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BEFORE THE PUBLIC UTILITIES COMMISSION OF COLORADO

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IN THE MATTER OF THE APPLICATION OF PUBLIC SERVICE COMPANY OF COLORADO FOR APPROVAL OF 2007 COLORADO RESOURCE PLAN AND PETITION FOR WAIVER OF COMPETITIVE PROCUREMENT RULES TO REPLACE CAMEO AND ARAPAHOE COAL UNITS WITH A NATURAL GAS COMBINED CYCLE PLANT AT ARAPAHOE STATION

ANSWER TESTIMONY OF LESLIE GLUSTROM

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INTRODUCTION AND SUMMARY

Q: PLEASE STATE YOUR NAME AND CONTACT INFORMATION.

A: My name is Leslie Glustrom. I am a citizen intervener in this Docket representing myself. My address is 4492 Burr Place, Boulder, Colorado 80303, my phone number is 303-245-8637 and my e-mail is lglustrom@gmail.com. A resume is attached as Attachment ZZ.

Q: PLEASE SUMMARIZE THE PURPOSE OF YOUR TESTIMONY.

A: The purpose of my testimony is to provide the Commission with key information on climate change, coal supplies, Concentrating Solar Power ("CSP") and information received from Xcel that could be useful to the Commission as it makes its decision in this Docket and as it sets the stage for the next Resource Plan which Xcel has indicated will be submitted in 2009.

Q: ARE YOU GENERALLY SUPPORTIVE OF XCEL'S PLAN AS PROPOSED?

A: Yes, I am very grateful to Xcel for their visionary plan and the hard work that the Xcel personnel are doing in this and several other Dockets before the Commission as we all work to find ways to "keep the lights on" while reducing emissions of carbon dioxide ("CO2"). While I have a number of concerns about the plan and some of the assumptions, I would like these concerns to be seen in a larger context of respect and gratitude for all that Xcel is doing to lead the way into the post-fossil fuel era.

Q: WHAT ARE THE MAIN POINTS YOU WILL BE MAKING?

A: The main points made in this testimony are:

- Climate change is real and extremely serious. Current events are going faster than predicted by models, feedback cycles are beginning and the need for action is urgent. To stabilize the climate of the planet we need to reduce emissions of greenhouse gases, including CO2, drastically. Even when emissions are drastically curtailed, the planet will continue to warm and feedback cycles will lead to natural emissions of greenhouse gases such as CO2 and methane ("CH4") from the oceans, vegetation and the melting permafrost. The scientists are telling us in very clear terms that the planet as we know it is at risk. Urgent action is needed to reduce emissions of greenhouse gases.

- Assumptions presented by Xcel regarding future prices of coal do not appear to be well supported and Xcel is already paying more for coal than they have projected they will be paying in 2020. It is important for the Commission to address this issue before moving into Phase II and as the state debates the proper time to retire existing coal plants. In addition, there are a number of environmental liabilities associated with coal plants and these should be factored into decisions on which coal plants to retire. Also, since we will have to soon retire many of Xcel's coal plants, it probably doesn't make much sense to spend a lot of money on capital expenditures. Rather the money should be spend on building a carbon-free infrastructure.
- Concentrating Solar Power provides an important key to rapid decarbonization. Prices are expected to drop and capacity factors to increase. We can beat the "rush" and avoid large operating costs associated with carbon management, emissions control and coal costs by making plans now to build significant amounts of CSP in Colorado. We have over 200 GW of potential and we only need about 12 GW for the entire state.

Q: PLEASE SUMMARIZE YOUR RECOMMENDATIONS

A: My recommendations are as follows:

1) Recognize that the scientific literature is indicating that the climate crisis is quickly becoming even more dire than the already dire 2007 Intergovernmental Panel on Climate Change presented.

2) Recognize the need to greatly reduce emissions of CO2 in order to stabilize the climate.

3) Recognize that CO2 is a very long-lived pollutant with approximately 25% of the CO2 we emit over the next decade will still be in the atmosphere in the year 3007 and this will have very serious consequences for our planet and all the species that we share the planet with.

4)Recognize that coal fired electric generation is the largest single source of CO2 in the state

5) Recognize the geologic constraints affecting coal supplies and their probable costs of future coal supplies

6) Recognize that Xcel's predictions for the price of coal are not well founded.

7) Require sensitivity analyses for coal prices when evaluating coal plant retirements

8) Recognize the numerous operating costs associated with keeping aging coal plants running and include these in an evaluation of the retirement of Cherokee for this Resource Plan. These operating costs should include

-Realistic estimates for the costs of coal
-Costs of carbon regulation
-Costs of mercury control
-Capital investments in plant upgrades
-Cost of cooling water
-Cost of coal ash disposal
-Cost of emissions control for ozone compliance
-Actual and potential legal costs for emissions

9) Analyze the retirement of Cherokee when the alternative is Concentrating Solar Power or geothermal, not natural gas

10)Ask that in 2009 Xcel present a detailed analysis of the operating costs of all of its coal plants over the next 4 decades using a list like the one above and present an economic analysis of replacing these coal plants with carbon free (or low carbon) sources.

11) Recognize and consider the serious environmental and health risks involved in natural gas exploration, production and delivery.

12) Recognize the risks of excessive reliance on natural gas and run sensitivity analyses of natural gas prices during bid evaluations.

13) Develop a mechanism for taking the cost of externalities into account when evaluating bids. One possibility is to develop a matrix where these externalities are assigned a score on say a scale of 1-5 and then, in addition to the bid price, these externalities are also accounted for. For example if two bid prices are close and one has a high externality score and one has a low externality score than the bid with the slightly higher cost might be accepted due to its lower externality score. The list of externalities which should be considered include:

-Climate change
-Mercury emissions
-SO2
-NOx
-Particulates
-Volatile Organic Compounds
-Contributions to Ozone formation
-Environmental impacts of natural gas drilling
-Health impacts of natural gas exploration and drilling

14) Develop a mechanism for taking non-energy benefits into account. One possibility is to develop a matrix where these non-energy benefits are assigned a score on say a scale of 1-5

and then in addition to the bid price, these non-energy benefits are also accounted for. Then, for example if two bid prices are close and one has a high non-energy benefits score and one has a low non-energy benefits score than the bid with the slightly higher cost might be accepted due to its higher non-energy benefits score. The list of non-energy benefits should include those listed in C.R.S. § 40-2-123 (1) as well as in the preamble to Amendment 37 and codified in Rule 3651 as follows:

-Contributions to Colorado's energy security (C.R.S. § 40-2-123 (1))
-Contributions to Colorado's economic prosperity (C.R.S. § 40-2-123 (1))
-Contributions to Colorado's environmental protection (C.R.S. § 40-2-123 (1))
-Insulation from fuel price increases (C.R.S. § 40-2-123 (1))
-Save consumers and businesses money (PUC Rule 3651)
-Attract new businesses and jobs (PUC Rule 3651)
-Promote development of rural economies (PUC Rule 3651)
-Minimize water use for electricity generation (PUC Rule 3651)
-Diversify Colorado's energy resources (PUC Rule 3651)
-Reduce the impact of volatile fuel prices (PUC Rule 3651)
-Improve the natural environment of the state (PUC Rule 3651)
-Develop and utilize renewable energy resources to the maximum practicable extent (PUC Rule 3651)

15) Recognize that the capacity factor for Concentrating Solar Power is likely to increase over the Resource Acquisition Period and certainly over the Planning Period

16) Add a provision in the bid analysis process to consider the value of the electricity produced—i.e. likelihood that it will produce during the summer peak.

Q: BEFORE PROCEEDING, ON WHAT BASIS ARE YOU SUBMITTING THIS TESTIMONY?

A: Under Colorado Revised Statute (C.R.S.) § 40-6-109 (1), persons who are "interested in or affected by" an order of the Commission and who have become parties to a proceeding "shall be entitled to be heard, examine and cross-examine witnesses, and introduce evidence." The evidence I am submitting is from highly credible sources including top scientific journals, government and other highly credible reports as well information from Xcel obtained in Discovery. This evidence clearly has the "reliable probative value" referred to in PUC Rule 1501 (a).

I. CLIMATE CHANGE—THE CRISIS IS REAL AND EXTREMELY SERIOUS

A. THE IPCC FOURTH ASSESSMENT—AN INTRODUCTION

Q: YOU HAVE SUBMITTED SEVERAL EXCERPTS FROM THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) FOURTH ASSESSMENT REPORT. PLEASE EXPLAIN WHY YOU HAVE SUBMITTED THEM.

A: All of the reports of the Intergovernmental Panel on Climate Change (IPCC)[1] are available to download for free from the IPCC website at www.ipcc.ch and I hereby ask the Commission to take administrative notice of these IPCC reports. Given the urgency of the situation and my concern that the staff of the Commission and other parties may not take the time to actually read what the IPCC is trying to tell us, I have gone to considerable trouble and expense to submit actual excerpts from their reports.[2] In addition, Dr. Kevin Trenberth, a coordinating lead author for Chapter 3 of the IPCC Working Group I Report is expected to

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[1] Information about the IPCC can be found at http://www.ipcc.ch/about/index.htm. According to this website as accessed on April 20, 2008, the mandate of the IPCC is as follows:

> The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage.

[2] I will attach pdfs of several parts of the IPCC AR4 with my testimony, but in the interest of reducing copying costs, I am only submitting certain (though extensive) parts of these reports with the paper copy of my testimony.

testify in this proceeding and will summarize the IPCC findings. In addition, several other top climate change scientists are also expected to testify in this Docket to summarize recent key scientific findings for the Commission and the parties.[3] While these scientists will summarize the results of the science, it is my goal to give the Commission and the staff some sense for the depth and breadth of the science that underlies the conclusions of the IPCC as well as the observations that have been made in the last couple of years.

Q: THERE ARE SEVERAL DIFFERENT EXCERPTS FROM THE IPCC FOURTH ASSESSMENT REPORT. PLEASE EXPLAIN HOW THEY ARE RELATED.

A: The IPCC reports summarize a massive amount of scientific data as will soon become obvious. In an effort to make this data accessible to non-scientists, the IPCC has issued a number of reports intended to make this easier for "the policy makers," including, of course the Colorado Public Utilities Commission ("PUC") and the parties to this Docket. The IPCC Fourth Assessment Report ("AR4") was issued in 2007 and I have included the following excerpts from the report as attachments to this testimony.

- **Attachment 1**"Climate Change 2007: Synthesis Report: Summary for Policymakers," (Entire SPM, 22 pages)
- **Attachment 2**"Climate Change 2007: Synthesis Report—Synthesis Report" (Cover page, Treatment of Uncertainty (page 27), Topics 5 and 6 (pages 63-73)
- **Attachment 3**"Climate Change 2007: Impacts, Adaptation and Vulnerability—Chapter 4: Ecosystems, their properties, goods and services," Excerpts—Cover

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[3] Since many of the participants in PUC proceedings are attorneys or engineers and may not be familiar with climate change science, it is worth noting that the four scientists who will be testifying in this Docket are at the top of their fields. To make an analogy to the field of law, it is as if we had gotten four United States Supreme Court justices to testify. A quick glance at these scientists' resumes will confirm their stature and experience. It is also worth noting, though, that many scientists are typically self-effacing and reticent by nature. This humility is typically a product of their make-up, their training and their deep understanding of how little even scientists at the top of their field understand about this planet we all call home.

Page, Table of Contents, Executive Summary (pages 213-214), Section 4.6.3 Implications for biodiversity (pages 247-248) and References (pages 252-272)

As will soon be clear, each of these parts of the IPCC AR4 offers a different level of understanding of the science with the "Summary for Policymakers" being the most general—and also the most densely packed with information (which ironically makes it rather difficult for policymakers to digest...). Then the Synthesis Report provides more scientific details and is a little less dense. Then the actual Working Group Reports (of which there are three) provide further details, as well as references to the actual scientific literature. Attachments 1 to 3 to this Answer Testimony provide just one example of how this telescoping detail works.

B. THE IPCC FOURTH ASSESSMENT—SPECIES EXTINCTION

Q: PLEASE PROVIDE AN EXAMPLE OF HOW THIS 'TELESCOPING' DETAIL IN THE IPCC REPORT WORKS. AS AN EXAMPLE, WHY DON'T YOU USE THE QUESTION OF THE EFFECT OF WARMING ON SPECIES EXTINCTION AND PLEASE EXPLAIN WHY WE SHOULD CARE ABOUT EXTINCTION AT ALL.

A: Climate change will bring very serious changes to our planet. These changes are likely to involve significant loss of life as well as property. Indeed, whole countries are likely to disappear. Cities may need to be rebuilt in whole or part, and thousands and thousands of human lives (and probably millions) are likely to be lost prematurely over the coming decades due to the impact of global warming on our planet. Yet, as terrible as these outcomes are, there is one set of outcomes from which there will be no recovery—ever—and that is species loss. Each species is the result of thousands and millions of years of evolution and is extremely unlikely to ever again be replicated on the planet. Individuals of any species all come and go—that is part of the flow of life—but for species, once they are gone—they are gone forever. Each species on the planet plays a host of important roles in the ecosystem it occupies. Unfortunately we don't know yet what that role is for millions of species. Indeed, for many species, the role they play won't become apparent until they are gone—and then, of course it is too late. Extinction is forever and we can only pull so many threads out of the fabric of life and expect the planet to continue to function in the way we've known. It is for these reasons that species extinction is, in my view, the ultimate concern with respect to climate change—even more important than heat waves or sea level rise or declining agricultural productivity or impacts on fresh water availability—though these are all extremely important also. So, let's see what the IPCC report has to say about species loss. Here is how the reports work:

- **The IPCC AR4 Summary for Policymakers (SPM) of the Synthesis Report (See Attachment 1)** —This document attempts to distill all the key findings of all three IPCC Working Groups into about 20 pages. This makes the conclusions accessible in one central location, but it makes for very dense reading. A key conclusion regarding biodiversity is found on page 19 of the Summary for Policymakers from the Climate Change 2007 Synthesis Report (Attachment 1) It states:

  > An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR (Third Assessment Report) as warming proceeds. There is *medium confidence* that 20 to 30 % of plant and animal species assessed so far are *likely* to be at increased risk for extinction if increases in global average temperature exceed 1.5 to 2.5 ° C above 1980-1999 levels.{5.2} (page 19, Summary for Policymakers of the Synthesis Report, IPCC AR4, Attachment 1; italics in the original; Note: "*medium confidence*" means "About 5 out of 10 chance" and "*likely*" means ">66%"—see page 27 in the Synthesis Report excerpts in Attachment 2.)

At the end of the paragraph containing this statement there is a "*{5.2}*" which then directs the reader to Section 5.2 in the full Synthesis Report which is described below and excerpts of which are included as Attachment 2 to this Answer Testimony.

- **The Synthesis Report (See Attachment 2)** is an effort to summarize the reports of the IPCC Working Group I (The Physical Science Basis), Working Group II (Impacts, Adaptation and Vulnerability) and Working Group III (Mitigation of Climate Change). Each of these reports is hundreds of pages long and each summarizes hundreds and thousands of scientific articles. The IPCC Synthesis Report attempts to summarize these three long reports into one 52 page report, of which there are a few excerpts in Attachment 2. Turning to Topic 5.2 in the IPCC AR4 Synthesis Report (page 64 in Attachment 2) we find an expansion of the effects on species that were summarized in the SPM. One of the statements in Section 5.2 is this:

  > The five 'reasons for concern' identified in the TAR (Third Assessment Report issued in 2001) **are now assessed to be stronger with many risks identified with higher confidence.** Some are projected to be stronger or to occur at lower increases in temperature. *{WGII 4.4, 5.4, 19ES, 19.3.7, TS 4.6; WGIII 3.5, SPM}*. (page 19, Synthesis Report of the IPCC AR4, emphasis and parenthetical explanation added.)

  Again, at the end of the paragraph with this statement there is a "*{WGII 4.4, 5.4, 19ES, 19.3.7, TS 4.6; WGIII 3.5, SPM}.*" These notations direct the reader to various parts of the Working Group II and Working Group III reports. An excerpt from Working Group II is included with this Testimony as Attachment 3 and is described below.

- **IPCC AR4 Working Group II, Chapter 4, Executive Summary, Section 4.6.3 and References.** Just as the Synthesis Report attempted to summarize the findings of Working Groups I, II and III, the Working Group report attempts to summarize literally thousands of scientific papers. In Attachment 3 to this testimony, I have included excerpts from one chapter ("WGII--Chapter 4: Ecosystems, their properties, goods and services") from the report of one Working Group of the IPCC (Working Group II—Climate Change 2007: Impacts, Adaptation and Vulnerability"). The opening paragraph on page 213 of the Executive Summary of Chapter 4 of the IPCC AR4 Working Group II report says this:

> **During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and in other global change drivers (especially land-use change, pollution, and over-exploitation of resources), if greenhouse gas emissions and other changes continue at or above current rates (high confidence).** (page 213, Chapter 4, Working Group II Report of the IPCC AR4, emphasis in the original; Note: "high confidence" means "about 8 out of 10" chance, see p. 27, IPCC AR4 Synthesis Report, Attachment 3)

As before, the Executive Summary for Chapter 4 of Working Group II refers the reader to multiple sections of the chapter. Turning to Section 4.6.3 (page 247) of Chapter 4 of Working Group II report of the IPCC AR4 we find the following statement.

> Many studies and assessments stress the adverse impacts of climate change on biodiversity (e.g. Gitay et al., 2002; Hannah and Lovejoy, 2003; Thomas et al., 2004a; Lovejoy and Hannah, 2005; Schroter et al., 2005; Thuiller et al., 2005b; van Vliet and Leemans, 2006), but comprehensive appraisals of adaptation options to deal with declining biodiversity are rare. (page 247, Chapter 4, "Ecosystems, their properties, goods and services," Working Group II report of the IPCC AR4)

Now, finally, we've telescoped down and the references in the quote above aren't to another part of the IPCC report, but rather to the scientific literature itself. The detailed references to the papers (and in some cases entire books)[4] cited in the chapters of the Working Group

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[4] For example, the reference to "Lovejoy and Hannah, 2005" is to a 418 page book entitled *Climate Change and Biodiversity,* published by Yale University Press.

reports are assembled at the end of each chapter. Included as part of Attachment 3 to this Answer Testimony is the list of references from Chapter 4 of Working Group II report for the IPCC AR4. As can be seen in Attachment 3, each page is filled with about 40 references to the scientific literature and there are 20 pages—for this chapter alone. That is, Chapter 4 of Working Group II report is summarizing approximately 800 scientific references—and there are 20 chapters in the Working Group II report alone. One of the references mentioned in the quote above is "Thomas et al. 2004a." This reference and several others will be discussed further below.[5]

C. THE IPCC FOURTH ASSESSMENT—WARMING IS UNEQUIVOCAL

Q: NOW THAT WE UNDERSTAND GENERALLY HOW THE IPCC REPORTS ARE STRUCTURED, WHAT WAS THE KEY CONCLUSION OF THE IPCC FOURTH ASSESSMENT?

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[5] Readers can note that in the list of references in Attachment 3you will find several references listed under "Kleypas, J.A." As just one example of how deep this science goes (and of the critical role played by Colorado scientists in this endeavor), "Kleypas, J.A." refers to Dr. Joanie Kleypas, one of the country's top marine scientists who is based at the Cooperative Institute for Research in Environmental Studies (CIRES) at the University of Colorado-Boulder. Dr. Kleypas submitted e-mail comments and key information on ocean acidification to this docket on April 9, 2008. Indeed, Boulder (Colorado) is home to literally hundreds of top climate change scientists based at the University of Colorado-Boulder as well as at the federal research laboratories (NOAA, NCAR and UCAR). Undoubtedly many of these scientists would be happy to help answer any further questions that the Commission or its staff have about the science of climate change. (NOAA is the National Oceanic and Atmospheric Administration. NCAR is the National Center for Atmospheric Research.UCAR is the University Corporation for Atmospheric Research. They are all easy to find on the Internet.)

A: Turning to Attachment 1, page 2, the first conclusion in the Summary for Policymakers for the IPCC AR4 states the following:

> 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. (page 2, Summary for Policymakers of the Synthesis Report of the IPCC AR4, Attachment 1. emphasis added)

The Summary for Policy Makers goes on for another 20 pages summarizing key scientific findings in paragraph after paragraph. After each conclusion there is a parenthetical notation referring the reader to sections of the Synthesis Report, as explained above, and then each section of the Synthesis Report refers the reader to the more detailed explanations of the Working Group reports and the Working Group reports refer the reader to the underlying scientific literature.

It is important to note that the choice of the term **"unequivocal"** in the Summary for Policymakers is very important. Scientists (especially the best ones) are, by their nature, typically reticent and understated and they are famous for their "on the one hand, and on the other hand" equivocation.[6] It is, therefore, extremely significant that they have chosen the word "unequivocal" to describe what is happening to the climate system of our planet. There is <u>no doubt whatsoever</u> among scientists who publish in the peer-reviewed literature[7,8] that the

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[6] I note that the approach of scientists is typically very different from that of attorneys. Attorneys' livelihoods depend on their persuasive ability which can often involve "stretching the truth" and doing so with seemingly great "authority." This is in direct contrast to the ethic of the scientific community which is to understate the truth and to do so with great reticence and humility. A lot of this humility grows out of the practice of science and knowing that even if you are the world's "foremost authority" on a subject—you still only know a very small fraction of what there is to know and typically you'd like to be left alone to try and answer the next set of questions that follow inexorably from whatever knowledge you and your fellow scientists may have so far teased out of the natural world.

[7] It is important for non-scientists to understand that among scientists, the term "scientist" means someone who has published extensively in the peer-reviewed literature on the subject they are discussing. The best scientists publish in the top journals such as *Science* and *Nature* and in the case of climate science *Geophysical Research Letters* as well as several others as seen in the references included in Attachment 3. The misuse of the term scientist and a misunderstanding of what the distinction is between being a Ph. D (i.e. "Dr.") and being a scientist has caused monumental confusion in press reports related to climate science. A scientist almost always

earth is warming and that this will have serious impacts on our planet, such as those summarized in the Summary for Policymakers (and elaborated on in the Synthesis Report, the Working Group Reports and in the underlying scientific literature.) [9] While no one alive presently will ever know how serious these impacts will be because they can be expected to go on for centuries (and probably millennia) due to the inertia in the carbon-climate system,[10]

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has a Ph.D but the degree is nowhere near sufficient to be called a scientist. A "scientist" only really gains that distinction after publishing extensively in the peer-reviewed literature—a process that often takes up to a decade after obtaining a Ph.D. The press has often quoted from people like "Dr. Fred Singer" or "Dr. Pat Michaels" over the last decade to imply that there are scientists on both sides of the climate change question. Yet, "Dr. Singer" (who is now well past retirement age) and "Dr. Michaels" have not published extensively in the peer-reviewed literature on climate change. Rather, they are merely individuals with Ph. D's who have received funding from the fossil fuel industry and who were used as part of a deliberate misinformation campaign. The references documenting these facts about "Dr Singer" and "Dr. Michaels" are available upon request for anyone that is interested.

[8] As an example of what it takes to become a "scientist," the young (and very attractive and very personable…) biochemistry professor that I worked for at the University of Colorado-Boulder went to college when she was 16, then finished a "four year" undergraduate degree, a "six year" doctorate degree and a "three-year" post-doctorate degree in the next 10 years and became a professor at the University of Colorado-Boulder by the time she was 26. Then, for about the next 10 years she worked 60-80 hours a week, week in and week out teaching and overseeing the research that would lead to publications in the peer-reviewed literature. On top of all of this, she is about twice as efficient as anyone else I've ever known. Only after all of that, is she considered a "scientist"—and even now she is still considered rather a "junior" scientist since she has only published a few dozen articles in the scientific literature. Only after she has published 40-50 peer-reviewed articles will she begin to be seen as a "senior" scientist. People like "Dr. Singer" and "Dr. Michaels" have published very little (if at all) in the peer-reviewed literature. The full resumes of the four climate change scientists testifying in this Docket will quickly show that they are "senior" scientists.

[9] The Summary for Policymakers of the IPCC AR4 Synthesis Report is Attachment 1to this Answer Testimony. Excerpts from the IPCC AR4 Synthesis Report are Attachment 2 and Excerpts from Chapter 4 of the Working Group II report are Attachment 3. The full IPCC reports (including all of the figures and scientific references) are available from the IPCC website at www.ipcc.ch.

[10] The fact that the consequences of the warming climate can be expected to go on for centuries can be seen from statements such as the following from page 20 of the Summary for Policymakers from the IPCC AR4 Synthesis Report:

> "Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG (Greenhouse Gas) concentrations have stabilized, for any of the stabilization levels assessed, causing an eventual sea level rise much larger than projected for the 21st century." (p. 20, Summary for Policymakers of the IPCC AR4 Synthesis Report, Attachment 1to this Answer Testimony. Note that GHG concentrations will only stabilize AFTER emissions of GHGs are severely curtailed.)

This phenomenon of climate change impacts going on for centuries after GHG concentrations (not emissions) are stabilized is often referred to as 'the inertia" of the climate system. To use an example from every day life, it is as if you put the brakes on in a car and instead of taking a few seconds to stop it took a few minutes—which of course would mean that you'd want to put the brakes on a lot earlier than you used to. The inertia of the climate system also argues for "putting on the brakes" as fast as we can. The question of consequences going on for millennia will be discussed further below.

there is no doubt that the planet is warming and the consequences are going to be serious—it is "**unequivocal.**"

D. THE IPCC SCIENTIFIC BASIS IS OVERWHELMING

Q: YOU HAVE STATED THAT THE SCIENTIFIC BASIS FOR THE CONCLUSIONS OF THE IPCC REPORTS IS OVERWHELMING. CAN YOU GIVE A FEW MORE EXAMPLES?

A: Yes, the truth is the science has been accumulating for several decades and later we'll see some specific examples, but first let's look at the Working Group I Report to get a feel for the scientific basis for the conclusions of the IPCC. Table LWG-1 is a list of the chapters of the Working Group I report with a notation for the number of pages of references in the chapter and an estimate for how many references are therefore cited in each chapter.

Table LWG-1
Approximate Number of References by Chapter
IPCC Fourth Assessment Report
Working Group I— The Physical Science Basis

Chapter	Chapter Title (May Be Shortened)	Pages of References	Approx. Number of References
1	Historical Overview of Climate Change Science	5+ pages	>200
2	Changes in Atmospheric Constituents and in Radiative Forcing	17+ pages	>600
3	Observations: Surface and Atmospheric Climate Change	16+ pages	>600
4	Observations: Changes in Snow, Ice and Frozen Ground	6+ pages	>200
5	Observations: Oceanic Climate Change and Sea Level	6+ pages	>200
6	Paleoclimate	13+ pages	>500
7	Coupling Between Climate Change and Biogeochemistry	19+ pages	>700
8	Climate Models and Their Evaluation	14+ pages	>500
9	Understanding and Attributing Climate Change	10+ pages	>400

10	Global Climate Projections	11+ pages	>400
11	Regional Climate Projections	13+ pages	>500

While there may be some duplication of the references cited for the chapters in the Working Group I report, it is still clear that the Working Group reports rely on literally hundreds—and probably thousands—of scientific papers. It is also worth noting that a typical scientific paper represents 3-10 (or more) people-years worth of work. That is, each reference in the table above could take one person three years or two people 1.5 years each or five people working for two years etc. Moreover, scientists typically work 60 or more hours per week routinely and 70-90 hour per week when needed—and of course peer-reviewed papers have to rely on data—and lots of it—not just opinions or speculation.

Q: CLEARLY THE IPCC REPORTS ARE BASED ON HUNDREDS OF SCIENTIFIC PAPERS. COULD YOU GIVE US A FEW EXAMPLES OF WHAT THESE PAPERS LOOK LIKE?

A: Yes, I've included several individual scientific papers as attachments to this Answer Testimony. To start with, here are the title and sources for three of those papers:

- **Attachment 4**"Climatic Change: Are We on the Brink of a Pronounced Global Warming," Broecker, Wallace S., *Science* 189, 460 (1975). ("The Broecker 1975 paper.")
- **Attachment 5**"Extinction Risk from Climate Change," Thomas et al., *Nature* 427, 145 (2004) ("The Thomas 2004 paper.")
- **Attachment 6**"How Much More Global Warming and Sea Level Rise?" Meehl et al., *Science* 307, 1769 (2005) ("The Meehl 2005 paper.")

  Meehl 2005

Q: PLEASE DESCRIBE THE BROECKER 1975 PAPER THAT IS ATTACHMENT 4.

A: The Wallace Broecker paper from 1975 is interesting for a number of reasons:

- In 1975, Dr. Broecker (now considered one of the greats of climate science) predicted that the cooling caused by dust and aerosols would soon be overwhelmed by the CO2 effect and the composite curve found in Figure 1 is remarkably similar to what has been borne out in the three decades since this paper was published.
- In Table 1, Dr. Broecker predicted that there would be about 373 parts per million of CO2 in the atmosphere in 2000—and there was about 368 ppm.[11]
- Dr. Broecker based his prediction on the ice core data available then. In the intervening three decades the ice core data has been significantly lengthened, but the basic conclusions of Dr. Broecker's paper have been remarkably prescient.

Q: PLEASE DESCRIBE THE 2004 THOMAS PAPER ON SPECIES EXTINCTION IN ATTACHMENT 5.

A: The paper "Extinction Risk from Climate Change," by Chris D. Thomas et al. refers to the papers documenting the already apparent effect of climate change on plants and animals and uses three approaches to estimate extinction risks in the coming decades. The conclusion is that, "we predict, on the basis of mid-range climate warming scenarios for 2050 that 15-37% of the species in [the] sample regions and taxa will be 'committed to extinction.' As discussed below, emissions of greenhouse gases are greater than the IPCC predicted and many processes are moving faster than the IPCC models have predicted. There is a significant risk that these estimates of species extinction will be revised upward in the next IPCC report as

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[11] See Table SPM-1 on page 5 of the IPCC Climate Change 2001: Summary for Policymakers, available at www.ipcc.ch.

they were between the Third and Fourth IPCC Assessment Reports.[12] This raises very serious questions about the ability of the earth's vulnerable ecosystems to continue to function in the manner that we've known.

Q: PLEASE DESCRIBE THE MEEHL 2005 PAPER IN ATTACHMENT 6.

A: Dr. Gerald Meehl is a researcher at the National Center for Atmospheric Research in Boulder. He and the team of authors on this paper ran two models to determine how much "warming there is in the pipeline." Here is what the relevant parts of the abstract of the paper say:

> Two global climate models show that even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000, we are already committed to further global warming of another half degree[13] and an additional 320% sea level rise caused by thermal expansion by the end of the 21st century....At any given point in time, even if concentrations are stabilized, there is a commitment to future climate changes that will be greater than those we have already observed. "How Much More Global Warming and Sea Level Rise?" Meehl et al., *Science* 307, 1769 (2005). See Attachment 6. (Reference added.)

The conclusion of this paper is that there is already almost as much warming "in the pipeline" as we've already experienced—even if we stabilize concentrations of greenhouse gases at the 2000 level—which we are a far way from having done. [14]

Q: COULD YOU PLEASE EXPLAIN THE DISTINCTION BETWEEN "CONCENTRATIONS" AND "EMISSIONS" WHEN DISCUSSING GREENHOUSE GASES SUCH AS CO2.

Yes. This is a very important distinction.

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[12] See page 19 in the IPCC Summary for Policymakers in Attachment 1 regarding "new and stronger evidence" of impacts on unique and vulnerable systems and "increasing risk of species extinction...."

[13] In scientific papers "half degree" means degrees Celsius (°C). To convert a half degree C to °F, multiply by 1.8. So this is another 0.9 °F of warming that is "already in the pipeline."

[14] As will be discussed further below, the level of CO2 in the atmosphere increased by about 2.4 parts per million in 2007 and has gone up almost 10 ppm since 2004.

- **Concentrations** (say of CO2) in the atmosphere represent the cumulative amount and can be likened to the level of water in a bath tub. They are typically represented in "parts per million" or "ppm."
- **Emissions** refer to how much of a gas such as CO2 is emitted in a period of time such as a year. Emissions can be likened to the water flowing into the bathtub. Emissions are typically discussed in terms of "tons per year."

Emissions refer to a flow rate. Concentration refers to the cumulative level. In order to stabilize the level CO2 in the atmosphere (i.e. the concentration) we have to be prepared to greatly reduce the flow of CO2 (i.e. the emissions) into the atmosphere—just as to stabilize the level of water in a bathtub, you have to be prepared to turn off the flow of water-- unless there is a way to drain the tub. While a bathtub in working order has a drain, in the case of CO2 there is no good way to take significant amounts of CO2 out of the atmosphere once it is there. While approximately half of anthropogenic CO2 emissions are taken up by the oceans and vegetation, the other half is added to the atmosphere. Moreover, the uptake by the ocean and vegetation sinks is expected to decrease as the planet warms.[15] As discussed below, the only way to stabilize CO2 concentrations in the atmosphere is through drastic curtailment of emissions—a process often referred to as decarbonization. [16]

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[15] For a reference on ocean and vegetation uptakes decreasing as the planet warms, see page 7 of the Summary for Policymakers from the IPCC Fourth Assessment in Attachment 1. The size of this feedback mechanism is one of the things that the scientists will be attempting to quantify in the coming years but it is already widely accepted that the warming of the planet will increase the fraction of anthropogenic CO2 remaining in the atmosphere. It is just the magnitude of the feedback that is uncertain.

[16] Also as discussed further below, Colorado has the potential for over 300 Gigawatts of potential for electricity from wind and solar resources. There is significant geothermal potential on top of that. Xcel's system only requires 8-9 GW. Clearly, we can decarbonize if we decide to.

IV. THE IPCC MAKES DIRE PREDICTIONS

Q:BESIDES THE WARMING BEING "UNEQUIVOCAL" WHAT PREDICTIONS DOES THE IPCC FOURTH ASSESSMENT MAKE.

A: Examples of the predictions of the IPCC Fourth Assessment can be found in Table SPM 2 on page 11 of the Summary for Policymakers in Attachment 1. Here are a few of them:

Africa

-Between 75 and 250 million people projected to be exposed to increased water stress by 2020 due to climate change.

-In some countries, yields from rain-fed agriculture could be reduced up to 50% by 2020.

Europe

-Mountainous areas will face extensive species losses (in some areas up to 60% under high emission scenarios by 2080).

-In Southern Europe, climate change is expected to worsen conditions(high temperature and drought) in a region already vulnerable to climate variability.

North America

-Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources.

-Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves....

F. THE IPCC FOURTH ASSESSMENT WAS PROBABLY CONSERVATIVE

Q: THERE IS A LOT OF TALK ABOUT THE IPCC FOURTH ASSESSMENT BEING CONSERVATIVE. WHY IS THAT?

A: There are a number of reasons why the IPCC has probably been conservative. These include:

- It is a consensus process involving a couple of thousand scientists. It is amazing they can agree on anything...
- For the Fourth Assessment they stopped considering peer reviewed literature in the middle of 2006 which was mostly based no data from 2004 and 2005. Things have

moved very quickly in the last two years and the feedback cycles seem to be kicking in. This can be seen in Attachments 7-21.

- The Fourth Assessment didn't take dynamic ice melt or feedback cycles into strong consideration. This will probably be addressed in the next IPCC report which is typically 6years later (e.g. 2013), but things are moving very quickly. Scientists are warning us that we must turn the corner very quickly and even then there is significant warming already "dialed in," and the feedback cycles (e.g release of methane from the permafrost and CO2 from dying and burning forests) appear to be beginning.

G. THE PLANET AS WE KNOW IT IS AT RISK

The IPCC has made it clear that the consequences are very dire—and it appears that the IPCC has been conservative. It is urgent that we decarbonize as quickly as possible.

II. DESCRIPTION OF THE OTHER ATTACHMENTS

Q: THE REST OF THE ATTACHMENTS APPEAR TO BE RATHER SELF EXPLANATORY. COULD YOU PLEASE SUMMARIZE THEM BRIEFLY.

A: Yes, the rest of the attachments make a variety of points:

1) Increasing overburden in the Powder River Basin of Wyoming is likely to drive up coal costs substantially and Xcel no longer has long term coal contracts and their coal costs are beginning to go up dramatically. Indeed, they are already paying more for coal than they predicted the coal would cost until 2020. (See Figure 1.7-1 in the Resource Plan and compare to Attachment 1-4.)

2) There are serious operating costs for Xcel's coal plants—not considering CO2 or mercury controls. If we are to dramatically reduce our CO2 emissions, we will need to "trade

out our power plants." It probably doesn't make sense to put a lot of capital into these aging plants if we are to soon retire them.

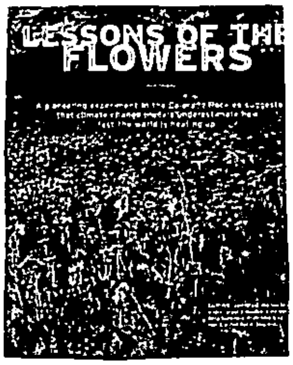
3) There are significant railroad constraints in the Western US and these are likely to cause some serious coal supply issues. These can be very expensive as seen in attachment 53.

4) Concentrating Solar Power has significant economic and environmental benefits and as can be seen from page 5 in Attachment 55, costs are expected to decline and capacity factors well above the 35% assumed by Xcel are likely to be achievable over the next 10-15 years.

III. CONCLUSION-- THIS IS A RACE AGAINST TIME AND WE ARE ALL ON THE SAME TEAM

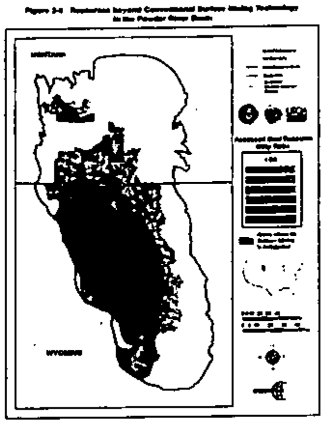
Q: PLEASE CONCLUDE:

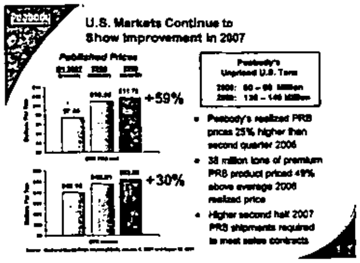
A: Yes, the scientists have made it clear that the planet as we know it is at risk. This is a race against time and we are all on the same team. As we transition to a post fossil fuel electric supply (and electric transportation) we can achieve great environmental and economic benefits, avoid future fossil fuel costs and clean up our air all simultaneously. If we start now we can beat the rush for turbines and other parts.



Warming Threatens Rocky Mountain Wildflowers
See Attachment 19

70% of the Coal in the PRB Not Surface Accessible
See Attachment 28



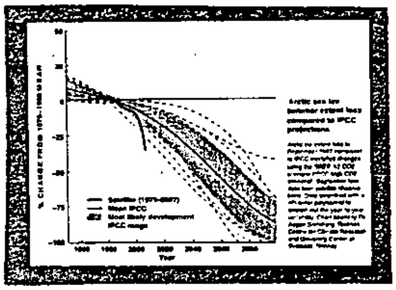


Coal Contracts Expired; Prices Rising Significantly
See Attachments 30-31

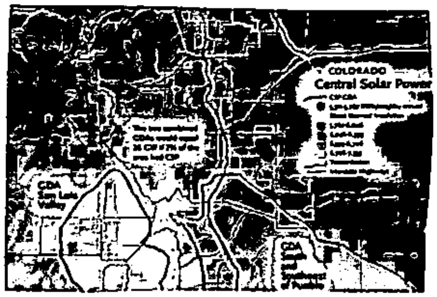
Before the Colorado PUC
Docket 07A-447E Xcel's 2007 Resource Plan

Answer Testimony
of
Leslie Glustrom

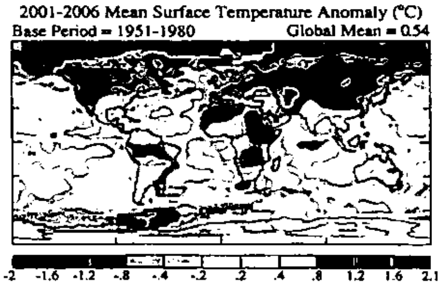
April 28, 2008



Arctic Sea Ice Melting Faster Than
Any IPCC Model Predicted
See Attachment 10



Concentrating Solar Power
Colorado Has the Potential for Over 200 GW
See page 64, SB 91 Report at www.colorado.gov/energy



Source: James Hansen, NASA, Feb 26, 2007 at the National Press Club "Connecting the Dots"

Warming Has Already Been Significant
See Attachments 1- 16

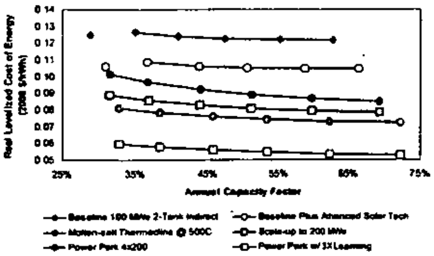


Figure 2. Potential Cost Reductions for Troughs source: NREL

Concentrating Solar Power
Projections for declining costs and increasing capacity factors
See Attachment 55

Attachment 1
Docket 07A-447E
Glustrom Answer Testimony

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Climate Change 2007: Synthesis Report

Summary for Policymakers

An Assessment of the Intergovernmental Panel on Climate Change

This summary, approved in detail at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

Based on a draft prepared by:

Lenny Bernstein, Peter Bosch, Osvaldo Canziani, Zhenlin Chen, Renate Christ, Ogunlade Davidson, William Hare, Saleemul Huq, David Karoly, Vladimir Kattsov, Zbigniew Kundzewicz, Jian Liu, Ulrike Lohmann, Martin Manning, Taroh Matsuno, Bettina Menne, Bert Metz, Monirul Mirza, Neville Nicholls, Leonard Nurse, Rajendra Pachauri, Jean Palutikof, Martin Parry, Dahe Qin, Nijavalli Ravindranath, Andy Reisinger, Jiawen Ren, Keywan Riahi, Cynthia Rosenzweig, Matilde Rusticucci, Stephen Schneider, Youba Sokona, Susan Solomon, Peter Stott, Ronald Stouffer, Taishi Sugiyama, Rob Swart, Dennis Tirpak, Coleen Vogel, Gary Yohe

Introduction

This Synthesis Report is based on the assessment carried out by the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

A complete elaboration of the Topics covered in this summary can be found in this Synthesis Report and in the underlying reports of the three Working Groups.

