.3 percent), and other renewables (2.5 percent). Fossil fuels can be partly replaced by renewable energy sources to provide heat or electricity, or through combined heat and power plants. The following discussion is summarized from the IPCC (2005a).

Hydroelectric

Large hydroelectric systems provided 16 percent of global electricity and 90 percent of renewable electricity in 2004. However, where hydro expansion is occurring, major social disruptions, ecological impacts on existing river ecosystems and fisheries and related evaporative water losses are stimulating public opposition. These and other environmental concerns may mean that obtaining resource permits is a constraint in future development. It is assumed that enough existing and new sites will be available to contribute approximately 17 percent of total electricity generation by 2030 as a result of displacing coal, gas and oil plants based on their current share of the base load. Increased use of hydroelectric power would result in 0.87 Gt CO_2-eq/yr reduction in emissions.

Wind

Wind provided approximately 0.5 percent of the total electricity production in 2004. New wind installation capacity has grown at an average of 28 percent per year since 2000, with a record 40 percent increase in 2005. Issues such as noise, electromagnetic force interference, airline flight paths, land use, protection of areas with high landscape value, and bird and bat strike remain constraints. On- and offshore wind power is assumed to reach a 7 percent share by 2030, and to displace new and existing fossil fuel power plants according to the relevant shares of coal, oil and gas in the baseline for each region. Increased use of wind power is project to result in 0.93 Gt CO_2-eq/yr reduction in emissions.

Bioenergy

Biomass continues to be the world's major source of food, stock fodder and fiber as well as a renewable resource of hydrocarbons for use as a source of heat, electricity, liquid fuels and chemicals. Bioenergy carriers range from a simple firewood log to a highly refined gaseous fuel or liquid biofuel. Globally, biomass is estimated to be over 10 percent of global primary energy, but with over two thirds consumed in developing countries as traditional biomass for household use. Biomass can be combined with fossil fuel technologies by co-firing solid biomass particles with coal; mixing synthesis gas, landfill gas or biogas with natural gas prior to combustion. There has been rapid progress since the Third Assessment Report in the development of the co-utilization of biomass materials in coal-fired boiler plants.

Large global resources of biomass could exist by 2030, but confidence in estimating the bioenergy heat and power potential is low since there will be competition for these feedstocks for biomaterials, chemicals and biofuels. The potential contribution to the electricity mix from biomass by 2030 is 7 percent, resulting in net emissions reductions of 1.22 Gt CO_2-eq/yr (for energy production only; not including transportation).

Geothermal

Geothermal resources have long been used for direct heat extraction for building and district heating, industrial processing, domestic water and space heating, and leisure applications. In 2004 installed geothermal generation capacity produced 0.3 percent of global electricity in 2004. Production is growing at around 20 percent per year, with an estimated total of 2 percent of generation by 2030. Increased use of geothermal resources is estimated to result in reduced emissions of 0.43 Gt CO_2-eq/yr.

Solar

Solar energy contributes to the total energy scenario through concentrating solar power (CSP) plants, solar photovoltaics (PV), and through solar heating and cooling. Solar PV and CSP plants accounted for less than 0.2 percent of the 2005 share of total supply of global energy sources. These sources could potentially account for 2 percent of the global electricity mix by 2030, resulting in emissions reductions of 0.25 Gt CO_2-eq/yr.

Ocean Energy

The potential marine-energy resource of wind-driven waves, gravitational tidal ranges, thermal gradients between warm surface water and colder water, salinity gradients, and marine currents is huge, but the amount that is currently exploitable economically is low. All the related technologies are at an early stage of development. The marine-energy industry is now in a similar stage of development to the wind industry in the 1980s. Ocean energy is immature and assumed unlikely to make a significant contribution to overall power needs by 2030.

5.1.3 Increased Efficiency

Reductions in CO_2 emissions can be gained by improving the efficiency of existing power generation plants by employing more advanced technologies using the same amount of fuel. For example, a 27 percent reduction in emissions is possible by replacing a 35 percent efficient coal-fired steam turbine with a 48 percent efficient plant using advanced steam, pulverized-coal technology. Replacing a natural gas single-cycle turbine with a combined cycle of similar output capacity helps reduce CO_2 emissions per unit of output by around 36 percent.

5.1.4 Carbon Dioxide Capture and Storage (CCS)

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).

Capture of CO_2 can best 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 and the impact of old and poorly sealed well bores. 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 world is not on course to achieve a sustainable energy future. 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).

5.2 Transportation

In 2004, transport was responsible for 23 percent of world energy-related GHG emissions with about three quarters coming from road vehicles. In 2004, the transport sector produced 6.3 Gt of

CO_2 emissions. Over the past decade, transport's GHG emissions have increased at a faster rate than any other energy using sector. Transport activity, a key component of economic development and human welfare, is increasing around the world as economies grow. Transport activity is expected to grow robustly over the next several decades. Unless there is a major shift away from current patterns of energy use, world transport energy use is projected to increase at the rate of about 2 percent per year, and the total transport energy use and carbon emissions is projected to be about 80 percent higher than current levels by 2030 (Kahn et al. 2007).

5.2.1 Road Transport

GHG emissions associated with vehicles can be reduced by four types of measures:

1. Reducing the loads (weight, rolling and air resistance and accessory loads on the vehicle, thus reducing the work needed to operate it).
2. Increasing the efficiency of converting the fuel energy to work by improving drive train efficiency and recapturing energy losses;
3. Changing to a less carbon-intensive fuel; and
4. Reducing emissions of non-CO_2 greenhouse gases from vehicle exhaust and climate controls.

Carbon emissions from 'new' light-duty road vehicles could be reduced by up to 50 percent by 2030 assuming continued technological advances and strong government policies to ensure that technologies are applied to increasing fuel economy rather than on increased horsepower and vehicle mass. Material substitution and advanced design could reduce the weight of light-duty vehicles by 20 to 30 percent. The use of hybrid technology with heavy intercity trucks could reduce fuel use by 10 to 20 percent. Road vehicle efficiency might be improved by 5 to 20 percent through strategies such as eco-driving styles, increased load factors, improved maintenance, in-vehicle technological aids, more efficient replacement tires, reduced idling and better traffic management and route choice. Total mitigation potential in 2030 of the energy efficiency options applied to light duty vehicles would be around 0.7 – 0.8 Gt CO_2-eq (Kahn et al. 2007).

5.2.2 Rail Transport

Although rail transport is one of the most energy efficient modes today, substantial opportunities for further efficiency improvements remain. Reduced aerodynamic drag, lower train weight, regenerative breaking and higher efficiency propulsion systems can make significant reductions in rail energy use. Shipping, also one of the least energy intensive modes of transport, still has some potential for increased energy efficiency. Studies assessing both technical and operational approaches have concluded that energy efficiency opportunities of a few percent up to 40 percent are possible (Kahn et al. 2007).

5.2.3 Aircraft

Passenger jet aircraft produced today are 70 percent more fuel efficient than the equivalent aircraft produced 40 years ago and continued improvement is expected. A 20 percent improvement over 1997 aircraft efficiency is likely by 2015 and possibly a 40 to 50 percent improvement is anticipated by 2050. Still greater efficiency gains will depend on the potential of novel designs such as blended wing body, or propulsion systems such as the unducted turbofan. For 2030 the estimated mitigation potential is 150 Mt CO_2. However, without policy intervention, projected annual improvements in aircraft fuel efficiency of the order of 1 to 2 percent will be surpassed by annual traffic growth of around 5 percent each year, leading to an annual increase of CO_2 emissions of 3 to 4 percent per year (Kahn et al. 2007).

5.2.4 Biofuels

Biofuels have the potential to replace a substantial part but not all petroleum use by transport. A recent analysis estimates that biofuels' share of transport fuel could increase to about 10 percent in 2030. The global potential for biofuels will depend on the success of technologies to utilize cellulose biomass (Kahn et al. 2007).

5.2.5 Public Transportation

Providing public transports systems and their related infrastructure and promotion non-motorized transport can contribute to greenhouse gas responses. However, local conditions determine how much transport can be shifted to less energy intensive modes. Occupancy rates and primary energy sources of the transport mode further determine the response impact. The energy requirements for urban transport are strongly influenced by the density and spatial structure of the built environment, as well as by location, extent and nature of transport infrastructure.

While transport demand certainly responds to price signals, the demand for vehicles, vehicle travel and fuel use are significantly price inelastic. As a result, large increases in prices or taxes are required to make major changes in greenhouse gas emissions. Since currently available response options will probably not be enough to prevent growth in transport's emissions, technology research and development is essential in order to create the potential for future, significant reductions in transport greenhouse gas emissions (Kahn et al. 2007).

5.3 Residential and Commercial Buildings

There is a broad array of accessible and cost-effective technologies and know-how which can abate GHG emissions in buildings to a significant extent. These include passive solar design, high-efficiency lighting and appliances, highly efficient ventilation and cooling systems, solar water heaters, insulation materials and techniques, high-reflectivity building materials and multiple glazing. The largest savings in energy use (75 percent or higher) occur for new buildings, through designing and operating buildings as complete systems. Realizing these savings requires an integrated design process involving architects, engineers, contractors and clients, with full consideration of opportunities for passively reducing building energy demands. Over the whole building stock the largest portion of potential carbon savings by 2030 is in retrofitting existing buildings and replacing energy-using equipment due to the slow turnover of the stock (Levine et al. 2007).

5.4 Industry

Many options exist for responding to GHG emissions from the industrial sector. These options can be divided into three categories:

- Sector-wide options, for example more efficient electric motors and motor-driven systems; high efficiency boilers and process heaters; fuel switching, including the use of waste materials; and recycling.
- Process-specific options, for example the use of the bioenergy contained in food and pulp and paper industry wastes turbines to recover the energy contained in pressurized blast furnace gas, and control strategies to minimize PFC emissions from aluminum manufacture.
- Operating procedures, for example control of steam and compressed air leaks, reduction of air leaks into furnaces, optimum use of insulation, and optimization of equipment size to ensure high capacity utilization.

Full use of available response options is not being made in either industrialized or developing nations. In many areas of the world, GHG responses are not demanded by either the market or government regulations. Industrial GHG investment decisions will continue to be driven by consumer preferences, costs, competitiveness and government regulation. Achieving sustainable development will require the implementation of cleaner production processes without compromising employment potential (Bernstein et al. 2007).