1. Observed changes in climate and their effects

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 (Figure SPM.1). *{1.1}*

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C[1] is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR) (Figure SPM.1). The temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans (Figures SPM.2, SPM.4). *{1.1, 1.2}*

Rising sea level is consistent with warming (Figure SPM.1). Global average sea level has risen since 1961 at an average rate of 1.8 [1.3 to 2.3] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear. *{1.1}*

Observed decreases in snow and ice extent are also consistent with warming (Figure SPM.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. *{1.1}*

From 1900 to 2005, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia but declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has *likely*[2] increased since the 1970s. *{1.1}*

It is *very likely* that over the past 50 years: cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is *likely* that: heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level[3] has increased worldwide. *{1.1}*

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970. *{1.1}*

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. *{1.1}*

Observational evidence[4] from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. *{1.2}*

Changes in snow, ice and frozen ground have with *high confidence* increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions and led to changes in some Arctic and Antarctic ecosystems. *{1.2}*

There is *high confidence* that some hydrological systems have also been affected through increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers and through effects on thermal structure and water quality of warming rivers and lakes. *{1.2}*

In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant and animal ranges are with *very high confidence* linked to recent warming. In some marine and freshwater systems, shifts in ranges and changes in algal, plankton and fish abundance are with *high confidence* associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. *{1.2}*

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Fig-

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[1] Numbers in square brackets indicate a 90% uncertainty interval around a best estimate, i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Uncertainty intervals are not necessarily symmetric around the corresponding best estimate.

[2] Words in italics represent calibrated expressions of uncertainty and confidence. Relevant terms are explained in the Box 'Treatment of uncertainty' in the Introduction of this Synthesis Report.

[3] Excluding tsunamis, which are not due to climate change. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

[4] Based largely on data sets that cover the period since 1970.

Changes in temperature, sea level and Northern Hemisphere snow cover

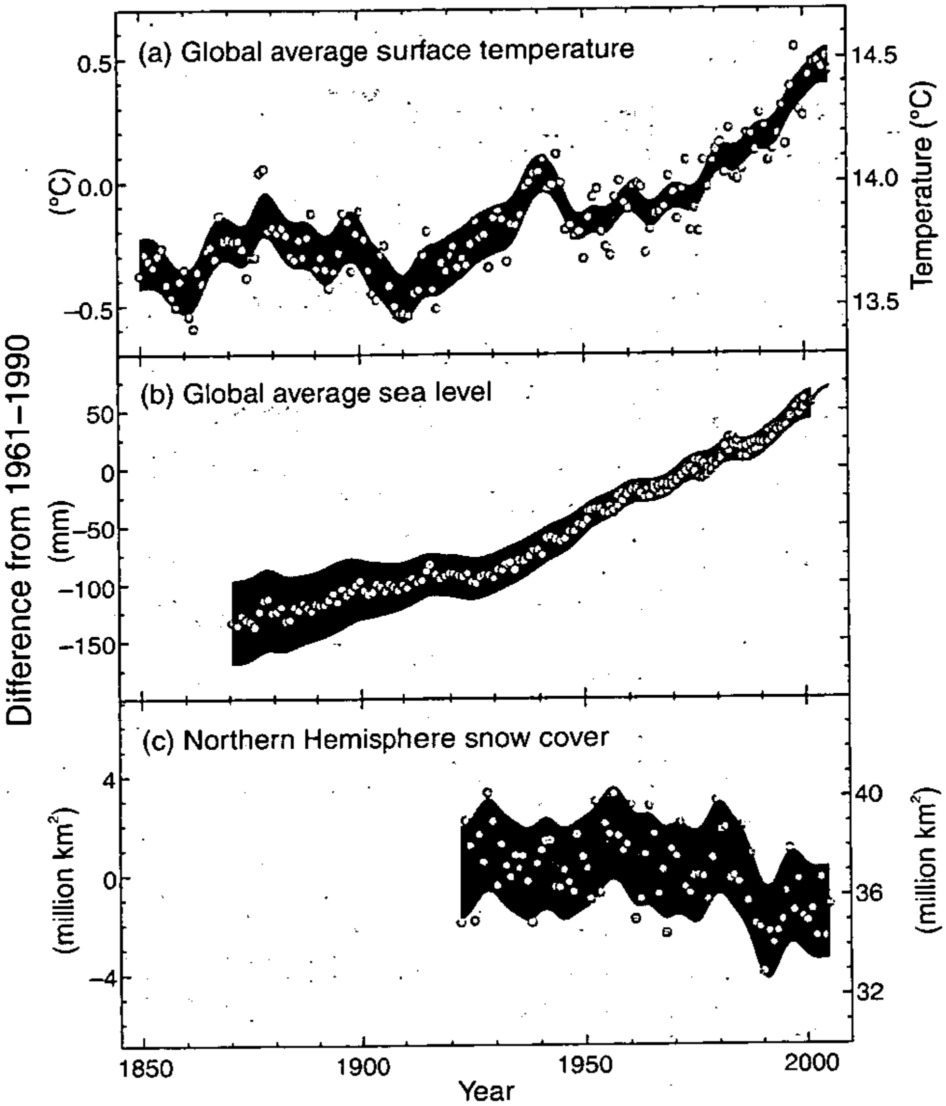


Figure SPM.1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {Figure 1.1}

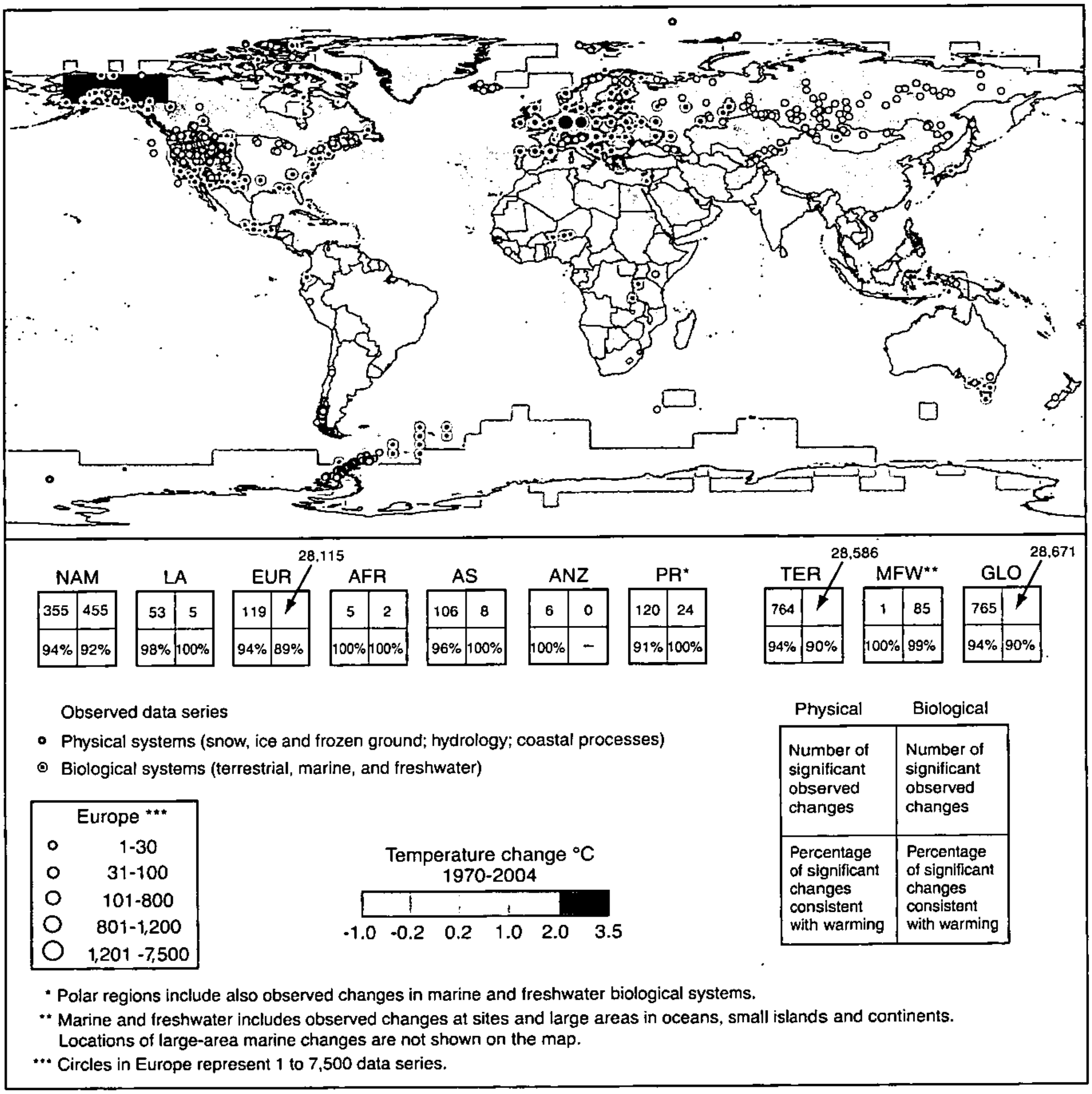
ure SPM.2). However, there is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. *{1.2, 1.3}*

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. *{1.2}*

They include effects of temperature increases on: *{1.2}*

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests
- some aspects of human health, such as heat-related mortality in Europe, changes in infectious disease vectors in some areas, and allergenic pollen in Northern Hemisphere high and mid-latitudes
- some human activities in the Arctic (e.g. hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports).

Changes in physical and biological systems and surface temperature 1970-2004



* Polar regions include also observed changes in marine and freshwater biological systems.

** Marine and freshwater includes observed changes at sites and large areas in oceans, small islands and continents. Locations of large-area marine changes are not shown on the map.

*** Circles in Europe represent 1 to 7,500 data series.

Figure SPM.2. Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, EUR, AFR, AS, ANZ, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. {Figure 1.2}

2. Causes of change

Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the energy balance of the climate system. *{2.2}*

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure SPM.3).[5] *{2.1}*

Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004. The long-term trend of declining CO_2 emissions per unit of energy supplied reversed after 2000. *{2.1}*

Global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. *{2.2}*

Atmospheric concentrations of CO_2 (379ppm) and CH_4 (1774ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. CH_4 growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. The increase in N_2O concentration is primarily due to agriculture. *{2.2}*

There is *very high confidence* that the net effect of human activities since 1750 has been one of warming.[6] *{2.2}*

Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.[7] It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (Figure SPM.4). *{2.4}*

During the past 50 years, the sum of solar and volcanic forcings would *likely* have produced cooling. Observed patterns of warming and their changes are simulated only by models that include anthropogenic forcings. Difficulties remain in simulating and attributing observed temperature changes at smaller than continental scales. *{2.4}*

Global anthropogenic GHG emissions

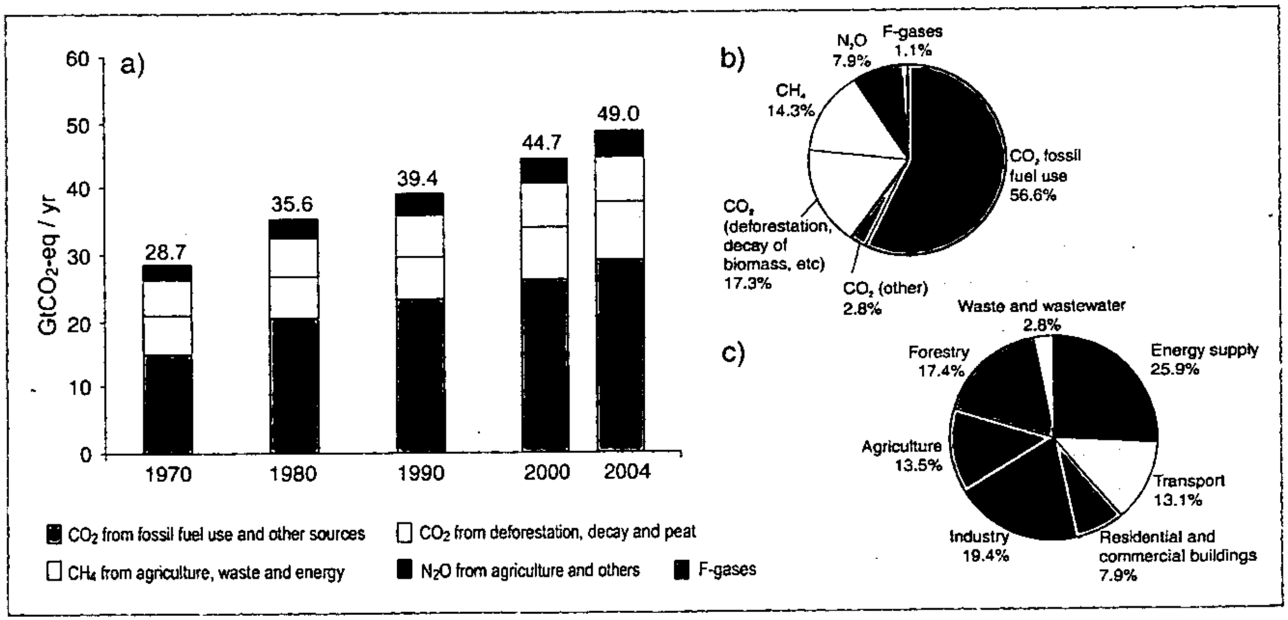


Figure SPM.3. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.) {Figure 2.1}

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[5] Includes only carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6), whose emissions are covered by the United Nations Framework Convention on Climate Change (UNFCCC). These GHGs are weighted by their 100-year Global Warming Potentials, using values consistent with reporting under the UNFCCC.

[6] Increases in GHGs tend to warm the surface while the net effect of increases in aerosols tends to cool it. The net effect due to human activities since the pre-industrial era is one of warming (+1.6 [+0.6 to +2.4] W/m²). In comparison, changes in solar irradiance are estimated to have caused a small warming effect (+0.12 [+0.06 to +0.30] W/m²).

[7] Consideration of remaining uncertainty is based on current methodologies.

Global and continental temperature change

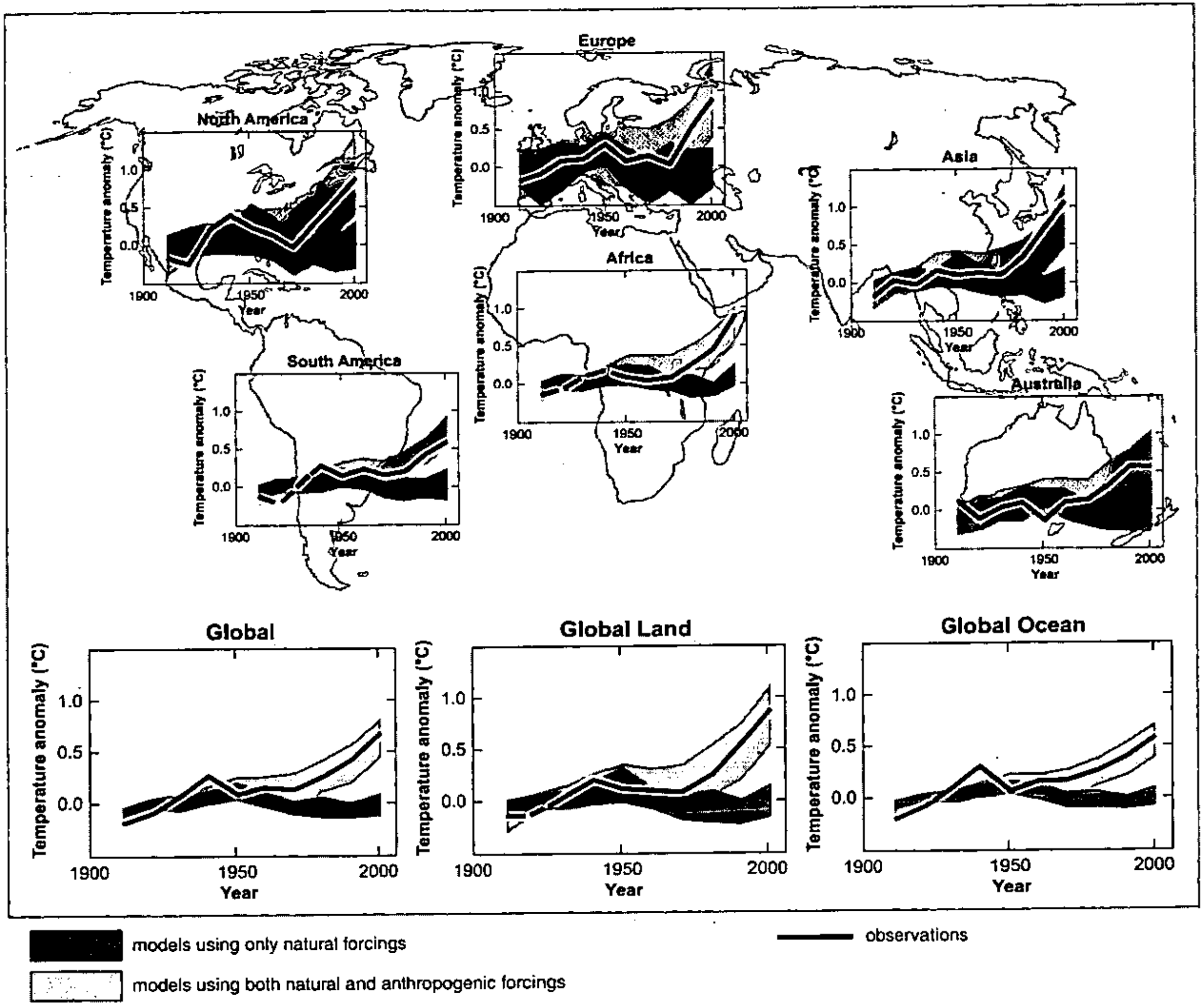

Figure SPM.4. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {Figure 2.5}

Advances since the TAR show that discernible human influences extend beyond average temperature to other aspects of climate. *{2.4}*

Human influences have: *{2.4}*

- *very likely* contributed to sea level rise during the latter half of the 20th century
- *likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
- *likely* increased temperatures of extreme hot nights, cold nights and cold days
- *more likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.

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. *{2.4}*

Spatial agreement between regions of significant warming across the globe and locations of significant observed changes in many systems consistent with warming is *very unlikely* to be due solely to natural variability. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming. *{2.4}*

More complete attribution of observed natural system responses to anthropogenic warming is currently prevented by the short time scales of many impact studies, greater natural climate variability at regional scales, contributions of non-climate factors and limited spatial coverage of studies. *{2.4}*

3. Projected climate change and its impacts

There is *high agreement* and *much evidence* that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. *{3.1}*

The IPCC Special Report on Emissions Scenarios (SRES, 2000) projects an increase of global GHG emissions by 25 to 90% (CO_2-eq) between 2000 and 2030 (Figure SPM.5), with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent scenarios without additional emissions mitigation are comparable in range.[8,9] *{3.1}*

Continued GHG 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 (Table SPM.1, Figure SPM.5). *{3.2.1}*

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios. *{3.2}*

The range of projections (Table SPM.1) is broadly consistent with the TAR, but uncertainties and upper ranges for temperature are larger mainly because the broader range of available models suggests stronger climate-carbon cycle feedbacks. Warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. The strength of this feedback effect varies markedly among models. *{2.3, 3.2.1}*

Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Table SPM.1 shows model-based projections

Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures

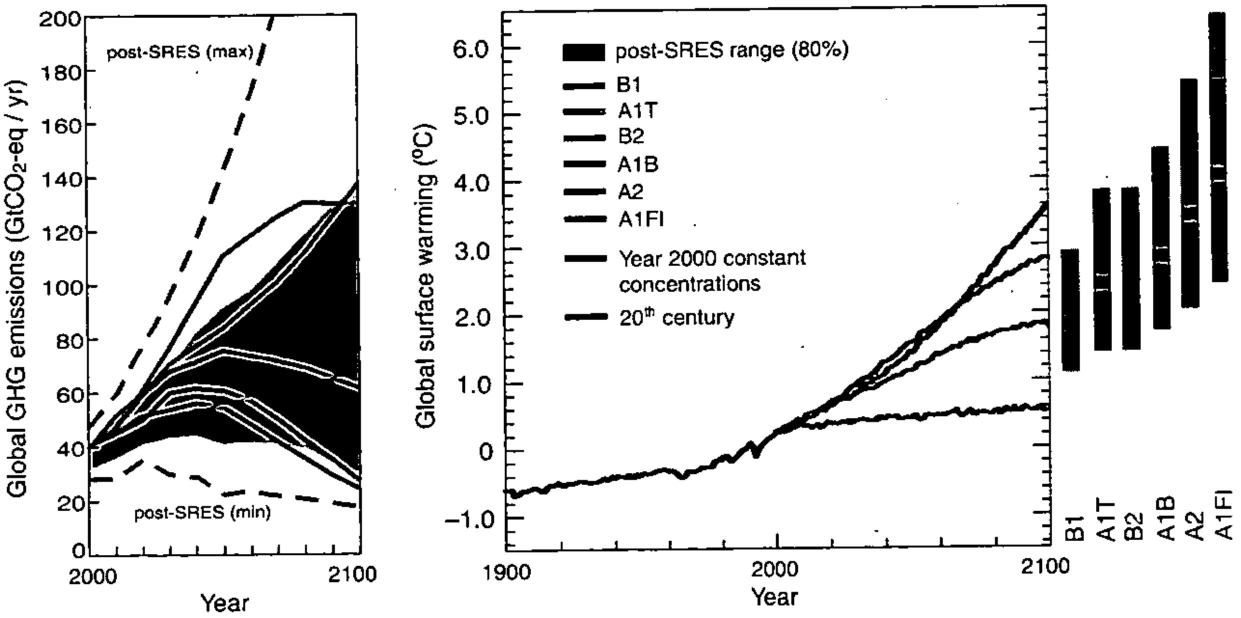

Figure SPM.5. ***Left Panel:*** *Global GHG emissions (in $GtCO_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases.* ***Right Panel:*** *Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. {Figures 3.1 and 3.2}*

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[8] For an explanation of SRES emissions scenarios, see Box 'SRES scenarios' in Topic 3 of this Synthesis Report. These scenarios do not include additional climate policies above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion.

[9] Emission pathways of mitigation scenarios are discussed in Section 5.

Table SPM.1. Projected global average surface warming and sea level rise at the end of the 21st century. {Table 3.1}

Case	Temperature change (°C at 2090-2099 relative to 1980-1999)[a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

a) Temperatures are assessed best estimates and *likely* uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the Working Group I TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.

d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

of global average sea level rise for 2090-2099.[10] The projections do not include uncertainties in climate-carbon cycle feedbacks nor the full effects of changes in ice sheet flow, therefore the upper values of the ranges are not to be considered upper bounds for sea level rise. They include a contribution from increased Greenland and Antarctic ice flow at the rates observed for 1993-2003, but this could increase or decrease in the future.[11] *{3.2.1}*

There is now higher confidence than in the TAR in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea ice. *{3.2.2}*

Regional-scale changes include: *{3.2.2}*

- warming greatest over land and at most high northern latitudes and least over Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends (Figure SPM.6)
- contraction of snow cover area, increases in thaw depth over most permafrost regions and decrease in sea ice extent; in some projections using SRES scenarios, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century
- *very likely* increase in frequency of hot extremes, heat waves and heavy precipitation
- *likely* increase in tropical cyclone intensity; less confidence in global decrease of tropical cyclone numbers
- poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation and temperature patterns
- *very likely* precipitation increases in high latitudes and *likely* decreases in most subtropical land regions, continuing observed recent trends.

There is *high confidence* that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics. There is also *high confidence* that many semi-arid areas (e.g. Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. *{3.3.1, Figure 3.5}*

Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. *{3.3.1, 3.3.2}*

Figure SPM.7 presents examples of this new information for systems and sectors. The top panel shows impacts increasing with increasing temperature change. Their estimated magnitude and timing is also affected by development pathway (lower panel). *{3.3.1}*

Examples of some projected impacts for different regions are given in Table SPM.2.

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[10] TAR projections were made for 2100, whereas the projections for this report are for 2090-2099. The TAR would have had similar ranges to those in Table SPM.1 if it had treated uncertainties in the same way.

[11] For discussion of the longer term, see material below.

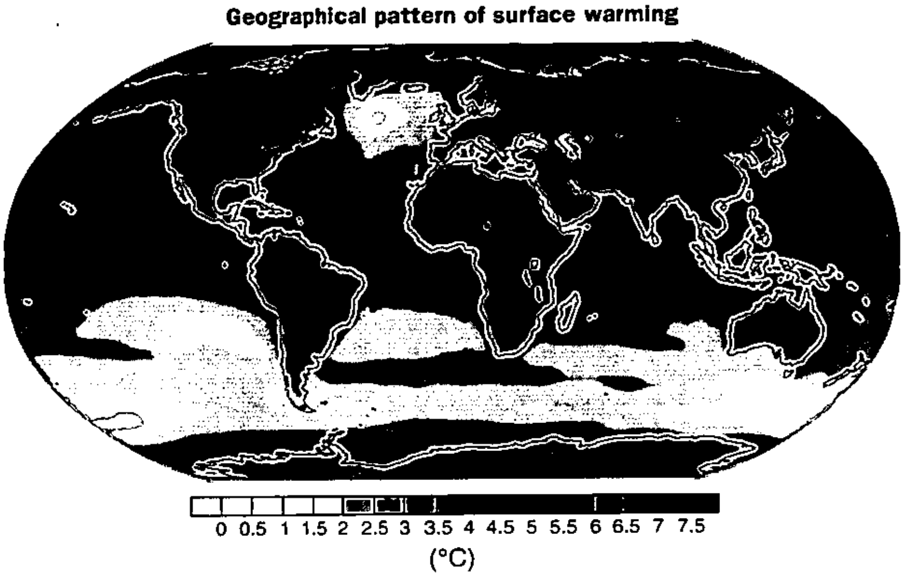

Figure SPM.6. Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average projection for the A1B SRES scenario. Temperatures are relative to the period 1980-1999. {Figure 3.2}

Some systems, sectors and regions are *likely* to be especially affected by climate change.[12] *{3.3.3}*

Systems and sectors: *{3.3.3}*

- particular ecosystems:
  - terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
  - coastal: mangroves and salt marshes, due to multiple stresses
  - marine: coral reefs due to multiple stresses; the sea ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes[13] and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions: *{3.3.3}*

- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children and the elderly) can be particularly at risk, and also some areas and some activities. *{3.3.3}*

Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO_2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species. *{3.3.4}*

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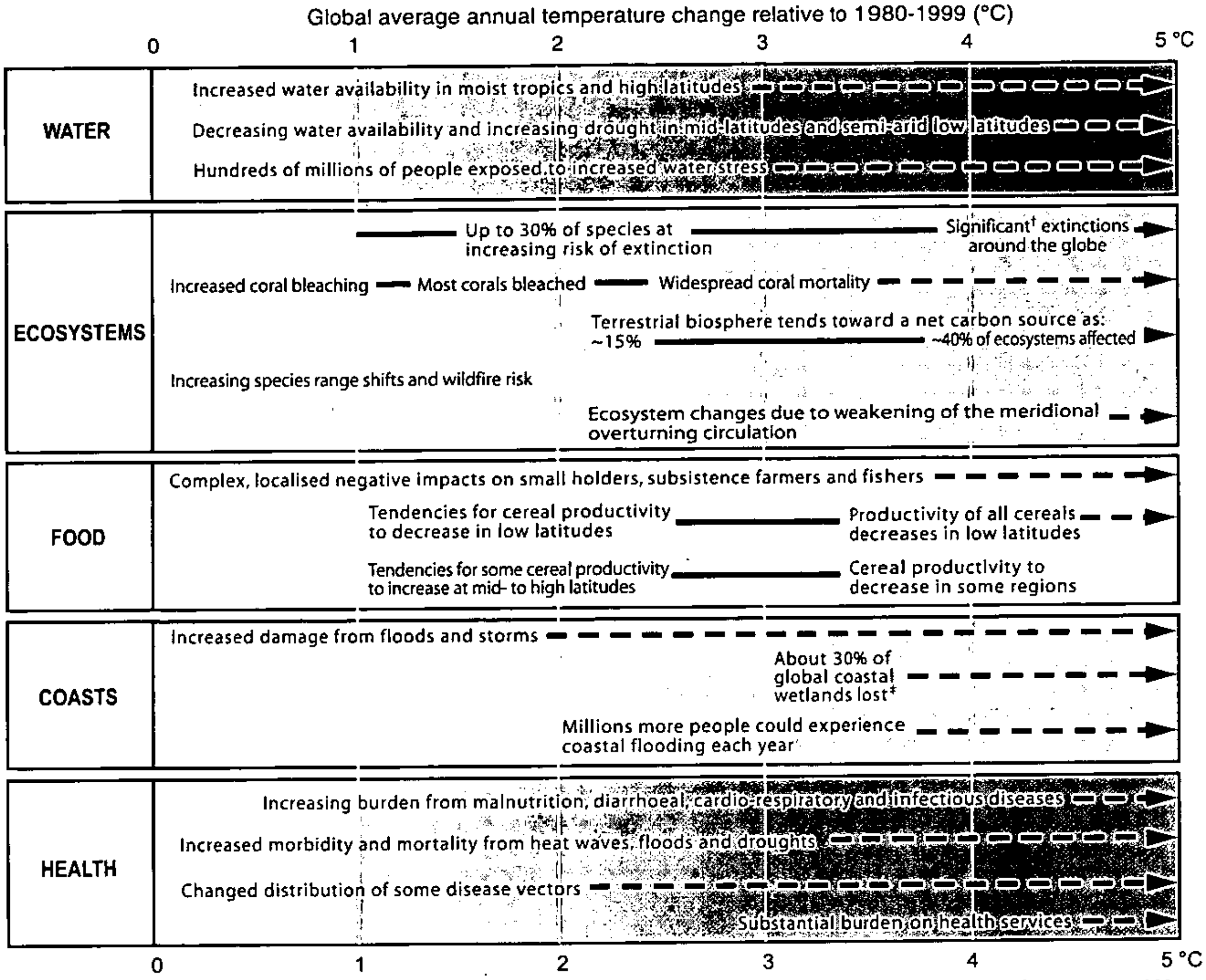
[12] Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

[13] Including arid and semi-arid regions.

Examples of impacts associated with global average temperature change
(Impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway)



† Significant is defined here as more than 40%. ‡ Based on average rate of sea level rise of 4.2mm/year from 2000 to 2080.

Warming by 2090-2099 relative to 1980-1999 for non-mitigation scenarios

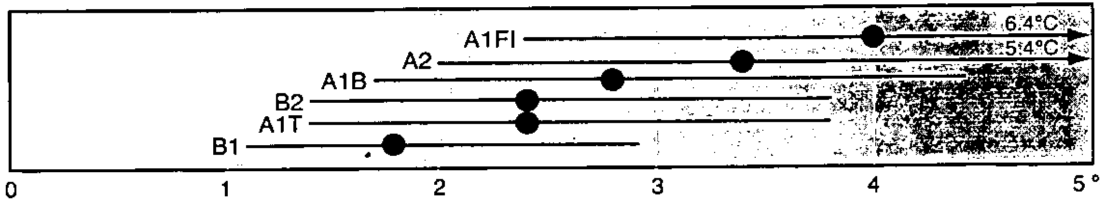


Figure SPM.7. Examples of impacts associated with projected global average surface warming. ***Upper panel:*** *Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are* high. ***Lower panel:*** *Dots and bars indicate the best estimate and* likely *ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. {Figure 3.6}*

Table SPM.2. Examples of some projected regional impacts. {3.3.2}

Africa	• By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. • By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. • Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of Gross Domestic Product (GDP). • By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (TS).
Asia	• By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease. • Coastal areas, especially heavily populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. • Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development. • Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle.
Australia and New Zealand	• By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. • By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. • By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. • By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.
Europe	• Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). • Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080). • In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. • Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires.
Latin America	• By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. • There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. • Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (TS; *medium confidence*). • Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.
North America	• Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. • In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. • Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. • Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.

continued...

Table SPM.2. continued...

Polar Regions	• The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. • For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. • Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. • In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.
Small Islands	• Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. • Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. • By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. • With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.

Note:
Unless stated explicitly, all entries are from Working Group II SPM text, and are either *very high confidence* or *high confidence* statements, reflecting different sectors (agriculture, ecosystems, water, coasts, health, industry and settlements). The Working Group II SPM refers to the source of the statements, timelines and temperatures. The magnitude and timing of impacts that will ultimately be realised will vary with the amount and rate of climate change, emissions scenarios, development pathways and adaptation.

Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems. *{3.3.5}*

Examples for selected extremes and sectors are shown in Table SPM.3.

Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. *{3.2.3}*

Estimated long-term (multi-century) warming corresponding to the six AR4 Working Group III stabilisation categories is shown in Figure SPM.8.

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m if global average warming were sustained for millennia in excess of 1.9 to 4.6°C relative to pre-industrial values. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when palaeoclimatic information suggests reductions of polar land ice extent and 4 to 6m of sea level rise. *{3.2.3}*

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. *{3.2.3}*

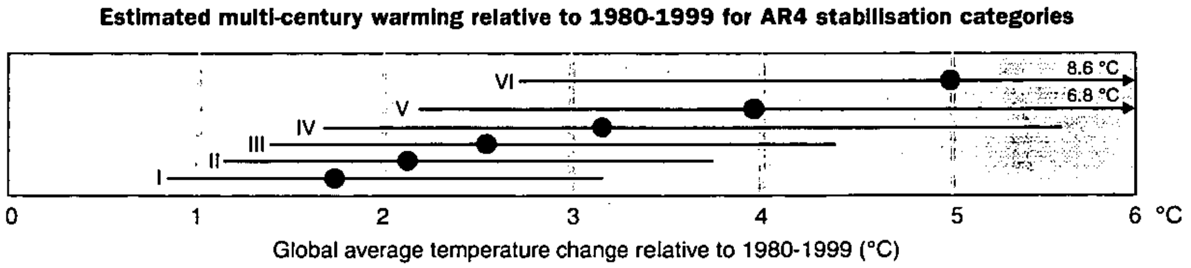


Figure SPM.8. Estimated long-term (multi-century) warming corresponding to the six AR4 Working Group III stabilisation categories (Table SPM.6). The temperature scale has been shifted by -0.5°C compared to Table SPM.6 to account approximately for the warming between pre-industrial and 1980-1999. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For GHG emissions scenarios that lead to stabilisation at levels comparable to SRES B1 and A1B by 2100 (600 and 850ppm CO_2-eq; category IV and V), assessed models project that about 65 to 70% of the estimated global equilibrium temperature increase, assuming a climate sensitivity of 3°C, would be realised at the time of stabilisation. For the much lower stabilisation scenarios (category I and II, Figure SPM.11), the equilibrium temperature may be reached earlier. {Figure 3.4}

Table SPM.3. Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column two relate to the phenomena listed in column one. {Table 3.2}

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlement and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	*Virtually certain*[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	*Very likely*	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	*Very likely*	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	*Likely*	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	*Likely*	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	*Likely*[d]	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:

a) See Working Group I Table 3.7 for further details regarding definitions.
b) Warming of the most extreme days and nights each year.
c) Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
d) In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. *{3.4}*

Partial loss of ice sheets on polar land could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur over millennial time scales, but more rapid sea level rise on century time scales cannot be excluded. *{3.4}*

Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20 to 30% of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. *{3.4}*

Based on current model simulations, the meridional overturning circulation (MOC) of the Atlantic Ocean will *very likely* slow down during the 21st century; nevertheless temperatures over the Atlantic and Europe are projected to increase. The MOC is *very unlikely* to undergo a large abrupt transition during the 21st century. Longer-term MOC changes cannot be assessed with confidence. Impacts of large-scale and persistent changes in the MOC are *likely* to include changes in marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation. Changes in terrestrial and ocean CO_2 uptake may feed back on the climate system. *{3.4}*

4. Adaptation and mitigation options[14]

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 are barriers, limits and costs, which are not fully understood. *{4.2}*

Societies have a long record of managing the impacts of weather- and climate-related events. Nevertheless, additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. Moreover, vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. *{4.2}*

Some planned adaptation to climate change is already occurring on a limited basis. Adaptation can reduce vulnerability, especially when it is embedded within broader sectoral initiatives (Table SPM.4). There is *high confidence* that there are viable adaptation options that can be implemented in some sectors at low cost, and/or with high benefit-cost ratios. However, comprehensive estimates of global costs and benefits of adaptation are limited. *{4.2, Table 4.1}*

Adaptive capacity is intimately connected to social and economic development but is unevenly distributed across and within societies. *{4.2}*

A range of barriers limits both the implementation and effectiveness of adaptation measures. The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. *{4.2}*

Both bottom-up and top-down studies indicate that there is *high agreement* and *much evidence* of substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels (Figures SPM.9, SPM.10).[15] While top-down and bottom-up studies are in line at the global level (Figure SPM.9) there are considerable differences at the sectoral level. *{4.3}*

No single technology can provide all of the mitigation potential in any sector. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed (Table SPM.5). *{4.3}*

Bottom-up studies suggest that mitigation opportunities with net negative costs have the potential to reduce emissions by around 6 $GtCO_2$-eq/yr in 2030, realising which requires dealing with implementation barriers. *{4.3}*

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[14] While this Section deals with adaptation and mitigation separately, these responses can be complementary. This theme is discussed in Section 5.

[15] The concept of '**mitigation potential**' has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of 'market mitigation potential' and 'economic mitigation potential'.

Market mitigation potential is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

Economic mitigation potential is the mitigation potential that takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

Mitigation potential is estimated using different types of approaches. ***Bottom-up studies*** are based on assessment of mitigation options, emphasising specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. ***Top-down studies*** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

Table SPM.4. Selected examples of planned adaptation by sector. {Table 4.1}

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; *italics = opportunities*)
Water	Expanded rainwater harvesting; water storage and conservation techniques; water re-use; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; *integrated water resources management; synergies with other sectors*
Agriculture	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological and financial constraints; access to new varieties; markets; *longer growing season in higher latitudes; revenues from 'new' products*
Infrastructure/ settlement (including coastal zones)	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; *integrated policies and management; synergies with sustainable development goals*
Human health	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthened health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; *upgraded health services; improved quality of life*
Tourism	Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); *revenues from 'new' attractions; involvement of wider group of stakeholders*
Transport	Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; *improved technologies and integration with key sectors (e.g. energy)*
Energy	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; *stimulation of new technologies; use of local resources*

Note:
Other examples from many sectors would include early warning systems.

Future energy infrastructure investment decisions, expected to exceed US$20 trillion[16] between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO_2 emissions to 2005 levels by 2030 would require a large shift in investment patterns, although the net additional investment required ranges from negligible to 5 to 10%. *{4.3}*

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[16] 20 trillion = 20,000 billion = 20×10^{12}

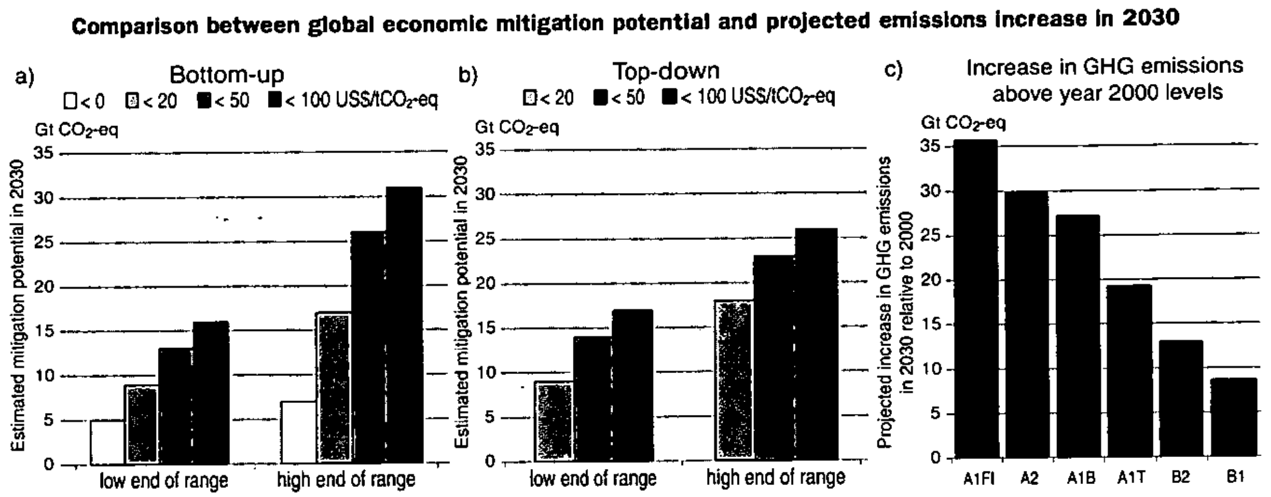

Figure SPM.9. Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 GtCO$_2$-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emission results. {Figure 4.1}

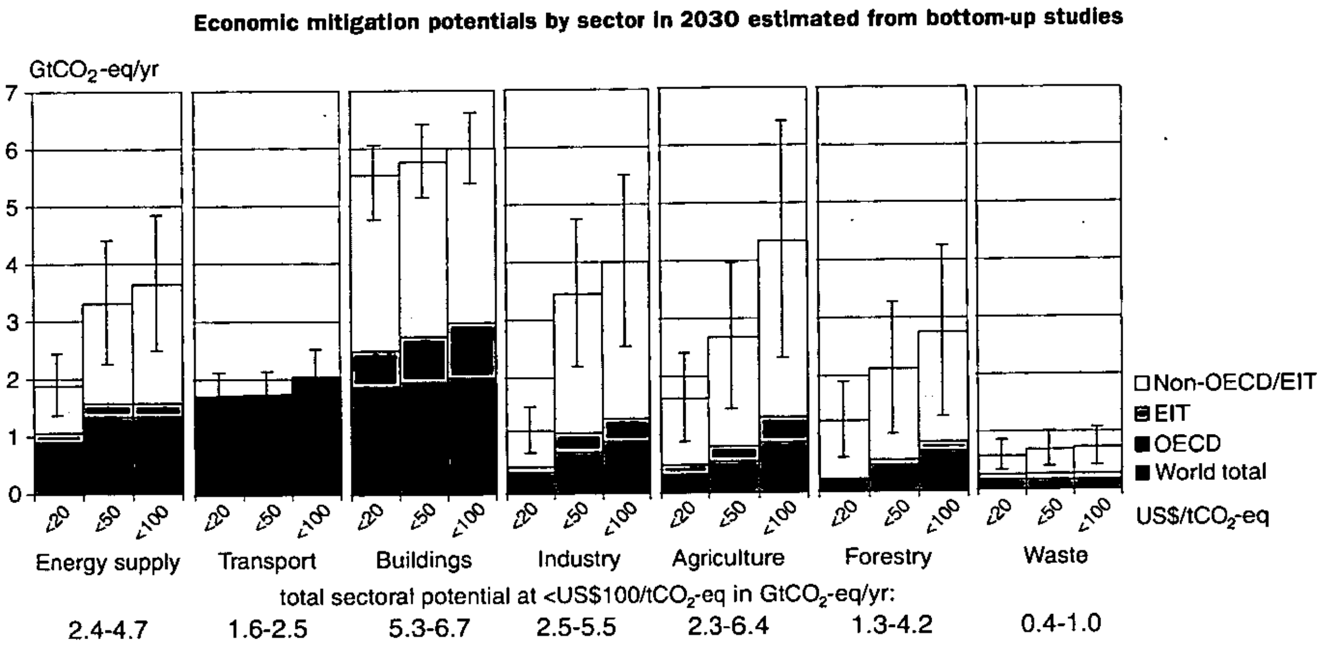

Figure SPM.10. Estimated economic mitigation potential by sector in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. The potentials do not include non-technical options such as lifestyle changes. {Figure 4.2}

Notes:

a) The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.

b) The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.

c) Sectors used different baselines. For industry, the SRES B2 baseline was taken, for energy supply and transport, the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.

d) Only global totals for transport are shown because international aviation is included.

e) Categories excluded are: non-CO$_2$ emissions in buildings and transport, part of material efficiency options, heat production and co-generation in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

Table SPM.5 Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {Table 4.2}

Sector	Key mitigation technologies and practices currently commercially available. *Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.*	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; *italics = opportunities*)
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO_2 from natural gas); *CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics*	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
		Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies	*May be appropriate to create markets for low-emissions technologies*
Transport	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; *second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries*	Mandatory fuel economy; biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
		Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing	Effectiveness may drop with higher incomes
		Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport	*Particularly appropriate for countries that are building up their transportation systems*
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; *integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings*	Appliance standards and labelling	Periodic revision of standards needed
		Building codes and certification	*Attractive for new buildings.* Enforcement can be difficult
		Demand-side management programmes	Need for regulations so that utilities may profit
		Public sector leadership programmes, including procurement	*Government purchasing can expand demand for energy-efficient products*
		Incentives for energy service companies (ESCOs)	*Success factor: Access to third party financing*
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and a wide array of process-specific technologies; *advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture*	Provision of benchmark information; performance standards; subsidies; tax credits	*May be appropriate to stimulate technology uptake.* Stability of national policy important in view of international competitiveness
		Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
		Voluntary agreements	Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertiliser application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; *improvements of crop yields*	Financial incentives and regulations for improved land management; maintaining soil carbon content; efficient use of fertilisers and irrigation	*May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation*
Forestry/ forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; *tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land-use change*	Financial incentives (national and international) to increase forest area, to reduce deforestation and to maintain and manage forests; land-use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. *Can help poverty alleviation*
Waste	Landfill CH_4 recovery; waste incineration with energy recovery; composting of organic waste; controlled wastewater treatment; recycling and waste minimisation; *biocovers and biofilters to optimise CH_4 oxidation*	Financial incentives for improved waste and wastewater management	*May stimulate technology diffusion*
		Renewable energy incentives or obligations	Local availability of low-cost fuel
		Waste management regulations	Most effectively applied at national level with enforcement strategies

A wide variety of policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and sectoral context (Table SPM.5). ***{4.3}***

They include integrating climate policies in wider development policies, regulations and standards, taxes and charges, tradable permits, financial incentives, voluntary agreements, information instruments, and research, development and demonstration (RD&D). *{4.3}*

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show that global carbon prices rising to US\$20-80/tCO_2-eq by 2030 are consistent with stabilisation at around 550ppm CO_2-eq by 2100. For the same stabilisation level, induced technological change may lower these price ranges to US\$5-65/tCO_2-eq in 2030.[17] *{4.3}*

There is *high agreement* and *much evidence* that mitigation actions can result in near-term co-benefits (e.g. improved health due to reduced air pollution) that may offset a substantial fraction of mitigation costs. *{4.3}*

There is *high agreement* and *medium evidence* that Annex I countries' actions may affect the global economy and global emissions, although the scale of carbon leakage remains uncertain.[18] *{4.3}*

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spillover depends strongly on assumptions related to policy decisions and oil market conditions. *{4.3}*

There is also *high agreement* and *medium evidence* that changes in lifestyle, behaviour patterns and management practices can contribute to climate change mitigation across all sectors. *{4.3}*

Many options for reducing global GHG emissions through international cooperation exist. There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to climate change, stimulation of an array of national policies, and the creation of an international carbon market and new institutional mechanisms that may provide the foundation for future mitigation efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional international initiatives have been suggested. ***{4.5}***

Greater cooperative efforts and expansion of market mechanisms will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Efforts can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development-oriented actions; or expanding financing instruments. *{4.5}*

In several sectors, climate response options can be implemented to realise synergies and avoid conflicts with other dimensions of sustainable development. Decisions about macroeconomic and other non-climate policies can significantly affect emissions, adaptive capacity and vulnerability. ***{4.4, 5.8}***

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions and reduce vulnerability, but there may be barriers to implementation. On the other hand, it is *very likely* that climate change can slow the pace of progress towards sustainable development. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. *{5.8}*

5. The long-term perspective

Determining what constitutes "dangerous anthropogenic interference with the climate system" in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled 'key'. ***{Box 'Key Vulnerabilities and Article 2 of the UNFCCC', Topic 5}***

Key vulnerabilities[19] may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. *{Box 'Key Vulnerabilities and Article 2 of the UNFCCC', Topic 5}*

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[17] Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least-cost approach to mitigation portfolios, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

[18] Further details may be found in Topic 4 of this Synthesis Report.