Industry is vulnerable to the impacts of climate change, particularly to the impacts of extreme weather. Companies can adapt to these potential impacts by designing facilities that are resistant to projected changes in weather and climate, relocating plants to less vulnerable locations, and diversifying raw material sources, especially agricultural or forestry inputs. Industry is also vulnerable to the impacts of changes in consumer preference and government regulation in response to the threat of climate change. Companies can respond to these by mitigating their own emissions and developing lower-emission products (Bernstein et al. 2007).

5.5 Agriculture

A variety of options exists as possible responses to GHG emissions in agriculture. The most prominent options are improved crop and grazing land management (e.g., improved agronomic practices, nutrient use, tillage, and residue management), restoration of organic soils that are drained for crop production and restoration of degraded lands. Lower but still significant responses are possible with improved water and rice management; set-asides, land use change (e.g., conversion of cropland to grassland) and agro-forestry; as well as improved livestock and manure management. Many opportunities use current technologies and can be implemented immediately, but technological development will be a key driver ensuring the efficacy of additional measures in the future. Soil carbon sequestration (enhanced sinks) is the mechanism responsible for most of the response potential, with an estimated 89 percent contribution to the technical potential (Smith et al. 2007).

Greenhouse gas emissions could also be reduced by substituting fossil fuels with energy produced from agricultural feed stocks (e.g., crop residues, dung, energy crops), which would be counted in sectors using the energy. Deployment of new practices for livestock systems and fertilizer applications will be essential to prevent an increase in emissions from agriculture after 2030 (Smith et al. 2007).

5.6 Forestry

The carbon response potentials from reducing deforestation, forest management, afforestation (establishment of a new forest by seeding or planting on nonforested land), and agro-forestry differ greatly by activity, regions, system boundaries and the time horizon over which the options are compared. In the short term, the carbon response benefits of reducing deforestation are greater than the benefits of afforestation. That is because deforestation is the single most important source, with a net loss of forest area between 2000 and 2005 of 7.3 million ha/yr (Naburrs et al. 2007).

Response options by the forestry sector include extending carbon retention in harvested wood products, product substitution, and producing biomass for bioenergy. This carbon is removed from the atmosphere and is available to meet society’s needs for timber, fiber, and energy. In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fiber or energy from the forest, will generate the largest sustained benefit. The combined effects of reduced deforestation and degradation, afforestation, forest management, agro-forestry and bioenergy have the potential to increase from the present to 2030 and beyond (Naburrs et al. 2007).

5.7 Waste Management

Existing waste-management practices can provide effective responses to GHG emissions from this sector: a wide range of mature, environmentally effective technologies are available to provide public health, environmental protection, and sustainable development co-benefits. Collectively, these technologies can directly reduce GHG emissions (through landfill gas recovery, improved landfill practices, engineered wastewater management) or avoid significant greenhouse gas generation (through controlled composting of organic waste, state-of-the-art incineration and expanded sanitation coverage). In addition, waste minimization, recycling and re-use represent an important and increasing potential for indirect reduction of GHG emissions through the conservation of raw materials, improved energy and resource efficiency and fossil fuel avoidance (Bogner et al. 2007).

5.8 Sustainable Development

The concept of sustainable development is defined as, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

There is growing emphasis in the literature on the two-way relationship between responses to climate change and sustainable development. The relationship may not always be mutually beneficial. In most instances, responses can have ancillary benefits or co-benefits that contribute to other sustainable development goals (climate first). Development that is sustainable in many other respects can create conditions in which responses can be effectively pursued (development first). Climate policy alone will not solve the climate problem. Making development more sustainable by changing development paths can make a major contribution to climate goals (Sathaye et al. 2007).

5.9 Natural Biological Sinks

Natural sinks for CO_2 already play a significant role in determining the concentration of CO_2 in the atmosphere. They may be enhanced to take up carbon from the atmosphere. Examples of natural sinks that might be used for this purpose include forests and soils. Enhancing these sinks through agricultural and forestry practices could significantly improve their storage capacity but this may be limited by land use practice, and social or environmental factors. Carbon stored biologically already includes large quantities of emitted CO_2 but storage may not be permanent (IPCC 2005b).

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Appendix SIR-2A

Dixie National Forest Greenhouse Gas Emission Annual Estimates

November 11, 2009

Memorandum

TO: Brian Buck

FROM: Dan Heiser, Dave Strohm, and Melissa Armer

RE: Dixie National Forest Greenhouse Gas Emission Annual Estimates

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Overview

The purpose of this memo is to address greenhouse gas (GHG) emissions as part of the Dixie National Forest's (Dixie) Oil and Gas Environmental Impact Statement (EIS). The activities which are anticipated to contribute to GHG emissions are listed below:

- Exploration drilling
- Production operations- drilling and pumping
- Transportation of crude oil from field to refinery
- Refining of crude oil into final product
- Transportation of final product to end user
- End use of product

This memo provides emissions estimates for each activity listed above and includes assumptions, methods, sources of information, and calculations used to develop the emissions. Detailed emission calculations are included in the Attachment. Emissions are reported in metric tons of Carbon Dioxide Equivalent (CO_{2e}) which is the standard unit of measure established by the Environmental Protection Agency (EPA) for GHG emissions. Carbon dioxide equivalency allows all GHGs to be compared on a common basis. Non-CO_2 gases are converted to CO_{2e} by multiplying by the Global Warming Potential (GWP) for each gas.