[19] Key vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

The five 'reasons for concern' identified in the TAR remain a viable framework to consider key vulnerabilities. These 'reasons' are assessed here to be stronger than in the TAR. Many risks are identified with higher confidence. Some risks are projected to be larger or to occur at lower increases in temperature. Understanding about the relationship between impacts (the basis for 'reasons for concern' in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. *{5.2}*

This is due to more precise identification of the circumstances that make systems, sectors and regions especially vulnerable and growing evidence of the risks of very large impacts on multiple-century time scales. *{5.2}*

- *Risks to unique and threatened systems.* There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-industrial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of indigenous communities in the Arctic and small island communities to warming is projected. *{5.2}*
- *Risks of extreme weather events.* Responses to some recent extreme events reveal higher levels of vulnerability than the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. *{5.2}*
- *Distribution of impacts and vulnerabilities.* There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. Moreover, there is increased evidence that low-latitude and less developed areas generally face greater risk, for example in dry areas and megadeltas. *{5.2}*
- *Aggregate impacts.* Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude of warming, while damages would be higher for larger magnitudes of warming. The net costs of impacts of increased warming are projected to increase over time. *{5.2}*
- *Risks of large-scale singularities.* There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. *{5.2}*

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. *{5.3}*

Adaptation is necessary in the short and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs, but these are not fully understood. Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. The time at which such limits could be reached will vary between sectors and regions. Early mitigation actions would avoid further locking in carbon intensive infrastructure and reduce climate change and associated adaptation needs. *{5.2, 5.3}*

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 stabilisation levels. Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. *{5.3, 5.4, 5.7}*

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter. The lower the stabilisation level, the more quickly this peak and decline would need to occur.[20] *{5.4}*

Table SPM.6 and Figure SPM.11 summarise the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium global warming and long-

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[20] For the lowest mitigation scenario category assessed, emissions would need to peak by 2015, and for the highest, by 2090 (see Table SPM.6). Scenarios that use alternative emission pathways show substantial differences in the rate of global climate change.

term sea level rise due to thermal expansion only.[21] The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. *{5.4, 5.7}*

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. The long time scales of thermal expansion and ice sheet response to warming imply that stabilisation of GHG concentrations at or above present levels would not stabilise sea level for many centuries. *{5.3, 5.4}*

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers. *{5.5}*

All assessed stabilisation scenarios indicate that 60 to 80% of the reductions would come from energy supply and use and industrial processes, with energy efficiency playing a key role in many scenarios. Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Low stabilisation levels require early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies. *{5.5}*

Without substantial investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. *{5.5}*

Table SPM.6. *Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.*[a] *{Table 5.1}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).

b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.

c) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure SPM.3).

d) The best estimate of climate sensitivity is 3°C.

e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 21).

f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

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[21] Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels, global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure SPM.11), the equilibrium temperature may be reached earlier.

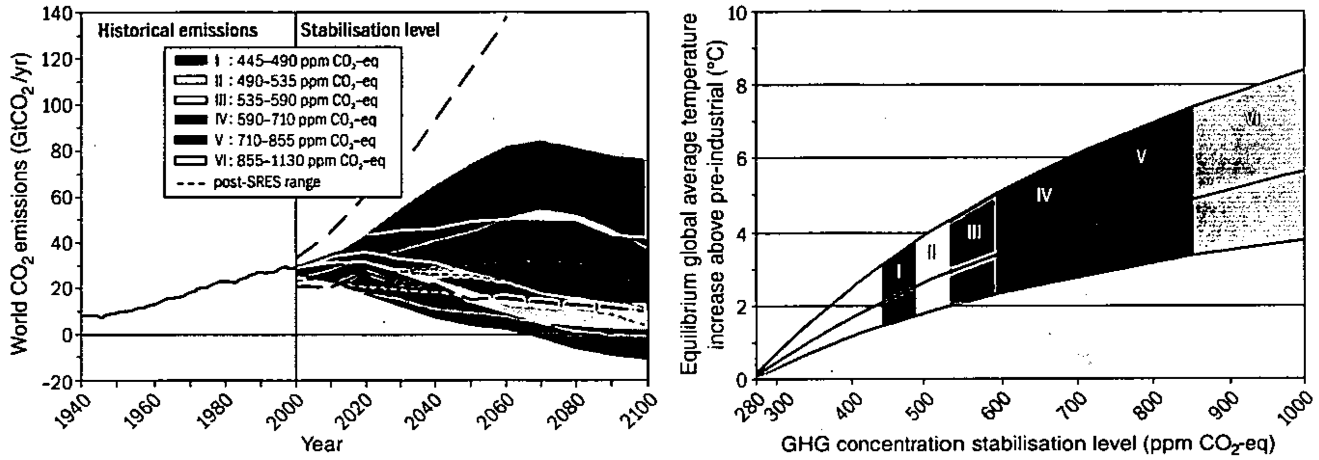
CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

Figure SPM.11. Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely *equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of* likely *range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of* likely *range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10th to 90th percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {Figure 5.1}*

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target (Table SPM.7). For specific countries and sectors, costs vary considerably from the global average.[22] *{5.6}*

In 2050, global average macro-economic costs for mitigation towards stabilisation between 710 and 445ppm CO_2-eq are between a 1% gain and 5.5% decrease of global GDP (Table SPM.7). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. *{5.6}*

Table SPM.7. Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {Table 5.2}

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points)[c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		< 3	< 5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:

Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.

a) Global GDP based on market exchange rates.

b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO_2-eq) gives the upper bound estimate of the literature only.

c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.

d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

e) The values correspond to the highest estimate for GDP reduction shown in column three.

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[22] See Footnote 17 for more detail on cost estimates and model assumptions.

Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk. *{5.1}*

Impacts of climate change are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. Peer-reviewed estimates of the social cost of carbon[23] in 2005 average US$12 per tonne of CO_2, but the range from 100 estimates is large (-\$3 to \$95/tCO_2). This is due in large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses and discount rates. Aggregate estimates of costs mask significant differences in impacts across sectors, regions and populations and *very likely* underestimate damage costs because they cannot include many non-quantifiable impacts. *{5.7}*

Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that they are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. *{5.7}*

Climate sensitivity is a key uncertainty for mitigation scenarios for specific temperature levels. *{5.4}*

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. *{5.7}*

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[23] Net economic costs of damages from climate change aggregated across the globe and discounted to the specified year.

Attachment 2
Docket 07A-447E
Glustrom Answer Testimony

Climate Change 2007: Synthesis Report

Synthesis Report

An Assessment of the Intergovernmental Panel on Climate Change

This underlying report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

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Treatment of uncertainty

The IPCC uncertainty guidance note[1] defines a framework for the treatment of uncertainties across all WGs and in this Synthesis Report. This framework is broad because the WGs assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or the social sciences. WG I focuses on the former, WG III on the latter, and WG II covers aspects of both.

Three different approaches are used to describe uncertainties each with a distinct form of language. Choices among and within these three approaches depend on both the nature of the information available and the authors' expert judgment of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III through a series of self-explanatory terms such as: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc.*

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: *very high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* > 50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WG II has used a combination of confidence and likelihood assessments and WG I has predominantly used likelihood assessments.

This Synthesis Report follows the uncertainty assessment of the underlying WGs. Where synthesised findings are based on information from more than one WG, the description of uncertainty used is consistent with that for the components drawn from the respective WG reports.

Unless otherwise stated, numerical ranges given in square brackets in this report indicate 90% uncertainty intervals (i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range). Uncertainty intervals are not necessarily symmetric around the best estimate.

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[1] See http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/uncertainty-guidance-note.pdf

5

The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development

5.1 Risk management perspective

Responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity and attitudes to risk. *{WGII 20. 9, SPM; WGIII SPM}*

Risk management techniques can explicitly accommodate sectoral, regional and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures. Risk is generally understood to be the product of the likelihood of an event and its consequences. Climate change impacts depend on the characteristics of natural and human systems, their development pathways and their specific locations. *{SYR 3.3, Figure 3.6; WGII 20.2, 20.9, SPM; WGIII 3.5, 3.6, SPM}*

5.2 Key vulnerabilities, impacts and risks – long-term perspectives

The five 'reasons for concern' identified in the TAR are now assessed to be stronger with many risks identified with higher confidence. Some are projected to be larger or to occur at lower increases in temperature. This is due to (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and GHG concentrations, including vulnerability to present-day climate variability, (2) more precise identification of the circumstances that make systems, sectors, groups and regions especially vulnerable and (3) growing evidence that the risk of very large impacts on multiple century time scales would continue to increase as long as GHG concentrations and temperature continue to increase. Understanding about the relationship between impacts (the basis for 'reasons for concern' in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. *{WGII 4.4, 5.4, 19.ES, 19.3.7, TS.4.6; WGIII 3.5, SPM}*

The TAR concluded that vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity. Adaptation can reduce sensitivity to climate change while mitigation can reduce the exposure to climate change, including its rate and extent. Both conclusions are confirmed in this assessment. *{WGII 20.2, 20.7.3}*

No single metric can adequately describe the diversity of key vulnerabilities or support their ranking. A sample of relevant impacts is provided in Figure 3.6. The estimation of key vulnerabilities in any system, and damage implied, will depend on exposure (the rate and magnitude of climate change), sensitivity, which is determined in part and where relevant by development status, and adaptive capacity. Some key vulnerabilities may be linked to thresholds; in some cases these may cause a system to shift from one state to another, whereas others have thresholds that are defined subjectively and thus depend on societal values. *{WGII 19.ES, 19.1}*

The five 'reasons for concern' that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to "aid readers in making their own determination" about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in the AR4. *{TAR WGII Chapter 19; WGII SPM}*

- ***Risks to unique and threatened systems.*** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-indus-

Key Vulnerabilities and Article 2 of the UNFCCC

Article 2 of the UNFCCC states:

"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Determining what constitutes "dangerous anthropogenic interference with the climate system" in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled 'key'. *{SYR 3.3, WGII 19.ES}*

Key vulnerabilities[25] may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. *{WGII 19.ES}*

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments. *{WGII SPM}*

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[25] Key Vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

trial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of Arctic indigenous communities and small island communities to warming is projected. *{SYR 3.3, 3.4, Figure 3.6, Table 3.2; WGII 4.ES, 4.4, 6.4, 14.4.6, 15.ES, 15.4, 15.6, 16.ES, 16.2.1, 16.4, Table 19.1, 19.3.7, TS.5.3, Figure TS.12, Figure TS.14}*

- ***Risks of extreme weather events.*** Responses to some recent extreme climate events reveal higher levels of vulnerability in both developing and developed countries than was assessed in the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. As summarised in Table 3.2, increases in drought, heat waves and floods are projected in many regions and would have mostly adverse impacts, including increased water stress and wild fire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure. *{SYR 3.2, 3.3, Table 3.2; WGI 10.3, Table SPM.2; WGII 1.3, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3, Table 19.1, Table SPM.1}*
- ***Distribution of impacts and vulnerabilities.*** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. There is greater confidence in the projected regional patterns of climate change (see Topic 3.2) and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions (see Topic 3.3). Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and megadeltas. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small island communities. *{SYR 3.2, 3.3, 5.4; WGI 11.2-11.7, SPM; WGII 3.4.3, 5.3, 5.4, Boxes 7.1 and 7.4, 8.1.1, 8.4.2, 8.6.1.3, 8.7, 9.ES, Table 10.9, 10.6, 16.3, 19.ES, 19.3, Table 19.1, 20.ES, TS.4.5, TS.5.4, Tables TS.1, TS.3, TS.4, SPM}*
- ***Aggregate impacts.*** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude and therefore sooner than was assessed in the TAR. It is *likely* that there will be higher damages for larger magnitudes of global temperature increase than estimated in the TAR, and the net costs of impacts of increased warming are projected to increase over time. Aggregate impacts have also been quantified in other metrics (see Topic 3.3): for example, climate change over the next century is *likely* to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased malnutrition and increased health impacts. *{SYR 3.3, Figure 3.6; WGII 19.3.7, 20.7.3, TS.5.3}*
- ***Risks of large-scale singularities.***[26] As discussed in Topic 3.4, during the current century, a large-scale abrupt change in the meridional overturning circulation is *very unlikely*. There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. Complete deglaciation of the Greenland ice sheet would raise sea level by 7m and could be irreversible. *{SYR 3.4; WGI 10.3, Box 10.1; WGII 19.3.7, SPM}*

5.3 Adaptation and mitigation

There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short term and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs that are not fully understood. Adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change. ***{WGII 4.ES, TS 5.1, 18.4, 18.6, 20.7, SPM; WGIII 1.2, 2.5, 3.5, 3.6}***

Adaptation will be ineffective for some cases such as natural ecosystems (e.g. loss of Arctic sea ice and marine ecosystem viability), the disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres[27]. It will be less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). There is *high confidence* that the ability of many ecosystems to adapt naturally will be exceeded this century. In addition, multiple barriers and constraints to effective adaptation exist in human systems (see Topic 4.2). *{SYR 4.2; WGII 17.4.2, 19.2, 19.4.1}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs. *{WGII 18.1, SPM}*

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[26] See glossary

[27] While it is technically possible to adapt to several metres of sea level rise, the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation. {WGII 17.4.2, 19.4.1}

Efforts to mitigate GHG emissions to reduce the rate and magnitude of climate change need to account for inertia in the climate and socio-economic systems. *{SYR 3.2; WGI 10.3, 10.4, 10.7, SPM; WGIII 2.3.4}*

After GHG concentrations are stabilised, the rate at which the global average temperature increases is expected to slow within a few decades. Small increases in global average temperature could still be expected for several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that eventually decreases from that reached before stabilisation, due to ongoing heat uptake by oceans. *{SYR 3.2, WGI 10.3, 10.4, 10.7, SPM}*

Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, reduce the rate of climate change and reduce the adaptation needs associated with higher levels of warming. *{WGII 18.4, 20.6, 20.7, SPM; WGIII 2.3.4, 3.4, 3.5, 3.6, SPM}*

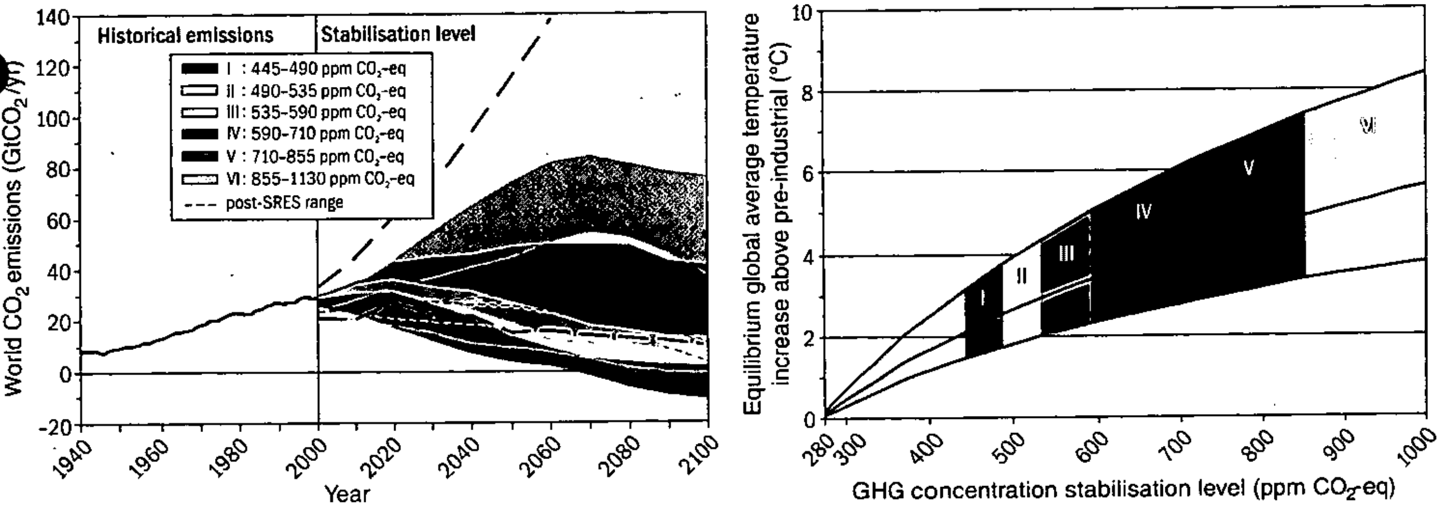
5.4 Emission trajectories for stabilisation

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter.[28] The lower the stabilisation level, the more quickly this peak and decline would need to occur (Figure 5.1).[29] *{WGIII 3.3, 3.5, SPM}*

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of GHG concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. *{WGIII 3.3, 3.5, SPM}*

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.1). *{WGIII 3.5, SPM}*

Table 5.1 summarises the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium



CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

Figure 5.1. Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of likely range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of likely range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10^{th} to 90^{th} percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {WGIII Figures SPM.7 and SPM.8}

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[28] Peaking means that the emissions need to reach a maximum before they decline later.

[29] For the lowest mitigation scenario category assessed, emissions would need to peak by 2015 and for the highest by 2090 (see Table 5.1). Scenarios that use alternative emission pathways show substantial differences on the rate of global climate change. {WGII 19.4}

Table 5.1. Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] *{WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).

b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.

c) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure 2.1).

d) The best estimate of climate sensitivity is 3°C.

e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 30).

f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

global average temperature increases, using the 'best estimate' of climate sensitivity (see Figure 5.1 for the *likely* range of uncertainty). Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak and requires greater emissions reductions by 2050.[30] Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet specific temperature levels. The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. *{WGIII 3.3, 3.4, 3.5, 3.6, SPM}*

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century (Table 5.1). If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3 to 0.8m. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. These long-term consequences would have major implications for world coastlines. The long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries. *{WGI 10.7}*

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change. Climate-carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms (see Topics 2.3 and 3.2.1), but mitigation studies have not yet incorporated the full range of these feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate-carbon cycle feedbacks, model studies suggest that stabilising CO_2 concentrations at, for example, 450ppm[31] could require cumulative emissions over the 21st century to be less than 1800 [1370 to 2200] $GtCO_2$, which is about 27% less than the 2460 [2310 to 2600] $GtCO_2$ determined without consideration of carbon cycle feedbacks. *{SYR 2.3, 3.2.1; WGI 7.3, 10.4, SPM}*

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[30] Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier.

[31] To stabilise at 1000ppm CO_2, this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] $GtCO_2$ to approximately 4030 [3590 to 4580] $GtCO_2$. {WGI 7.3, 10.4, SPM}

5.5 Technology flows and development

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers. ***{WGIII SPM}***

Worldwide deployment of low-GHG emission technologies as well as technology improvements through public and private RD&D would be required for achieving stabilisation targets as well as cost reduction.[32] Figure 5.2 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of different technologies varies over time and region and depends on the baseline development path, available technologies and relative costs, and the analysed stabilisation levels. Stabilisation at the lower of the assessed levels (490 to 540ppm CO_2-eq) requires early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies over the next decades (2000-2030) and higher contributions across abatement options in the long term (2000-2100). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed with appropriate incentives. *{WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}*

Without sustained investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. *{WGIII 13.3, SPM}*

There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60 to 80% of the reductions over the course of the century would come from energy supply and use and industrial processes. Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and time scales. For lower stabilisation levels, scenarios put more emphasis on the use of low-carbon energy sources, such as renewable energy, nuclear power and the use of CO_2 capture and storage (CCS). In these scenarios, improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past (Figure 5.2). *{WGIII 3.3, 3.4, TS.3, SPM}*

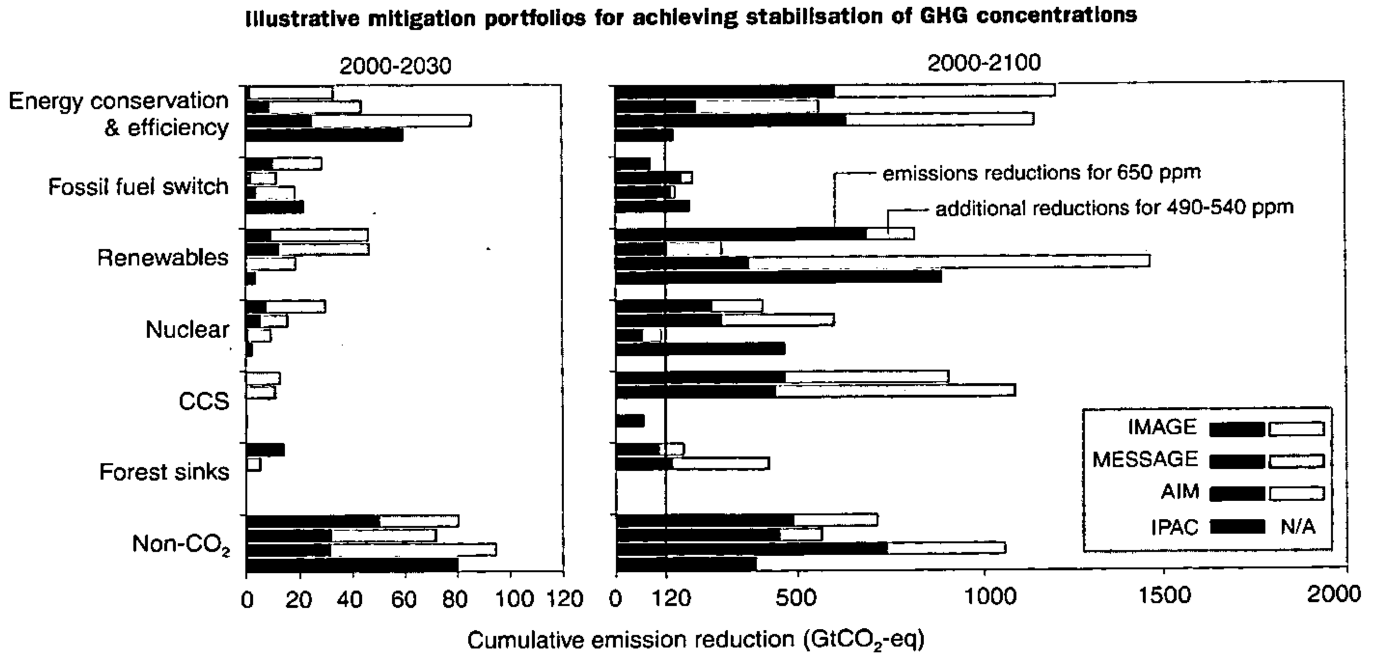
Illustrative mitigation portfolios for achieving stabilisation of GHG concentrations

Figure 5.2 Cumulative emissions reductions for alternative mitigation measures for 2000-2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490 to 540ppm CO_2-eq) and intermediate levels (650ppm CO_2-eq) respectively. Dark bars denote reductions for a target of 650ppm CO_2-eq and light bars denote the additional reductions to achieve 490 to 540ppm CO_2-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes CO_2 capture and storage from biomass. Forest sinks include reducing emissions from deforestation. The figure shows emissions reductions from baseline scenarios with cumulative emissions between 6000 to 7000 $GtCO_2$-eq (2000-2100). {WGIII Figure SPM.9}

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[32] By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level. {WGIII 2.7, 3.4, 4.5, 11.5, 13.2}

5.6 Costs of mitigation and long-term stabilisation targets

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target and are relatively higher when derived from baseline scenarios characterised by high emission levels. *{WGIII SPM}*

There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445ppm CO_2-eq are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.[33] *{WGIII 3.3, 13.3, SPM}*

5.7 Costs, benefits and avoided climate impacts at global and regional levels

Impacts of climate change will vary regionally. Aggregated and discounted to the present, they are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. *{WGII SPM}*

For increases in global average temperature of less than 1 to 3°C above 1980-1999 levels, some impacts are projected to produce market benefits in some places and sectors while, at the same time, imposing costs in other places and sectors. Global mean losses could be 1 to 5% of GDP for 4°C of warming, but regional losses could be substantially higher. *{WGII 9.ES, 10.6, 15.ES, 20.6, SPM}*

Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change aggregated across the globe and discounted to the present) for 2005 have an average value of US$12 per tonne of CO_2, but the range from 100 estimates is large (-$3 to $95/t$CO_2$). The range of published evidence indicates that the net damage costs of climate change are projected to be significant and to increase over time. *{WGII 20.6, SPM}*

It is *very likely* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is *virtually certain* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average. *{WGII 7.4, 20.ES, 20.6, 20.ES, SPM}*

Limited and early analytical results from integrated analyses of the global costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. *{WGIII SPM}*

Comparing the costs of mitigation with avoided damages would require the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. *{WGII 18.ES}*

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. *{WGIII SPM}*

Many impacts can be avoided, reduced or delayed by mitigation. *{WGII SPM}*

Although the small number of impact assessments that evaluate stabilisation scenarios do not take full account of uncertainties in projected climate under stabilisation, they nevertheless provide indications of damages avoided and risks reduced for different

Table 5.2. Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {WGIII 3.3, 13.3, Tables SPM.4 and SPM.6}

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points)[c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		<3	<5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:

Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.

a) Global GDP based on market exchange rates.

b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO_2-eq) gives the upper bound estimate of the literature only.

c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.

d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

e) The values correspond to the highest estimate for GDP reduction shown in column three.

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[33] See Footnote 24 for further details on cost estimates and model assumptions.

amounts of emissions reduction. The rate and magnitude of future human-induced climate change and its associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.2 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change throughout the 21st century. Some of the impacts at the high temperature end of Figure 3.6 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Figure 3.6. *{SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}*

Figure 3.6 illustrates how reduced warming could reduce the risk of, for example, affecting a significant number of ecosystems, the risk of extinctions, and the likelihood that cereal productivity in some regions would tend to fall. *{SYR 3.3, Figure 3.6; WGII 4.4, 5.4, Table 20.6}*

5.8 Broader environmental and sustainability issues

Sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways. ***{WGII SPM}***

It is *very likely* that climate change can slow the pace of progress toward sustainable development either directly through increased exposure to adverse impacts or indirectly through erosion of the capacity to adapt. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. *{WGII SPM}*

Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Their combined impacts may be compounded in future in the absence of integrated mitigation and adaptation measures. *{WGII 20.3, 20.7, 20.8, SPM}*

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. ***{WGII 20.8; WGIII 12.2, SPM}***

Both adaptive and mitigative capacities can be enhanced through sustainable development. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through mitigation). At present, however, few plans for promoting sustainability have explicitly included either adapting to climate change impacts, or promoting adaptive capacity. Similarly, changing development paths can make a major contribution to mitigation but may require resources to overcome multiple barriers. *{WGII 20.3, 20.5, SPM; WGIII 2.1, 2.5, 12.1, SPM}*

6

Robust findings, key uncertainties

Robust findings, key uncertainties

As in the TAR, a robust finding for climate change is defined as one that holds under a variety of approaches, methods, models and assumptions, and is expected to be relatively unaffected by uncertainties. Key uncertainties are those that, if reduced, could lead to new robust findings. *{TAR SYR Q.9}*

Robust findings do not encompass all key findings of the AR4. Some key findings may be policy-relevant even though they are associated with large uncertainties. *{WGII 20.9}*

The robust findings and key uncertainties listed below do not represent an exhaustive list.

6.1 Observed changes in climate and their effects, and their causes

Robust findings

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. *{WGI 3.9, SPM}*

Many natural systems, on all continents and in some oceans, are being affected by regional climate changes. Observed changes in many physical and biological systems are consistent with warming. As a result of the uptake of anthropogenic CO_2 since 1750, the acidity of the surface ocean has increased. *{WGI 5.4, WGII 1.3}*

Global total annual anthropogenic GHG emissions, weighted by their 100-year GWPs, have grown by 70% between 1970 and 2004. As a result of anthropogenic emissions, atmospheric concentrations of N_2O now far exceed pre-industrial values spanning many thousands of years, and those of CH_4 and CO_2 now far exceed the natural range over the last 650,000 years. *{WGI SPM; WGIII 1.3}*

Most of the global average warming over the past 50 years is *very likely* due to anthropogenic GHG increases and it is *likely* that there is a discernible human-induced warming averaged over each continent (except Antarctica). *{WGI 9.4, SPM}*

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. *{WGII 1.4, SPM}*

Key uncertainties

Climate data coverage remains limited in some regions and there is a notable lack of geographic balance in data and literature on observed changes in natural and managed systems, with marked scarcity in developing countries. *{WGI SPM; WGII 1.3, SPM}*

Analysing and monitoring changes in extreme events, including drought, tropical cyclones, extreme temperatures and the frequency and intensity of precipitation, is more difficult than for climatic averages as longer data time-series of higher spatial and temporal resolutions are required. *{WGI 3.8, SPM}*

Effects of climate changes on human and some natural systems are difficult to detect due to adaptation and non-climatic drivers. *{WGII 1.3}*

Difficulties remain in reliably simulating and attributing observed temperature changes to natural or human causes at smaller than continental scales. At these smaller scales, factors such as land-use change and pollution also complicate the detection of anthropogenic warming influence on physical and biological systems. *{WGI 8.3, 9.4, SPM; WGII 1.4, SPM}*

The magnitude of CO_2 emissions from land-use change and CH_4 emissions from individual sources remain as key uncertainties. *{WGI 2.3, 7.3, 7.4; WGIII 1.3, TS.14}*

6.2 Drivers and projections of future climate changes and their impacts

Robust findings

With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. *{WGIII 3.2, SPM}*

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. *{WGI 10.3, 10.7, SPM}*

Continued GHG 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. *{WGI 10.3, 11.1, SPM}*

The pattern of future warming where land warms more than the adjacent oceans and more in northern high latitudes is seen in all scenarios. *{WGI 10.3, 11.1, SPM}*

Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions that remains in the atmosphere. *{WGI 7.3, 10.4, 10.5, SPM}*

Anthropogenic warming and sea level rise would continue for centuries even if GHG emissions were to be reduced sufficiently for GHG concentrations to stabilise, due to the time scales associated with climate processes and feedbacks. *{WGI 10.7, SPM}*

Equilibrium climate sensitivity is *very unlikely* to be less than 1.5°C. *{WGI 8.6, 9.6, Box 10.2, SPM}*

Some systems, sectors and regions are *likely* to be especially affected by climate change. The systems and sectors are some ecosystems (tundra, boreal forest, mountain, mediterranean-type, mangroves, salt marshes, coral reefs and the sea-ice biome), low-lying coasts, water resources in some dry regions at mid-latitudes and in the dry topics and in areas dependent on snow and ice melt, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. The regions are the Arctic, Africa, small islands and Asian and African megadeltas. Within other regions, even those with high incomes, some people, areas and activities can be particularly at risk. *{WGII TS.4.5}*

Impacts are *very likely* to increase due to increased frequencies and intensities of some extreme weather events. Recent events have demonstrated the vulnerability of some sectors and regions, including in developed countries, to heat waves, tropical cyclones, floods and drought, providing stronger reasons for concern as compared to the findings of the TAR. *{WGII Table SPM.2, 19.3}*

Key uncertainties

Uncertainty in the equilibrium climate sensitivity creates uncertainty in the expected warming for a given CO_2-eq stabilisation scenario. Uncertainty in the carbon cycle feedback creates uncertainty in the emissions trajectory required to achieve a particular stabilisation level. *{WGI 7.3, 10.4, 10.5, SPM}*

Models differ considerably in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks, although progress has been made in these areas. Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer time averaging periods. *{WGI 7.3, 8.1-8.7, 9.6, 10.2, 10.7, SPM; WGII 4.4}*

Aerosol impacts on the magnitude of the temperature response, on clouds and on precipitation remain uncertain. *{WGI 2.9, 7.5, 9.2, 9.4, 9.5}*

Future changes in the Greenland and Antarctic ice sheet mass, particularly due to changes in ice flow, are a major source of uncertainty that could increase sea level rise projections. The uncertainty in the penetration of the heat into the oceans also contributes to the future sea level rise uncertainty. *{WGI 4.6, 6.4, 10.3, 10.7, SPM}*

Large-scale ocean circulation changes beyond the 21st century cannot be reliably assessed because of uncertainties in the meltwater supply from the Greenland ice sheet and model response to the warming. *{WGI 6.4, 8.7, 10.3 }*

Projections of climate change and its impacts beyond about 2050 are strongly scenario- and model-dependent, and improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks. *{WGII TS.6}*

Impacts research is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. *{WGII TS.6}*

Understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited. *{WGII 19.4, 20.2, 20.4, 20.9, TS.6}*

6.3 Responses to climate change

Robust findings

Some planned adaptation (of human activities) is occurring now; more extensive adaptation is required to reduce vulnerability to climate change. *{WGII 17.ES, 20.5, Table 20.6, SPM}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. *{WGII 20.7, SPM}*

A wide range of mitigation options is currently available or projected to be available by 2030 in all sectors. The economic mitigation potential, at costs that range from net negative up to US$100/$tCO_2$-equivalent, is sufficient to offset the projected growth of global emissions or to reduce emissions to below current levels in 2030. *{WGIII 11.3, SPM}*

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 stabilisation levels. Delayed emissions reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. *{WGII SPM, WGIII SPM}*

The range of stabilisation levels for GHG concentrations that have been assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades, provided that appropriate and effective incentives are in place and barriers are removed. In addition, further RD&D would be required to improve the technical performance, reduce the costs and achieve social acceptability of new technologies. The lower the stabilisation levels, the greater the need for investment in new technologies during the next few decades. *{WGIII 3.3, 3.4}*

Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation and to reducing vulnerability. *{WGII 18.7, 20.3, SPM; WGIII 13.2, SPM}*

Decisions about macro-economic and other policies that seem unrelated to climate change can significantly affect emissions. *{WGIII 12.2}*

Key uncertainties

Understanding of how development planners incorporate information about climate variability and change into their decisions is limited. This limits the integrated assessment of vulnerability. *{WGII 18.8, 20.9}*

The evolution and utilisation of adaptive and mitigative capacity depend on underlying socio-economic development pathways. *{WGII 17.3, 17.4, 18.6, 19.4, 20.9}*

Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints. *{WGII SPM}*

Estimates of mitigation costs and potentials depend on assumptions about future socio-economic growth, technological change and consumption patterns. Uncertainty arises in particular from assumptions regarding the drivers of technology diffusion and the potential of long-term technology performance and cost improvements. Also little is known about the effects of changes in behaviour and lifestyles. *{WGIII 3.3, 3.4, 11.3}*

The effects of non-climate policies on emissions are poorly quantified. *{WGIII 12.2}*

Attachment 3
Docket 07A-447E
Glustrom Answer Testimony

4

Ecosystems, their properties, goods and services

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Executive summary

During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification) and in other global change drivers (especially land-use change, pollution and over-exploitation of resources), if greenhouse gas emissions and other changes continue at or above current rates (high confidence).

By 2100, ecosystems will be exposed to atmospheric CO_2 levels substantially higher than in the past 650,000 years, and global temperatures at least among the highest of those experienced in the past 740,000 years (very high confidence) [4.2, 4.4.10, 4.4.11; Jansen et al., 2007]. This will alter the structure, reduce biodiversity and perturb functioning of most ecosystems, and compromise the services they currently provide (high confidence) [4.2, 4.4.1, 4.4.2-4.4.9, 4.4.10, 4.4.11, Figure 4.4, Table 4.1]. Present and future land-use change and associated landscape fragmentation are very likely to impede species' migration and thus impair natural adaptation via geographical range shifts (very high confidence) [4.1.2, 4.2.2, 4.4.5, 4.4.10].

Several major carbon stocks in terrestrial ecosystems are vulnerable to current climate change and/or land-use impacts and are at a high degree of risk from projected unmitigated climate and land-use changes (high confidence).

Several terrestrial ecosystems individually sequester as much carbon as is currently in the atmosphere (very high confidence) [4.4.1, 4.4.6, 4.4.8, 4.4.10, 4.4.11]. The terrestrial biosphere is likely to become a net source of carbon during the course of this century (medium confidence), possibly earlier than projected by the IPCC Third Assessment Report (TAR) (low confidence) [4.1, Figure 4.2]. Methane emissions from tundra frozen loess ('yedoma', comprising about 500 Pg C) and permafrost (comprising about 400 Pg C) have accelerated in the past two decades, and are likely to accelerate further (high confidence) [4.4.6]. At current anthropogenic emission rates, the ongoing positive trends in the terrestrial carbon sink will peak before mid-century, then begin diminishing, even without accounting for tropical deforestation trends and biosphere feedback, tending strongly towards a net carbon source before 2100, assuming continued greenhouse gas emissions and land-use change trends at or above current rates (high confidence) [Figure 4.2, 4.4.1, 4.4.10, Figure 4.3, 4.4.11], while the buffering capacity of the oceans will begin to saturate [Denman et al., 2007, e.g., Section 7.3.5.4]. While some impacts may include primary productivity gains with low levels of climate change (less than around 2°C mean global change above pre-industrial levels), synergistic interactions are likely to be detrimental, e.g., increased risk of irreversible extinctions (very high confidence) [4.4.1, Figure 4.2, 4.4.10, Figure 4.3, 4.4.11].

Approximately 20 to 30% of plant and animal species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels (medium confidence) [4.4.10, 4.4.11, Figure 4.4, Table 4.1].

Projected impacts on biodiversity are significant and of key relevance, since global losses in biodiversity are irreversible (very high confidence) [4.4.10, 4.4.11, Figure 4.4, Table 4.1]. Endemic species richness is highest where regional palaeoclimatic changes have been muted, providing circumstantial evidence of their vulnerability to projected climate change (medium confidence) [4.2.1]. With global average temperature changes of 2°C above pre-industrial levels, many terrestrial, freshwater and marine species (particularly endemics across the globe) are at a far greater risk of extinction than in the recent geological past (medium confidence) [4.4.5, 4.4.11, Figure 4.4, Table 4.1]. Globally about 20% to 30% of species (global uncertainty range from 10% to 40%, but varying among regional biota from as low as 1% to as high as 80%) will be at increasingly high risk of extinction, possibly by 2100, as global mean temperatures exceed 2 to 3°C above pre-industrial levels [4.2, 4.4.10, 4.4.11, Figure 4.4, Table 4.1]. Current conservation practices are generally poorly prepared to adapt to this level of change, and effective adaptation responses are likely to be costly to implement (high confidence) [4.4.11, Table 4.1, 4.6.1].