Exploration Drilling

Exploratory drilling is predicted to occur at unspecified locations in the Forest as part of the Reasonably Foreseeable Development Scenario (RFDS). GHG emissions estimates were developed utilizing the impacts of a single diesel fueled drill rig operation that will be able to drill and complete three exploratory wells per year. Each well was assumed to take approximately 90 days to drill and assumed 24 hour per day operation. Emissions were calculated utilizing emission factors from the Mandatory Greenhouse Gas Reporting final rule, 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1. The factors utilized were for "Distillate Fuel Oil #2" which is consistent with the diesel fuel used during drilling.

In addition to direct drill rig emissions, a conservative assumption was made that natural gas encountered during drilling would be flared at the drill site. GHG flare emissions were calculated assuming a flare combustion efficiency of 98%, which is consistent with the combustion efficiency listed in the mandatory GHG reporting rule. The flare combustion emissions were then calculated using emission factors from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas." The 2% of non-combusted natural gas was estimated to be composed of

90% methane[1] and the emissions from this non-combusted portion were also reported. The total amount of natural gas used to calculate the exploration flare emissions was assumed to be 100 mmscf/yr. This value is consistent with the volume of natural gas used to calculate the criteria pollutant emissions for the project.

The combination of these emission sources were calculated and reported as total exploratory drilling emissions. The result was estimated at 9,993 metric tons of CO_2e/yr. This total represents the emissions that would occur during any single year of drilling during the exploration phase.

Production Operations - Drilling and Pumping

Once exploratory drilling leads to developable liquid mineral resources, the RFDS will move into extraction/production. The production field will be developed over many years utilizing the same drilling process (and resultant GHG emissions) as that expressed during the exploratory drilling phase. Once a complete well field is developed, full production will commence. This GHG analysis sought to predict maximum potential GHG emissions and therefore assumed that a full 20 well production field was already in place for the production emissions scenario (a theoretical 20 well production field is used in other analyses for the EIS). The theoretical production field was comprised of 20 active oil well pumps fueled by diesel fuel. Emissions for natural gas and electric fueled well pumps were also developed, but diesel was utilized during this analysis as it produced the highest GHG emissions per barrel of oil developed. In addition to the oil well pumps, the theoretical field included equipment for the recovery, treatment and flaring of reasonably foreseeable amounts of natural gas.

For conservatism, the field was assumed to contain 20 heater/treater apparatus (one for each well location), a central natural gas fired compressor, two natural gas dehydrators and a single production flare. Finally, the field also included ongoing drilling operations for either exploration or additional production well development. The emissions for these pieces of equipment were included in a fashion analogous to that described in the exploration drilling section and directly mirrors the scenario used during the modeling and emissions development of criteria pollutants for the project. The emission factors inherent to the combustion calculations were sourced from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1.

In addition to combustion GHG emissions during the production phase, fugitive methane emissions from production equipment were also estimated. Typical sources of fugitive methane emissions in oil systems include the following:[2]

- Leaks from system components- connections, valves, flanges and instruments
- Process vents- glycol dehydrators and storage tanks
- Emissions from starting and stopping reciprocating engines
- Emissions during drilling activities, *e.g.*, gas migration from reservoirs through wells.

Detailed emission calculations associated with each piece of well field equipment as well as fugitive methane emissions are included in Attachment A. The combination of all production well field emissions were calculated and reported as total production emissions. The result was estimated at 43,443 metric tons of CO_2e/yr.

[1] NaturalGas.org- Overview and Background of natural gas- Typical composition is 70-90% methane
[2] Methods for Estimating Methane Emissions from Natural Gas and Oil Systems, 1999 Vol 8. Ch.3.

Transportation from Field to Refinery

After the crude oil is extracted, it will be transported via tanker truck to a refinery. It is assumed a likely destination for the crude oil would be a refinery in the Salt Lake City, Utah area. There are five oil refineries located in the north Salt Lake City (SLC) area with a combined refining capacity of 167,700 barrels per day (bpd) crude oil. The RFDS for the DNF EIS analysis is that the oil field would produce about 2,000 bpd of crude oil. It is assumed this amount of crude oil could be refined at one of the SLC refineries. Assuming 365 day/yr production the project would yield an estimated 730,000 bbl annually.

In order to determine the greenhouse gas emissions associated with trucking of the produced crude, a distance needed to be calculated from the extraction point to the refinery. Since no well locations have been selected at this time, numerous extraction points located throughout the DNF were selected. The distance from these points to the nearest SLC refinery were calculated and the numerical average of these distances was used for the transport emission calculations. The average distance from the extraction points to the refinery was calculated to be 300 miles. Assuming a lead tank truck and pull trailer configuration with an average capacity of 293 bbl (12,300 gallons) this results in a total of 2,491 trips per year.[3]

The primary GHG emissions resulting from transport of crude oil to the refinery is CO_2. Transportation emission factors were taken from the World Resources Institute GHG Protocol[4] tool for mobile combustion. This tool utilizes default emission factors from the EPA based on vehicle class, fuel combusted, and distance traveled. The same emission factors were also used to calculate the emissions caused by the return of empty tanker trucks from the refinery back to the oil field. In addition to the GHG emissions caused by mobile combustion during transport, fugitive methane emissions from loading and unloading tanker trucks as well as tanker truck vents were estimated.