Substantial changes in structure and functioning of terrestrial ecosystems are very likely to occur with a global warming of more than 2 to 3°C above pre-industrial levels (high confidence).

Between about 25% (IPCC SRES B1 emissions scenario; 3.2°C warming) and about 40% (SRES A2 scenario; 4.4°C warming) of extant ecosystems will reveal appreciable changes by 2100, with some positive impacts especially in Africa and the Southern Hemisphere arid regions, but extensive forest and woodland decline in mid- to high latitudes and in the tropics, associated particularly with changing disturbance regimes (especially through wildfire and insects) [4.4.2, 4.4.3, 4.4.5, 4.4.10, 4.4.11, Figure 4.3].

Substantial changes in structure and functioning of marine and other aquatic ecosystems are very likely to occur with a mean global warming of more than 2 to 3°C above pre-industrial levels and the associated increased atmospheric CO_2 levels (high confidence).

Climate change (very high confidence) and ocean acidification (medium confidence) will impair a wide range of planktonic and shallow benthic marine organisms that use aragonite to make their shells or skeletons, such as corals and marine snails (pteropods), with significant impacts particularly in the Southern Ocean, where cold-water corals are likely to show large reductions in geographical range this century [4.4.9, Box 4.4]. Substantial loss of sea ice will reduce habitat for dependant species (e.g., polar bears) (very high confidence) [4.4.9, 4.4.6, Box 4.3, 4.4.10, Figure 4.4, Table 4.1, 15.4.3, 15.4.5]. Terrestrial tropical and sub-tropical aquatic systems are at significant risk under at least SRES A2 scenarios; negative impacts across about 25% of Africa by 2100 (especially southern and western Africa) will cause a decline in both water quality and ecosystem goods and services (high confidence) [4.4.8].

Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change, depending on imminence of exposure to ecosystem-specific, critical thresholds (very high confidence).
Most vulnerable ecosystems include coral reefs, the sea-ice biome and other high-latitude ecosystems (e.g., boreal forests), mountain ecosystems and mediterranean-climate ecosystems (high confidence) [Figure 4.4, Table 4.1, 4.4.9, Box 4.4, 4.4.5, 4.4.6, Box 4.3, 4.4.7, 4.4.4, 4.4.10, 4.4.11]. Least vulnerable ecosystems include savannas and species-poor deserts, but this assessment is especially subject to uncertainty relating to the CO_2-fertilisation effect and disturbance regimes such as fire (low confidence) [Box 4.1, 4.4.1, 4.4.2, Box 4.2, 4.4.3, 4.4.10, 4.4.11].

4.1 Introduction

An ecosystem can be practically defined as a dynamic complex of plant, animal and micro-organism communities, and the non-living environment, interacting as a functional unit (Millennium Ecosystem Assessment, Reid et al., 2005). Ecosystems may be usefully identified through having strong interactions between components within their boundaries and weak interactions across boundaries (Reid et al., 2005, part 2). Ecosystems are well recognised as critical in supporting human well-being (Reid et al., 2005), and the importance of their preservation under anthropogenic climate change is explicitly highlighted in Article 2 (The Objective) of the United Nations Framework Convention on Climate Change (UNFCCC).

In this chapter the focus is on the properties, goods and services of non-intensively managed and unmanaged ecosystems and their components (as grouped by widely accepted functional and structural classifications, Figure 4.1), and their potential vulnerability to climate change as based on scenarios mainly from IPCC (see Chapter 2 and IPCC, 2007). Certain ecosystem goods and services are treated in detail in other sectoral chapters (this volume): chapters 3 (water), 5 (food, fibre, fisheries), 6 (coasts) and 8 (health). Key findings from this chapter are further developed in the synthesis chapters 17 to 20 (this volume). Region-specific aspects of ecosystems are discussed in chapters 9 to 16 (this volume). This chapter is based on work published since the Third Assessment Report of the IPCC (TAR) (Gitay et al., 2001). We do not summarise TAR findings here, but refer back to relevant TAR results, where appropriate, to indicate confirmation or revision of major findings.

Projecting the impacts of climate change on ecosystems is complicated by an uneven understanding of the interlinked temporal and spatial scales of ecosystem responses. Processes at large spatial scales, i.e., the biosphere at the global scale, are generally characterised by slow response times on the order of centuries, and even up to millennia (Jansen et al., 2007). However, it is also important to note that some large-scale responses in the palaeorecord (Jansen et al., 2007) and to current climate anomalies such as El Niño events may emerge at much shorter time-scales (Holmgren et al., 2001; Sarmiento and Gruber, 2002; Stenseth et al., 2002; van der Werf et al., 2004). At continental scales, biomes (see Glossary) respond at decadal to millennial time-scales (e.g., Davis, 1989; Prentice et al., 1991; Lischke et al., 2002; Neilson et al., 2005), and groups of organisms forming ecological communities at the regional scale have shorter response times of years to centuries. Responses of populations (i.e., interbreeding individuals of the same species) occur at intermediate temporal scales of months to centuries, and underpin changes in biodiversity. These include changes at the genetic level that may be adaptive, as demonstrated for example for trees (Jump et al., 2006) and corals (Coles and Brown, 2003). Fast physiological response times (i.e., seconds, hours, days, months) of micro-organisms, plants and animals operate at small scales from a leaf or organ to the cellular level; they underlie organism responses to environmental conditions, and are assessed here if they scale up to have a significant impact at broader spatial scales, or where the mechanistic understanding assists in assessing key thresholds in higher level responses.

The spatial distribution of ecosystems at biome scale has traditionally been explained only in terms of climate control (Schimper, 1903), but it is increasingly apparent that disturbance regimes such as fire or insects may strongly influence vegetation structure somewhat independently of climate (e.g., Andrew and

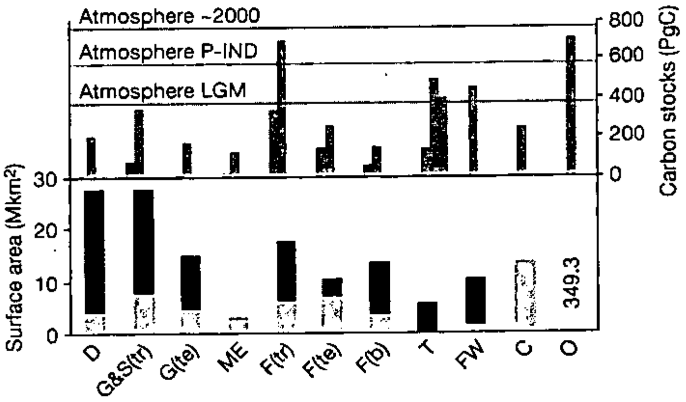

Figure 4.1. *Major ecosystems addressed in this report, with their global areal extent (lower panel, Mkm²), transformed by land use in yellow, untransformed in purple, from Hassan et al. (2005), except for mediterranean-climate ecosystems, where transformation impact is from Myers et al. (2000), and total carbon stores (upper panel, PgC) in plant biomass (green), soil (brown), yedoma/permafrost (light blue). D = deserts, G&S(tr) = tropical grasslands and savannas, G(te) = temperate grasslands, ME = mediterranean ecosystems, F(tr) = tropical forests, F(te) = temperate forests, F(b) = boreal forests, T = tundra, FW = freshwater lakes and wetlands, C = croplands, O = oceans. Data are from Sabine et al. (2004, Table 2.2, p. 23), except for carbon content of yedoma permafrost and permafrost (light blue columns, left and right, respectively, Zimov et al., 2006), ocean organic carbon content (dissolved plus particulate organic; Denman et al., 2007, Section 7.3.4.1), and ocean surface area from Hassan et al. (2005, Summary, Table C2, p. 15, inserted as a number). Figures here update the TAR (Prentice et al., 2001), especially through considering soil C to 3 m depth (Jobbagy and Jackson, 2000), as opposed to 1 m. Approximate carbon content of the atmosphere (PgC) is indicated by the dotted lines for last glacial maximum (LGM), pre-industrial (P-IND) and current (about 2000).*

often more prone to local extirpations than larger, more widespread populations (e.g., Gitay et al., 2002; Davis et al., 2005; Lovejoy and Hannah, 2005). Although connectivity, genetic diversity and population size are important current conservation goals, climate change increases their importance. The reduction and fragmentation of habitats may also be facilitated through increases in agricultural productivity (e.g., Goklany and Trewavas, 2003) reducing pressures on natural ecosystems. However, increasing demand for some types of biofuels may negate this potential benefit (e.g., Busch, 2006).

Reducing stress on ecosystems is difficult, especially in densely populated regions. Recent studies in southern Africa have signalled the need for policy to focus on managing areas outside protected areas (e.g., subsistence rangelands – Von Maltitz et al., 2006). This can, in part, be achieved through the devolution of resource ownership and management to communities, securing community tenure rights and incentives for resource utilisation. This argument is based on the observation that greater species diversity occurs outside protected areas that are more extensive (Scholes et al., 2004). Species migration between protected areas in response to shifting climatic conditions is likely to be impeded, unless assisted by often costly interventions geared towards landscapes with greater ecological connectivity. Strategic national policies could co-ordinate with communal or private land-use systems, especially when many small reserves are involved and would be particularly cost-effective if they address climate change proactively. Finally, migration strategies are very likely to become substantially more effective when they are implemented over larger regions and across national borders (e.g., Hansen et al., 2003).

Controlled burning and other techniques may be useful to reduce fuel load and the potential for catastrophic wildfires. It may also be possible to minimise the effect of severe weather events by, for example, securing water rights to maintain water levels through a drought, or by having infrastructure capable of surviving floods. Maintaining viable and widely dispersed populations of individual species also minimises the probability that localised catastrophic events will cause significant negative effects (e.g., hurricane, typhoon, flood).

Climate change is likely to increase opportunities for invasive alien species because of their adaptability to disturbance (Stachowicz et al., 2002; Lake and Leishman, 2004). Captive breeding for reintroduction and translocation or the use of provenance trials in forestry are expensive and likely to be less successful if climate change is more rapid. Such change could result in large-scale modifications of environmental conditions, including the loss or significant alteration of existing habitat over some or all of a species' range. Captive breeding and translocation should therefore not be perceived as panaceas for the loss of biological diversity that might accompany large changes in the climate. Populations of many species are already perilously small, and further loss of habitat and stress associated with severe climate change may push many taxa to extinction.

A costly adaptation option would be the restoration of habitats currently under serious threat, or creation of new habitats in areas where natural colonisation is unlikely to occur (Anonymous, 2000). In many cases the knowledge of ecosystem interactions and species requirements may be lacking. Engineering habitats to facilitate species movements may call for an entirely new field of study. Engineering interactions to defend coastlines, for example, that change the connectivity of coastal ecosystems, facilitate the spread of non-native species (Bulleri, 2005) as well as warm-temperate species advancing polewards (Helmuth et al., 2006; Mieszkowska et al., 2006).

Ultimately, managers may need to enhance or replace diminished or lost ecosystem services. This could mean manual seed dispersal or reintroducing pollinators. In the case of pest outbreaks, the use of pesticides may be necessary. Enhancing or replacing other services, such as contributions to nutrient cycling, ecosystem stability and ecosystem biodiversity may be much more difficult. The loss or reduced capacity of ecosystem services is likely to be a major source of 'surprises' from climate change.

4.6.2 Assessing the effectiveness and costs of adaptation options

There are few factual studies that have established the effectiveness and costs of adaptation options in ecosystems. Unfortunately, this makes a comprehensive assessment of the avoided damages (i.e., benefits) and costs impossible (see also Section 4.5). But the costs involved in monitoring, increasing the resilience of conservation networks and adaptive management are certainly large. For example, the money spent annually on nature conservation in the Netherlands was recently estimated to be €1 billion (Milieu en Natuurplanbureau, 2005). Of this amount, €285 million was used to manage national parks and reserves and €280 million was used for new reserve network areas and habitat improvement; the main objective being to reduce fragmentation between threatened populations and to respond to other threats. The reserve network planned for the Netherlands (to be established by 2020) will increase the resilience of species, populations and ecosystems to climate change, but at a high cost. Although not defined explicitly in this way, a significant proportion of these costs can be interpreted as climate adaptation costs.

4.6.3 Implications for biodiversity

Many studies and assessments stress the adverse impacts of climate change on biodiversity (e.g., Gitay et al., 2002; Hannah and Lovejoy, 2003; Thomas et al., 2004a; Lovejoy and Hannah, 2005; Schröter et al., 2005; Thuiller et al., 2005b; van Vliet and Leemans, 2006), but comprehensive appraisals of adaptation options to deal with declining biodiversity are rare.

The UN Convention on Biological Diversity (CBD, http://www.biodiv.org) aims to conserve biodiversity, to sustainably use biodiversity and its components and to fairly and equitably share benefits arising from the utilisation of biodiversity. This goes much further than most national biodiversity policies. The CBD explicitly recognises the use of biodiversity, ecosystems and their services and frames this as a developmental issue. As such, it extends beyond UNFCCC's objective of "avoiding dangerous human interference with the climate system at levels where ecosystems cannot adapt naturally". The main tool proposed by the CBD is the ecosystem approach (Smith and Malthby, 2003) based on integrated response options that intentionally and actively address ecosystem services (including biodiversity) and human well-being simultaneously, and involve all stakeholders at different institutional levels. The ecosystem approach resembles sustainable forest management projects (FAO, 2001). In theory, the ecosystem approach helps the conservation and sustainable use of biodiversity, but applications of the approach have had limited success (Brown et al., 2005a). Integrated responses include, however, learning by doing; a proactive approach that should increase the resilience of ecosystems and biodiversity.

4.6.4 Interactions with other policies and policy implications

Formulating integrated policies that cut across multiple UN conventions, such as the UNFCCC, CBD and Convention to Combat Desertification (CCD), could produce win-win situations in addressing climate change, increasing resilience and dealing with other policy issues (Nnadozie, 1998). Strategies aimed at combating desertification, for example, contribute towards increased soil carbon and moisture levels. Mitigation strategies focused on afforestation, including projects under the Clean Development Mechanism (CDM, see Glossary), could help ecosystem adaptation through improved ecological connectivity. The ecosystem approach can fulfil objectives specified by different conventions (Reid et al., 2005) and, in assessing adaptation strategies, such synergies could be identified and promoted.

4.7 Implications for sustainable development

Over the past 50 years, humans have converted and modified natural ecosystems more rapidly and over larger areas than in any comparable period of human history (e.g., Steffen et al., 2004). These changes have been driven by the rapidly growing demands for food, fish, freshwater, timber, fibre and fuel (e.g., Vitousek et al., 1997) and have contributed to substantial net gains in human well-being and economic development, while resulting in a substantial and largely irreversible loss of biodiversity and degradation in ecosystems and their services (Reid et al., 2005).

The consequences of policies to address the vulnerability of ecosystems to climate change at both the national and international level are not yet fully understood. There is growing evidence that significant impacts on the environment may result from perverse or unintended effects of policies from other sectors, which directly or indirectly have adverse consequences on ecosystems and other environmental processes (Chopra et al., 2005). Land re-distribution policies, for example, while designed to increase food self-sufficiency also contribute to reducing carbon sequestration and loss of biodiversity through extensive clear-cutting.

Effective mechanisms to analyse cross-sectoral impacts and to feed new scientific knowledge into policy-making are necessary (Schneider, 2004). There is substantial evidence to suggest that developing and implementing policies and strategies to reduce the vulnerability of ecosystems to climate change is closely linked to the availability of capacity to address current needs (e.g., Chanda, 2001). Thus, prospects for successful adaptation to climate change will remain limited as long as factors (e.g., population growth, poverty and globalisation) that contribute to chronic vulnerability to, for example, drought and floods, are not resolved (Kates, 2000; Reid et al., 2005).

4.7.1 Ecosystems services and sustainable development

Large differences in natural and socio-economic conditions among regions mitigate against simple solutions to the problem of ecosystem degradation and loss of services. Many interactions, lags and feedbacks, including those that operate across a range of spatial, temporal and organisational scales generate complex patterns which are not fully understood. Past actions to slow or reverse the degradation of ecosystems have yielded significant results, but these improvements have generally not kept pace with growing pressures (Reid et al., 2005). However, sound management of ecosystem services provides several cost-effective opportunities for addressing multiple development goals in a synergistic manner (Reid et al., 2005).

Progress achieved in addressing the Millennium Development Goals (MDGs) is unlikely to be sustained if ecosystem services continue to be degraded (Goklany, 2005). The role of ecosystems in sustainable development and in achieving the MDGs involves an array of stakeholders (Jain, 2003; Adeel et al., 2005). Evidence from different parts of the world shows that in most cases it is far from clear who is 'in charge' of the long-term sustainability of an ecosystem, let alone of the situation under future climates. Responding and adapting to the impacts of climate change on ecosystems calls for a clear and structured system of decision making at all levels (Kennett, 2002). Impacts of climate change on ecosystems also show strong interrelationships with ecosystem processes and human activities at various scales over time. Addressing these impacts requires a co-ordinated, integrated, cross-sectoral policy framework with a long-term focus; a strategy that so far has not been easy to implement (Brown, 2003).

4.7.2 Subsistence livelihoods and indigenous peoples

The impacts of climate change on ecosystems and their services will not be distributed equally around the world. Dryland, mountain and mediterranean regions are likely to be more vulnerable than others (Gitay et al., 2001) and ecosystem degradation is largest in these regions (Hassan et al., 2005). Climate change is likely to cause additional inequities, as its impacts are unevenly distributed over space and time and disproportionately affect the poor (Tol, 2001; Stern, 2007). The term 'double exposure' has been used for regions, sectors, ecosystems and social groups that are confronted both by the impacts of climate change and by the consequences of economic globalisation (O'Brien and Leichenko, 2000). Thus special attention needs to be given to indigenous peoples with subsistence livelihoods and groups with limited access to information and few means of

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Table 1. Data for the determination of the turquoise bead source area; ppm, parts per million.

Element	Snaketown			Himalaya		Crescent
	Group A	Group B	Unclassified	Group A	Group B	
	Trace element data (ppm)					
Co	1.67	1.78	1.95	1.30	1.78	1003.0
Cr	1.66	1.44	1.20	1.54	2.30	67.3
Eu	0.26	0.32	0.28	0.27	0.63	*
Sb	2.10	2.90	1.43	1.76	2.10	4.66
Sc	35.1	101.5	15.1	36.2	106.4	65.3
Ta	*	*	*	*	*	326.0
	Similarity coefficients					
Snaketown						
Group A	1.000					
Group B	.825	1.000				
Unclassified	.544	.337	1.000			
Himalaya						
Group A	.946	.808	.613	1.000		
Group B	.861	.991	.565	.840	1.000	
Crescent	.143	.177	.092	.208	.101	1.000

*Not detected.

limits for the Himalaya-Snaketown turquoise, but were present in many of the other samples. These basic differences served to distinguish the California source area from other localities by simple examination of the data.

The Snaketown beads fell into two groups of five and seven samples each, based on Sc contents of 35 ppm (group A) and 100 ppm (group B), with 1 sample unclassified. The data for samples from the Himalaya mine also fell into the same two groups, emphasizing the need for multiple samples from each geographic source area.

In order to characterize the mine areas statistically, it was necessary to compare the concentrations of all trace elements simultaneously. The multivariate statistic devised by Borchardt *et al.* (*8*), in which the ratio of each element concentration in a pair of samples is summed and divided by the number of elements, was found to be the most useful for these data (*9*). The coefficients thus obtained are representative of the degree of similarity, or dissimilarity, between two or more samples. That is, the coefficients are a means of quantifying the degree of correlation based on sample analytical data. Perfect similarity results in a value of 1.0, and large differences result in coefficients near zero. Borchardt *et al.* determined by replicate analyses that coefficients above .800 were indicative of an accurate correlation at the 95 percent confidence level. Conversely, values below .560 indicated that a pair of samples probably were not from the same site.

Table 1 shows the correlation coefficient matrix for the two Snaketown groups, the unclassified bead, the two Himalaya mine groups, and for the Crescent mine in Nevada. On the basis of Borchardt's criterion, there is good correlation between samples from Snaketown A and Himalaya A, and between Snaketown B and Himalaya B. The Crescent sample is clearly unrelated.

The similarity coefficients, then, substantiated the conclusion that trace element patterns for the Snaketown beads correlated with that of turquoise from the Himilaya group of mines near Halloron Springs, but not with the data from the 23 other mines analyzed. The 13 turquoise beads, however, represent only a portion of the turquoise from the site. Since turquoise was widely traded in the Southwest, it is possible that other sources may by represented in other artifacts from Snaketown.

Cultures and cultural ties are constantly changing, and it is expected that trade pat- [illegible] of detecting, or monitoring, these changes. Further identification of source areas utilized by particular cultural groups should provide additional information on the nature of prehistoric resource acquisition and exchange routes.

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References and Notes

1. The chemical formula for turquoise is CuAl$_6$(PO$_4$)$_4$(OH)$_8$ · 4H$_2$O.
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3. These are Mineral Park, Canyon Creek, and Courtland, Arizona; Miami, Morenci, and Bisbee have no reported prehistoric workings.
4. E. W. Haury, *Kiva* **31**, 1 (1965).
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6. R. A. Schmitt, T. A. Linn, Jr., W. Wakita, *Radiochim. Acta* **13**, 200 (1970); G. E. Gordon, K. Randle, G. G. Goles, J. B. Corliss, M. H. Beeson, S. S. Oxley, *Geochim. Cosmochim. Acta* **32**, 369 (1968).
7. F. J. Flanagan, *Geochim. Cosmochim. Acta* **37**, 1189 (1973).
8. G. A. Borchardt, P. J. Aruscavage, H. T. Millard, Jr., *J. Sediment. Petrol.* **42**, 301 (1972).
9. The similarity coefficient

$$d_{ab} = \sum_{1}^{n} R_i/n$$

where $R_i = X_{ia}/X_{ib}$ if $X_{ib} \geq X_{ia}$; or X_{ib}/X_{ia} if $X_{ia} > X_{ib}$; X_{ia} = the content of element i in sample a; X_{ib} = content of element i in sample b; and n = the number of elements.

10. I thank G. W. Nelson and M. E. Wacks for help with the analytical aspects of this research; the Arizona State Museum, Tucson, for the artifacts; Geodata Systems, Inc., for permission to collect turquoise samples on their property; and G. A. Borchardt for the use of his similarity coefficient program.

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Climatic Change: Are We on the Brink of a Pronounced Global Warming?

Abstract. *If man-made dust is unimportant as a major cause of climatic change, then a strong case can be made that the present cooling trend will, within a decade or so, give way to a pronounced warming induced by carbon dioxide. By analogy with similar events in the past, the natural climatic cooling which, since 1940, has more than compensated for the carbon dioxide effect, will soon bottom out. Once this happens, the exponential rise in the atmospheric carbon dioxide content will tend to become a significant factor and by early in the next century will have driven the mean planetary temperature beyond the limits experienced during the last 1000 years.*

The fact that the mean global temperature has been falling over the past several decades has led observers to discount the warming effect of the CO$_2$ produced by the burning of chemical fuels. In this report I present an argument to show that this complacency may not be warranted. It is possible that we are on the brink of a several-decades-long period of rapid warming. Briefly, the argument runs as follows. The ^{18}O record in the Greenland ice core (*1*) strongly suggests that the present cooling is one of a long series of similar natural climatic fluctuations. This cooling has, over the last three decades, more than compensated for the warming effect produced by the CO$_2$ released into the atmosphere as a by-product of chemical fuel combustion. By analogy with similar events in the past, the present natural cooling will, however, bottom out during the next decade or so. Once this happens, the CO_2 effect will tend to become a significant factor and by the first decade of the next century we may experience global temperatures warmer than any in the last 1000 years. The remainder of this report will be devoted to the elaboration of the assumptions used in constructing the curves shown in Fig. 1 which displays this projection.

Of the climatic effects induced by man, only that for CO_2 can be conclusively demonstrated to be globally significant. It is difficult to determine the significance of the next most important climatic effect induced by man, "dust," because of uncertainties with regard to the amount, the optical properties, and the distribution of man-made particles (*2, 3*). Man-made heat currently runs a poor third to CO_2 and dust. Its effects will, for at least a few decades, remain entirely local (*4*). In this report only the interaction of the CO_2 effect and natural climatic change is considered. As other anthropogenic effects are shown to be significant and as means to quantitatively predict their future influence on global temperatures are developed, they can be included in models such as this. Meanwhile it is important to consider the potential impact of the two causes of change for which we do have quantitative information.

A number of people have made estimates of the change in global temperature that would result if the atmospheric CO_2 content were to double. These estimates range from 0.8° to 3.6°C. Manabe and Wetherald's value (*5*) of 2.4°C, based on a model assuming fixed relative humidity and cloudiness, is the most widely used. The difference between this estimate and that of 0.8°C by Rasool and Schneider (*3*) has been largely resolved. When an improved infrared radiation scheme is introduced into the Manabe-Wetherald calculation, the result drops to 1.9°C (*6*). However, Manabe and Wetherald (*6*) have suggested, on the basis of some preliminary three-dimensional calculations, that the effect in polar regions is much larger than for the "typical" atmospheric column. This polar amplification leads to an enhancement of the global effect, bringing the value up to somewhat above 2.4°C. Although surprises may yet be in store for us when larger computers and a better knowledge of cloud physics allow the next stage of the modeling to be accomplished, the magnitude of the CO_2 effect has probably been pinned down to within a factor of 2 to 4 (*7*).

The response of the global temperature to the atmospheric CO_2 content is not linear. As the CO_2 content of the atmosphere rises, the absorption of infrared radiation will "saturate" over an ever greater portion of the band. Rasool and Schneider (*3*) point out that the temperature increases as the logarithm of the atmospheric CO_2 content. Thus, if doubling of the CO_2 content raises the temperature by 2.4°C, then a 10 percent increase in the CO_2 content will raise the temperature by 0.32°C.

With respect to the amounts of CO_2 to be expected in the atmosphere, we are in a position to make fairly accurate estimates. Measurements carried out by Keeling and his co-workers on the island of Hawaii over the past 15 years suggest that the CO_2 content of the atmosphere rose an average of 0.7 part per million (ppm) per year from 1958 to 1972 (*8*). Had all the CO_2 generated by the burning of chemical fuels remained in the atmosphere, the rate of increase in the atmospheric CO_2 content should have been about 1.5 ppm/year. Thus, about half of the CO_2 added to the atmosphere is seemingly being removed to the sea (through combination with the CO_3^{2-} ion) and to the terrestrial biosphere (through enhanced photosynthesis). Calculations based on the model of Broecker *et al.* suggest that uptake by the sea can account for the removal of 35 ± 10 percent of the CO_2 produced (*9*). Other investigators (*10*), using oceanic mixing models which neglect short-term transfer between the surface ocean and the main oceanic thermocline, conclude that considerably smaller fractions of the CO_2 have gone into the ocean. In order to match the observed rate of increase in the atmospheric CO_2 content, these authors are required to put what I consider to be an inordinately large part of the CO_2 into the terrestrial biosphere. If the ocean is currently the main sink for the "missing" CO_2, the models suggest that, if our CO_2 production continues to increase at the rate of several percent per year, the fraction of this CO_2 remaining in the atmosphere will remain nearly constant over the next several decades (*9*). If, on the other hand, a major fraction of the chemical fuel CO_2 is being removed to the terrestrial biosphere, we are not in as good a position to state how the distribution coefficient between the atmosphere and other reservoirs will change with time. On the time scale of a few dec-

Table 1. Reconstruction and prediction of atmospheric CO_2 contents based on fuel consumption data.

Year	Chemical fuel CO_2 ($\times 10^{16}$ g)	Excess atmospheric CO_2* ($\times 10^{16}$ g)	Excess atmospheric CO_2 (%)	Excess atmospheric CO_2 (ppm)	CO_2 content of the atmosphere† (ppm)	Global temperature increase‡ (°C)
1900	3.8	1.9	0.9	2	295	0.02
1910	6.3	3.1	1.4	4	297	.04
1920	9.7	4.8	2.2	6	299	.07
1930	13.6	6.8	3.1	9	302	.09
1940	17.9	8.9	4.1	12	305	.11
1950	23.3	11.6	5.3	16	309	.15
1960	31.2	15.6	7.2	21	314§	.21
1970	44.0	22.0	10.2	29	322§	.29
1980‖	63	31	14	42	335	.42
1990‖	88	44	20	58	351	.58
2000‖	121	60	28	80	373	.80
2010‖	167	83	38	110	403	1.10

*On the assumption that 50 percent of the CO_2 produced by the burning of fuel remains in the atmosphere. †The preindustrial atmospheric partial pressure of CO_2 is assumed to be 293 ppm. ‡Assumes a 0.3°C global temperature increase for each 10 percent rise in the atmospheric CO_2 content. §Value observed on Hawaii for 1960, 314 ppm; value for 1970, 322 ppm (*8*). ‖Post-1972 growth rate taken to be 3 percent per year.

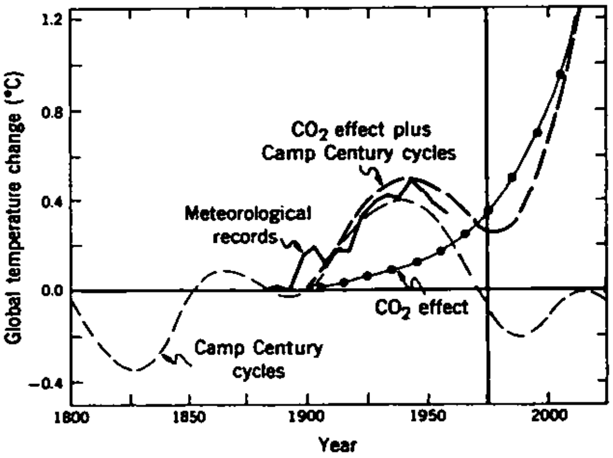

Fig. 1. Curves for the global temperature change due to chemical fuel CO_2, natural climatic cycles, and the sum of the two effects. The measured temperature anomaly for successive 5-year means from meteorological records over the last century is given for comparison.

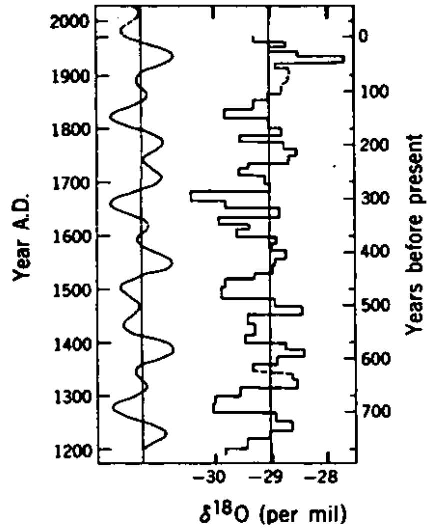

Fig. 2. Difference (per mil) between the $^{18}O/^{16}O$ ratio in decade composites of Greenland ice from the Camp Century site and mean ocean water as obtained by Dansgaard and his co-workers (*1*). A decrease of 1 per mil in the ^{18}O content corresponds to a 1.5°C drop in air temperature. The curve on the left is the simulation of the isotope curve obtained by combining sinusoidal curves with periods of 80 and 180 years.

ades, however, there is no reason to believe that it will change greatly.

The global temperature increase due to CO_2 in Fig. 1 is calculated on the basis of the following assumptions: (i) 50 percent of the CO_2 generated by the burning of chemical fuels has in the past and will in the near future remain in the atmosphere; (ii) the United Nations fuel consumption estimates are used to 1960 (*11*); between 1960 and 1975 a growth rate of 4.5 percent per year is used, and from 1975 on a 3 percent growth rate is predicted; (iii) for each 10 percent increase in the atmospheric CO_2 content the mean global temperature increases by 0.3°C. These calculations are summarized in Table 1.

Meteorological records of the mean global temperature are adequate only over the last century. The mean global temperature (successive 5-year means) obtained from these records by Mitchell (*12*) is given in Fig. 1. From this record alone little can be said about the causes of climatic fluctuations. It is too short and may be influenced by pollution. Obtaining comparable information from historic and natural records for previous centuries has proved very difficult. There is no simple relation between the indices used and the temperature, and regional noise tends to mask the global picture. In my estimation the only existing record which may give a picture of the natural fluctuations in global temperature over the last 1000 years is that from the ice core taken at Camp Century in northwestern Greenland. The air temperature over this site is being recorded in terms of the ratio of ^{18}O to ^{16}O in the snow which falls. Because of the polar amplification of global climatic changes [noted both in this century's meteorological records (*12*) and in models (*6*)], a strong signal emerges from the regional noise. Measurements on snow generated over a range of polar temperatures show that for each 1°C of cooling the ^{18}O content of the precipitation drops by about 0.7 per mil (*13*). The time scale is obtained by extrapolation of the accumulation rates established by counting seasonal couplets (*14*). The widely quoted results of Dansgaard and his co-workers of measurements on the Camp Century core (*1*) are reproduced in Fig. 2. Clearly the fluctuation in global temperature documented by meteorological observations over the last century is not unique; similar changes have occurred in a more or less regular fashion throughout the last 1000 years. Dansgaard and his co-workers have shown by power spectral techniques that cycles of 80 and 180 years appear in this record. The model curve to the left of the isotopic curve (Fig. 2) is their best fit to the data based on the use of only 80- and 180-year cycles.

The amplitude of the last half "cycle" in Greenland (1900 to 1940) as recorded in the ice is about the same as that recorded by meteorological observations (both give about 1.5°C warming) (*2, 3*). Also the ice core record is roughly in phase with the global change recorded meteorologically. Consistent with the Manabe-Wetherald model (*6*), the amplitude of the temperature change in the polar region is several times larger than the global average.

The curve of natural fluctuations drawn in Fig. 1 was obtained as follows. The pattern of the fluctuations is that obtained by Dansgaard and his co-workers (*1*), assuming that the 80- and 180-year periods dominate the natural record. The amplitude of the curve is reduced so that, when summed with the CO_2 effect, it yields a reasonable match to the global temperature curve for the last century (that is, a fourfold reduction due to polar amplification is made).

Table 2. Projections based on an analogy to individual Camp Century cycles over the last 800 years.

Warm peak No.*	Years to next cold minimum*	Projected date for next cold minimum
1	40	1980
2	25	1965
3	40	1980
4	35	1975
5	55	1995
6	30	1970
7	25	1965
8	35	1975
9	35	1975
Mean	35	1975
Simulation†	50	1990

*See Fig. 3. †See Fig. 2.

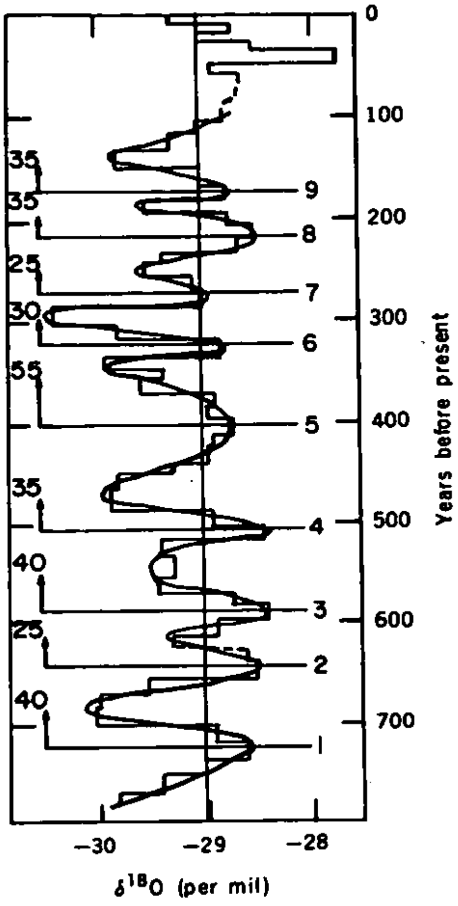

Fig. 3. Spacings between warm maxima and cold minima for the "smoothed" Camp Century ice core ^{18}O curve.

The resultant curve obtained by combining the CO_2 effect with the simulated natural curve shows dramatically what will happen if the natural cooling trend bottoms out and swings into the next warming phase according to the schedule postulated here. Global temperature would begin a dramatic rise which would continue for about four decades (that is, half the 80-year cycle). This warming would by the year 2000 bring average global temperatures beyond the range experienced during the last 1000 years. Until chemical fuel consumption is dramatically reduced, global temperatures would continue to rise. Future natural cycles would merely modulate this ever-steepening rise (40-year periods of more rapid increase followed by 40-year periods of less rapid increase).

Although the details of the argument presented here depend largely on the results of Dansgaard *et al.* (*1*), simulation of the Camp Century cycles, the sense of the argument, is not dependent on these results. As shown in Fig. 3 and Table 2, a similar conclusion with regard to the timing of the forthcoming natural minima would be reached by analogy with almost any portion of the Greenland record over the last 700 years. If anything, the simulation puts the next minimum farther into the future than would estimates based strictly on analogies with previous "cycles." Thus, whereas the exact date of the minimum shown in the extended natural climate curve (Fig. 1) is uncertain, its occurrence in the next decade is probable. The rate of warming beyond the minimum is also open to question. As the CO_2 effect will dominate, the uncertainty here lies mainly in the estimates of future chemical fuel use and in the magnitude of the warming per unit of excess atmospheric CO_2. The major point of the argument is that over the past 30 years the warming trend due to CO_2 has been more than countered by a natural cooling. This compensation cannot long continue both because of the rapid growth of the CO_2 effect and because the natural cooling will almost certainly soon bottom out. We may be in for a climatic surprise. The onset of the era of CO_2-induced warming may be much more dramatic than in the absence of natural climatic variations.

The agricultural consequences of this ensuing warming are not obvious (neither are the implications to global sea level). A knowledge of the mean global temperature tells us little about the rainfall patterns in the chief grain-producing regions. There is little doubt, however, that this gradual warming will lead to changes in the pattern of global precipitation. Our efforts to understand and eventually to predict these changes must be redoubled.

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Chlorinated Hydrocarbon Pollutants and Photosynthesis of Marine Phytoplankton: A Reassessment

Abstract. *The chlorinated hydrocarbons DDT and PCB's (polychlorinated biphenyls), ubiquitous pollutants of the marine environment, have been observed to reduce the cell division rate of marine phytoplankton, thereby indirectly reducing the total photosynthetic carbon fixation in treated cultures. The photosynthetic capacity of each cell was not affected. Total marine photosynthesis will likely remain undiminished by these compounds, although alterations in phytoplankton communities through selective toxicity could affect herbivore populations.*

Several persistent and ubiquitous chlorinated hydrocarbon pollutants of the marine environment, most notably PCB's (polychlorinated biphenyls) and DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane], can reduce the growth rate (*1, 2*) and have been reported to reduce photosynthesis (*2–4*) in some marine phytoplankton cultures. The decrease in carbon fixation observed in treated cultures (*2–4*), as measured by the incorporation of ^{14}C-labeled bicarbonate, could have resulted from an inhibition of the photosynthetic process itself, or it may have been due to a depressed growth rate, that is, fewer cells photosynthesizing in treated than in control cultures.

I conducted an experiment to determine whether algal photosynthesis on a per cell basis, as well as on a per culture basis, was affected by PCB's or DDT. The organochlorine concentrations used were above those found in natural waters (*5*); no attempt was made to determine the toxicity of environmentally realistic concentrations of these compounds, as was done elsewhere (*6*). The purpose of this study was to establish whether, in algae, photosynthetic carbon fixation itself is inhibited or whether just growth is affected by these chemicals.

The three algal species studied (*7*) were selected on the basis of their sensitivity to chlorinated hydrocarbons: the growth of *Thalassiosira pseudonana* and *Skeletonema costatum*, common marine diatoms, is affected by PCB's and DDT (*1*), and photosynthetic carbon fixation in cultures of *Coccolithus huxleyi* and the two diatoms is reportedly reduced by DDT (*2, 3*). Culture conditions and procedures have been described elsewhere (*8*). Methanolic solutions of PCB's (Aroclor 1254) or DDT were injected (*1*) into the cell suspensions at time zero to give initial PCB concentrations of 10 μg/liter (parts per billion) and DDT concentrations of 50 ppb in the medium. Equal volumes of methanol were added to the control cultures (*9*). These organochlorine compounds, at similar concentrations (or doses per cell), have been reported to substantially depress the net carbon fixation in monocultures of these algal species (*2, 3*). At 48 hours, 1 ml of medium was removed from each tube so that cell counts could be determined (*10*), 0.2 μc of [^{14}C]NaHCO$_3$ was added (*11*), and the cultures were incubated as before for about 5 hours. The same procedure was also carried out for dark controls. The cells were then gently filtered through 0.8-μm Millipore filters and washed with filtered seawater; the radioactivity of the filters was counted in a liquid scintillation counter (Tri-Carb, Packard). The entire experiment was repeated with the two diatom species.

Table 1 presents the 48-hour cell counts, photosynthetic carbon fixation per culture, and carbon uptake per cell (α). The dark uptake of ^{14}C, which varied with each species (being 2 percent of the illuminated *T. pseudonana* ^{14}C uptake, less than 1 percent with *S. costatum*, and 10 percent with *C. huxleyi*), was subtracted from the raw

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Extinction risk from climate change

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Climate change over the past ~30 years has produced numerous shifts in the distributions and abundances of species[1,2] and has been implicated in one species-level extinction[3]. Using projections of species' distributions for future climate scenarios, we assess extinction risks for sample regions that cover some 20% of the Earth's terrestrial surface. Exploring three approaches in which the estimated probability of extinction shows a power-law relationship with geographical range size, we predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in our sample of regions and taxa will be 'committed to extinction'. When the average of the three methods and two dispersal scenarios is taken, minimal climate-warming scenarios produce lower projections of species committed to extinction (~18%) than mid-range (~24%) and maximum-change (~35%) scenarios. These estimates show the importance of rapid implementation of technologies to decrease greenhouse gas emissions and strategies for carbon sequestration.

The responsiveness of species to recent[1–3] and past[4,5] climate change raises the possibility that anthropogenic climate change could act as a major cause of extinctions in the near future, with the Earth set to become warmer than at any period in the past 1–40 Myr (ref. 6). Here we use projections of the future distributions of 1,103 animal and plant species to provide 'first-pass' estimates of extinction probabilities associated with climate change scenarios for 2050.

For each species we use the modelled association between current climates (such as temperature, precipitation and seasonality) and present-day distributions to estimate current distributional areas[7–12]. This 'climate envelope' represents the conditions under which populations of a species currently persist in the face of competitors and natural enemies. Future distributions are estimated by assuming that current envelopes are retained and can be projected for future climate scenarios[7–12]. We assume that a species either has no limits to dispersal such that its future distribution becomes the entire area projected by the climate envelope model or that it is incapable of dispersal, in which case the new distribution is the overlap between current and future potential distributions (for example, species with little dispersal or that inhabit fragmented landscapes)[11]. Reality for most species is likely to fall between these extremes.