The total emissions resulting from roundtrip crude oil transport from the Forest to the refinery as well as fugitive releases are estimated to be 2,161 metric tons CO_2e/yr.

Refining into Final Product

Emission estimates were also completed for the emissions which would result from refining the crude into final products. Emissions were estimated based on a crude oil life cycle case study published in the Oil and Gas Journal.[5] An average emission factor from five crude oil life cycle case studies was used to estimate refining emissions. The refinery modeling used in the life cycle analyses was based on a selected truncated version of T.J. McCann & Associates Ltd.'s refinery capital planning model programs. The emissions from refining are estimated to be 21,019 metric tons CO_2e/yr.

Transportation of Final Product to End User

After the crude oil is refined into a final product it is assumed to be transported via tanker truck to terminals for final distribution and end use.

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[3] Per phone conversation on 10/27/09 with Beall, trailers and parts representative Brett Durfee located in SLC, Utah.
[4] World Resources Institute (2008). GHG Protocol tool for mobile combustion. Version 2.0
[5] McCann, Tom, Magee, Phil (1999). Crude Oil Greenhouse Gas Life Cycle Analysis Helps Assign Values For CO 2

Emissions. *Oil and Gas Journal, 97* (8).

In 2008 Utah's petroleum product consumption was in excess of in-state production so it is assumed that all refinery products will be consumed within Utah.[6] The average one-way distance from the representative SLC refinery to the end user is assumed to be 150 miles. It was assumed that the total crude refined produces 682,550 bbl/yr of the following products: gasoline, distillate fuel, jet fuel, residual fuel oil, LPG and still gas. All of the products are assumed to be transported to market in tanker trucks except the small amount of still gas which is assumed to be consumed at the refinery.

Assuming a lead tank truck with pull trailer configuration with an average capacity of 319 bbl (13,400 gallons) equates to a total of 2,066 trips per year. Emission calculations were completed as described above for Transportation from the Field to the Refinery. Emission calculations were completed based on the total round-trip distance for transport from the refinery to the end user. The emissions resulting from roundtrip product transport from the refinery to the end user are estimated to be 868 metric tons CO_2e/yr.

End Use

Emission estimates were also completed for the emissions that are caused by the complete combustion or oxidation of each petroleum product produced at the refinery from the subject crude oil during the calendar year. According to the Mandatory Greenhouse Gas Reporting Rule[7] suppliers of petroleum products are required to report the CO_2 emissions associated with the final use of the products. Since N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion or oxidation emissions of the subject products, only CO_2 emissions estimates are included for this analysis.

The following product mix was assumed, based on 2008 Utah overall refinery production data.[4]

- 49.2% motor gasoline
- 24.9% distillate fuel
- 7.8% jet fuel
- 5.1% residual fuel oil
- 3.3% LPG
- 3.2% still gas
- 6.5% other, mostly unfinished oil and coke (not burned)

The end use emission calculations utilized 40 CFR Part 86 equation MM-1 and emission factors from Table MM-1. Below is a list of assumptions made in selecting the emission factors for end use emission calculations.

- Emission factors for motor gasoline assume the average of various products blend formulations
- Jet fuel emission factor assumed to be "Kerosene-Type Jet Fuel"
- Residual Fuel Oil: Emission factor assumes average of "Residual Fuel Oil No. 5 and Residual Fuel Oil No.6"
- LPG emission factor assumes 60% propane; 40% butane mix

The emissions resulting from the complete combustion or oxidation of each petroleum product produced during the calendar year are estimated to be 268,312 metric tons CO_2e/yr.

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[6] Utah Geological Survey: Utah Energy and Mineral Statistics http://geology.utah.gov/emp/energydata/index.htm
[7] "EPA Final Mandatory Greenhouse Gas Reporting Rule." 40 CFR Part 86 Subpart MM Suppliers of Petroleum Products (September 22, 2009).

Conclusion

The overall estimated GHG emissions as part of the Dixie Oil and Gas EIS from the activities outlined in this memo are 345,796 metric tons CO_2e/yr.

Attachment
Detailed Emission Calculations

Summary of Greenhouse Gas Emission for Proposed EIS Activities

Process	GHG Emissions CO_2 (metric tons)	Total GHG Emissions, CO_2 (metric tons CO_2e)
Exploration[1]	9,993	9,993
Production[2]	43,443	43,443
Transportation of Crude	2,161	2,161
Refining	21,019	21,019
Transportation of Refined Products	868	868
Product End Use	268,312	268,312
Total		**345,796 metric tons**

Assumptions:

[1] Assumes highest emissions associated with a single exploratory well and associated exploratory flare.

[2] Assumes 20 production wells with natural gas burning engines as well as natural gas recovery equipment and a diesel fueled exploratory drill rig engine.