We explore three methods to estimate extinction, based on the species–area relationship, which is a well-established empirical power-law relationship describing how the number of species relates to area ($S = cA^z$, where S is the number of species, A is area, and c and z are constants)[13]. This relationship predicts adequately the numbers of species that become extinct or threatened when the area available to them is reduced by habitat destruction[14,15]. Extinctions arising from area reductions should apply regardless of whether the cause of distribution loss is habitat destruction or climatic unsuitability.

Because climate change can affect the distributional area of each species independently, classical community-level approaches need to be modified (see Methods). In method 1 we use changes in the summed distribution areas of all species. This is consistent with the traditional species–area approach: on average, the destruction of half of a habitat results in the loss of half of the distribution area summed across all species restricted to that habitat. However, this analysis tends to be weighted towards species with large distributional areas. To address this, in method 2 we use the average proportional loss of the distribution area of each species to estimate the fraction of species predicted to become extinct. This approach is faithful to the species–area relationship because halving the habitat area leads on average to the proportional loss of half the distribution of each species. Method 3 considers the extinction risk of each species in turn. In classical applications of the species–area approach, the fraction of species predicted to become extinct is equivalent to the mean probability of extinction per species. Thus, in method 3 we estimate the extinction risk of each species separately by substituting its area loss in the species–area relationship, before averaging across species (see Methods). Our conclusions are not dependent on which of these methods is used. We use $z = 0.25$ in the species–area relationship throughout, given its previous success in predicting proportions of threatened species[14,15], but our qualitative conclusions are not dependent on choice of z (Supplementary Information). As there are gaps in the data (not all dispersal/climate scenarios were available for each region), a logit–linear model is fitted to the extinction risk data to produce estimates for missing values in the extinction risk table (Table 1). Balanced estimates of extinction risk, averaged across all data sets, can then be calculated for each scenario.

For projections of maximum expected climate change, we estimate species-level extinction across species included in the study to be 21–32% (range of the three methods) with universal dispersal, and 38–52% for no dispersal (Table 1). For projections of mid-range climate change, estimates are 15–20% with dispersal and 26–37% without dispersal (Table 1). Estimates for minimum expected climate change are 9–13% extinction with dispersal and 22–31% without dispersal. Projected extinction varies between parts of the world and between taxonomic groups (Table 1), so our estimates are affected by the data available. The species–area methods differ from one another by up to 1.41-fold (method 1 versus method 3) in estimated extinction, whereas the two dispersal scenarios produce a 1.98-fold difference, and the three climate scenarios generate 2.05-fold variation.

Given its role in conservation planning, we also use a different approach to estimate extinction, modified from the IUCN Red Data Book listing procedure[16]: this is semi-numerical and includes components of expert judgement. Species are assigned to different threat categories based on distribution sizes and declines, with each category carrying a specified probability of extinction[16] (see Methods and Supplementary Information). For scenarios of maximum expected climate change, 33% (with dispersal) and 58% (without dispersal) of species are expected to become extinct (Table 1). For mid-range climate change scenarios, 19% or 45% (with or without dispersal) of species are expected to become extinct, and for minimum expected climate change 11% or 34% (with or without dispersal) of species are projected to become extinct.

We can compare these values with the proportions of species projected to become extinct as the result of global habitat losses, currently the most widely recognized extinction threat. We apply the species–area relationship to changes in global land use that have taken place since human land conversion began[17]. Estimates of extinction range from 1% to 29%, depending on the biome (considering only species restricted to single biomes; Table 2). Given that a high proportion of the world's species reside in tropical forests (extinction estimate 4%; Table 2), global extinction related to habitat loss would be expected to be in the lower half of the range, and thus lower than the rate projected for scenarios of mid-range climate change (24%; average of area methods). Projected conversion of humid tropical forest at an annual rate of 0.43% (ref. 18) from 1990 to 2050 predicts a further 6.3% of species committed to extinction.

Regional differences are expected, so we also compare the relative risks during 2000–2050 associated with land use and climate change (using area approaches) for the three region–taxon combinations that correspond most closely to single habitat or biome types. First, for montane Queensland forests[12], extinction risk is dominated by climate change (7–13% and 43–58% predicted extinction for minimum and maximum climate scenarios, respectively; 0% predicted on the basis of further habitat destruction, given its legal protection). Second, for cerrado vegetation in Brazil, high rates of habitat destruction[19] make it possible that only current reserves will survive. Making this pessimistic assumption, an estimated additional 34% of all original species will be committed to extinction due to habitat destruction during 2000–2050, a value lower than the 48–56% of woody plant species projected to be committed to extinction for mid-range climate warming (38–45% for minimum warming). Last, for South African Proteaceae, 27% of all original species are projected to become extinct as a result of land use

Table 1 **Projected percentage extinctions for different taxa and regions**

Taxon	Region	With dispersal			No dispersal		
		Minimum expected climate change	Mid-range climate change	Maximum expected climate change	Minimum expected climate change	Mid-range climate change	Maximum expected climate change
Mammals	Mexico $n = 96$	2, 4, 5 **5**	2, 5, 7 **8**	–	9, 14, 18 **24**	10, 15, 20 **26**	–
	Queensland $n = 11$	10, 13, 15 **16**	-	48, 54, 80 **77**	–	–	-
	South Africa $n = 5$	–	24, 32, 46 **0**	–	–	28, 36, 59 **69**	-
Birds	Mexico $n = 186$	2, 2, 3 **4**	3, 3,4 **5**	–	5, 7, 8 **9**	5, 7, 8 **8**	–
	Europe $n = 34$	-	–	4, 6, 6 **7**	–	–	13, 25, 38 **48**
	Queensland $n = 13$	7, 9, 10 **12**	–	49, 54, 72 **85**	–	–	–
	South Africa $n = 5$	-	28, 29, 32 **0**	–	-	33, 35, 40 **51**	–
Frogs	Queensland $n = 23$	8, 12, 18 **13**	–	38, 47, 67 **68**	–	–	–
Reptiles	Queensland $n = 18$	7, 11, 14 **9**	-	43, 49, 64 **76**	–	–	–
	South Africa $n = 26$	-	21, 22, 27 **0**	–	-	33, 36, 45 **59**	–
Butterflies	Mexico $n = 41$	1, 3, 4 **7**	3, 4, 5 **7**	–	6, 9, 11 **13**	9, 12, 15 **19**	–
	South Africa $n = 4$	-	13, 7, 8 **0**	–	-	35, 45, 70 **78**	–
	Australia $n = 24$	5, 7, 7 **7**	13, 15, 16 **23**	21, 22, 26 **33**	9, 11, 12 **16**	18, 21, 23 **35**	29, 32, 36 **54**
Other invertebrates	South Africa $n = 10$	-	18, 15, 24 **0**	-	-	28, 46, 80 **85**	–
Plants	Amazonia $n = 9$	–	-	44, 36, 79 **69**	-	-	100, 100, 99 **87**
	Europe $n = 192$	3, 4, 5 **6**	3, 5, 6 **7**	4, 5, 6 **8**	9, 11, 14 **18**	10, 13, 16 **22**	13, 17, 21 **29**
	Cerrado $n = 163$	-	–	–	38, 39, 45 **66**	48, 48, 57 **75**	-
	South Africa Proteaceae $n = 243$	–	24, 21, 27 **38**	–	–	32, 30, 40 **52**	–
All species		9, 10, 13 **11** $n = 604$	15, 15, 20 **19** $n = 832$	21, 23, 32 **33** $n = 324$	22, 25, 31 **34** $n = 702$	26, 29, 37 **45** $n = 995$	38, 42, 52 **58** $n = 259$

Projected percentage extinction values are given, based on species–area (for $z = 0.25$) and Red Data Book (bold) approaches. The three species–area estimates are ordered in each cell with method 1 given first, followed by method 2, then method 3. Values for 'All species' are based on both these raw values and estimates interpolated for the empty (–) cells (see Methods). In each instance, n is the number of species assessed directly.

Table 2 **Estimated eventual extinction based on habitat loss**

Biome	Percentage of world surface area (from ref. 17)			Percentage of species expected to go extinct by the species–area approach ($z = 0.25$)
	Undisturbed	1990	Area lost	
Cropland	0.0	10.9	0.0	0.0
Pasture	0.0	23.1	0.0	0.0
Ice	1.7	1.7	0.0	0.0
Tundra	4.8	4.6	0.2	1.0
Wooded tundra	2.0	1.9	0.1	1.1
Boreal forest	13.0	12.5	0.5	0.9
Cool conifer forest	2.7	2.1	0.6	6.1
Temperate mixed forest	5.2	2.2	3.0	19.2
Temperate deciduous forest	4.5	1.5	3.0	24.2
Warm mixed forest	4.7	1.9	2.8	20.3
Grassland/steppe	13.7	6.9	6.8	15.7
Hot desert	14.9	11.8	3.1	5.6
Scrubland	7.3	1.9	5.4	28.9
Savannah	11.9	6.2	5.7	15.1
Tropical woodland	6.1	4.4	1.7	8.0
Tropical forest	7.6	6.4	1.1	4.0

changes during 2000–2050 (for a pessimistic linear extrapolation of land use scenarios after 2020)[20], falling between the 30–40% (without dispersal) and 21–27% (with ubiquitous dispersal, which is unlikely for these plants) projected extinction for mid-range climate scenarios.

Many unknowns remain in projecting extinctions, and the values provided here should not be taken as precise predictions. Analyses need to be repeated for larger samples of regions and taxa, and the selection of climate change scenarios need to be standardized. Some of the most important uncertainties follow (see also Supplementary Information). We estimate proportions of species committed to future extinction as a consequence of climate change over the next 50 years, not the number of species that will become extinct during this period. Information is not currently available on time lags between climate change and species-level extinctions, but decades might elapse between area reduction (from habitat loss) and extinction[14]. Land use should also be incorporated into analyses: extinction risks might be higher than we project if future locations of suitable climate do not coincide with other essential resources (such as soil type or food resources). There is also uncertainty over which species will inhabit parts of the world projected to have climates for which no current analogue exists[6]. Equally importantly, all parts of the world will have historically unprecedented CO_2 levels[6], which will affect plant species and ecosystems[21,22] and herbivores[23], resulting in novel species assemblages and interactions.

Despite these uncertainties, we believe that the consistent overall conclusions across analyses establish that anthropogenic climate warming at least ranks alongside other recognized threats to global biodiversity. Contrary to previous projections[24], it is likely to be the greatest threat in many if not most regions. Furthermore, many of the most severe impacts of climate-change are likely to stem from interactions between threats, factors not taken into account in our calculations, rather than from climate acting in isolation. The ability of species to reach new climatically suitable areas will be hampered by habitat loss and fragmentation, and their ability to persist in appropriate climates is likely to be affected by new invasive species.

Minimum expected (that is, inevitable) climate-change scenarios for 2050 produce fewer projected 'committed extinctions' (18%; average of the three area methods and the two dispersal scenarios) than mid-range projections (24%), and about half of those predicted under maximum expected climate change (35%). These scenarios would diverge even more by 2100. In other words, minimizing greenhouse gas emissions and sequestering carbon[25] to realize minimum, rather than mid-range or maximum, expected climate warming could save a substantial percentage of terrestrial species from extinction. Returning to near pre-industrial global temperatures as quickly as possible could prevent much of the projected, but slower-acting, climate-related extinction from being realized. ☐

Methods

Climate-envelope modelling

The statistical match between climate variables and the boundaries of a species' distribution (climate envelope) represents conditions in which a species (normally) shows a positive demographic balance (rarely the absolute physical limits of a species, but the set of conditions under which it survives in at least some multi-species communities). The statistical approach is generic, but specific methods vary between studies (Supplementary Information). The approach has been validated by successfully predicting distributions of invading species when they arrive in new continents and by predicting distributional changes in response to glacial climate changes; its scope has been discussed widely (see, for example, refs 12, 26–29). Dispersal is assumed to be universal or zero (main text), except for the Mexican study in which 'universal dispersal' is movement through contiguous habitats[11].

Climate scenarios

Climate projections for 2050 were divided into three categories: minimum expected change resulting in a mean increase in global temperature of 0.8–1.7 °C and in CO_2 of 500 p.p.m. by volume (p.p.m.v.); mid-range scenarios with temperature increases of 1.8–2.0 °C and CO_2 increases of 500–550 p.p.m.v.; and maximum expected scenarios with temperature increases of >2.0 °C and CO_2 increases >550 p.p.m.v. (ref. 30). Projections for the year 2100 were allocated to 2050 scenarios according to their end temperatures and CO_2 levels (Supplementary Information).

Species

Within each region we use only data for endemic species (near-endemic in two cases). Near-endemics are defined as >90% of the distribution area known to occur (European birds) or thought to occur (cerrado plants, given incomplete data) within the region modelled. For European birds, near-endemics are included only if their extra-European distribution is similar to climate space within Europe. The focus on endemics permits us to model all range boundaries of each species (Supplementary Information).

Species–area approaches

Method 1 analyses overall changes in distribution areas, summed across species. The proportion of species in a region going extinct (E_1) is estimated as

$$E_1 = 1 - (\Sigma A_{\text{new}} / \Sigma A_{\text{original}})^z$$

where A_{original} is the area initially occupied by a species, and A_{new} is the future area projected for the same species, with summation carried out across species.

Method 2 is based on the average proportional change in distribution area, averaged across species. Regional extinction risk (E_2) is

$$E_2 = 1 - \{(1/n)[\Sigma(A_{\text{new}} / A_{\text{original}})]\}^z$$

where n is the number of species and $A_{\text{new}}/A_{\text{original}}$ is the proportional distribution change for each species in turn.

Method 3 estimates the extinction risk of each species in turn, averaging across species to derive regional estimates of extinction (E_3):

$$E_3 = (1/n)\Sigma[1 - (A_{\text{new}} / A_{\text{original}})^z]$$

Species for which $A_{\text{new}} > A_{\text{original}}$ were analysed as though $A_{\text{new}} = A_{\text{original}}$; that is, zero extinction would be returned by each equation if every species was projected to expand (Supplementary Information). It is important to recognize that further work is required to establish empirically how the absolute and proportional area losses of individual species (in other words, the type of data from climate envelope projections) are related to extinction risk. As yet, no agreed standard method exists for such calculations: assumptions and uncertainties inherent in the three methods will be considered in detail elsewhere.

Extinction probability estimates were not available for all scenarios in every region/taxon, so means of scenarios were calculated after using a least-squares analysis of variance model to impute missing values. Region/taxon mean probabilities of extinction for each scenario were logit-transformed and a three-way analysis of variance was fitted (region/taxon × climate scenario × dispersal scenario; weighted by $\sqrt{N_{\mathrm{species}}}$ per region/taxon study). The fitted model was used to impute expected values of the probability of extinction for those region/taxon and scenario combinations for which direct estimates were not available. Scenario means were then calculated from the combined direct estimates and imputed values, using $\sqrt{N_{\mathrm{species}}}$ for each region/taxon as weights.

Red Data Book criteria

Each species is assigned to a threat category[16], or classified 'Not Threatened' (0% risk), depending on the projected decline in area over 50 or 100 years (Supplementary Information) and the final distribution area. Existing areas were considered, so we present only the extra extinction attributable to climate change. Logit-transformed three-way analysis of variance was used to estimate extinction risks for empty cells, as with the species–area approaches.

Extinct: species with a projected future area of zero (100% of species assumed to be committed to eventual extinction).

Critically endangered: projected future distribution area $<10\,\mathrm{km}^2$, or decline by >80% in 50 years (species assigned a 75% chance of extinction[16]).

Endangered: projected area $10\text{–}500\,\mathrm{km}^2$, or 50–80% decline in 50 years (species assigned a 35% chance of extinction[16]).

Vulnerable: projected area $500\text{–}2{,}000\,\mathrm{km}^2$, or >50% decline in 100 years on the basis of linear extrapolation of 50-year projection (species assigned a 15% chance of extinction[16]).

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Derivation of embryonic germ cells and male gametes from embryonic stem cells

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Egg and sperm cells (gametes) of the mouse are derived from a founder population of primordial germ cells that are set aside early in embryogenesis. Primordial germ cells arise from the proximal epiblast, a region of the early mouse embryo that also contributes to the first blood lineages of the embryonic yolk sac[1]. Embryonic stem cells differentiate *in vitro* into cystic structures called embryoid bodies consisting of tissue lineages typical of the early mouse embryo[2,3]. Because embryoid bodies sustain blood development, we reasoned that they might also support primordial germ cell formation. Here we isolate primordial germ cells from embryoid bodies, and derive continuously growing lines of embryonic germ cells. Embryonic germ cells show erasure of the

tral case). For the CE commitment, sea level rises at about 25 cm/century (uncertainty range, 7 to more than 50 cm/century). The fractions arising from unforced contributions to sea level rise are less than those in the CC case.

The CE results reinforce the common knowledge that, in order to stabilize global-mean temperatures, we eventually need to reduce emissions of greenhouse gases to well below present levels (*21*). The CC results are potentially more alarming, because they are based on a future scenario that is clearly impossible to achieve and so represent an extreme lower bound to climate change over the next few centuries. For temperature, they show that the inertia of the climate system alone will guarantee continued warming and that this warming may eventually exceed 1°C. For sea level, a continued rise of about 10 cm/century for many centuries is the best estimate. Although such a slow rate may allow many coastal communities to adapt, profound long-term impacts on low-lying island communities and on vulnerable ecosystems (such as coral reefs) seem inevitable.

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Tables S1 and S2

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How Much More Global Warming and Sea Level Rise?

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Two global coupled climate models show that even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000, we are already committed to further global warming of about another half degree and an additional 320% sea level rise caused by thermal expansion by the end of the 21st century. Projected weakening of the meridional overturning circulation in the North Atlantic Ocean does not lead to a net cooling in Europe. At any given point in time, even if concentrations are stabilized, there is a commitment to future climate changes that will be greater than those we have already observed.

Increases of greenhouse gases (GHGs) in the atmosphere produce a positive radiative forcing of the climate system and a consequent warming of surface temperatures and rising sea level caused by thermal expansion of the warmer seawater, in addition to the contribution from melting glaciers and ice sheets (*1*, *2*). If concentrations of GHGs could be stabilized at some level, the thermal inertia of the climate system would still result in further increases in temperatures, and sea level would continue to rise (*2*–*9*). We performed multimember ensemble simulations with two global coupled three-dimensional climate models to quantify how much more global warming and sea level rise (from thermal expansion) we could experience under several different scenarios.

The Parallel Climate Model (PCM) has been used extensively for climate change experiments (*10*–*15*). This model has a relatively low climate sensitivity as compared to other models, with an equilibrium climate sensitivity of 2.1°C and a transient climate response (TCR) (the globally averaged surface air temperature change at the time of CO_2 doubling in a 1% CO_2 increase experiment) of 1.3°C. The former is indicative of likely atmospheric feedbacks in the model, and the latter includes ocean heat uptake and provides an indication of the transient response of the coupled climate system (*6*, *12*). A second global coupled climate model is the newly developed Community Climate System Model version 3 (CCSM3), with higher horizontal resolution (atmospheric gridpoints roughly every 1.4° as compared to the PCM, with gridpoints about every 2.8°) and improved parameterizations in all components of atmosphere, ocean, sea ice, and land surface (*16*). The CCSM3 has somewhat higher sensitivity, with an equilibrium climate sensitivity of 2.7°C and TCR of 1.5°C. Both models have about 1° ocean resolution (0.5° in the equatorial tropics), with dynamical sea ice and land surface schemes. These models were run for four- and eight-member ensembles for the PCM and CCSM3, respectively, for each scenario (except for five members for A2 in CCSM3).

The 20th-century simulations for both models include time-evolving changes in forcing from solar, volcanoes, GHGs, tropospheric and stratospheric ozone, and the direct effect of sulfate aerosols (*14*, *17*). Additionally, the CCSM3 includes black carbon distributions scaled by population over the 20th century, with those values scaled by sulfur dioxide emissions for the rest of the future climate simulations. The CCSM3 also uses a different solar forcing data set for the 20th century (*18*). These 20th-century forcing differences between CCSM3 and PCM are not thought to cause large differences in response in the climate change simulations beyond the year 2000.

The warming in both the PCM and CCSM3 is close to the observed value of about 0.6°C for the 20th century (*19*), with PCM warming 0.6°C and CCSM3 warming 0.7° (averaged over the period 1980–1999 in relation to 1890–1919). Sea level rises are 3 to 5 cm, respectively, over the 20th century as com-

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pared to the observed estimate of 15 to 20 cm. This lower value from the models is consistent with the part of 20th-century sea level rise thought to be caused by thermal expansion (*20, 21*), because as the ocean warms, seawater expands and sea level rises. Neither model includes contributions to sea level rise due to ice sheet or glacier melting. Partly because of this, the sea level rise calculations for the 20th century from the models are probably at least a factor of 3 too small (*20, 21*). Therefore, the results here should be considered to be the minimum values of sea level rise. Contributions from future ice sheet and glacier melting could perhaps at least double the projected sea level rise produced by thermal expansion (*1*).

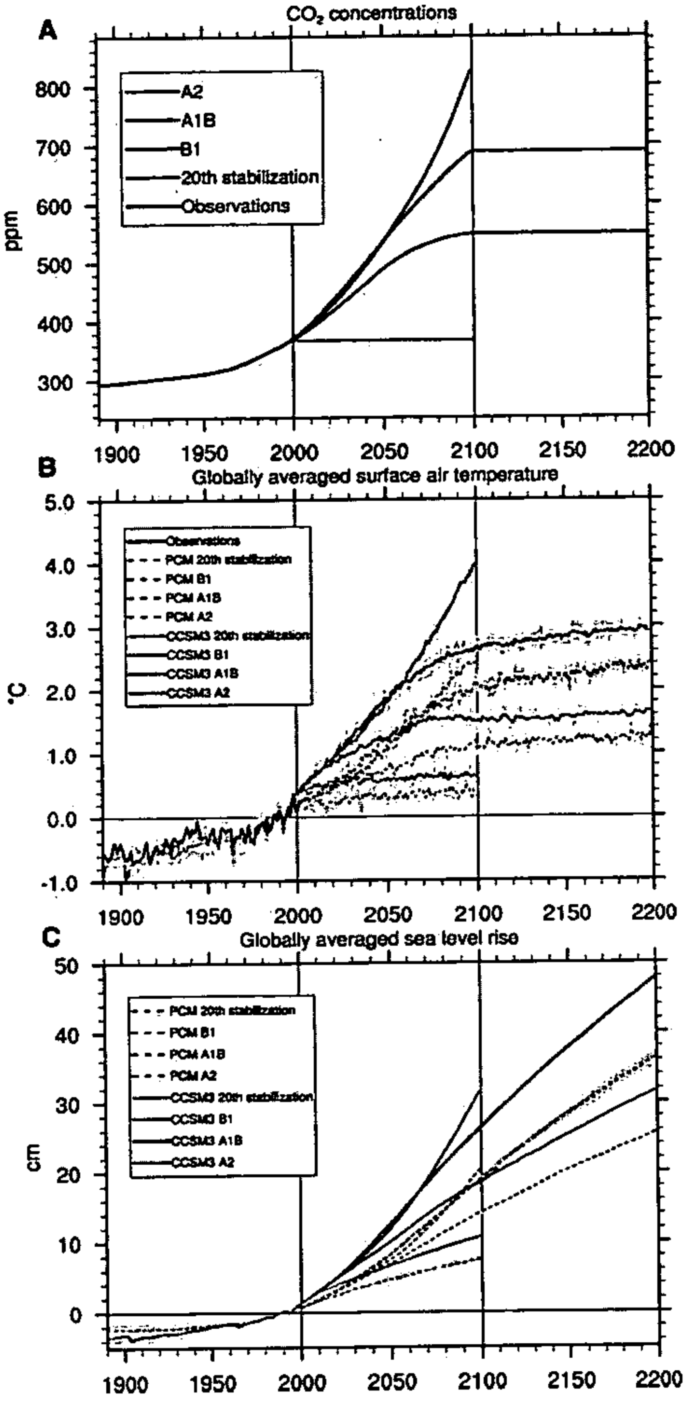

Fig. 1. (A) Time series of CO$_2$ concentrations for the various scenarios. (B) Time series of globally averaged surface air temperatures from the PCM and CCSM3. (C) Same as (B), except that sea level rise comes from thermal expansion only. In (C), the control drift is first subtracted from each experiment, and then in (B) and (C), the base period for calculating anomalies is 1980–1999. Solid lines are ensemble means, and shading indicates the range of ensemble members. Line identifiers for the various scenarios and the two models are given in each panel.

Table 1. Globally averaged surface temperature differences (in °C) comparing equilibrium climate sensitivity from the two models with simulated warming for the 20th century, mid-21st century, and late 21st century for the different experiments. Midcentury differences are calculated for 2041–2060 minus 1980–1999, and late century differences are for 2080–2099 minus 1980–1999. A2 at 2100 has more than double present-day CO$_2$ amounts (Fig. 1A).

Model	Equilibrium sensitivity	20th century	2050 stabilized	2050 B1	2050 A1B	2050 A2	2100 stabilized	2100 B1	2100 A1B	2100 A2
PCM	2.1	0.6	0.3	0.7	1.2	1.1	0.4	1.1	1.9	2.2
CCSM3	2.7	0.7	0.6	1.2	1.9	1.8	0.6	1.5	2.6	3.5

Atmospheric CO$_2$ is the dominant anthropogenic GHG (*22*), and its time evolution can be used to illustrate the various scenarios (Fig. 1A). The three Special Report for Emissions Scenarios (SRES) show low (B1), medium (A1B), and high (A2) increases of CO$_2$ over the course of the 21st century. Three stabilization experiments were performed: one with concentrations of all constituents held constant at year 2000 values and two (B1 and A1B) with concentrations held constant at year 2100 values. Although these are idealized stabilization experiments, it would take a significant reduction of emissions below 1990 values within a few decades and within about a century to achieve stabilized concentrations in B1 and A1B, respectively (*23*).

Even if we could have stopped any further increases in all atmospheric constituents as of the year 2000, the PCM and CCSM3 indicate that we are already committed to 0.4° and 0.6°C, respectively, more global warming by the year 2100 as compared to the 0.6°C of warming observed at the end of the 20th century (Table 1 and Fig. 1B). (The range of the ensembles for the climate model temperature anomalies here and to follow is about ±0.1°C.) But we are already committed to proportionately much more sea level rise from thermal expansion (Fig. 1C).

At the end of the 21st century, as compared to the end of the 20th century (1980–1999 base period), warming in the low-estimate climate change scenario (SRES B1) is 1.1° and 1.5°C in the two models (Table 1 and Fig. 1B), with sea level rising to 13 and 18 cm above year 1999 levels. The spread among the ensembles for sea level in all cases amounts to less than ±0.3 cm. A medium-range scenario (SRES A1B) produces a warming at the end of the 21st century of 1.9° and 2.6°C, with about 18 and 25 cm of sea level rise in the two models. For the high-estimate scenario (A2), warming at 2100 is about 2.2° and 3.5°C, and sea level rise is 19 and 30 cm. The range of transient temperature response in the two models for the 20th century through the mid-21st century is considerably less than the range in their equilibrium climate sensitivities (Table 1) due in part to less than doubled CO$_2$ forcing as well as ocean heat uptake characteristics (*24*). Thus, our confidence in model simulations of 20th-century climate change and projections for much of the 21st century (as represented by the range in the transient response of the models) is considerably better than that represented by the larger uncertainty range of the equilibrium climate sensitivity among the models.

If concentrations of all GHGs and other atmospheric constituents in these simulations are held fixed at year 2100 values, we would be committed to an additional warming by the year 2200 for B1 of about 0.1° to 0.3°C for the models (Fig. 1B). This small warming commitment is related to the fact that CO_2 concentrations had already started to stabilize at about 2050 in this scenario (Fig. 1A). But even for this small warming commitment in B1, there is almost double the sea level rise seen over the course of the 21st century by 2200, or an additional 12 and 13 cm (Fig. 1C). For A1B, about 0.3°C of additional warming occurs by 2200, but again there is roughly a doubling of 21st-century sea level rise by the year 2200, or an additional 17 and 21 cm. By 2300 (not shown), with concentrations still held at year 2100 values, there would be less than another 0.1°C of warming in either scenario, but yet again about another doubling of the committed sea level rise that occurred during the 22nd century, with additional increases of 10 and 18 cm from thermal expansion for the two models for the stabilized B1 experiment, and 14 and 21 cm for A1B as compared to year 2200 values. Sea level rise would continue for at least two more centuries beyond 2300, even with these stabilized concentrations of GHGs (*2*).

The meridional overturning maximum in the North Atlantic, indicative of the thermohaline circulation in the ocean, is stronger in the preindustrial simulation in the PCM (32.1 sverdrups) compared to the CCSM3 (21.9 sverdrups), with the latter closer to observed estimates that range from 13 to 20 sverdrups (*25–27*). The mean strength of the meridional overturning and its changes are an indication of ocean ventilation, and they contribute to ocean heat uptake and consequent time scales of temperature response in the climate system (*12*, *24*, *28*).

The model with the higher sensitivity (CCSM3) has the greater temperature and sea level rise response at the year 2100 for the B1, A1B, and A2 scenarios (Fig. 1, B and C) and also the larger decrease in meridional overturning in the North Atlantic (–4.0, –5.3, and –6.2 sverdrups or –18, –24, and –28%, respectively) as compared to the model that is less sensitive (PCM), with the lower forced response for B1, A1B, and A2 with decreases of meridional overturning in the Atlantic that are about a factor of 2 less (–1.0, –3.5, and –4.5 sverdrups, or –3, –11, and –14%, respectively). This is consistent with the idea that a larger percentage decrease in meridional overturning would be associated with greater ocean heat uptake and greater surface temperature warming (*12*, *24*).

The warming commitment for 20th-century forcing held fixed at year 2000 values is larger in the CCSM3 than in the PCM (0.6° versus 0.4°C). This is also consistent with the recovery of the meridional overturning in the 21st century after concentrations are stabilized in the PCM (net recovery of +0.2 sverdrups) compared to the CCSM3 (meridional overturning continues to weaken by –0.3 sverdrups before a modest recovery).

Therefore, the PCM, with less climate sensitivity and lower TCR but with greater mean meridional overturning in the Atlantic, has less reduction of North Atlantic meridional overturning and less forced response. The meridional overturning recovers more quickly in the PCM, contributing to even less warming commitment after concentrations are stabilized at year 2000 values. On the other hand, the CCSM3, with higher sensitivity and weaker mean meridional overturning, has a larger reduction of meridional overturning due to global warming (and particularly a larger percent decrease of meridional overturning) than the PCM and contributes to more warming commitment for GHG concentrations stabilized at year 2000 values.

The processes that contribute to these different warming commitments involve small radiative flux imbalances at the surface (on the order of several tenths of a watt per square meter) after atmospheric GHG concentrations are stabilized. This small net heat flux into the ocean is transferred to the deeper layers through mixing, convection, and ventilation processes such as the meridional overturning circulation that connects the Northern and Southern Hemisphere high-latitude deep

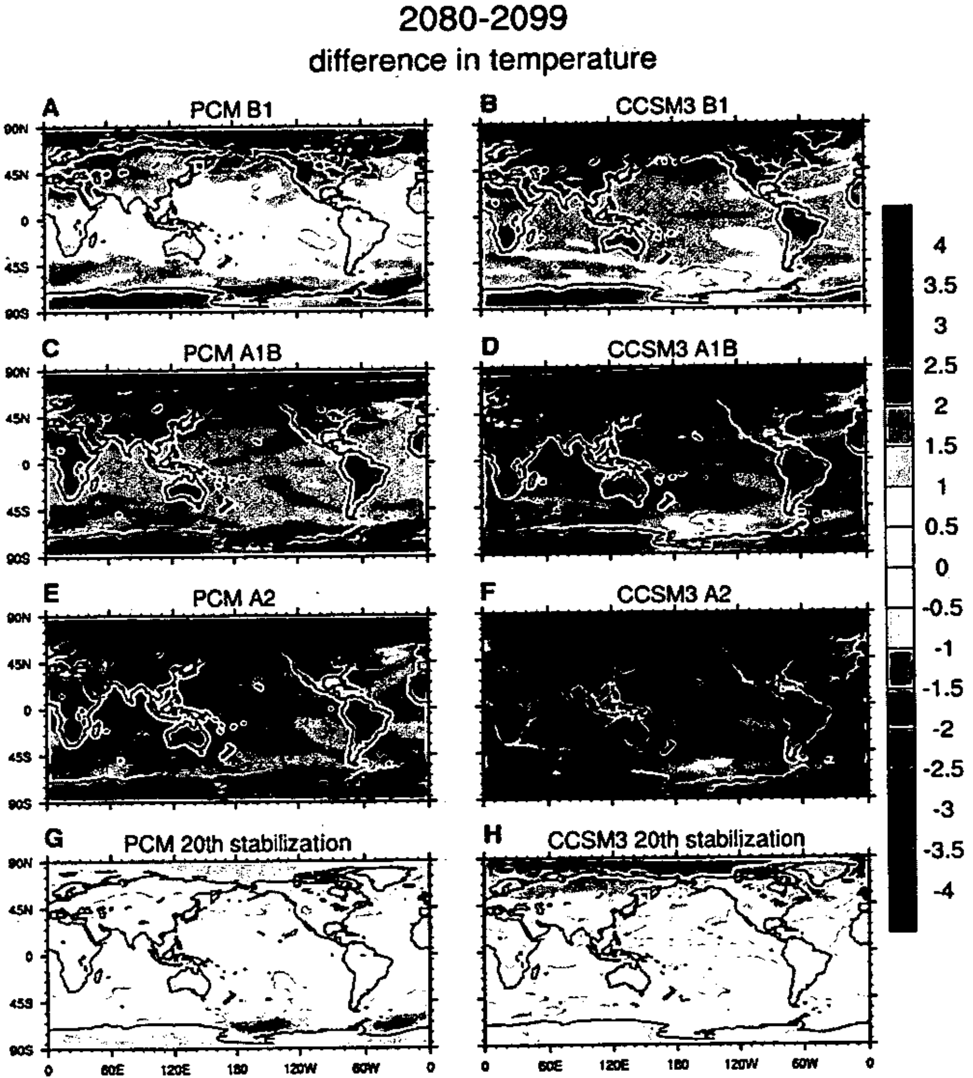

Fig. 2. Surface temperature change for the end of the 21st century (ensemble average for years 2080–2099) minus a reference period at the end of the 20th century (ensemble average for years 1980–1999) from 20th-century simulations with natural and anthropogenic forcings. (**A**) The PCM for the B1 scenario. (**B**) The CCSM3 for the B1 scenario. (**C**) The PCM for the A1B scenario. (**D**) The CCSM3 for the A1B scenario. (**E**) The PCM for the A2 scenario. (**F**) The CCSM3 for the A2 scenario. (**G** and **H**) Temperature commitment for GHG concentrations stabilized at year 2000 values; ensemble average for years 2080–2099 minus a reference period ensemble average for years 1980–1999 from 20th-century simulations. More than 95% of the values in each panel are significant at the 10% level from a Student's *t* test, and a similar proportion exceed 1 SD of the intraensemble standard deviations.

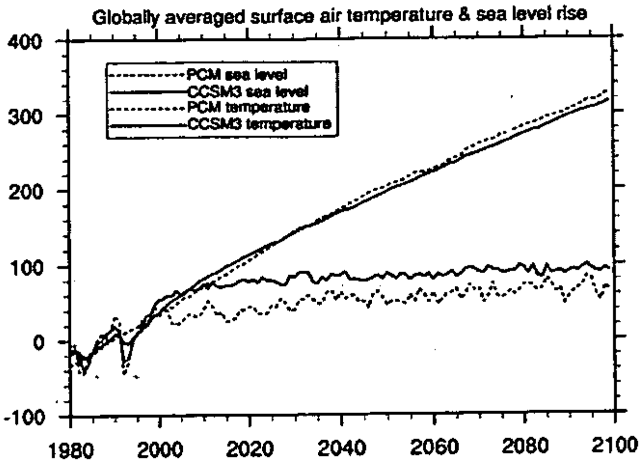

Fig. 3. Ensemble mean percent increase of globally averaged surface air temperature and sea level rise from the two models computed relative to values for the base period 1980–1999 for the experiment in which GHG concentrations and all other atmospheric constituents were stabilized at the end of the 20th century.

ocean circulations (*29*). Thus, in addition to changes in the meridional overturning circulation, the strength of the mean circulation also plays a role (*12*, *24*, *28*). The temperature difference between the upper and lower branches of the Atlantic meridional overturning circulation is smaller in the PCM than in the CCSM3 because of the stronger rate of mean meridional overturning in the PCM that induces a greater heat exchange or ventilation between the upper and deeper ocean. In the PCM, recovery of the meridional overturning is more rapid in the 21st century, thus producing even greater mixing and less warming commitment, whereas the CCSM3 recovers more slowly, with greater warming commitment by the year 2200 and on to 2300.

Geographic patterns of warming (Fig. 2) show more warming at high northern latitudes and over land, generally larger-amplitude warming in the CCSM3 as compared to the PCM, and geographic temperature increases roughly proportional to the amplitude of the globally averaged temperature increases in the different scenarios (Fig. 1B). Slowdowns in meridional overturning in the respective models (which are greater percentage-wise in the CCSM3 than the PCM) are not characterized by less warming over northern Europe in either model. The warming produced by increases in GHGs overwhelms any tendency toward decreased high-latitude warming from less northward heat transport by the weakened meridional overturning circulation in the Atlantic. There is more regional detail in the higher-resolution CCSM3 as compared to the PCM, with an El Niño–like response (*30*) in the equatorial Pacific (greater warming in the equatorial central and eastern Pacific than in the western Pacific) in the CCSM3 as compared to the PCM. This is related to cloud feedbacks in the CCSM3 involving the improved prognostic cloud liquid water scheme, as compared to the diagnostic cloud liquid water formulation in the PCM (*31*).

The warming commitment from the 20th-century stabilization experiments (Fig. 2, bottom) shows the same type of pattern in the forced experiments, with greater warming over high latitudes and land areas. For regions such as much of North America, even after stabilizing GHG concentrations, we are already committed to more than an additional half a degree of warming in the two models. The pattern of the 20th-century stabilization experiments is similar to those produced in the 21st-century stabilization experiments with A1B and B1 (not shown).

Though temperature increase shows signs of leveling off 100 years after stabilization, sea level continues to rise unabated with proportionately much greater increases compared to temperature, with these committed increases over the 21st century more than a factor of 3 greater, percentage-wise, for sea level rise (*32*) than for temperature change (Fig. 3). Thus, even if we could stabilize concentrations of GHGs, we are already committed to significant warming and sea level rise no matter what scenario we follow. These results confirm and quantify earlier studies with simple and global models in that the sea level rise commitment is considerably more than the temperature change commitment.

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Attachment 7
Docket 07A-447E
Glustrom Answer Testimony

Recent Climate Observations Compared to Projections

Stefan Rahmstorf,[1] Anny Cazenave,[2] John A. Church,[3] James E. Hansen,[4] Ralph F. Keeling,[5] David E. Parker,[6] Richard C. J. Somerville[5]

Observations of the climate system are crucial to establish actual climatic trends, whereas climate models are used to project how quantities like global mean air temperature and sea level may be expected to respond to anthropogenic perturbations of the Earth's radiation budget. We compiled the most recent observed climate trends for carbon dioxide concentration, global mean air temperature, and global sea level, and we compare these trends to previous model projections as summarized in the 2001 assessment report of the Intergovernmental Panel on Climate Change (IPCC) (*1*). The IPCC scenarios and projections start in the year 1990, which is also the base year of the Kyoto protocol, in which almost all industrialized nations accepted a binding commitment to reduce their greenhouse gas emissions. Although published in 2001, these model projections are essentially independent from the observed climate data since 1990: Climate models are physics-based models developed over many years that are not "tuned" to reproduce the most recent temperatures, and global sea-level data were not yet available at the time. The data now available raise concerns that the climate system, in particular sea level, may be responding more quickly than climate models indicate.

Carbon dioxide concentration follows the projections almost exactly (Fig. 1), bearing in mind that the measurements shown from Mauna Loa (Hawaii) have a slight positive offset due to the slightly higher CO_2 concentration in the Northern Hemisphere compared with the global mean. The level of agreement is partly coincidental, a result of compensating errors in industrial emissions [based on the IS92a scenario (*1*)] and carbon sinks in the projections.

The global mean surface temperature increase (land and ocean combined) in both the NASA GISS data set and the Hadley Centre/Climatic Research Unit data set is 0.33°C for the 16 years since 1990, which is in the upper part of the range projected by the IPCC. Given the relatively short 16-year time period considered, it will be difficult to establish the reasons for this relatively rapid warming, although there are only a few likely possibilities. The first candidate reason is intrinsic variability within the climate system. A second candidate is climate forcings other than CO_2: Although the concentration of other greenhouse gases has risen more slowly than assumed in the IPCC scenarios, an aerosol cooling smaller than expected is a possible cause of the extra warming. A third candidate is an underestimation of the climate sensitivity to CO_2 (i.e., model error). The dashed scenarios shown are for a medium climate sensitivity of 3°C for a doubling of CO_2 concentration, whereas the gray band surrounding the scenarios shows the effect of uncertainty in climate sensitivity spanning a range from 1.7° to 4.2°C.

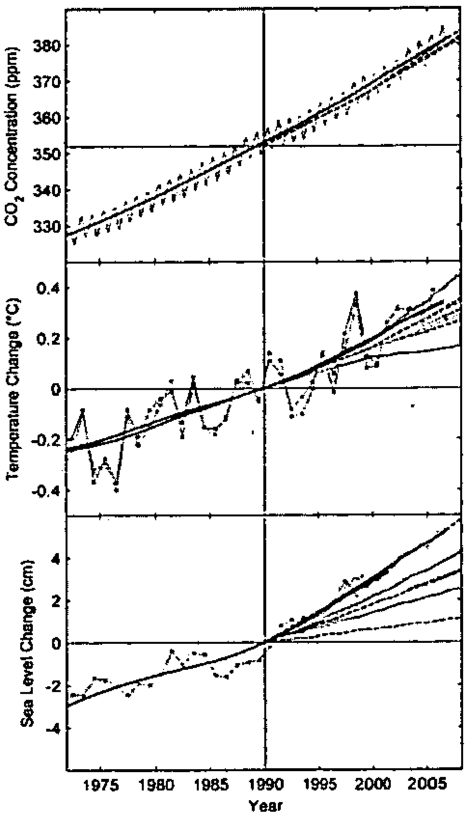

Fig. 1. Changes in key global climate parameters since 1973, compared with the scenarios of the IPCC (shown as dashed lines and gray ranges). **(Top)** Monthly carbon dioxide concentration and its trend line at Mauna Loa, Hawaii (blue), up to January 2007, from Scripps in collaboration with NOAA. ppm, parts per million. **(Middle)** Annual global-mean land and ocean combined surface temperature from GISS (red) and the Hadley Centre/Climatic Research Unit (blue) up to 2006, with their trends. **(Bottom)** Sea-level data based primarily on tide gauges (annual, red) and from satellite altimeter (3-month data spacing, blue, up to mid-2006) and their trends. All trends are nonlinear trend lines and are computed with an embedding period of 11 years and a minimum roughness criterion at the end (*6*), except for the satellite altimeter where a linear trend was used because of the shortness of the series. For temperature and sea level, data are shown as deviations from the trend line value in 1990, the base year of the IPCC scenarios.

Since 1990 the observed sea level has been rising faster than the rise projected by models, as shown both by a reconstruction using primarily tide gauge data (*2*) and, since 1993, by satellite altimeter data (*3*) (both series are corrected for glacial isostatic adjustment). The satellite data show a linear trend of 3.3 ± 0.4 mm/year (1993–2006) and the tide gauge reconstruction trend is slightly less, whereas the IPCC projected a best-estimate rise of less than 2 mm/year. Sea level closely follows the upper gray dashed line, the upper limit referred to by IPCC as "including land-ice uncertainty." The rate of rise for the past 20 years of the reconstructed sea level is 25% faster than the rate of rise in any 20-year period in the preceding 115 years. Again, we caution that the time interval of overlap is short, so that internal decadal climate variability could cause much of the discrepancy; it would be premature to conclude that sea level will continue to follow this "upper limit" line in future. The largest contributions to the rapid rise come from ocean thermal expansion (*4*) and the melting from nonpolar glaciers as a result of the warming mentioned above. Although the ice sheet contribution has been small, observations are indicating that it is rapidly increasing, with contributions both from Greenland and Antarctica [e.g., (*5*)].

Overall, these observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change, in particular for sea level.

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Attachment 8
Docket 07A-447E
Glustrom Answer Testimony

Arctic sea ice decline: Faster than forecast

Julienne Stroeve,[1] Marika M. Holland,[2] Walt Meier,[1] Ted Scambos,[1] and Mark Serreze[1]

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[1] From 1953 to 2006, Arctic sea ice extent at the end of the melt season in September has declined sharply. All models participating in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) show declining Arctic ice cover over this period. However, depending on the time window for analysis, none or very few individual model simulations show trends comparable to observations. If the multi-model ensemble mean time series provides a true representation of forced change by greenhouse gas (GHG) loading, 33–38% of the observed September trend from 1953–2006 is externally forced, growing to 47–57% from 1979–2006. Given evidence that as a group, the models underestimate the GHG response, the externally forced component may be larger. While both observed and modeled Antarctic winter trends are small, comparisons for summer are confounded by generally poor model performance. **Citation:** Stroeve, J., M. M. Holland, W. Meier, T. Scambos, and M. Serreze (2007), Arctic sea ice decline: Faster than forecast, *Geophys. Res. Lett.*, *34*, L09501, doi:10.1029/2007GL029703.

1. Introduction

[2] Climate models are in near universal agreement that Arctic sea ice extent will decline through the 21st century in response to atmospheric greenhouse gas (GHG) loading [*Zhang and Walsh*, 2006]. Through fostering large heat fluxes to the atmosphere, delayed autumn and winter ice growth will promote increases in surface air temperature (SAT) over the Arctic Ocean that are outsized compared to the globe as a whole [*Holland and Bitz*, 2003]. Ice loss will also likely influence mid-latitude patterns of atmospheric circulation and precipitation [e.g., *Sewall and Sloan*, 2004].

[3] From 1953–2006, Arctic sea ice extent at the end of the summer melt season in September has declined at a rate of −7.8%/decade. Over the period of modern satellite observations (1979–2006) the trend is even larger (−9.1% per decade). Trends for March (the climatological maximum ice extent), while much smaller, are also downward, at −1.8% and −2.9%/decade over these two time periods.

[4] Although it is tempting to attribute these statistically significant (99% level) trends to GHG loading, the observed sea ice record has strong imprints of natural variability. An overall rise in SATs over the Arctic Ocean is consistent with ice loss [*Comiso*, 2003], but rates of change depend strongly on season, the time period analyzed, as well as the data set employed [*Serreze and Francis*, 2006]. Variability in the Northern Annular Mode (NAM) and other atmospheric patterns has played a role through impacts on ice circulation [e.g., *Rigor and Wallace*, 2004], as have changes in oceanic heat transport [*Polykov et al.*, 2005; *Shimada et al.*, 2006]. However, a role of GHG loading finds strong support in the recent study of *Zhang and Walsh* [2006]. They show that from 1979–1999 the multi-model mean annual trend from models participating in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) is downward, as are trends from most individual models.

[5] This paper makes three points: (1) if the IPCC AR4 multi-model mean time series properly reflect the response to GHG loading, then both natural variability and forced change have been strong players in the observed September and March trends, with the latter becoming more dominant during 1979–2006; (2) given evidence that that the IPCC models as a group are too conservative regarding their GHG response, the GHG imprint may be larger; and (3) there is more consistency between models and observations regarding much smaller sea ice trends in the Antarctic.

2. Data and Observations

[6] Gridded fields of observed and modeled sea ice concentration were used to derive comparative time series of sea ice extent (summing the area of all grid cells with at least 15% ice concentration) for September and March, representing the climatological minimum and maximum extent in the Arctic and vice versa in the Antarctic.

[7] Observations for the Arctic make use of a blended record described by *Meier et al.* [2007] spanning 1953–2006. The primary source is the Hadley Centre sea ice and sea surface temperature data set (HadISST) [*Rayner et al.*, 2003]. Prior to 1979, estimates of sea ice concentration are based on early satellite observations, aircraft and ship reports. After 1979, reliance is placed on satellite passive microwave observations using the NASA Team sea ice algorithm [*Cavalieri et al.*, 1996] and augmented by *Fetterer and Knowles* [2004]. A significant inconsistency occurs between 1996 and 1997 when the HadISST developers switched to a different source for sea ice concentration. To improve consistency, values for 1997–2006 were reprocessed using updated sea ice concentrations based on the NASA team algorithm. In the Antarctic, use is made of a combined passive microwave record starting in 1973 [see *Cavalieri et al.*, 2003] adjusted to match the ongoing record through 2006.

[8] IPCC AR4 simulations are available from the Program for Climate Model Diagnosis and Intercomparison (PCMDI, available at http://www-pcmdi.llnl.gov/about/index.php). All simulations apply external forcings over

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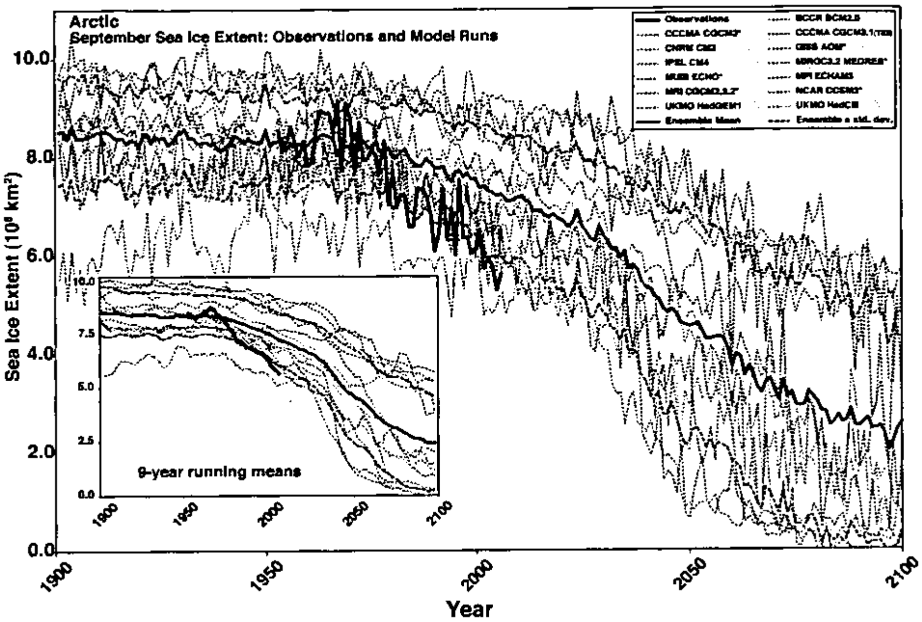

Figure 1. Arctic September sea ice extent (× 10^6 km^2) from observations (thick red line) and 13 IPCC AR4 climate models, together with the multi-model ensemble mean (solid black line) and standard deviation (dotted black line). Models with more than one ensemble member are indicated with an asterisk. Inset shows 9-year running means.

the 20th and 21st centuries. The 20th century integrations specify forcings based on observed records and offline chemical transport models. Different centers use different external forcings over the 20th century. They all include changing greenhouse gas concentrations, but may also include variations in solar input, volcanic forcing and ozone concentrations. To compare model hindcasts with projections through the 21st century, we employ runs with 21st century forcings based on the SRES A1B "business as usual" scenario, where CO_2 is projected to reach 720 ppm by 2100 (compared to approximately 370 ppm in 2000).

[9] Of the 18 models examined for the Arctic and 15 for the Antarctic, we focus on those with mean ice extent within 20% of observations (from 1953–1995 for the Arctic, and 1973–1995 for the Antarctic). This screening resulted in 13 and 18 models for the September and March Arctic comparisons, respectively. For Antarctica, 12 models were used for September and only 5 for March. Some models have more than one ensemble member which are used to generate the ensemble mean for that particular model. A multi-model ensemble mean and its inter-model standard deviation are computed. We also summarize Arctic September trends for three time periods, and the range between different ensemble members. All trends are reported as % per decade.

3. Comparisons for the Arctic

[10] Figure 1 shows September sea ice extent (× 10^6 km^2) from observations and the screened IPCC AR4 models while Table 1 summarizes trends. The observed trend from 1953–2006 is −7.8 ± 0.6 %/decade, three times larger than the multi-model mean trend of −2.5 ± 0.2%/decade. More striking is that none of the models or their individual ensemble members have trends as large as observed for this period. The largest negative trend from any individual model run is −5.4 ± 0.4 %/decade (an ensemble member from NCAR CCSM3).

[11] For the shorter, yet more reliable period of observations based on modern satellite records (1979–2006), both the observed (−9.1 ± 1.5%/decade) and multi-model mean trend (−4.3 ± 0.3%/decade) are larger, but there is again a strong mismatch, and trends from only 5 of 29 individual ensemble runs (from only two models: NCAR CCSM3, UKMO HadGEM1) are comparable to observations. Over the last 11 years (1995–2006), observed and multi-model mean trends are even larger at −17.9 ± 5.9 %/decade and −6.6 ± 0.6 %/decade, respectively, and only 6 individual ensemble members (from NCAR CCSM3, GISS AOM3, and MIUB ECHO) are within 20% of the observed trend.

[12] March trends are not as dramatic (Figure 2), but the modeled values are again smaller. Over 1953–2006, the multi-model mean of −0.6 ± 0.1%/decade is one third of the observed value of −1.8 ± 0.1%/decade and only two simulations (CCCMA GCM3, UKMO HadGEM1) have trends within 20% of observations. Over the satellite era, the observed trend grows to −2.9 ± 0.3%/decade, over twice the model mean value of −1.2 ± 0.2%/decade. Trends from 5 out of 18 models are within 20% of observations, and some show increasing ice extent.

[13] To summarize, there is qualitative agreement between observations and models regarding an overall decline in September ice extent. This points to an imprint of GHG loading [*Zhang and Walsh*, 2006]. Since both observed and modeled September trends have become larger in more recent years, it appears that GHG imprints are growing. Simulations run with pre-industrial GHG concentrations do not produce the magnitude of September trends just discussed.

[14] As expected, observed and modeled March trends are much smaller. In the early stages of a GHG-driven

Table 1. September Ice Extent Trends and Standard Deviations from IPCC AR4 Models and Observations for 1953–2006, 1979–2006, and 1995–2006[a]

IPCC Model ID	Trend 1953–2006, % dec^{-1}	Trend 1979–2006, % dec^{-1}	Trend 1995–2006, % dec^{-1}
BCCR BCM2.0	−0.47 ± 0.35	−2.16 ± 0.89	−2.80 ± 3.92
CCCMACGCM 3	−1.79 ± 0.21	−1.85 ± 0.54	−1.87 ± 2.27
Ensemble mean Range	−2.86,−0.89	−2.53,−1.27	−2.74,−0.30
CCCMA CGCM3.1 (T63)	−2.50 ± 0.25	−2.47 ± 0.64	−4.72 ± 2.54
CNRM CM3	−3.18 ± 0.44	−4.03 ± 1.36	−12.56 ± 4.51
GISS AOM	−2.82 ± 0.36	−4.13 ± 1.17	−5.97 ± 3.43
Ensemble mean Range	−2.94,−2.70	−5.74,−2.49	−10.97,−1.10
IPSL CM4	−4.50 ± 0.63	−7.74 ± 1.51	−8.06 ± 7.15
MIROC3.2 MED	−2.21 ± 0.29	−3.07 ± 0.65	−5.03 ± 1.80
Ensemble mean Range	−2.91,−1.77	−6.04,−1.03	−8.11, ± 0.39
MIUB ECHO	−1.53 ± 0.47	−5.11 ± 1.21	−11.79 ± 2.90
Ensemble mean Range	−1.84,−1.00	−7.18,−3.49	−13.96,−7.96
MPI ECHAM5	−0.82 ± 0.30	−3.25 ± 0.69	−2.68 ± 1.53
Ensemble mean Range	−1.01,−0.64	−4.24,−2.27	−2.72,−2.64
MRI CGCM2.3.2	−1.41 ± 0.19	−1.70 ± 0.66	+6.95 ± 1.89
Ensemble mean Range	−1.65,−1.08	−1.76,−1.65	+4.98, +8.12
NCAR CCSM3	−3.96 ± 0.32	−7.24 ± 0.86	−19.12 ± 1.33
Ensemble mean Range	−5.44,−2.52	−10.84,−2.65	−28.29,−10.66
UKMO HadGEM	−4.85 ± 0.63	−9.03 ± 1.42	−9.66 ± 6.24
UKMO HadCM3	−4.77 ± 0.60	−5.82 ± 1.70	−19.37 ± 6.30
Multi-model Ensemble mean	−2.55 ± 0.16	−4.26 ± 0.25	−6.65 ± 0.59
Satellite/in situ observations	−7.77 ± 0.60	−9.12 ± 1.54	−17.91 ± 5.98

[a]September ice extent trends (%/decade). Results are only given for models with September ice extent within 20% of observations from 1953–1995. When more than one ensemble member was available for a particular model, the range in trends is also given.

warming, ice extent should still recover in the cold season, albeit with thinner ice. With only a small externally-forced trend in extent, effects of internal variability will be especially strong. Indeed, some models actually show increasing ice extent over the observational record. Only with continued GHG loading through the 21st century do all models show declining March ice extent. Nevertheless, the results for September, and to a lesser extent March, indicate decay of the ice cover is proceeding more rapidly than expected based on the model simulations.

4. Synthesis

[15] One interpretation of these results is that the observed September trend is a statistically rare event and imprints of natural variability strongly dominate over any

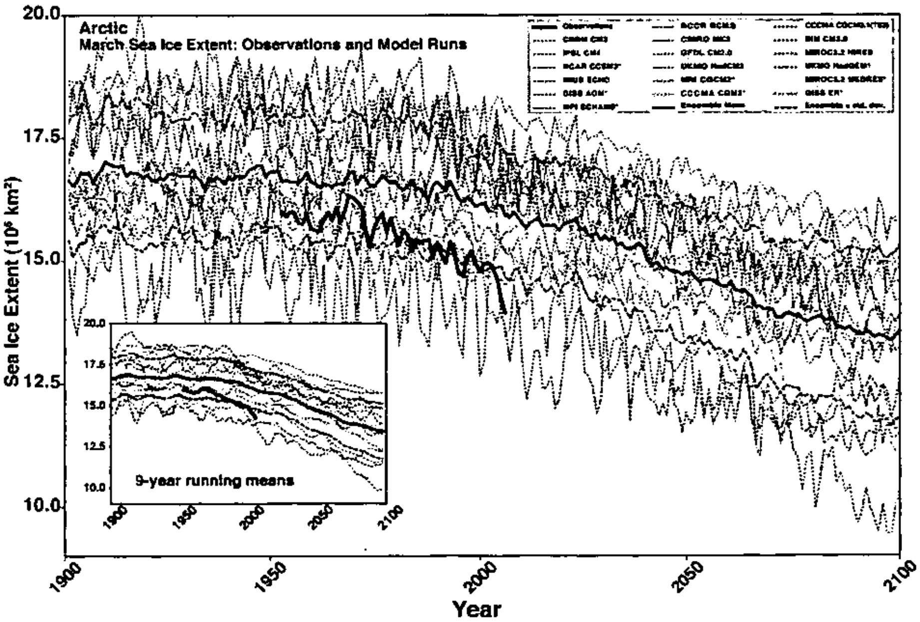

Figure 2. Arctic March sea ice extent (× 10^6 km^2) from observations (thick red line) and 18 IPCC AR4 climate models together with the multi-model ensemble mean (solid black line) and standard deviation (dotted black line). Models with more than one ensemble member are indicated with an asterisk. Inset shows 9-year running means.

effect of GHG loading. In this line of reasoning, one could argue that the sample of model simulations is too small for any of the models to capture the magnitude of the observed trend. If instead we accept that the suite of simulations is a representative sample, an alternative conclusion is that as a group, the models are deficient in their response to anthropogenic forcing.

[16] Some support for the first interpretation, particularly in terms of the strong mismatch between modeled and observed trends over the last 11 years, comes from impacts of the strong positive state of the winter NAM during 1989–1995 (highest in over 100 years). Altered wind patterns flushed much of the Arctic Ocean's store of thick ice into the Atlantic via Fram Strait. While the NAM has subsequently regressed back to a more neutral phase, this episode left the Arctic with thinner ice, more apt to melt in summer, contributing to sharply lower September ice extent in recent years [*Rigor and Wallace*, 2004]. Atmospheric variability in the post-positive NAM era has also favored ice loss [*Maslanik et al.*, 2007] as have changes in Atlantic heat inflow [*Polyakov et al.*, 2005] and the transport of Pacific-derived waters [*Shimada et al.*, 2006]. Assuming these processes reflect natural variability, it is likely that in their absence, the September trend would be smaller than observed.

[17] However, the observed September trend from 1953–2001 of −6.9 ± 0.7%/decade, which eliminates the extremely large ice losses of the last four years, remains much larger than the multi-model mean of −2.2 ± 0.2%/decade and larger than that for any of the individual ensemble members (the largest being −4.3 ± 0.5%/decade). Nevertheless, it seems the more general rise of the winter NAM from the 1960s into the mid-1990s has also contributed to declining ice extent [*Rigor et al.*, 2002].

[18] Regarding the second interpretation, while IPCC AR4 models incorporate many improvements compared to their predecessors, shortcomings remain. Modes of atmospheric variability like the NAM are represented with questionable fidelity. While some studies suggest anthropogenic forcing may favor a positive NAM mode [e.g., *Gillett et al.*, 2003], there is evidence that climate models underestimate NAM-like variability [e.g., *Gillett*, 2005; *Stenchikov et al.*, 2006]. Most models do not parameterize a sub-grid scale ice thickness distribution, which is important for sea ice-related feedbacks [*Holland et al.*, 2006a]. Ocean circulation and vertical structure are often poorly represented [e.g., *Tremblay et al.*, 2007]. Ice-albedo feedback and oceanic heat flux are implicated as critical factors that may cause abrupt reductions in the future Arctic summer ice cover [*Holland et al.*, 2006b]. Notably, the two models that best match observations over the satellite record incorporate relatively sophisticated sea ice models (e.g., with a sub-grid scale ice thickness distribution) [*McLaren et al.*, 2006; *Meehl et al.*, 2006].

[19] If we assume the September time series from the multi-model ensemble mean over the period 1953–2006 allows for a correct depiction of the externally forced trend, we can estimate the forced component of the observed trend. As one estimate, we divide the multi-model mean trend by the observed trend. As another, we compute anomalies of the multi-model mean time-series for each year with respect to 1953, subtract these from the observed time series, and then re-compute the trend from the adjusted observations. These calculations indicate that 33% to 38% of the observed trend is externally forced. The same calculations for the satellite era (1979–2006) point to larger forced contributions of 47% and 57%. Calculations for March indicate that 34 to 39% and 45 to 52% of the trend is externally forced from 1953–2006 and 1979–2006, respectively. However, if the models as a group under-represent the GHG response the forced components must be larger.

[20] The residual time series for individual simulations after removing the multi model-mean trend include a combination of each simulation's natural variability and departures in GHG sensitivity with respect to the multi-model mean. The larger downward residual trends will tend to include those simulations especially sensitive to GHG loading that (by chance) are paired with a downward trend associated with natural variability. Since none of the negative residual trends from 1953–2006 are comparable to that from the observations after removing the forced component, this implies that natural variability in the models is underestimated. However, this again assumes that the multi-model ensemble mean time series correctly represents the GHG response.

[21] It is useful at this point to turn briefly to the Antarctic. In contrast to the Arctic, Antarctic ice extent has shown little change. The observed September (end of austral winter) trend from 1973–2006 is essentially zero. The corresponding March trend is −1.7 ± −2.3%/decade, but given the high variability in the Antarctic March extent, the trend is not statistically significant.

[22] This is consistent with the notion that surface heat in the southern ocean is rapidly removed from the surface, and hence does not readily influence the ice cover. Deeper water in the southern ocean is observed to be warming [*Gille*, 2002], but the majority of the sea ice is in contact with a near-surface cold-water layer formed by the interaction of a katabatic outflow from the continent with coastal water. Where warmer, deeper water is brought near the surface, near the western Antarctic Peninsula, there is a significant downward trend in sea ice extent [*Martinson*, 2005; *Zwally et al.*, 2002]. It is likely that stratospheric cooling from springtime ozone depletion favors the positive phase of the Southern Annular Mode (SAM), promoting a cooler climate over most of the coastline but warming over the Antarctic Peninsula [*Thompson and Solomon*, 2002]. Some IPCC-AR4 models simulate this positive trend in the SAM [e.g., *Raphael and Holland*, 2005].

[23] The multi-model mean for September from 1973–2006 is also small at −1.8 ± 0.2 %/decade, (almost identical to the trend over 1900 to 2100) and modeled trends range widely, with 3 of 12 showing increasing ice extent during the satellite era. While one might argue that the large scatter in the modeled March trends (−6.5%/decade to 0.1%/decade) is broadly consistent with the insignificant observed trend, only the 5 of the 15 models passed the initial performance screening described earlier. The appropriate conclusion is that there are strong shortcomings in the ability of most models to simulate March Antarctic ice extent.

5. Conclusions

[24] Observations indicate a downward trend in September Arctic sea ice extent from 1953–2006 that is larger than any of the IPCC AR4 simulations, and current summer minima

are approximately 30 years ahead of the ensemble mean model forecast. However, the multi-model mean downward trend is still substantial. If this trend is a true representation of forced change by greenhouse gas loading, we conclude that 33–38% of the observed trend is externally forced. For the more recent period 1979–2006, and despite apparent strong impacts of natural processes, these estimates rise to 47–57%. To the extent that the evidence presented here supports the contention that the model GHG response is too weak, the externally forced component may be larger. Either way, it appears that impacts of GHG loading on Arctic sea ice in September are strong, and growing, and have also impacted March ice extent. By contrast, while both observed and modeled Antarctic winter trends are small, few models give reasonable assessments of Antarctic summer ice extent.

[25] The IPCC AR4 models indicate with the "business as usual" SRES A1B scenario, an essentially ice-free Arctic Ocean in September (less than 1.0×10^6 km^2) may be realized anywhere from 2050 to well beyond 2100. However, if the models as a group underestimate the impacts of GHG loading, this transition to a new Arctic state is more likely to occur well within this century. The Arctic has often been viewed as a region where the effects of GHG loading will be manifested early on, especially through loss of sea ice. The sensitivity of this region may well be greater than the models suggest.

[26] **Acknowledgments.** We acknowledge the modeling groups for providing their data for analysis, PCMDI for collecting and archiving model output, and the JSC/CLIVAR Working Group on Coupled Modeling for organizing model data analysis activity. The multi-model data archive is supported by the Office of Science, U.S. Department of Energy. This work was funded under NASA contracts NNG06GB26G, NNG04GH04G, and NSF grants ARC-0229651, OPP-0242125, and ARC-0531040.

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Attachment 9
Docket 07A-447E
Glustrom Answer Testimony

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VOLUME 89 NUMBER 2
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PAGES 13–20

Arctic Sea Ice Extent Plummets in 2007

PAGES 13-14

Arctic sea ice declined rapidly to unprecedented low extents in the summer of 2007, raising concern that the Arctic may be on the verge of a fundamental transition toward a seasonal ice cover.

Arctic sea ice extent typically attains a seasonal maximum in March and minimum in September. Over the course of the modern satellite record (1979 to present), sea ice extent has declined significantly in all months, with the decline being most pronounced in September. By mid-July 2007, it was clear that a new record low would be set during the summer of 2007.

Monthly ice extent for September 2007 was a mere 4.28×10^6 square kilometers, 23% smaller than the previous benchmark of 5.56×10^6 square kilometers set in September 2005. This ice loss relative to September 2005 equates to an area the size of Texas and California combined. Including September 2007, the linear trend in ice extent over the satellite record now stands at -10.7% per decade. Even the August mean of 5.32×10^6 square kilometers broke the previous record of September 2005.

On the basis of an extended time series from the Met Office Hadley Centre [*Rayner et al.*, 2002], we calculated that ice extent in September 2007 was 50% lower than conditions in the 1950s to the 1970s (Figure 1). While ice is now growing in response to autumn and winter cooling, ice extent remains far below normal.

Understanding Sea Ice Loss

Key factors behind this record ice loss include thinning of the pack ice in recent decades [*Nghiem et al.*, 2007a; *Maslanik et al.*, 2007b], making large areas prone to becoming ice-free during the summer melt season, coupled with an unusual pattern of atmospheric circulation.

The ice pack contains a mixture of first-year ice and multiyear ice (ice that has survived for one or more melt seasons). In general, older ice is thicker than younger ice. On the basis of an ice-tracking algorithm, we estimated that the area of ice exceeding 5 years in age decreased by 56% between 1982 and 2007 [*Maslanik et al.*, 2007b]. Within the central Arctic Ocean, the coverage of old ice over this period declined by 88% and ice that is at least 9 years old essentially disappeared. This change toward younger ice translates to a decrease in mean thickness of ice over the Arctic Ocean from 2.6 meters in March 1987 to 2.0 meters in 2007 (Figure 2). While the loss of old ice was accentuated in the 1990s by anomalous wind patterns over the Arctic Ocean that led to increased ice export through Fram Strait, recent loss in the central Arctic is due to old ice failing to survive westward transport north of the Alaskan and eastern Siberian coasts (e.g., through the Beaufort Gyre).

While this thinning set the stage for pronounced summer ice loss, its effects were compounded by a favorable pattern of atmospheric circulation. An anticyclonic pattern over the central Arctic Ocean that formed in early June persisted for 3 months and was coupled with low pressures over central and western Siberia. Satellite data reveal that skies under the anticyclone were predominantly clear, fostering strong melt. Persistent southerly winds between the high- and low-pressure centers gave rise to above-average air temperatures north of Siberia that promoted melt and also transported ice away from the Siberian coast. While this basic pressure pattern has become more frequent in recent years, helping to reduce sea ice cover in the western Arctic [*Maslanik et al.*, 2007a], it was unusually persistent in 2007.

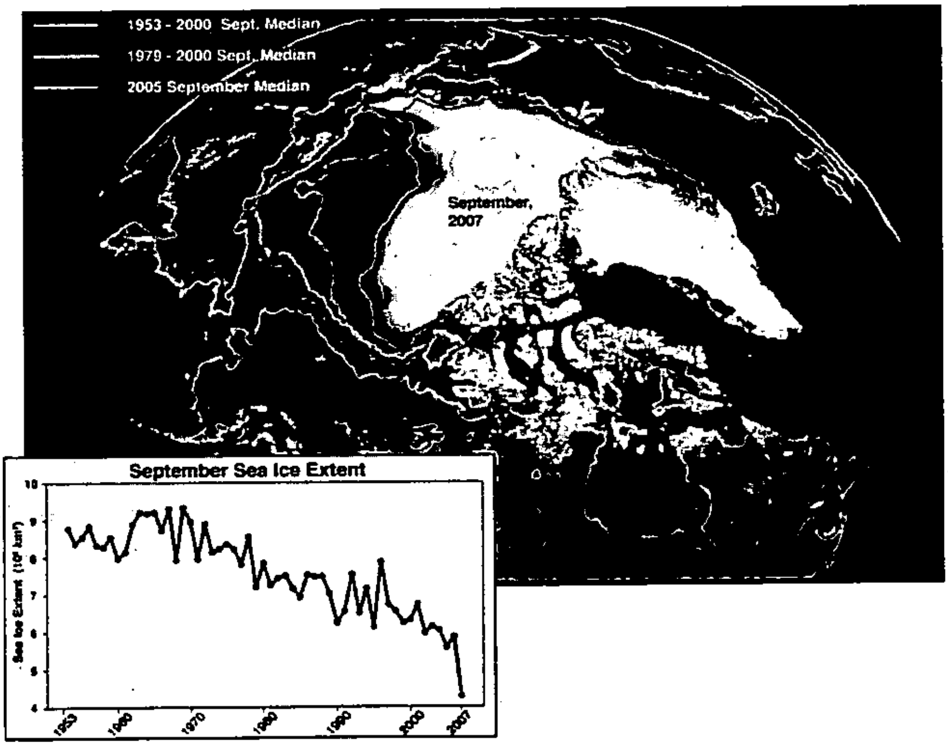

Fig. 1. Sea ice concentration for September 2007, along with Arctic Ocean median extent from 1953 to 2000 (red curve), from 1979 to 2000 (orange curve), and for September 2005 (green curve). September ice extent time series from 1953 to 2007 is shown at the bottom.

BY J. STROEVE, M. SERREZE, S. DROBOT, S. GEARHEARD, M. HOLLAND, J. MASLANIK, W. MEIER AND T. SCAMBOS

Sea surface temperatures (SSTs) over the Chukchi and East Siberian seas have increased since the year 2000. During the summer of 2007, SSTs over parts of these seas reached more than 3.5°C. Increased SSTs and attendant upper ocean warming are consistent with loss of sea ice, allowing for enhancing absorption of solar energy at the ocean surface [*Steele et al.*, 2008]. Increased ocean warmth appears to be inhibiting autumn ice growth. The large summer heat gains in 2007 are likely to be expressed as thinner than normal ice at the start of the 2008 melt season.

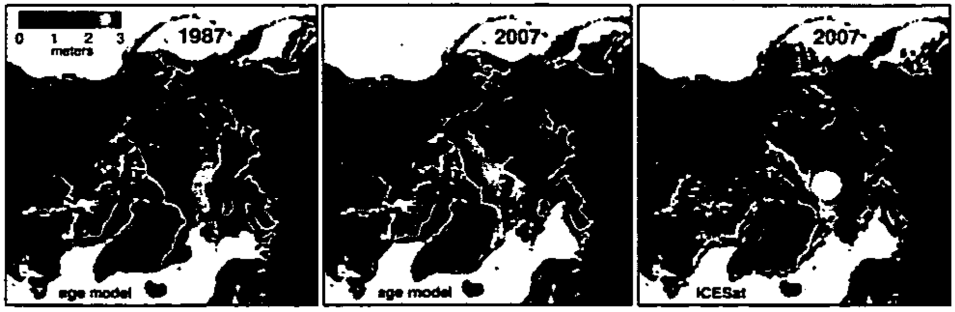

Fig. 2. March sea ice thickness for 1987 and 2007 from Maslanik et al. *[2007b] ice-tracking algorithm, and for March 2007 from ICESat (data provided by D. Yi and J. Zwally, NASA).*

Biogeophysical Implications and Consequences

Even before 2007, ice loss was affecting Arctic residents. Their use of the ice requires detailed knowledge of ice conditions for safety and success in hunting, which is a primary means for providing food and a mainstay of culture and social organization. Dramatic changes described in recent years [*Gearheard et al.*, 2006] include later ice freeze-up and earlier breakup, increased coverage of thin ice over which travel is dangerous, and shifts in the location of the ice edge [e.g., *George et al.*, 2004]. Hunters are responding by altering hunting locations, making greater use of new technologies (e.g., GPS, satellite phones), and avoiding hunting practices that have become too risky [e.g., *Ford et al.*, 2006].

Changing ice conditions are also affecting animal species. Seals and walruses use sea ice for their breeding and pupping grounds. With less ice, seal populations in some areas, such as Canada's Hudson Bay, are decreasing. This affects polar bear populations, who depend on seals for food and use the ice as a platform for hunting them.

Grebmeier et al. [2006] found that a reduction of sea ice, combined with increased air and ocean temperatures, has reduced the summertime extent of the cold pool that maintains food web production in the northern Bering Sea. This has resulted in the northward displacement of fish populations as well as ice-related marine mammals and sea birds, with effects on subsistence harvests and commercial fisheries. *Grebmeier et al.* [2006] argue that similar changes will soon become more widespread.

The extreme conditions of 2007 portend an increased access to the Arctic. Summer 2007 saw the opening of the Northwest Passage, a potential shortcut for shipping between the Atlantic and Pacific oceans. During August and September, the passage was more navigable than at any time since routine monitoring by the Canadian Ice Service began in 1972.

The likelihood of more frequent and longer openings in coming years has raised issues of sovereignty and environmental impacts. The year 2007 saw renewed interest in economically viable oil and gas extraction and efforts by several countries to enhance their seabed economic resource claims of the Arctic Ocean.

The Future of the Sea Ice Cover

Could the summer of 2007 be remembered as the first year of a rapid shift to a seasonally ice-free Arctic Ocean? Simulations from the National Center for Atmospheric Research's Community Climate System Model version 3 (CCSM3), with the middle-range A1B emissions scenario, show that after the ice thins to a more vulnerable state in response to rising greenhouse gas (GHG) concentrations, a reinforcing kick from natural variability may trigger an initial, abrupt ice loss. Rapid decay of the remaining summer ice cover can then ensue due to the albedo feedback mechanism. Other models show similar events [*Holland et al.*, 2006].

Interestingly, data from ICESat (a satellite laser altimeter) show that the record low ice extent seen in September 2007 was preceded by a March ice thickness averaged across the Arctic comparable to the ice thickness preceding the rapid ice loss events in CCSM3. These thickness comparisons raise the intriguing possibility that the stage is now set for rapid loss of the remaining summer ice cover, with the unusual atmospheric circulation of 2007 serving as a trigger.

While natural variability may instead stabilize the ice cover for the next few years, the long-term outlook is disturbing. All models evaluated in the Intergovernmental Panel on Climate Change Fourth Assessment Report show declining September sea ice from 1953 to 2006. While these models point to a role of GHG forcing, as a group they significantly underrepresent the observed trend [*Stroeve et al.*, 2007]. The reasons for this underrepresentation remain to be fully resolved, but overly thick ice in several of the models provides a partial explanation. Given these conservative model results, along with the remarkable events of 2007, our view is that a seasonally ice-free Arctic Ocean might be realized as early as 2030.

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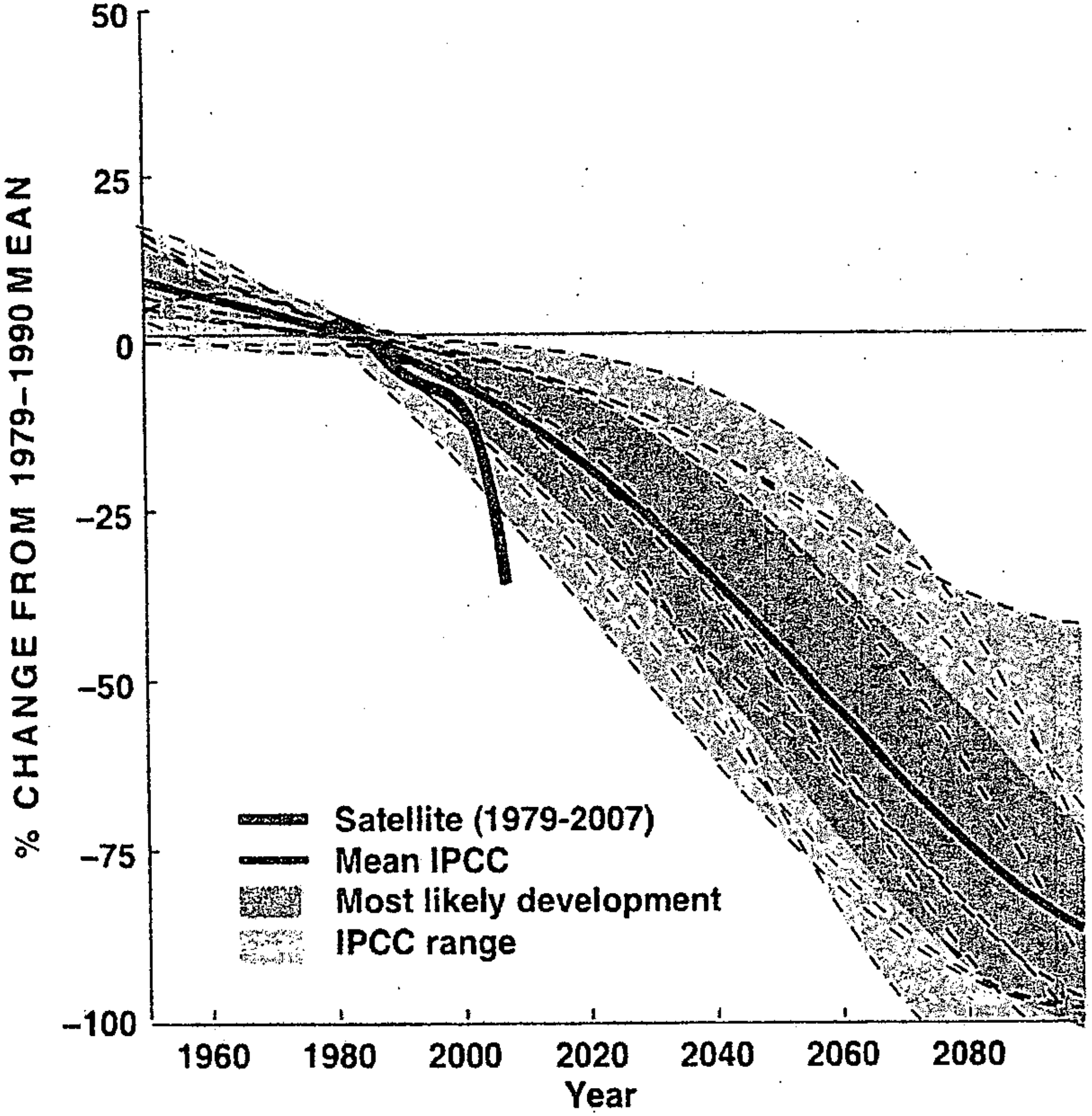
Attachment 10
Docket 07A-447E
Glustrom Answer Testimony



Arctic sea ice summer extent loss compared to IPCC projections

Arctic ice extent loss to September 2007 compared to IPCC modelled changes using the SRES A2 CO2 scenario (IPCC high CO2 scenario). September loss data from satellite observations. Data smoothed with a 4th order polynomial to smooth out the year-to-year variability. Chart courtesy Dr Asgeir Sorteberg, Bjeknes Centre for Climate Research and University Center at Svalbard, Norway.

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L19707, doi:10.1029/2007GL030905, 2007

Attachment 11
Docket 07A-447E
Glustrom Answer Testimony

Long term fate of anthropogenic carbon

Alvaro Montenegro,[1] Victor Brovkin,[2] Michael Eby,[1] David Archer,[3] and Andrew J. Weaver[1]

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[1] Two earth-system models of intermediate complexity are used to study the long term response to an input of 5000 Pg of carbon into the atmosphere. About 75% of CO_2 emissions have an average perturbation lifetime of 1800 years and 25% have lifetimes much longer than 5000 years. In the simulations, higher levels of atmospheric CO_2 remain in the atmosphere than predicted by previous experiments and the average perturbation lifetime of atmospheric CO_2 for this level of emissions is much longer than the 300–400 years proposed by other studies. At year 6800, CO_2 concentrations between about 960 to 1440 ppmv result in global surface temperature increases between 6 and 8°C. There is also significant surface ocean acidification, with pH decreasing from 8.16 to 7.46 units between years 2000 and 2300. **Citation:** Montenegro, A., V. Brovkin, M. Eby, D. Archer, and A. J. Weaver (2007), Long term fate of anthropogenic carbon, *Geophys. Res. Lett.*, *34*, L19707, doi:10.1029/2007GL030905.

1. Introduction

[2] Most studies of the future impact of anthropogenic CO_2 on the climate system focus their attention on the next few decades, or at most up to the end of the 21st century. These periods are comparable to policy planning and implementation times and comprehensible in terms of human life span. The less scrutinized climate response on longer time scales (10^3 to 10^4 years) can offer insight into pertinent scientific questions, like the onset of the next glaciation [*Archer and Ganopolski*, 2005] or how the dynamics of sediment $CaCO_3$ influence atmospheric CO_2 concentrations. Also, as in the cases of nuclear wastes or human-induced species extinctions [*Novacek and Cleland*, 2001], the depth of the impact in time could be used in the social and political arenas as a way to quantify the seriousness of such impact.

[3] Different processes, with very distinct time scales, are responsible for determining the perturbation lifetime of anthropogenic CO_2. For time scales of decades to centuries, the response to excess CO_2 includes ocean uptake, changes in land carbon associated with increase in soil respiration, CO_2 fertilization and alterations to vegetation cover. In scales of centuries to about 5000–10000 years, ocean uptake becomes dominant, with $CaCO_3$ compensation [*Broecker and Peng*, 1987] playing a significant role in the longer time scales within this interval. Models that have simulated the long time response to the consumption of all available fossil fuel reserves (~5000 PgC [*Rogner*, 1997]) have indicated that roughly 80% of the anthropogenic input has an average perturbation lifetime in the atmosphere of approximately 300–450 years. The remaining 20% could remain in the atmosphere for more than 5 thousand years after emissions cease and the atmosphere would still hold 5% to 10% of the anthropogenic CO_2 hundreds of thousands of years into the future [*Archer et al.*, 1997, 1998; *Archer*, 2005; *Lenton and Britton*, 2006]. Apart from the rate with which CO_2 is removed from the atmosphere, the fraction of the perturbation remaining in the atmosphere depends on the ocean's buffering capacity, which is inversely proportional to the magnitude of the perturbation. The result is that the portion of the anthropogenic CO_2 left in the atmosphere increases as emissions increase [*Sarmiento and Gruber*, 2006; *Archer et al.*, 1997].

[4] Here we use two earth-system models of intermediate complexity (EMIC) to analyze the long term (4500 years after the end of emissions) response of the climate system to an anthropogenic input of 5000 PgC into the atmosphere. The aim is to describe the fate of anthropogenic CO_2, its pathways through the different components of the carbon system and the mechanisms responsible for this partition. The effects of climate change on the carbon cycle are also analyzed.