EXPLORATION AND PRODUCTION SUMMARY

Source Name	Number of Units Exploration Drill Scenario	Number of Units 20 Well Scenario [1]	Size	Unit	CO_{2e} (Metric Tons/Year)	Notes/Status
EXPLORATION						
Drill Rig Engine	1	1	800.00	Hp	2,683.86	Diesel engine operating 90 days/well & 24 hr/day.
Mud Degassing						No significant greenhouse gas emissions.
Exploration Flares	1	1	100	mmscf/yr	7,309.23	Operating hours same as drill rig.
PRODUCTION						
Heater Treater		20	0.50	mmbtu/hr	4,644.55	Assume 20 Treaters @ 0.5 (No Suggestions)/hr one for each wells.
Dehydrator		2	0.50	mmbtu/hr	464.46	Assume 2 Dehydrators @ 0.5 MMBtu/hr one for each 10 wells. NG combustion, for low volume gas production
Production Flare		1	300.0	mmscf/yr	18,273.07	One production flare per well field.
Compressor Engine		1	300	Hp	747.58	Assumed (1) NG compressors @ 500 Hp each operating for 3,000 hrs/yr. Used to transport oil through lines.
Well Pumps (NG)		20	100	Hp	8,731.76	With 20 NG pumps 1 for each well @ 100 Hp each. Operating continuously.
Well Pumps (diesel)		20	100	Hp	9,070.45	With 20 diesel pumps 1 for each well @ 100 Hp each. Operating continuously.
Well pumps(electric)		20	100	Hp	0.00	With 20 electric pumps 1 for each well @ 100 Hp each. Operating continuously.
Production Fugitives					250.01	

EXPLORATION AND PRODUCTION SUMMARY CONT.

Exploration

Single Exploratory Well Being Drilled with Exploratory Flare				9,993.09	Highest Exploratory Scenario Reported For GHG Summary
Production with On-Going Exploration					
while drilling one well, NG well pumps				43,104.51	
while drilling one well, diesel well pumps				43,443.20	Highest Production Scenario Reported For GHG Summary
while drilling one well, electric well pumps				34,372.75	
without any drilling, diesel well pumps				33,450.12	
without any drilling, NG well pumps				33,111.42	
without any drilling, electric well pumps				24,379.66	

[1] A 20 well oil field is proposed for the reasonably foreseeable development scenario for the production of oil on the forest.

ENGINE EMISSION CALCULATIONS

Calculation Formula for Drill Rig Engine Emissions

Emission factor (kg/mmbtu) * Fuel Heating Value (mmbtu/gal) * (gal/yr) * 0.001 = Emission Rate (metric tons/yr)

Source Name	# Wells per Year	HP Rating	Op Hours[1]	Fuel
Drill Rig Engine	3	800	6,480	Diesel Fuel
Brake-Specific Fuel Consumption: 7,000 Btu/hp-hr[3]		**Fuel Heat Value** 138,000 Btu/gal		**Annual Fuel Usage** 262,957 gallons
Constituent	**Emission Factor (kg/mmbtu)**			**Potential Emission Rate (Metric tons/yr)**
CO_2[2]	7.40E+01			2,684

[1]Based on each w ell taking 90 days to drill and 24 hrs of operation per day

[2] CO_2 emission factor from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Distillate Fuel Oil #2"

CO_2 emissions assume a fuel heat value of 0.138mmbtu/gal. Since N2O and CH4 emissions comprise a relatively small proportion of overall combustion emissions, only CO2 emissions estimates are included

[3]Brake-Specific Fuel Consumption AP-42 Table 3.3-1

Calculation Formula for Diesel Well Pump Emissions

Emission factor (kg/mmbtu) * Fuel Heating Value (mmbtu/gal) * (gal/yr) * 0.001 = Emission Rate (metric tons/yr)

Source Name	# Wells per Year	HP Rating	Op Hours[1]	Fuel
Well Pumps	1	100	8,760	Diesel
Brake-Specific Fuel Consumption: 7,000 Btu/hp-hr[3]		**Fuel Heat Value** 138,000 Btu/gal		**Annual Fuel Usage** 44,435 gallons
Constituent	**Emission Factor (kg/mmbtu)**			**Potential Emission Rate (Metric tons/yr)**
CO_2[2]	7.40E+01			454

[1] Based on each w ell taking 90 days to drill and 24 hrs of operation per day

[2] CO_2 emission factor from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Distillate Fuel Oil #2"

CO_2 emissions assume a fuel heat value of 0.138mmbtu/gal. Since N2O and CH4 emissions comprise a relatively small proportion of overall combustion emissions, only CO2 emissions estimates are included

[3]Brake-Specific Fuel Consumption AP-42 Table 3.3-1

Calculation Formula for Natural Gas Well Pump Emissions

Emission factor (kg/mmbtu) * Fuel Heating Value (mmbtu/scf) * (mmscf/yr) * 10^6 * 0.001 = Emission Rate (metric tons/yr)

Source Name	# Wells per Year	HP Rating	Op Hours	Fuel
Well Pumps	1	100	8,760	Natural Gas
Brake-Specific Fuel Consumption: 9,400 Btu/hp-hr [2]		**Fuel Heat Value** 1,028 Btu/scf		**Annual Fuel Usage** 8.01 mmscf
Constituent	**Emission Factor (kg/mmbtu)**			**Potential Emission Rate (Metric tons/yr)**
CO_2[1]	5.30E+01			437

[1] CO_2 emission factor from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"

CO_2 emissions assume a fuel heat value of 1.028×10^{-3} mmbtu/scf from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"

Since N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion emissions, only CO_2 emissions estimates are included

[2] Brake-Specific Fuel Consumption w as based on default BSFC value for natural gas from the June 2003 edition of the American Oil and Gas Reporter article "Artificial Lift Technology" by Kavas Mistry

COMPRESSOR EMISSION CALCULATIONS

Calculation Formula
Emission factor (kg/mmbtu) * Fuel Heating Value (mmbtu/scf) * (mmscf/yr) * 10^6 * 0.001 = Emission Rate (metric tons/yr)

Source Name	# Compressors	HP Rating	Op Hours	Fuel
Compressors	1	500	3,000	Natural Gas
Brake-Specific Fuel Consumption: 9,400 Btu/hp-hr[2]		Fuel Heat Value 1,028 Btu/scf		Annual Fuel Usage 13.72 mmscf
Constituent	Emission Factor (kg/mmbtu)	Emission Factor (lb/hp-hr)	Emission Rate (lb/hr)	Potential Emission Rate (Metric tons/yr)
CO_2[1]	5.30E+01		498.39	748

[1] CO_2 emission factor from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"
CO_2 emissions assume a fuel heat value of $1.028x10^{-3}$ mmbtu/scf from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"
Since N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion emissions, only CO_2 emissions estimates are included

[2] Brake-Specific Fuel Consumption was based on default BSFC value for natural gas from the June 2003 edition of the American Oil and Gas Reporter article "Artificial Lift Technology" by Kavas Mistry

HEATER EMISSIONS

Average Saturated Gas Heating Value (btu/scf) = 1,028

Calculation Formula
Emission factor (kg/mmbtu) * Fuel Heating Value (mmbtu/scf) * (mmscf/yr) * 10^6 * 0.001 = Emission Rate (metric tons/yr)

Emissions per unit

Source Name	Annual Hours of Operation	Heat Input (mmbtu/hr)	Annual Fuel Usage (mmscf)	CO_2[1] Emission Factor 53.02 (kg/mmbtu) Metric Tons/yr
Heater Treater	8,760	0.50	4.26	232.23
Dehydrator/ Reboiler	8,760	0.50	4.26	232.23
		Totals	**8.52**	**464.46**

[1] CO_2 emission factor from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"
CO_2 emissions assume a fuel heat value of $1.028x10^{-3}$ mmbtu/scf from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"
Since N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion emissions, only CO_2 emissions estimates are included

FLARE EMISSIONS

Calculation Formula

Emission factor (kg/mmbtu) * Fuel Heating Value (mmbtu/scf) * Flared Volume (mmscf/yr) * 10^6 * 0.001 = Emission Rate (metric tons/yr)

Methane Fugitives

Total methane released (MMscf/yr) *Density CH4 (0.7 kg/m3) ÷ 35.3 ft3/m3 * 10^6 * 0.001 = metric tons methane/yr

Source Name	Annual Hours of Operation	Heating Value (Btu/scf)	Annual MMscf	Volume Flared (mmscf/yr)[1]	Fugitive Releases (mmscf/yr)	Average Heat Input (mmbtu/hr)	CO_2[3] Emission Factor	CH_4[2] Fugitives	Total CO_2 Equivalent[4]
							53.02		
							kg/mmbtu		
							Metric tons/yr	Metric tons/yr	Metric tons/yr
Exploration Flare	6,480	1050.0	100	98.00	2.00	16.20	5,341	35.69	6,091
Exploration Blooie Line	6,480	1050.0	20	19.60	0.40	3.24	1,068	7.14	1,218
Production Flare	8,760	1050.00	300	294.00	6.00	35.96	16,024	107.08	18,273
Totals			**420**				**22,434**	**149.92**	**25,582**

[1] Assume a flare combustion efficiency of 98%. 98% of natural gas is combusted and 2% is released as fugitives.

[2] Assume methane is 90% of the natural gas fugitives released. Assume a CH_4 density of 0.7 kg/m3

[3] CO_2 emission factor from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"

CO_2 emissions assume a fuel heat value of 1.028×10^{-3} mmbtu/scf from 40 CFR Chapter I Subchapter C Part 98 Subpart C Table C-1 for "Natural Gas"

Since N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion emissions, only CO_2 emissions estimates are included

[4] Assume GWP of CH4 = 21

FUGITIVE METHANE EMISSIONS

Methane Fugitives

Annual Production (bbl/yr) * Heating Value (mmbtu/bbl) * Emission Factor (lb CH_4/mmbtu) ÷ 2.2 lb/kg * 0.001 = metric tons methane/yr

Source Name	Annual Production (bbl)	Heating Value (mmbtu/bbl)[2]	CH_4[1] Fugitive Emission Factor (lb CH_4/mmbtu)	Total CH_4 Emissions (metric tons/yr)	Total CO_2 Equivalent[3] (metric tons/yr)
Oil Production Operation	730,000	5.8	0.0062	12	250
Crude Oil Transportation	730,000	5.8	0.0017	3	69
			Totals	**15**	**319**

[1] Methods for Estimating Methane Emissions From Natural Gas and Oil Systems, 1999 Vol 8. Ch.3. Assumes median emission factor from Table 3.4-4 from oil production

[2] Energy Information Administration (EIA), (1997), Annual Energy Review : 1996, US Department of Energy, Washington, DC, July 1997, p. 354.