2. Model Descriptions

[5] CLIMBER-2 is a coupled climate-carbon cycle model with a 2.5-dimensional dynamical-statistical atmosphere model with a spatial resolution of 10° latitude and 51° longitude, a 3-basin, zonally-averaged ocean model and a sea-ice model with latitudinal resolution of 2.5° [*Sitch et al.*, 2005; *Petoukhov et al.*, 2000]. The oceanic carbon cycle includes standard inorganic biogeochemistry [*Brovkin et al.*, 2002] and a marine biota NPZD model [*Six and Maier-Reimer*, 1996]. CLIMBER-2 also includes a dynamic sediment model [*Archer et al.*, 1998] which allows for $CaCO_3$ compensation. Due to its box-like form this model overestimates the deep ocean volume. To correct for this factor in the oceanic biogeochemistry module, a globally-averaged hypsometric function is taken into account in calculation of deep sea floor and volume [*Brovkin et al.*, 2007].

[6] The University of Victoria Earth System Climate Model (UVic ESCM) has horizontal resolution of 1.8° × 3.6°. It consists of a vertically integrated, energy-moisture balance, atmospheric model, coupled to the MOM2 ocean general circulation model with 19 vertical levels and a dynamic-thermodynamic sea-ice model [*Weaver et al.*, 2001]. The terrestrial carbon model is a modified version of the MOSES2 land surface model and the TRIFFID

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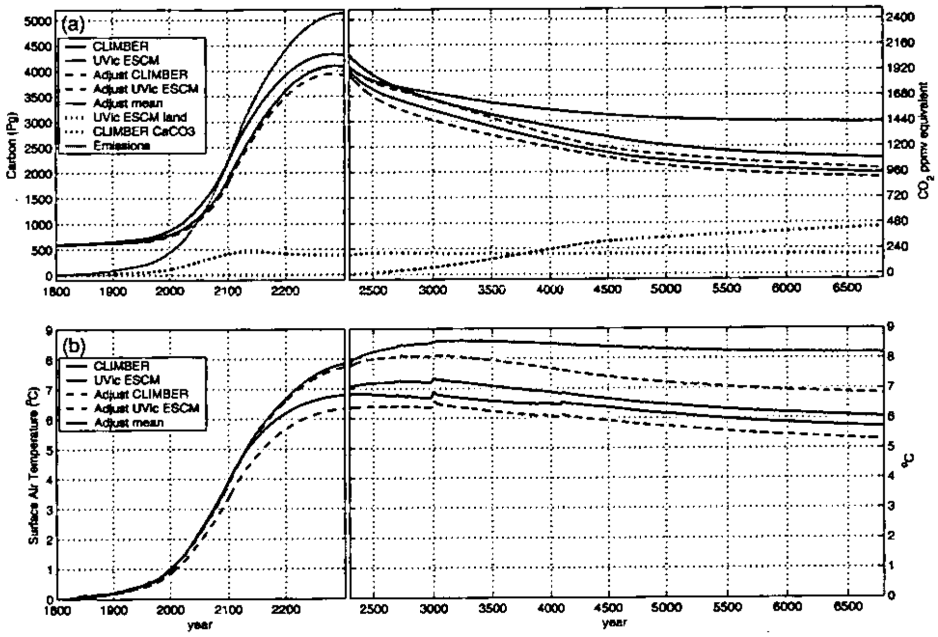

Figure 1. (a) Carbon stocks for the coupled experiments. Emissions, green; atmospheric carbon for CLIMBER-2, solid blue; adjusted CLIMBER-2, dashed blue; UVic, solid red; adjusted UVic, dashed red; average of adjusted values, solid black; UVic land carbon anomaly, dotted blue; CLIMBER-2 carbon from dissolved $CaCO_3$ anomaly, dotted red. Gap indicates change in temporal resolution at year 2300. On the right vertical axis carbon stocks are expressed in terms of equivalent atmospheric CO_2 concentration. (b) Surface air temperature anomaly, same colour coding as in Figure 1a.

dynamic vegetation model [*Meissner et al.*, 2003; *Matthews et al.*, 2005]. Ocean inorganic carbon is based on the OCMIP abiotic protocol. Ocean biology is simulated by an ecosystem model of nitrogen cycling [*Schmittner et al.*, 2005; *Oschlies and Garçon*, 1999]. Water, energy and carbon are conserved with no flux adjustments. It should be noted that in a recent carbon cycling intercomparison project, the response of atmospheric carbon of both CLIMBER and UVic models to anthropogenic CO_2 emissions of about 2200 Pg C were well within the range of the other nine models analyzed [*Friedlingstein et al.*, 2006].

3. Experiments

[7] Both models are integrated for 5000 years starting from equilibrium at year 1800. The simulations are forced with CO_2 emissions prescribed by historical values up to the year 2000 [*Marland et al.*, 2006] and according to the IPCC A2 scenario [*Intergovernmental Panel on Climate Change*, 2000] from 2000 to 2100. After year 2100, emissions decline linearly to zero at 2300, resulting in 5134 Pg of carbon (Pg C) being added to the system (Figure 1a).

[8] To examine the climate-carbon cycle feedback, two distinct integrations are performed with each model. In one set (coupled simulations), the radiative forcing associated with atmospheric CO_2 concentration is taken into account; in the other set (uncoupled simulations), atmospheric CO_2 concentrations have no direct effect on the radiative forcing.

[9] The CLIMBER-2 simulations reported here did not include terrestrial carbon dynamics. A rationale was an absence of land use dynamics and the uncertainty in future land use scenario which can turn land into a sink or a source [*Sitch et al.*, 2005]. While the UVic ESCM model takes into consideration biological $CaCO_3$ dynamics in the water column, it has no ocean sediment component and no input of $CaCO_3$ into the ocean due to weathering.

[10] To compare model results, adjustments are made to both CLIMBER-2 and UVic ESCM atmospheric CO_2. These adjustments are conducted a *posteriori* and do not influence the numerical experiments. The assumption is that the missing components act as sinks to atmospheric carbon.

[11] The CLIMBER-2 results are adjusted by removing from the atmosphere the amount of carbon equivalent to the UVic ESCM terrestrial carbon anomaly. The adjustment to the UVic ESCM consists in reducing its atmospheric CO_2 in direct proportion to the amount of $CaCO_3$ dissolved from CLIMBER-2's sediment and weathering model. This is because dissolution of $CaCO_3$ modifies the alkalinity in such a way as to eventually cause the draw down of an equivalent amount of CO_2. In reality this draw down would take some time to occur, depending on mixing the alkalinity signal from the sediments to the surface, so this is an overestimate (or at least a faster estimate) of the draw down. Both adjustments are time dependent (Figure 1a). The adjusted atmospheric carbon is used to generate adjusted surface air temperature series based on the time dependent atmospheric temperature to carbon ratios (Figure 1b).

[12] Had the processes associated with the adjustments been represented in the simulations the atmospheric CO_2 values during the integrations would have been lower. This in turn would have resulted in smaller oceanic and terrestrial carbon uptake than actually recorded. The simulations then will overestimate carbon draw down and the adjusted values should be considered a lower bound on atmospheric carbon stocks. This is confirmed for the UVic ESCM model by an experiment where the dissolved $CaCO_3$ from CLIMBER-2

Table 1. Comparison to Previous Experiments[a]

Emissions Pg C	CO_2 Year 3000, ppmv	CO_2 Year 6800, ppmv	Land Carbon	Sediment $CaCO_2$	Ocean Dynamics[b]	Reference
5134	1708 [0.58]	1427 [0.47]	yes	no	yes	UVic ESCM
5134	1642 [0.55]	985 [0.29]	yes	†[c]	yes	Adj. UVic ESCM
5134	1617 [0.54]	1063 [0.32]	no	yes	yes	CLIMBER-2
4000	∼1200 [0.48]	-	yes	no	yes	[*Lenton et al.*, 2006]
5134	1423 [0.46]	886 [0.25]	†[c]	yes	yes	Adj. CLIMBER-2
4546	∼1180 [0.41]	∼700 [0.19]	no	yes	no	[*Archer et al.*, 1998]
6579	∼1200 [0.38]	-	yes	yes	yes	[*Mikolajewicz et al.*, 2007]
5000	1120 [0.35]	833 [0.23]	no	yes	no	[*Archer*, 2005]
4173	∼918 [0.32]	∼640[.18]	no	yes	yes	[*Ridgwell and Hargreaves*, 2005]
4546	923 [0.29]	∼700 [0.19]	yes	yes	no	[*Lenton and Britton*, 2006]
3817	∼343 [0.18]	-	yes	yes	yes	[*Mikolajewicz et al.*, 2007]

[a] Values preceded by ∼ were obtained by visual inspection of published figures. Numbers in brackets give the fraction of anthropogenic CO_2 present in the atmosphere.

[b] Ocean dynamics refers to the model's capability of representing changes in ocean state with climate.

[c] These processes are not considered by the model but represented through the adjustments described in the text. The CLIMBER-2 and UVic ESCM results are from the coupled simulations.

was introduced into the UVic ESCM ocean as the simulation progressed. At year 6800, the atmospheric carbon stock of this experiment (not shown) had 400 Pg more carbon than the adjusted UVic ESCM value and the global surface temperature was 0.52°C higher than the adjusted UVic ESCM temperature. The use of these adjustments is a compromise and presents some problems. Most notably, while we show adjusted results for the two models, these are not independent from each other. Also, the adjustments assume that the missing component on each model would have responded to the CO_2 forcing in the same manner as the other model did.

4. Results and Discussion

[13] The uptake by vegetation is characterized by the rapid increase in land carbon anomaly over the 21st century, which reaches a peak of 458 Pg C in year 2142. Between the end of emissions and the year 6800 the UVic ESCM land acts as a small source to the atmosphere, with terrestrial carbon anomaly declining 3% (from 389 Pg to 377 Pg). Both models also have rapid initial oceanic uptake, with ocean carbon increasing by 700 Pg between the years 2000 and 2150 (not shown).

[14] The $CaCO_3$ dissolution modelled by CLIMBER-2 is small at the beginning of the simulation but starts increasing at around year 2500, with peak dissolution rates occurring between years 3500 and 4500. By around year 4500 all sediment $CaCO_3$ has been depleted and any further $CaCO_3$ dissolution is associated with the input from continental weathering.

[15] The introduction of 5000 Pg C as CO_2 into the models generate adjusted global mean surface air temperatures ∼6°C warmer and nearly one third of the anthropogenic CO_2 still present in the atmosphere 4500 years after emissions stop (Figure 1b). Based on a exponential decay fit to the average of the adjusted CO_2 curves starting at year 2300, 75% of the anthropogenic CO_2 has an average perturbation lifetime of approximately 1800 years. The removal of the remaining 25% of the anthropogenic input requires silicate weathering, which has an estimated time scale of several hundred thousand years [*Archer*, 2005].

[16] In millennial time scale simulations which account for the effects of both sediment CaCO3 and vegetation dynamics, the anthropogenic CO_2 fraction present in the atmosphere at year 3000 range from 0.18 to 0.55. At year 6800, the range is from 0.19 to 0.29 (Table 1). The values from the UVic ESCM and CLIMBER-2 are at the higher limits of this distribution. The total amount of anthropogenic CO_2, the rate of emissions and the oceanic response to climate vary significantly among the simulations that make up this range, complicating comparisons between their results.

[17] In agreement with previous simulations [*Caldeira and Wickett*, 2003], global mean surface pH decreases, going from the initial state of 8.16 units to 7.42 units(UVic) and 7.41 units (CLIMBER) at the year 2300. It has been estimated [*Orr et al.*, 2005] that surface pH levels of 7.8 to 7.9 would bring the aragonite saturation depth to the surface in the Southern Ocean, with large negative impacts to the biota.

4.1. Effects of Ocean Dynamics

[18] Decreases in CO_2 solubility due to higher oceanic temperatures [*Archer*, 2005] and changes in circulation and water mass distribution are factors influencing the response of atmospheric CO_2 to climate. While present results cannot be used to isolate and quantify the impact of changes in ocean dynamics, they offer insight into some potentially pertinent processes.

[19] One of these relate to changes in the overturning circulation. The Atlantic meridional overturning decreases by about 30% for both models between years 2005 and 2300, going from 19.5 to 13.2 Sv in the UVic ESCM and from 20.4 to 14.7 Sv in CLIMBER. In separate experiments (not shown), complete shut down of the overturning in the UVic ESCM model generates a positive feedback on atmospheric CO_2 on the order of 3%. While smaller overturning rates could have contributed to a slow down in the oceanic invasion of atmospheric CO_2, this was probably not the dominant factor.

[20] As in previous experiments [*Friedlingstein et al.*, 2001; *Bopp et al.*, 2005; *Ridgwell and Hargreaves*, 2005], the warming simulations registered a reduction in the global

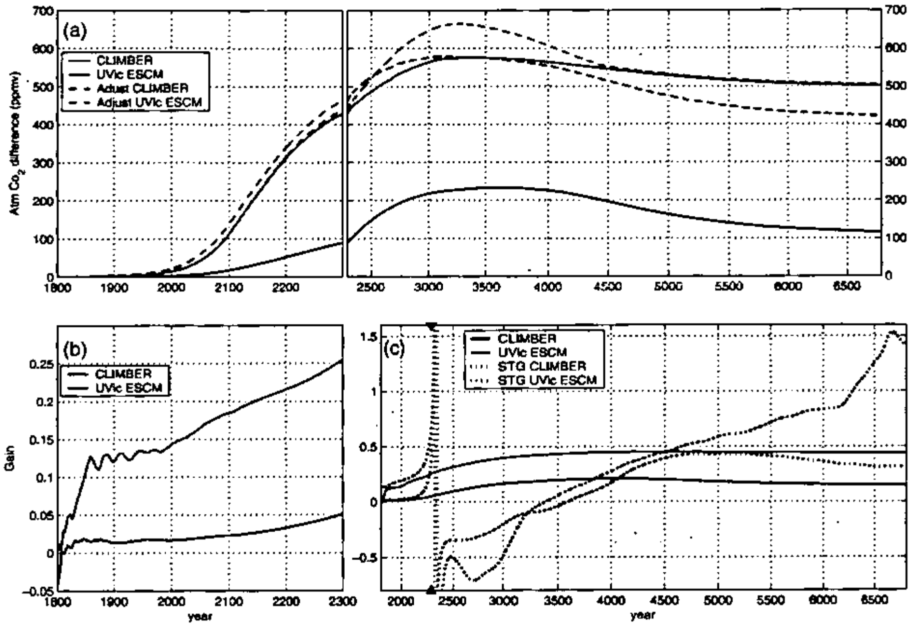

Figure 2. (a) Atmospheric CO_2 concentration difference between coupled and uncoupled simulations, same colour coding as in Figure 1. (b) Atmospheric carbon gain for the first 500 years of the simulation. (c) Atmospheric carbon gain for the whole experiment (solid lines) and the short term gain starting at year 2400 (dotted lines). The black triangles at year 2300 mark the end of the period shown in Figure 2b.

export of near surface particulate organic mater, which decreased by 10% (UVic) and by 4% (CLIMBER) between the years of 2005 and 2300. Part of this change could be related to the stronger stratification in the warmer climate state. In the UVic ESCM experiment, near surface stratification at year 2300 (estimated based on the mean buoyancy frequency of the first 400 m) is 25% to 40% larger than in the year 2000. Stronger stratification leads to less nutrient upwelling and warmer surface temperatures lead to greater nutrient recycling, reducing biological export to deeper waters. An increase in stratification would also reduce the physical downward transport of dissolved inorganic carbon.

4.2. Climate-Carbon Feedback

[21] The climate-carbon feedback of the UVic ESCM model is larger than CLIMBER-2's (Figure 2a), in part due to CLIMBER-2's lack of terrestrial carbon feedbacks which dominate the feedback of the UVic ESCM model during the first few hundred years. Even with its terrestrial carbon cycle, CLIMBER-2 shows a lower overall carbon-climate feedback compared to the UVic ESCM model [*Friedlingstein et al.*, 2006]. The adjusted CLIMBER-2 values (Figure 2a), are similar to the UVic ESCM feedback values.

[22] The larger input of carbon from $CaCO_3$ dissolution of the uncoupled run up to about year 4500 is caused by differences in sediment $CaCO_3$ dissolution and is associated with the higher CO_2 concentrations and the cooler temperatures of the deep ocean in the CLIMBER-2 uncoupled simulations. In both coupled and uncoupled experiments, sediment $CaCO_3$ is depleted at around year 4500. After this time, $CaCO_3$ dissolution is controlled by the terrestrial input from weathering, at the prescribed rate 0.12 Pg C/year. The end of sediment $CaCO_3$ dissolution is reflected in the convergence of the UVic ESCM original and adjusted atmospheric CO_2 differences (Figure 2a).

[23] The gain of the climate-carbon feedback (g) was estimated following [*Friedlingstein et al.*, 2006, equation 1]:

$$g = 1 - \frac{\Delta C_A^u}{\Delta C_A^c} \qquad (1)$$

where ΔC_A^u and ΔC_A^c refer, respectively, to the uncoupled and coupled atmospheric CO_2 anomaly. The gain varies in time in all experiments and reaches values larger than 0.4 in the UVic ESCM experiments. (Figures 2b and 2c).

[24] As defined by equation 1, with anomalies referenced to initial CO_2 concentrations, the gain index is not well suited to deal with periods of declining atmospheric CO_2. We estimate the climate gain over the latter portion of the simulation using a slightly different calculation. We define "short term gain" using equation 1 but calculating $\Delta\ C_A^u$ and ΔC_A^c locally, as anomalies over the past 10 years and not referenced to the initial atmospheric concentration. Short term gain values are close to the regular estimate in the beginning of the simulation but tend to positive and then negative infinity as it approaches and goes over the inflection point of maximum atmospheric carbon. During the period of diminishing atmospheric CO_2, the short term gain shows that both UVic ESCM and CLIMBER-2 uncoupled experiments have larger drawdown up to about years 3400–3500 (negative short term gain, Figure 2c). This is caused by larger drawdown due to the lower water temperatures of the uncoupled simulations. After year 3500, the short term gain is positive, a consequence of a reduction of the uncoupled oceanic drawdown and the larger atmospheric concentrations of the coupled experiments.

5. Summary

[25] In experiments that have emissions similar to all known fossil fuel reserves it is estimated that 75% of the

anthropogenic CO_2 has an average perturbation lifetime of ~1800 years with the remaining 25% having average lifetime much longer than 5000 years. This conclusion is not dependent on the adjustments performed on model results. Global temperatures are shown to raise between 6 and 8°C and remain at least 5°C higher than preindustrial for more than 5000 years. These conclusions are supported by two very different EMICs and are considered to be conservative estimates.

[26] The results also suggest that changes in ocean dynamics due to climate change may cause a positive long term feedback for atmospheric CO_2. Over the next 300 years, the modelled carbon gain due to climate-carbon feedback tends to increase, with values at year 2300 that range from ~5% to ~25%. The higher value is mainly due to much lower terrestrial carbon stocks registered under warmer climate.

[27] Our simulations show higher levels of atmospheric CO_2 remaining in the atmosphere longer than predicted by previous modelling experiments [*Archer*, 2005; *Archer and Ganopolski*, 2005; *Lenton and Britton*, 2006]. The average perturbation lifetime of 1800 years is much longer than the 300–450 years proposed by some other studies [*Archer et al.*, 1997; *Archer*, 2005]. Given the large differences in model type and experiment set up between the present and previous experiments, these comparisons should be made with care. While there still is a great deal of uncertainty at these longer timescales, our results indicate that the long term consequences of anthropogenic climate change may be much greater than previously thought.

[28] **Acknowledgments.** We are grateful for funding from CFCAS through its Polar Climate Stability and Operating grant programs.

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Attachment 12
Docket 07A-447E
Glustrom Answer Testimony

Stabilizing climate requires near-zero emissions

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[1] Current international climate mitigation efforts aim to stabilize levels of greenhouse gases in the atmosphere. However, human-induced climate warming will continue for many centuries, even after atmospheric CO_2 levels are stabilized. In this paper, we assess the CO_2 emissions requirements for global temperature stabilization within the next several centuries, using an Earth system model of intermediate complexity. We show first that a single pulse of carbon released into the atmosphere increases globally averaged surface temperature by an amount that remains approximately constant for several centuries, even in the absence of additional emissions. We then show that to hold climate constant at a given global temperature requires near-zero future carbon emissions. Our results suggest that future anthropogenic emissions would need to be eliminated in order to stabilize global-mean temperatures. As a consequence, any future anthropogenic emissions will commit the climate system to warming that is essentially irreversible on centennial timescales. **Citation:** Matthews, H. D., and K. Caldeira (2008), Stabilizing climate requires near-zero emissions, *Geophys. Res. Lett.*, *35*, L04705, doi:10.1029/2007GL032388.

1. Introduction

[2] Avoiding dangerous anthropogenic interference in the climate system has been a key international policy goal since the publication of the United Nations Framework Convention on Climate Change in 1992 [*United Nations*, 1992]. Since that time, scientific and policy literature concerning climate change mitigation has been centered around stabilizing concentrations of greenhouse gases in the atmosphere [*Wigley*, 2005; *Stern*, 2006; *Meehl et al.*, 2005]. However, stable greenhouse gas concentrations do not equate to a stable global climate. Model simulations have demonstrated that global temperatures continue to increase for many centuries beyond the point of CO_2 stabilization [e.g., *Matthews*, 2006]. As such, we are committed to future warming, even with stable greenhouse gas concentrations [*Hansen et al.*, 1985; *Wigley*, 2005; *Meehl et al.*, 2005]. This implies that stabilizing global climate within the next several centuries would require decreasing, rather than stabilized, greenhouse gas levels. In this paper, we demonstrate that to achieve atmospheric carbon dioxide levels that lead to climate stabilization, the net addition of CO_2 to the atmosphere from human activities must be decreased to nearly zero.

[3] Recent research has highlighted the very long lifetime of anthropogenic carbon in the atmosphere; while approximately half of the carbon emitted is removed by the natural carbon cycle within a century, a substantial fraction of anthropogenic CO_2 will persist in the atmosphere for several millennia [*Archer*, 2005]. A recent analysis by *Montenegro et al.* [2007] found that 25% of emitted CO_2 will have an atmospheric lifetime of more than 5000 years. Studies of the climate response to declining CO_2 concentrations have generally assumed that global temperatures will decrease in response to decreases in atmospheric CO_2 [*Friedlingstein and Solomon*, 2005]. However, as we demonstrate here, because of the high heat capacity of the ocean, global temperatures may not parallel decreases in atmospheric concentrations of greenhouse gases, but rather will increase and remain elevated for at least several centuries. Thus, fossil fuel CO_2 emissions may produce climate change that is effectively irreversible on human timescales.

[4] In this paper, we present a series of idealized climate simulations to assess the centennial-scale climate response to anthropogenic CO_2 emissions, and conversely, to quantify the emissions requirements for climate stabilization. We have used the University of Victoria Earth System Climate Model (UVic ESCM), an intermediate complexity global climate model which includes an interactive global carbon cycle. We present first a series of 500-year simulations forced by CO_2 emissions, in which a specified amount of carbon was added to the atmosphere either instantaneously, or following a business-as-usual emissions scenario. The model was then run for up to 500 years without additional carbon emissions to determine the persistence of climate warming resulting from past emissions. Second, we specified hypothetical future temperature trajectories for the UVic ESCM, and controlled emissions such that the specified future temperature changes were achieved. We used this method to estimate the CO_2 emissions requirements for climate stabilization at levels between 1 and 4 degrees above pre-industrial temperatures.

2. Methods

[5] We used version 2.8 of the UVic ESCM, an intermediate complexity coupled climate-carbon model with spatial resolution of 1.8 degrees latitude by 3.6 degrees longitude. The ocean is a 19-layer general circulation model, driven by specified wind stress at the surface and coupled to a dynamic-thermodynamic sea-ice model. The atmosphere is a vertically-integrated single layer model; both temperature and moisture are transported horizontally by a combination of diffusion and advection by specified wind fields [*Weaver et al.*, 2001]. Terrestrial vegetation distributions are calculated dynamically as a function of simulated regional climatic conditions, with the result that vegetation is able to both respond to and affect simulated climate changes

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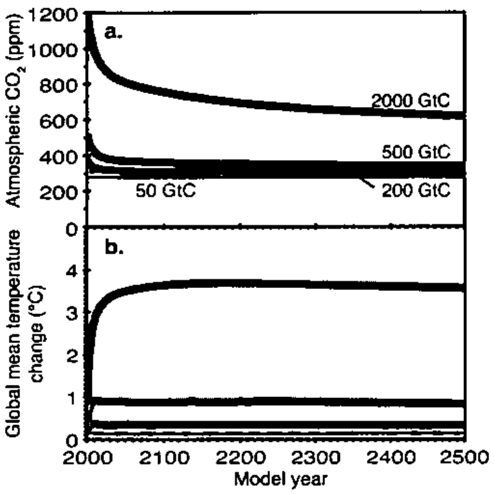

Figure 1. Climate response to an instantaneous carbon emission pulse at year zero. (a) Simulated atmospheric CO$_2$. (b) Simulated change in global mean surface air temperature, relative to pre-industrial.

[*Meissner et al.*, 2003]. Additionally, the UVic ESCM includes an interactive global carbon cycle [*Schmittner et al.*, 2008] which allows for the direct simulation of coupled carbon cycle and climate responses to anthropogenic carbon emissions. The version of the UVic ESCM used here does not include a sedimentary carbon model; as such we have restricted our simulations to a 500-year timescale over which time the effect of carbonate compensation on ocean carbon uptake is negligible.

[6] In forward mode, specified carbon emissions elicit climate and carbon cycle model responses. We ran the model in this mode for a series of idealized pulse-response simulations, in which emissions of 50, 200, 500 and 2000 billion tonnes (giga-tonnes of carbon: GtC) were added instantaneously to the atmosphere under pre-industrial conditions; we then ran the model with prognostic CO$_2$ and carbon sinks for 500 years with no additional carbon emission. In a second series of zero-emissions commitment scenarios, the model was spun-up transiently using historical CO$_2$ concentrations from 1800 to 2000. We then specified future business-as-usual emissions and calculated cumulative emissions relative to the year 2005. We set emissions to zero at cumulative emission levels of 0, 50, 200, 500 and 2000 GtC after 2005, and ran the model until the year 2500 with no further CO$_2$ emissions. In addition, we performed four simulations in which emissions were reduced linearly to zero from 2005 levels, such that total carbon emissions after 2005 were equal to 50, 200, 500 and 2000 GtC, respectively.

[7] In inverse mode, we are able to specify a desired global temperature trajectory and calculate anthropogenic carbon emissions which are consistent with this specified temperature profile. Emissions (E) were calculated at each model timestep as $E = K\,(T' - T_m)$, where T' is the desired target temperature and T_m is a running one-year global average of modelled surface air temperature. K is a constant which represents the approximate temperature response per unit of CO$_2$ emission, divided by the timescale of temperature response to CO$_2$ forcing. Emissions diagnosed in this way represent the total anthropogenic addition of carbon to the atmosphere, including both fossil fuel and net land-use change emissions.

[8] Historical temperatures were specified as an exponential curvefit to observed temperature data from 1880 to 2005. From 2005 to 2500, we constructed nine temperature profiles whereby global temperatures increased at constant rates of 0.1, 0.2 and 0.4°C/decade to stabilization levels of 1, 2 and 4 degrees above pre-industrial temperature. The transition from a fixed rate of temperature increase to temperature stabilization was smoothed using a 30-year running average.

3. Results and Discussion

[9] Figure 1 shows the climate response to an instantaneous pulse emission of carbon dioxide of between 50 and 2000 GtC. After 500 years, between 20 and 35% of the initial emission pulse remained in the atmosphere (with higher airborne fractions associated with larger emission pulses); the remaining carbon was split approximately 60/40 between ocean and land carbon sinks. The emissions pulse was followed immediately by climate warming, which then persisted for the remainder of the simulation. Averaged over the last 450 years of the simulation, temperatures increased by 0.09, 0.34, 0.88 and 3.6°C for emissions pulses of 50, 200, 500 and 2000 GtC, respectively. Historical emissions from fossil fuels and land-use change total approximately 450 GtC, which would represent about 0.8 degrees warming in the context of these pulse-response simulations. These numbers correspond roughly to a 0.175°C temperature increase for every 100 GtC emitted. This version of the UVic ESCM has an equilibrium climate sensitivity of 3.5°C for a doubling of atmospheric CO$_2$; as such, every 100 GtC emitted resulted in a step-wise warming of about 5% of the model's climate sensitivity.

[10] The amount of climate warming per unit of carbon emitted did not depend strongly on the timing nor duration of emissions. Figure 2 (thick lines) shows the result of a series of transient zero-emissions commitment simulations in which CO$_2$ emissions were set to zero when cumulative carbon emissions after 2005 reached 0, 50, 200, 500 and 2000 GtC (Figure 2a). After emissions were set to zero, simulated atmospheric CO$_2$ decreased as a function of time as natural carbon sinks continued to take up carbon (Figure 2b). Ocean temperatures increased throughout the simulation showing continued heat uptake, though the rate of heat uptake slowed as a function of time (Figure 2c). This slowing of ocean heat uptake balanced the decreasing radiative forcing from atmospheric CO$_2$; as a result, surface temperatures remained approximately constant (Figure 2d).

[11] Figure 2 also shows four additional simulations (thin lines) in which emissions were reduced to zero gradually such that total cumulative emissions after 2005 were equivalent to the thick-line zero-emissions commitment simulations. In these thin-line simulations, atmospheric CO$_2$ and global temperatures increased more gradually in response to gradually declining emissions; however, the final stabilization temperature was unchanged. Furthermore, the amount of additional warming that resulted per unit of carbon emitted in both sets of simulations was equivalent to the pulse-response cases shown above (approximately 5% of climate sensitivity per 100 GtC emitted), despite both higher

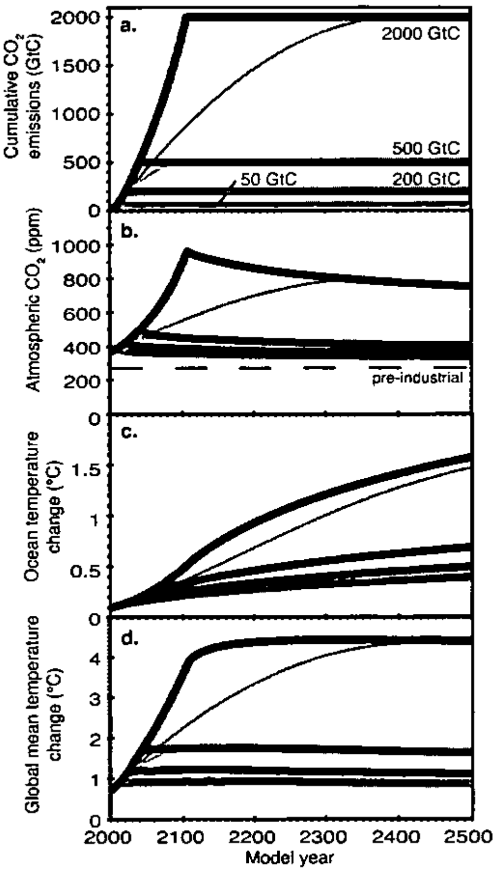

Figure 2. Climate response to transient followed by zero CO_2 emissions. (a) Specified cumulative CO_2 emissions relative to the year 2005. (b) Simulated atmospheric CO_2. (c) Simulated change in global mean ocean temperature relative to pre-industrial. (d) Simulated change in global mean surface air temperature relative to pre-industrial. Thick lines show business-as-usual followed by an abrupt elimination of emissions. Thin lines show the same post-2005 cumulative emissions but with a gradual reduction from 2005 emission levels to zero.

initial CO_2 levels in the atmosphere and the distribution of emissions over the next 10 to 100 years. This result is consistent with previous research which has shown that the declining radiative forcing per unit CO_2 increase at higher CO_2 levels is approximately counter-balanced by increased airborne fraction of emissions due to weakened carbon sinks [*Caldeira and Kasting*, 1993].

[12] The results shown here differ importantly from previous zero-emissions commitment analyses [e.g., *Friedlingstein and Solomon*, 2005], which have neglected the heat capacity of the deep ocean, and have therefore concluded that after emissions are stopped, global temperatures would decrease in response to declining atmospheric CO_2 concentrations. Our results also differ from previous studies of warming commitment which have analyzed the future warming commitment resulting from constant radiative forcing associated with stable atmospheric greenhouse gas levels [*Wigley*, 2005; *Meehl et al.*, 2005]. In contrast with these studies, our results suggest that if emissions were eliminated entirely, radiative forcing from atmospheric CO_2 would decrease at a rate closely matched by declining ocean heat uptake, with the result that while future warming commitment may be negligible, atmospheric temperatures may not decrease appreciably for at least 500 years.

[13] In the simulations described above, eliminating CO_2 emissions resulted in stable global temperatures for the following five centuries of model simulation. This result implies that stabilizing climate at a given temperature would require that anthropogenic CO_2 emissions be decreased to near-zero. We demonstrate this in a series of transient model simulations in which global temperatures in the UVic ESCM were constrained to follow a desired future climate trajectory. Results from these simulations are shown in Figure 3 for temperature stabilization levels of 1, 2 and 4°C above pre-industrial temperatures, with temperatures approaching stabilization at rates of 0.1, 0.2 and 0.4°C per decade after the year 2005. Also shown is a simulation in which climate was stabilized at year-2005 temperatures.

[14] Simulated global mean surface air temperatures for the ten temperature stabilization simulations followed closely the prescribed temperature trajectories (Figure 3a). Atmospheric CO_2 concentrations consistent with simulated temperature changes are shown in Figure 3b; in all cases, CO_2 concentrations reached a maximum value at the time of temperature stabilization, followed by a gradual decrease consistent with that shown in Figures 1 and 2. Also consistent with Figure 2, ocean temperatures increased throughout the simulation, though the rate of ocean heat uptake slowed with time after atmospheric temperatures were stabilized (Figure 3c). Cumulative CO_2 emissions from each simulation are shown in Figure 3d. At the year 2500, cumulative emissions depended only on the level of temperature stabilization, and not on the path taken to stabilization. Stabilizing climate change at 1°C above pre-industrial (approximately 0.2°C above present) required cumulative carbon emissions (from any source) after 2005 to be confined to less than 150 GtC. Stabilizing at 2 or 4°C above pre-industrial required cumulative emissions after 2005 of less than 725 and 1825 GtC, respectively. In all cases, annual emissions consistent with temperature-stabilization were reduced to nearly zero. Notably, stabilizing global temperature at present-day (year-2005) levels required emissions to be reduced to near-zero within a decade.

[15] The result shown here that each unit of CO_2 emissions results in a quantifiable step-wise increase of global temperatures, and its corollary that temperature stabilization requires near-zero CO_2 emissions, is not model specific; this same qualitative result can be demonstrated using a simple analytic model of the global climate-carbon system (see auxiliary material).[1] However, the specific amount by which global temperatures increased per unit of CO_2 emission—and correspondingly, the cumulative CO_2 emissions required to meet a given temperature target—does depend on several important model characteristics and assumptions. For example, future changes in non-CO_2 climate forcings (both natural and anthropogenic) could have an important effect on the magnitude of temperature changes associated with future carbon emissions. Furthermore, different models vary considerably with respect to both the strength of

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[1] Auxiliary materials are available in the HTML. doi:10.1029/2007GL032388.

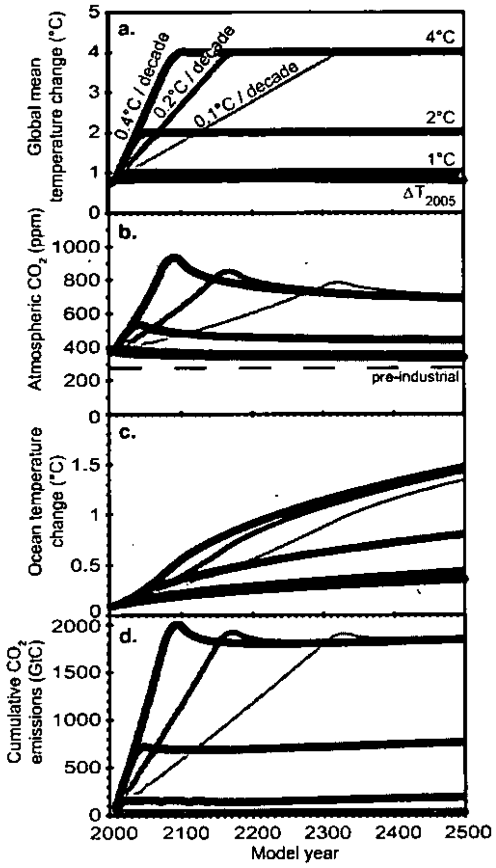

Figure 3. CO_2 emissions required for climate stabilization.. (a) Simulated global mean surface air temperature relative to pre-industrial. (b) Simulated atmospheric CO_2. (c) Simulated change in global mean ocean temperature relative to pre-industrial. (d) Cumulative carbon emissions relative to the year 2005 (where near-constant cumulative emissions reflect near-zero yearly emissions). Colors indicate climate stabilization at 1 (red lines), 2 (green lines), and 4 (blue lines) °C above pre-industrial temperatures. Line styles indicate rates of warming (between 2005 and the time of temperature-stabilization) of 0.1 (thick lines), 0.2 (medium lines), and 0.4 (thin lines) °C per decade. The solid grey line shows climate stabilization at year-2005 temperatures.

carbon sinks (the carbon cycle sensitivity to CO_2 and climate changes) as well as the climate system's sensitivity to CO_2 increases (climate sensitivity).

[16] To examine the dependence of our results on the model's climate sensitivity, we repeated the temperature-stabilization simulations shown in Figure 3 with two additional versions of the model in which climate sensitivity after 2005 was approximately doubled and halved respectively by means of an adjustable temperature-longwave radiation feedback [*Matthews and Caldeira*, 2007]. Cumulative emissions from 2005 to 2500 for each of these simulations are given in Table 1. It is clear that the range of climate sensitivities explored here had a very large effect on the cumulative carbon emissions for a given temperature target. However, across all combinations of climate sensitivity and stabilization level, the rate of warming approaching a stabilization temperature had very little influence on the allowable cumulative emissions. This is consistent with the pulse-response and zero-emissions commitment experiments in which each unit of CO_2 emission produced a persistent increment of warming that was largely independent of the warming produced by other CO_2 emissions.

[17] In this study, we have made no attempt to construct economically optimal emissions scenarios for climate stabilization, but rather to quantify the climatic requirements for allowable emissions consistent with global temperature targets. It is evident that some of the temperature trajectories (and their associated emissions scenarios) illustrated here may not be economically feasible, as they require either abrupt transitions from very high to near-zero emissions, or even prolonged periods of negative emissions for combinations of high climate sensitivity and low temperature targets. It is also clear from these simulations that delays in emissions reductions now will lead to a requirement for much more rapid emissions reductions in the future in order to meet the same global temperature target. In addition, an important conclusion of our study is that if total future emissions can be constrained to within a given amount, the same long-term temperature target can be achieved by a wide range of specific emissions scenarios.

4. Conclusions

[18] International climate policies aimed at climate stabilization must reflect an understanding of the lasting effect of greenhouse gas emissions; as illustrated by a recent study, year-2050 emissions targets currently being proposed are likely insufficient to avoid substantial future climate warming [*Weaver et al.*, 2007]. We have shown here that the climate warming resulting from CO_2 emissions is not a transient phenomenon, but rather persists well beyond the timescale of human experience. In the absence of human intervention to actively remove CO_2 from the atmosphere [e.g., *Keith et al.*, 2006], each unit of CO_2 emissions must be viewed as leading to quantifiable and essentially permanent climate change on centennial timescales. We emphasize that a stable global climate is not synonymous with stable radiative forcing, but rather requires decreasing greenhouse gas levels in the atmosphere. We have shown here that stable global temperatures within the next several centuries can be achieved if CO_2 emissions are reduced to

Table 1. Effect of Climate Sensitivity on Cumulative Emissions Targets for Climate Stabilization[a]

Global temperature target (°C)	1			2			4		
Target rate of change (°C/yr)	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04
$\Delta T_{2x} \sim 1.8$ °C	787	789	788	1970	1977	1979	4806	4801	4794
$\Delta T_{2x} \sim 3.5$ °C	149	148	150	720	723	723	1823	1808	1804
$\Delta T_{2x} \sim 7$ °C	−166	−167	−167	115	115	116	633	607	599

[a] Effect of climate sensitivity measured by ΔT_{2x}. Cumulative emissions represent total GtC emitted from 2005 to 2500.

nearly zero. This means that avoiding future human-induced climate warming may require policies that seek not only to decrease CO_2 emissions, but to eliminate them entirely.

[19] **Acknowledgments.** We would like to acknowledge and thank M. Eby at the University of Victoria for his contribution to this research in the form of development of model code which enables simulation of specified global temperature input profiles. We would also like to thank A. Weaver, C. Jones and one anonymous reviewer for their helpful comments and suggestions.

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Attachment 13
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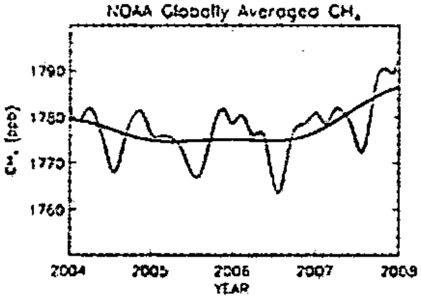
Glustrom Answer Testimony

http://www.noaanews.noaa.gov/stories2008/20080423_methane.html

Carbon Dioxide, Methane Rise Sharply in 2007

April 23, 2008



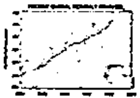
Global methane (CH_4) concentrations rose in 2007. The red line shows the trend together with seasonal variations. The black line indicates the trend that emerges when the seasonal cycle has been removed.

High Resolution (Credit: NOAA)

Last year alone global levels of atmospheric carbon dioxide, the primary driver of global climate change, increased by 0.6 percent, or 19 billion tons. Additionally methane rose by 27 million tons after nearly a decade with little or no increase. NOAA scientists released these and other preliminary findings today as part of an annual update to the agency's greenhouse gas index, which tracks data from 60 sites around the world.

The burning of coal, oil, and gas, known as fossil fuels, is the primary source of increasing carbon dioxide emissions. Earth's oceans, vegetation, and soils soak up half of these emissions. The rest stays in the air for centuries or longer. Twenty percent of the 2007 fossil fuel emissions of carbon dioxide are expected to remain in the atmosphere for thousands of years, according to the latest scientific assessment by the International Panel on Climate Change.

Viewed another way, last year's carbon dioxide increase means 2.4 molecules of the gas were added to every million molecules of air, boosting the global concentration to nearly 385 parts per million (ppm). Pre-industrial carbon dioxide levels hovered around 280 ppm until 1850. Human activities pushed those levels up to 380 ppm by early 2006.