[3] Assume GWP of CH_4 = 21

Transportation Emission Calculations

Source Description	Mode of Transport	Type of Activity Data	Activity Data				GHG Emission Factors	GHG Emissions
			Vehicle Type	Distance Traveled	Unit of Distance	Fuel Used	CO_2 (gm CO_2/km)	Total GHG Emissions, CO_2 (Metric Tons/Year)
Transportation of crude oil from field to refinery	Road	Fuel Use and Vehicle Distance	Heavy Duty Vehicle - Rigid - Diesel - Year 1960-present	747,300	Mile	On-Road Diesel Fuel	870	1,046
Transportation of empty trucks from refinery back to field	Road	Fuel Use and Vehicle Distance	Heavy Duty Vehicle - Rigid - Diesel - Year 1960-present	747,300	Mile	On-Road Diesel Fuel	870	1,046
Transportation of final refined product to end user	Road	Fuel Use and Vehicle Distance	Heavy Duty Vehicle - Rigid - Diesel - Year 1960-present	309,959	Mile	On-Road Diesel Fuel	870	434
Transportation of empty trucks from terminals back to refinery	Road	Fuel Use and Vehicle Distance	Heavy Duty Vehicle - Rigid - Diesel - Year 1960-present	309,959	Mile	On-Road Diesel Fuel	870	434
						Total	**Total**	**2,960**

Assumptions:

1. Since N_2O and CH_4 emissions comprise a relatively small portion of overall transportation emissions, only CO_2 emissions estimates are included

2. Assume tanker truck with capacity of 12,300 gallons = 293 bbl/trip
2,000 bbl/day * 365 days = 730,000 bbl/yr transported = 2,491 trips/yr
** Assume one-way distance of 300 miles = 747,300 miles/yr

3. Assume the total crude refined produces approximately 659,190 bbl/yr of final transported product (90.3% usable product; 6.5% coke; 3.2% still gas combusted at refinery)
** Average one-way distance for transportation of final refined product to end user (assumed within state of UT) to be 150 miles = 309,959 miles/yr

Emission Factor Reference:
World Resources Institute (2008). GHG protocol tool for mobile combustion. Version 2.0

Refinery Emission Calculations

Source Description	Activity Data		GHG Emission	GHG Emissions	
	Production (bbl/yr)	Production (cu m/yr)	CO_2 (metric tons CO_{2e}/cu m)	CO_2 (metric tons)	Total GHG Emissions, CO_2 (metric tons CO2e)
Refinery emissions	730,000	115,873	0.181	21,019	21,019
			Total	**Total**	**21,019**

Assumptions:

1. 1 cu m = 6.3 bbl
2. Average refinery emissions from Canadian Light, Brent North Sea, Saudi Light, 1995 average Syncrude and Suncor, 2005 average Syncrude and Suncor,

Reference:

McCann, Tom, Magee, Phil (1999). Crude Oil Greenhouse Gas Life Cycle Analysis Helps Assign Values For CO_2 Emissions. Oil and Gas Journal, 97 (8).

End Use Emission Calculations

Total Product Produced:	**730,000**	bbl/yr

Product	Product Mix (%)	Product Produced (bbl/yr)	GHG Emission Factors	GHG Emissions
			CO_2 (metric tons CO_2/bbl)	Total GHG Emissions, CO_2 (metric tons CO_2e)
Motor Gasoline	49%	359,160	0.375	134,685
Distillate fuel	25%	181,770	0.43	78,161
Jet fuel	8%	56,940	0.41	23,345
Residual Fuel Oil	5%	37,230	0.45	16,754
LPG	3%	24,090	0.25	6,023
Still Gas (combusted at refinery)	3%	23,360	0.4	9,344
Residual (not sold as product)	7%	47,450	0	0
		659,190	**Total**	**268,312**

Assumptions:

1. Suppliers of petroleum products must report the CO_2 emissions that would result from the complete combustion or oxidation of each petroleum product produced during the calendar year.
2. Calculate CO_2 emissions from each individual petroleum product using Equation MM-1 from 40 CFR Part 86 Subpart MM Suppliers of Petroleum Products
3. Since N_2O and CH_4 emissions comprise a relatively small proportion of overall combustion emissions, only CO_2 emissions estimates are included
4. Emissions factor for motor gasoline assumes the average of various products blend formulations
5. Jet fuel emission factor assumed to be "Kerosene-Type Jet Fuel" referenced in final rule Table MM-1
6. Residual Fuel Oil: Emission factor assumes average of "Residual Fuel Oil No.5 and Residual Fuel Oil No.6" referenced in final rule Table MM-1
7. LPG emission factor assumes 60% propane; 40% butane mix

Reference:

EPA Final Mandatory Greenhouse Gas Reporting Rule. September 22, 2009. 40 CFR Part 86 Subpart MM Suppliers of Petroleum Products
Utah Geological Survey: Utah Energy and Mineral Statistics http://geology.utah.gov/emp/energydata/index.htm