The 2007 rise in global carbon dioxide (CO_2) concentrations is tied with 2005 as the third highest since atmospheric measurements began in 1958. The red line shows the trend together with seasonal variations. The black line indicates the trend that emerges when the seasonal cycle has been removed.

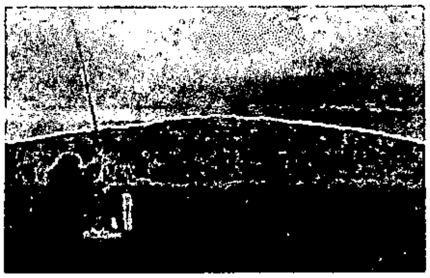
High Resolution (Credit: NOAA)

The rate of increase in carbon dioxide concentrations accelerated over recent decades along with fossil fuel emissions. Since 2000, annual increases of two ppm or more have been common, compared with 1.5 ppm per year in the 1980s and less than one ppm per year during the 1960s.

Methane levels rose last year for the first time since 1998. Methane is 25 times more potent as a greenhouse gas than carbon dioxide, but there's far less of it in the atmosphere—about 1,800 parts per billion. When related climate affects are taken into account, methane's overall climate impact is nearly half that of carbon dioxide.

Rapidly growing industrialization in Asia and rising wetland emissions in the Arctic and tropics are the most likely causes of the recent methane increase, said scientist Ed Dlugokencky from NOAA's Earth System Research Laboratory.

"We're on the lookout for the first sign of a methane release from thawing Arctic permafrost," said Dlugokencky. "It's too soon to tell whether last year's spike in emissions includes the start of such a trend."



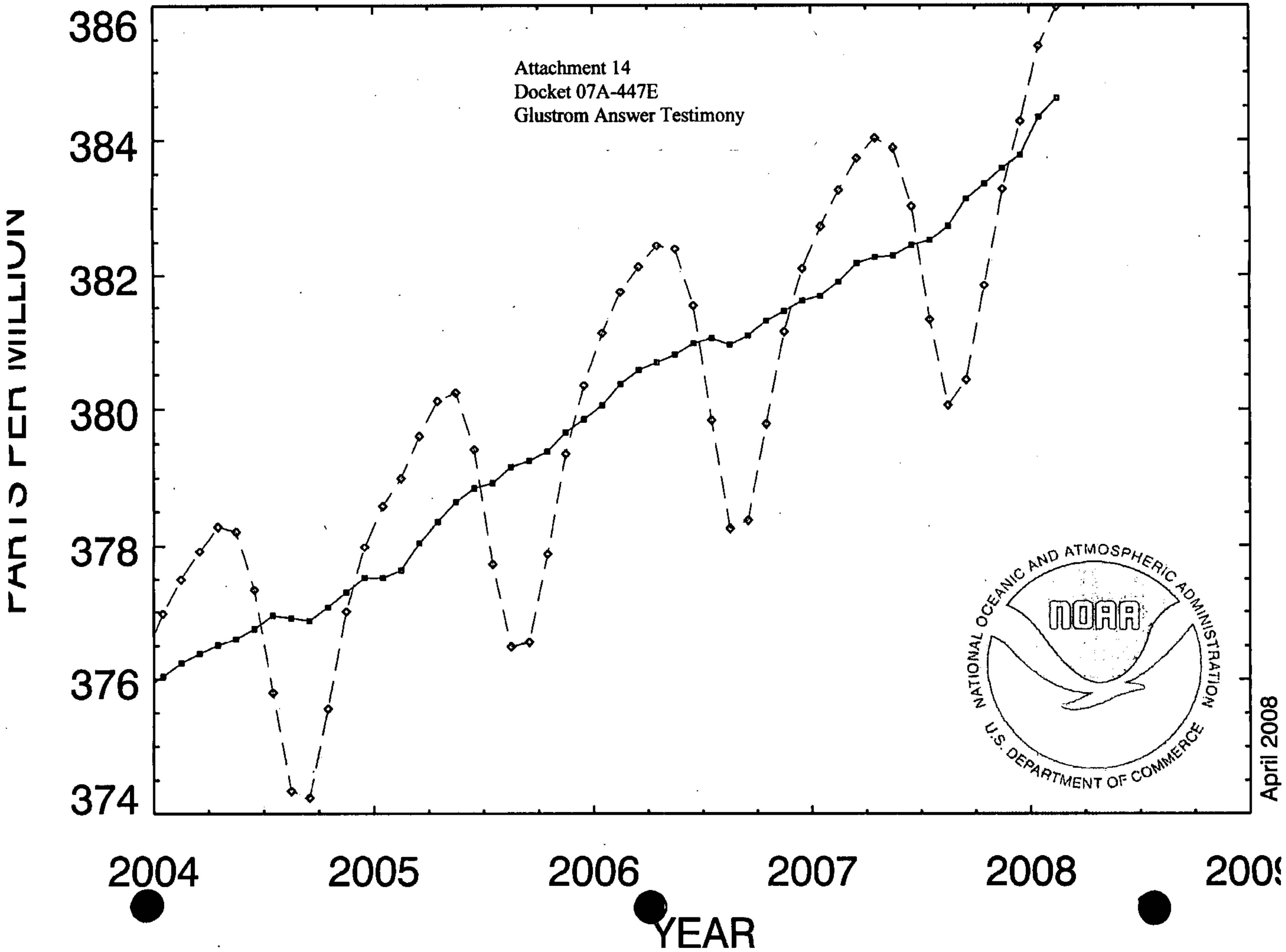
NOAA engineer Paul Fukumura-Sawada captures air near NOAA's Mauna Loa Observatory in Hawaii, using one of many methods to measure carbon dioxide and other greenhouse gases in Earth's atmosphere.

High Resolution (Credit: NOAA)

Permafrost, or permanently frozen ground, contains vast stores of carbon. Scientists are concerned that as the Arctic continues to warm and permafrost thaws, carbon could seep into the atmosphere in the form of methane, possibly fueling a cycle of carbon release and temperature rise.

NOAA is dedicated to enhancing economic security and national safety through the prediction and research of weather and climate-related events and information service delivery for transportation, and by providing environmental stewardship of our nation's coastal and marine resources. Through the emerging Global Earth Observation System of Systems (GEOSS), NOAA is working with its federal partners, more than 70 countries and the European Commission to develop a global monitoring network that is as integrated as the planet it observes, predicts and protects.n

RECENT GLOBAL MONTHLY MEAN CO_2



Attachment 14
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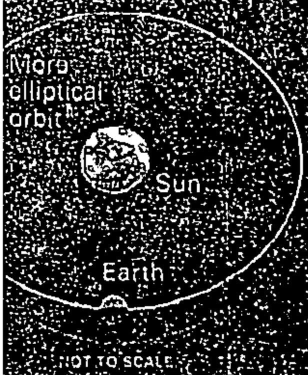
Glustrom Answer Testimony

April 2008

Attachment 15
Docket 07A-447E
Glustrom Answer Testimony



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■ Ancient pla
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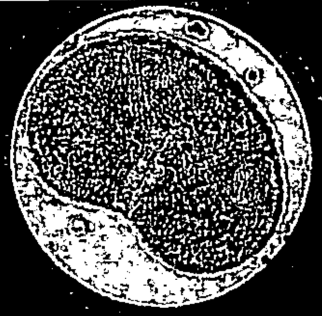
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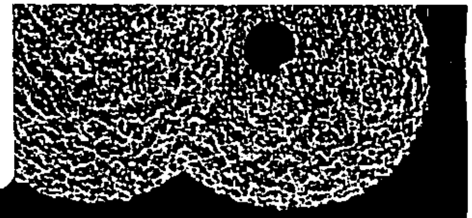
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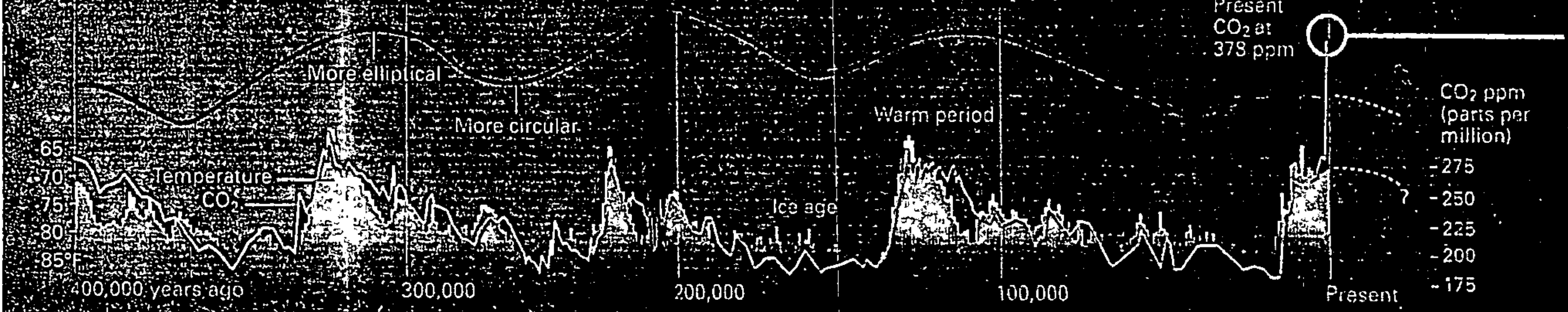

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quickly, and the Earth entered a warm interglacial period. Scientists believe this timing is partly determined by astronomical factors that affect the length of seasons and allow ice to build from one winter to the next.

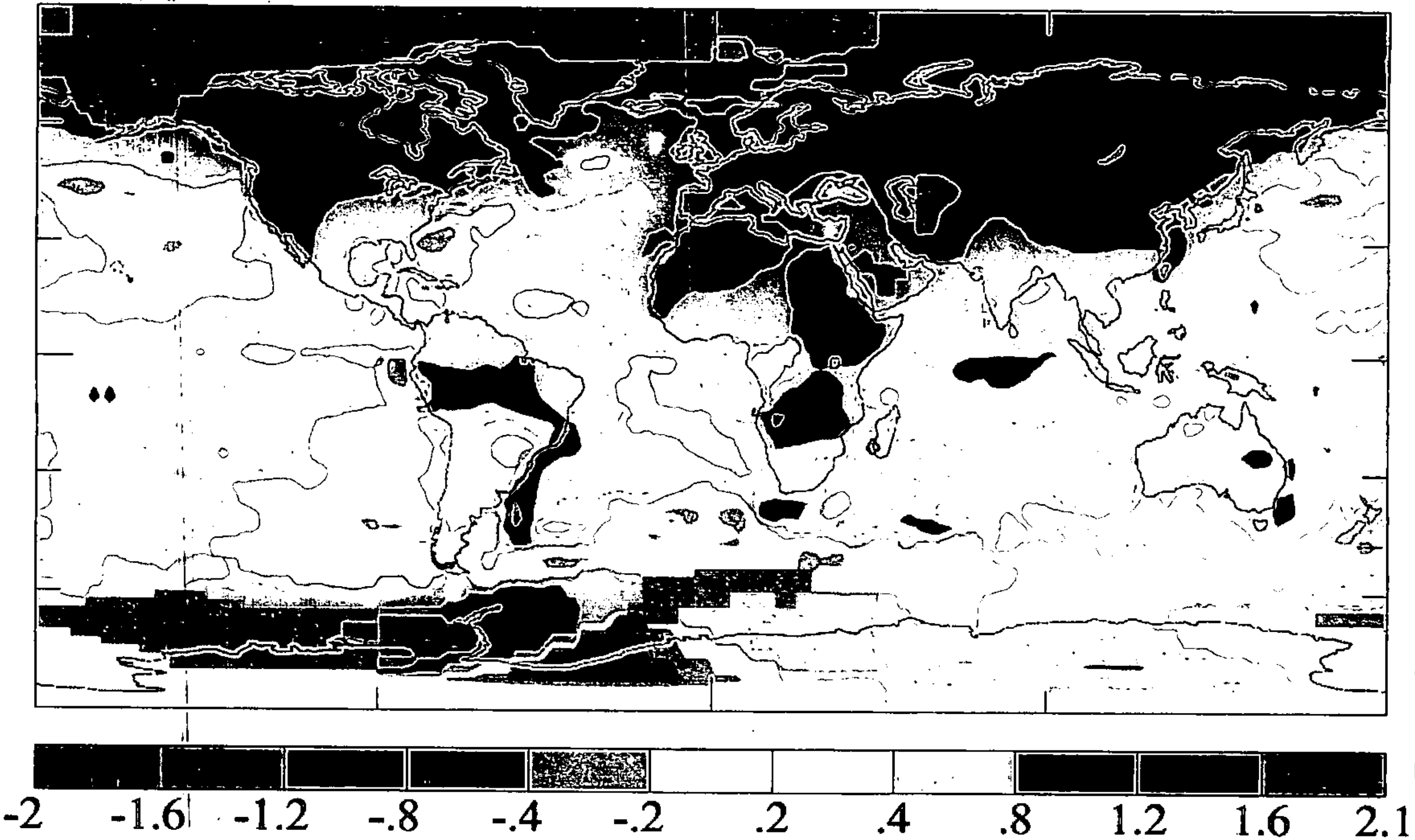
Following climate's ups and downs
With no temperature records from ancient times, scientists turn to clues left in ice or in sediments from the oceans and lakes. Past air temperatures affected the chemical makeup of the snow that fell to fo
ice sheets. Ocean temperatures ar
in certain marine organisms. And
fossil pollen reveals vegetation ty
indicator of climate.

National Geographic September 2004 (p. 65)
(Data from *Nature* June 3, 1999; Data back 650,000 years in *Science* November 25, 2005)

Attachment 16
Docket 07A-447E
Glustrom Answer Testimony

2001-2006 Mean Surface Temperature Anomaly (°C)

Base Period = 1951-1980 Global Mean = 0.54



Source: James Hansen, NASA, Feb 26, 2007 at the National Press Club "Connecting the Dots"

Attachment 17
Docket 07A-447E
Glustrom Answer Testimony

Beetle-kill trees could release tons of carbon dioxide

Warming caused outbreak; release adds to cycle

By Catherine Tsai
Associated Press

DENVER — An outbreak of mountain pine beetles in British Columbia is doing more than destroying millions of trees: By 2020, the beetles will have done so much damage that the forest is expected to release more carbon dioxide than it absorbs, according to new research.

The study, led by Werner Kurz of the Canadian Forest Service, estimates that over 21 years trees killed by the beetle outbreak could release 990 megatons of carbon dioxide into the atmosphere — roughly equivalent to five years of emissions from Canada's transportation sector.

The outbreak has affected about 33 million acres, or about 51,562 square miles, of lodgepole pines. Bark beetles also have killed huge swaths of pines in the western United States, including about 2,300 square miles of trees in Colorado.

"When trees are killed, they no longer are able to take carbon from the atmosphere. Then when dead trees start to decompose, that releases carbon dioxide into the atmosphere," Kurz said.

That could exacerbate global warming that contributed to the outbreaks in the first place. Warmer temperatures have allowed beetles to survive farther north and at higher elevations.

"This is the kind of feedback we're all very worried about in the carbon cycle — a warming planet leading to, in this case, an insect outbreak that increases carbon dioxide into the atmosphere, which can increase warming," said Andy Jacobson, a carbon cycle scientist for the National Oceanic and Atmospheric Administration in Boulder.

Boreal forests in Canada generally have been steady "carbon sinks," absorbing more carbon dioxide than they emit. Kurz's team expects the forest it studied to recover, but says that even by 2020 it may not be the carbon sink it previously was.

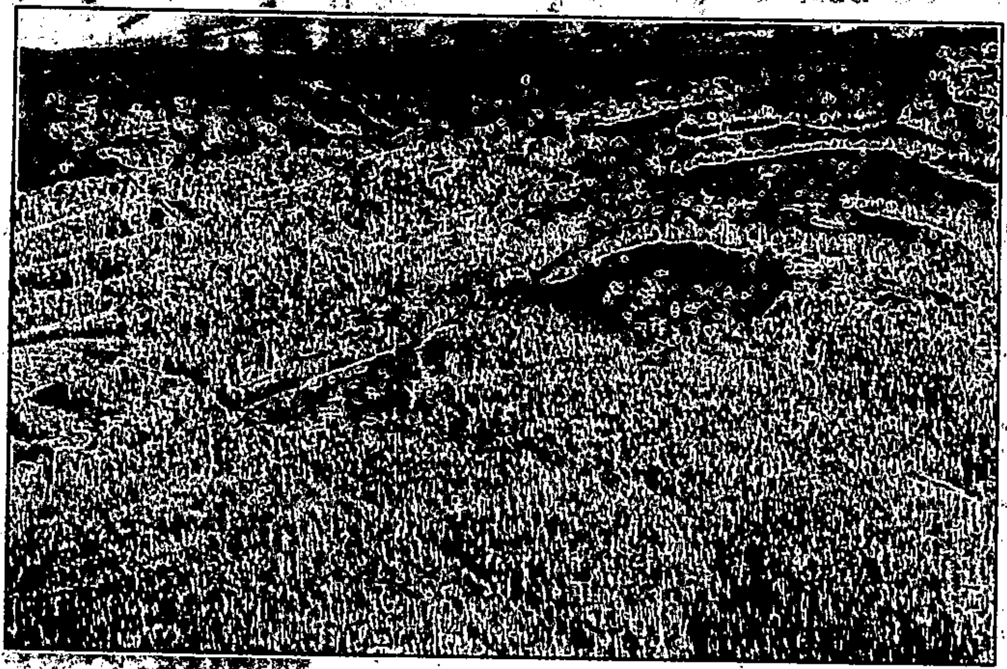
"This long-term effect, personally I find it frightening," said Jacobson, who was not involved in the study, which is being published this week in the journal Nature.

Using computer models, Kurz's team estimated that the maximum annual beetle impact in the study area in south-central British Columbia was 20 megatons of carbon. Forest fires in all of Canada produce an average of 27 megatons per year.

Kurz's team says the effect of pine beetles and other insects is significant and should be included in models of how much atmospheric carbon the world's forests can store.

"Many other insects also impact the forest carbon cycle," Kurz said. While outbreaks of other insects such as spruce beetles may be much smaller, their cumulative effect is significant, he said.

"If events such as this occur in other geographic parts of the world, then they really ought to be accounted for," Kurz said.



This undated aerial ph provided by the Colora State Forest Service sh rusty red pine trees kille beetles near Granby. Ar outbreak of mountain pl beetles in British Colum doing more than destro millions of acres of lodgepole pines: By 202 the beetles will have do enough damage that th forest is expected to rel more carbon dioxide th absorbs, according to research published in th journal Nature this week Bark beetles also have k swaths of pines in the western United States, including about 2,300 sc miles of trees in Colorad

Associated Press

nature International weekly journal of science
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Attachment 18
Docket 07A-447E
Glustrom Answer Testimony

Letter

Nature **452**, 987-990 (24 April 2008) | doi:10.1038/nature06777; Received 9 December 2007; Accepted 29 January 2008

Mountain pine beetle and forest carbon feedback to climate change

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The mountain pine beetle (*Dendroctonus ponderosae* Hopkins, Coleoptera: Curculionidae, Scolytinae) is a native insect of the pine forests of western North America, and its populations periodically erupt into large-scale outbreaks1, (#B1) 2, (#B2) 3 (#B3) . During outbreaks, the resulting widespread tree mortality reduces forest carbon uptake and increases future emissions from the decay of killed trees. The impacts of insects on forest carbon dynamics, however, are generally ignored in large-scale modelling analyses. The current outbreak in British Columbia, Canada, is an order of magnitude larger in area and severity than all previous recorded outbreaks4 (#B4). Here we estimate that

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the cumulative impact of the beetle outbreak in the affected region during 2000–2020 will be 270 megatonnes (Mt) carbon (or 36 g carbon m^{-2} yr^{-1} on average over 374,000 km^2 of forest). This impact converted the forest from a small net carbon sink to a large net carbon source both during and immediately after the outbreak. In the worst year, the impacts resulting from the beetle outbreak in British Columbia were equivalent to ~75% of the average annual direct forest fire emissions from all of Canada during 1959–1999. The resulting reduction in net primary production was of similar magnitude to increases observed during the 1980s and 1990s as a result of global change[5] (#B5). Climate change has contributed to the unprecedented extent and severity of this outbreak[6] (#B6). Insect outbreaks such as this represent an important mechanism by which climate change may undermine the ability of northern forests to take up and store atmospheric carbon, and such impacts should be accounted for in large-scale modelling analyses.

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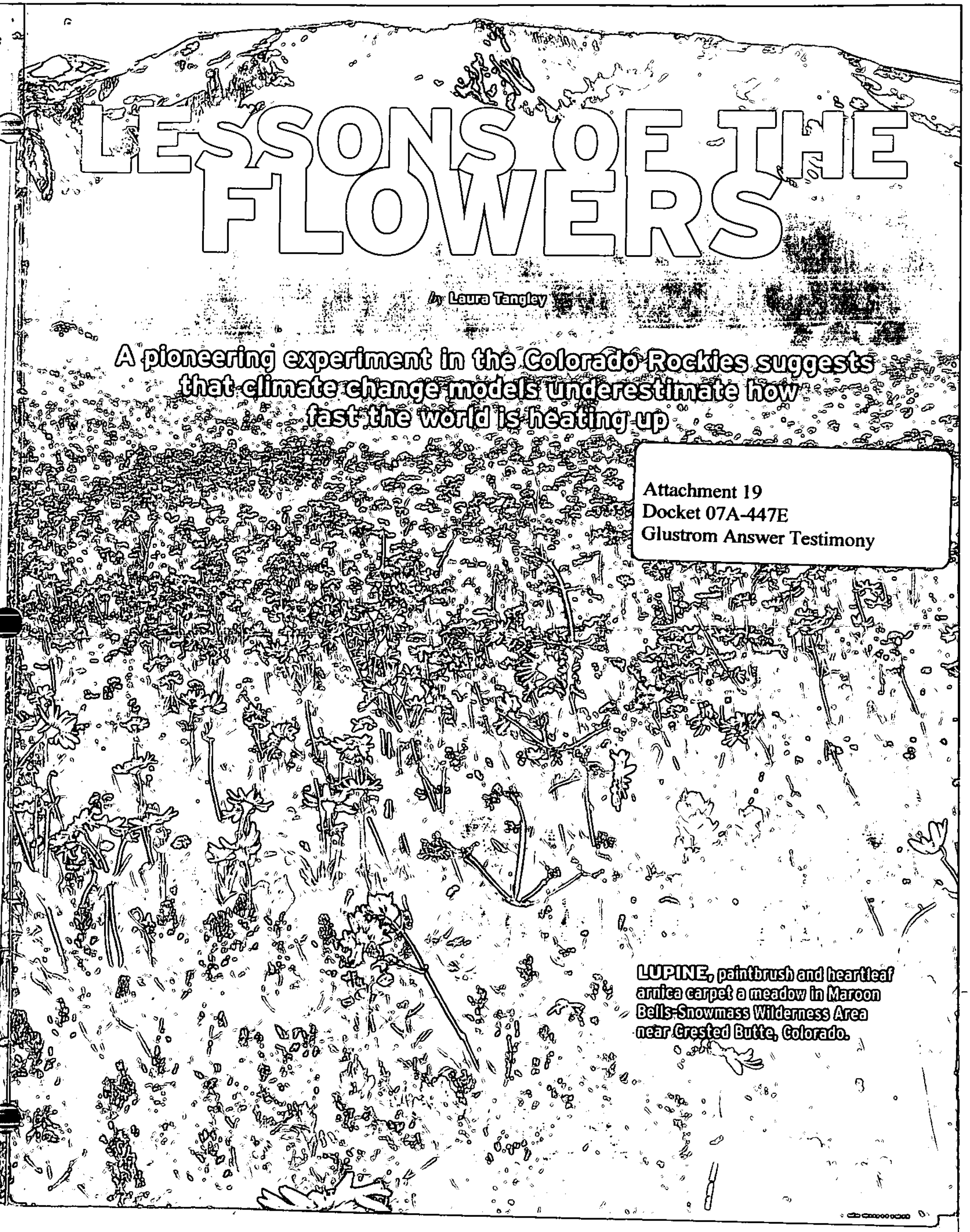

LESSONS OF THE FLOWERS

by Laura Tangley

A pioneering experiment in the Colorado Rockies suggests that climate change models underestimate how fast the world is heating up

Attachment 19
Docket 07A-447E
Glustrom Answer Testimony

LUPINE, paintbrush and heartleaf arnica carpet a meadow in Maroon Bells-Snowmass Wilderness Area near Crested Butte, Colorado.

Summertime in the Colorado Rockies is a wildflower lover's heaven on Earth. And no place in the region attracts more enraptured petal peepers than the Victorian town of Crested Butte. Nestled nearly 9,000 feet above sea level on the western slope of the mountains, Crested Butte has been officially designated the "Wildflower Capital of Colorado" by the state's legislature. In the coming months, its local paper will begin publishing a weekly "wildflower report," and in mid-July, thousands will throng to the town's annual festival for guided hikes, art exhibits and workshops on everything from flower pressing to cooking and wine-making with wildflowers. The main event, of course, will be viewing the blossoms in the surrounding countryside: field after field of larkspurs, lupines, gilias, sunflowers and daisies displaying every color of the rainbow against a backdrop of snow-capped mountain peaks.

Sadly, within a century, scientists warn that such iconic landscapes may vanish—not just from the Rockies, but on mountain slopes everywhere from the Sierra Nevada to the Swiss Alps to the Tibetan plateau. The evidence can be found eight miles up the road from Crested Butte at the Rocky Mountain Biological Laboratory (RMBL), where biologist John Harte leads a pioneering experiment on the effects of global warming on subalpine meadows. To simulate the temperature increase predicted for these habitats, Harte and his colleagues have used overhead heat lamps to warm a mountain meadow continuously for the past 18 years. They've discovered that higher temperatures spawn a major shift in vegetation—away from the grasses and colorful flowering plants that characterize subalpine meadows today toward drought-adapted shrubs such as sagebrush. "In the future, we may be known as the sagebrush capital rather than the wildflower capital of Colorado," laments Harte, a professor of energy and resources at the University of California–Berkeley.

The change would be more than aesthetic. While sagebrush provides wildlife food and shelter in its native lower-elevation range, scores of subalpine insects, birds and mammals in the Rockies depend completely on the seeds, leaves, pollen and nectar of nonwoody flowering plants. More significantly, as sagebrush crowds out wildflowers, Harte and his colleagues have found that the shift spurs a number of "positive feedbacks" that accelerate warming. Like the melting of the polar ice caps, "it's a case where warming begets warming," explains Harte. And because most climate models fail to factor in the impact of such ecosystem transformations, he believes it also is a worrisome sign that their projections, bad as they are, may underestimate how fast the planet is heating up.

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A HOVERFLY FEEDS on an Aspen sunflower (above) and Aspen fleabane blooms (right) in Colorado's Gunnison National Forest. Budding earlier than they once did, both flowers are frequent frost victims—a threat to butterflies, flies and other species that depend on them.

When Harte began planning his project in the mid-1980s, there had been few, if any, attempts to study the effects of warming on a natural ecosystem. "The problem with relying on historical data to project the future," he says, "is that it's hard to separate correlation from causation—which is why I wanted to try something experimental under controlled conditions." Calling his work "remarkable," for both its scale and longevity, University of Maryland biologist David Inouye, who studies the impact of climate change on native species, says the experiment "is helping to make our models more realistic."

The remote study site Harte selected features a patchwork of plants typically found in Rocky Mountain subalpine meadows: about 100 species of grasses and nonwoody flowering plants, or forbs. (At 9,600 feet, it also is near the highest elevation where sagebrush ordinarily grows.) Within the site, he and his assistants staked out ten 10-by-33-foot plots—five experimental and five control—that run along a natural altitudinal gradient. To monitor moisture and temperature, they sank 18 probes into the soil of each plot. Finally, above test plots only, the researchers strung up 15 infrared heat lamps, calibrated to mimic the average 3.6 degrees F of warming predicted by 2050 when Harte launched the project. ("Now we know it's getting hotter faster," he says.)

"IN THE FUTURE, WE MAY BE KNOWN AS THE SAGEBRUSH CAPITAL RATHER THAN THE WILDFLOWER CAPITAL OF COLORADO."

The scientists switched the heaters on in summer 1991, and they've been running nonstop ever since.

Harte's "warming meadow" started to look different within just a few years. Responding to higher air temperatures, soils in the experimental plots heated up by 1 to 2 degrees C and lost 20 percent of their moisture. Snow began melting about two weeks earlier, which lengthened the growing season in the heated plots. "But by far the biggest change," says Harte, "was a shift from the beautiful forbs people pay lots of money to come here and see to the sagebrush that already carpets so much of the arid West."

One flower that has suffered is Aspen fleabane (*Erigeron speciosus*), a pretty violet daisy with a yellow center. Common throughout Rocky Mountain meadows, the plant was flourishing in Harte's test plots when he started his research. But as the plots got warmer and drier, the daisy began to produce a third fewer flowers than it once had, and its flower heads grew smaller. "It's an example of a species that's going to be a loser," he says.

Even outside the heated plots, biologists are finding evidence that the daisy and other wildflowers are suffering. Since 1971, biologist Inouye has spent each summer monitoring more than 100 flowering plant species at RMBL. He's found that many plants are blooming up to a month and a half earlier than they did three decades ago—so early that nighttime freezes still commonly occur, killing their buds. "These frosts can have cascading effects throughout the ecosystem," says Inouye. A frequent frost victim, Aspen fleabane, for instance, is a critical nectar source for Mormon fritillary butterflies. In summers following heavy frost damage to the daisy, researchers have noted declines in the butterfly's numbers.

Birds and mammals are also feeling the heat. Since he began living at RMBL in the mid-1970s, year-round resident Billy Barr, the lab's business manager, has been taking meticulous notes on the seasonal behaviors of 20 animal species. A few years ago, he entered his data into an Excel spreadsheet and shared them with Inouye. The biologist's analyses confirmed what Barr suspected: "It seemed obvious that animals were coming back sooner and emerging from hibernation earlier than they used to," says Barr. It turns out that American robins, for example, are arriving more than two weeks earlier than they did in the 1970s, so soon that snow still covers the ground—along with the worms the birds need to prepare for the breeding season.

Similarly, Barr's data reveal that yellow-bellied marmots are leaving their hibernation dens more than a month sooner than they did in the 1970s. "Typically, marmots emerge in mid- to late April to make a decision about whether to go back and hibernate a few more weeks or to stay out," says Inouye. "The decision seems to be based on air temperature, which is rising in our area." The problem is that marmots now emerge when several feet of snow still cover the plants they eat. Deep snow also blocks the animals' escape burrows, so "more marmots are being caught by coyotes," says Barr.

More ominous, at least from a global perspective, are the changes Harte is seeing in plant communities. As sagebrush outcompetes forbs in the heated plots, one of the positive feedbacks he's found is that the landscape becomes darker and less reflective—or has lower albedo—than it once was. This means plants are absorbing more heat, speeding up warming and creating still better conditions for sagebrush. Extended over a large area, "even a small albedo difference can have a huge effect," he says.

Harte also has discovered that soils in the heated plots are storing less carbon. Active photosynthesizers, flowering plants take in more carbon dioxide than sagebrush, transferring it to the soil when they die back at the end of the growing season. "A single daisy is like

PEOPLE AND PLANTS

EXTINCTIONS ERODE BENEFITS TO HUMANITY

AS GLOBAL WARMING and other threats alter habitats by squeezing out native plants (such as California's endangered large-flowered fiddleneck, right), humans may suffer along with other animal species. A recent analysis summarizing results of 44 experiments worldwide showed that ecosystems with fewer plant species produce up to 50 percent less biomass than those with more "natural" diversity. That means "species extinctions could compromise the benefits that nature provides to society," says Bradley Cardinale, a biologist at the University of California-Santa Barbara and lead author of the study, published online in the *Proceedings of the National Academy of Sciences*. Such benefits range from controlling pests to absorbing the carbon dioxide that is largely responsible for global warming.

LIKELY LOSERS in Rocky Mountain meadows transformed by global warming include (clockwise from left): blue columbine, giant red Indian paintbrush, glacier lily (with spring beauty), globeflower and scarlet gilia (with Watson penstemon). A nearly two-decade-long experiment to study the effects of higher temperatures on subalpine meadows shows that sagebrush crowds out these and other wildflowers. Sagebrush habitats also store significantly less carbon, accelerating warming and creating even better conditions for the drought-adapted shrub.

YELLOW-BELLIED marmots on the grounds of Colorado's Rocky Mountain Biological Laboratory are emerging from hibernation dens more than a month earlier than they did in the 1970s—so soon that several feet of snow often cover the plants the animals eat.

tiny pump taking CO_2 from the atmosphere and depositing it into the soil," says Harte. By the project's fifth year, he and his colleagues found that the test plots had lost 20 percent of their soil carbon. Because the world's soils contain four times more carbon than the atmosphere, the implications of that discovery are worrisome: "If we lost 20 percent of soil carbon globally," says Harte, "it would mean nearly another doubling of atmospheric CO_2—or three times what humankind has done through emissions since the start of the Industrial Revolution."

Recent discoveries from other habitats reinforce that concern. Like sagebrush, lodgepole pine favors warmer, drier conditions than the Engelmann spruce and fir trees that now thrive at high elevations in the Rockies. To investigate the impact of a warming-induced shift from spruce-fir to pine forests—a change predicted by ecological models—biologist Lara Kueppers, Harte's former graduate student, measured soil carbon along a natural elevational gradient in Fossil Ridge Wilderness, a 45-minute drive south of RMBL. She found that the pine ecosystems stored significantly less carbon than spruce-fir forests. "If we get climate change that favors lodgepole pine over spruce-fir, we're likely to see a loss of carbon from these systems, setting up a feedback loop that favors even more warming," says Kueppers, a professor at the University of California–Merced.

At RMBL, meanwhile, real climate change is beginning to catch up with Harte's simulation. For many years, it looked like the lab's montane habitats were resisting many of the effects of warming so apparent at lower elevations. But since 2000, the area has been experiencing not only higher temperatures, but a tenacious drought that is causing snow to melt sooner in spring. According to Harte, conditions in his control plots now resemble those in the heated plots during the project's first five years: Sagebrush is invading, wildflowers are struggling, and soil carbon is beginning to decline. "It's a case of nature imitating science," he says, "and validating the experiment."

Senior Editor **LAURA TANGLEY** *visited RMBL last summer. To learn more about global warming and other research at the lab, see www.rmbl.org.*

NWF PRIORITY

[illegible]

Combating the threat global warming poses to subalpine meadows and other wildlife habitats is a top priority for NWF, which is backing congressional legislation to reduce greenhouse gases; publishing reports on warming's impact on wildlife and collaborating with state affiliates on grassroots efforts. In addition, NWF's *Campus Ecology*® program is helping colleges and universities confront global warming through climate-friendly practices that reduce their global footprint. Another program, *Cool It!*®, helps individuals see how everyday actions can make a difference—by conserving energy, organizing youth groups, protecting forests and recycling electronics, for example. For more information, go to www.nwf.org/globalwarming.

Attachment 20
Docket 07A-447E
Glustrom Answer Testimony

Water in the Southwest

Martin Hoerling – *NOAA Earth System Research Laboratory and* **Jon Eischeid** – *University of Colorado, CIRES*

Nobody relishes being "past peak" anything. Whether it's the prime of our human existence or the prime of Nature's abundance, the notion of having less rather than more is often vehemently denied. But demand growth in the face of production and storage decline has severe consequences, especially when existing uses already consume the available supply.

The lifeblood of the Southwest is the Colorado River, which is increasingly impacted by climate forces not previously experienced. The recent drought prompts concern among water users and water stewards alike, and requires the scientific community to probe whether a sustained threat is rising to our already perilous moisture balance. The consensus of the Intergovernmental Panel on Climate Change (IPCC, 2001) affirms that Earth's atmosphere is accumulating unprecedented quantities of carbon dioxide that are now causing detectable increases in surface air temperature.

Is this ongoing drought an early warning sign of something other than the historical norm, and the gateway to a future climate with more severe drought hazards? What is known about the sensitivity of moisture conditions in the Southwest to a changing climate? To seek answers to these questions, we have undertaken a systematic analysis of a new suite of climate model simulations from the arsenal of tools contributing to the 2007 IPCC Fourth Assessment Report (AR4). What is the news for the Southwest?

Even several of the wetter runs yield increasing drought due to the overwhelming effect of heat-related moisture loss.

A New Drought Study

A common practice in drought monitoring is to derive a meteorological quantity known as the Palmer Drought Severity Index (PDSI; Palmer 1965). The index calculates the cumulative effects of precipitation and temperature on surface moisture balance. Water storage is solely derived from a two-layer soil system, with no explict accounting for deep groundwater or water in manmade surface storage. Drought develops when evapotranspiration exceeds the supply available from precipitation and soil moisture relative to a region's "normal" water balance. The index ranges from -4 (extreme drought) to +4 (extreme moistness).

Reservoir storage is key for assessing water supply during the course of a year in the Southwest, and is not included in a PDSI drought monitor. However, when monitoring drought conditions on annual time scales, streamflow is strongly correlated with annual PDSI. The relationship between the annual virgin flow (the estimated flow of the stream if it were in its natural state and unaffected by the activities of man) at Lees Ferry, Arizona, and the PDSI averaged over the upper Colorado Basin drainage is

$$\text{FLOW} = A_0 + (A_1 \times \text{PDSI})$$

for FLOW greater than the estimated basal flow of 3 million acre-feet (maf). Using data from 1895-1989, the linear regression coefficients are

$$A_0 = 14.5 \text{ maf}, A_1 = 1.69 \text{ maf}.$$

During the 95-year reference period, annual PDSI explains 63 percent of the annual river flow variations at Lees Ferry.

Post-1989 data offer an independent period to confirm applicability of the above relation for predicting Lees Ferry flow. This period is one of warming temperatures, allowing us to test the prediction equation's fidelity in an environment of climate change. For 1990-2005, PDSI predicts 85 percent of the recent yearly fluctuations of flow at Lees Ferry, including the low flow regime during the recent drought.

To determine the probable hydrologic consequences of future climate change, the above formula was used to downscale future PDSI to Lees Ferry streamflow. The monthly PDSI was calculated for each of 42 climate simulations spanning 1895 to 2060, using multiple runs of 18 different coupled ocean-atmosphere-land models. The models were forced with the known changes in atmospheric constituents and solar variations from 1895-2000 and a business-as-usual assumption for future carbon emission after 2000.

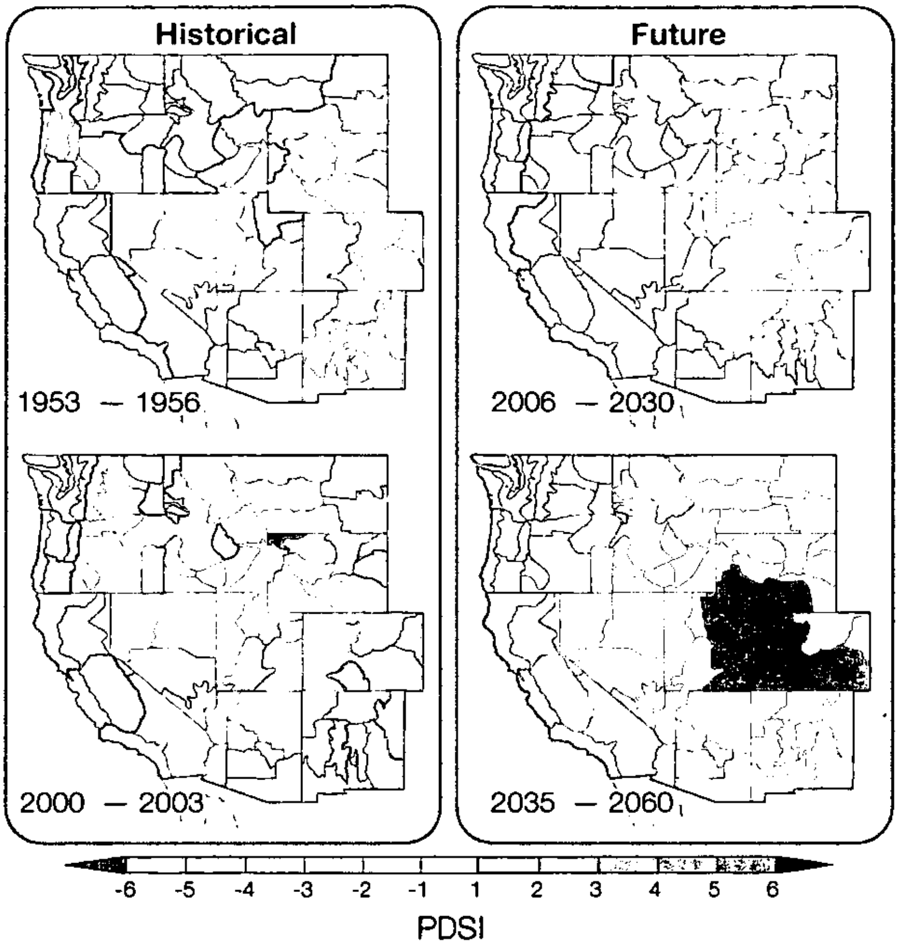
A Drastic Change in the Character of Drought

Sustained drought of severe intensity (PDSI < -3) occurred during 1953-1956, an event rivaled during 2000-2003. The average annual Lees Ferry flow was only 10 maf during both events, but the recent drought bears different properties than its predecessor. In particular, abnormally high temperatures have been more prevalent during the 2000-2003 drought, with the West nearly 1°C warmer than during the 1950s drought.

Climate simulations of PDSI for two near-term 25-year periods (2006-2030 and 2035-2060) show an increase in drought severity (relative to their 20th century "normals") that occurs in lockstep with surface warming (see figures, above right). Little net change in precipitation occurs in the average of all models, though variability among the simulations is considerable. Nonetheless, even several of the wetter runs yield increasing drought due to the overwhelming effect of heat-related moisture loss. The Southwest appears to be entering a new drought era. In the 20th century, drought was principally precipitation driven, and enhanced by temperature. Indications from the simulations are that a near perpetual state of drought will materialize in the coming decades as a consequence of increasing temperature.

To place these probable changes into context, projections for the next quarter century paint a sober landscape in which average PDSI equates to the 2000-2003 drought conditions. This occurs as the consequence of surface water loss due to increased evapotranspiration owing to an average 1.4°C warming (relative

see Past Peak, page 35



Palmer Drought Severity Index (PDSI). Values less than -3 denote severe drought conditions. Left panels illustrate the 4-year average drought conditions experienced during the 1950s drought and the recent drought. Right panels are future projections of the PDSI based on 42 simulations conducted to support the Fourth Assessment Report of the IPCC. By about 2050, average moisture balance conditions will mimic conditions experienced only rarely at the height of the most severe historical droughts.

Past Peak, continued from page 19

to 1895-2005) in the Colorado Basin. The subsequent quarter century (2035-2060) is projected to undergo a similar incremental warming: an average 2.8°C over the Upper Colorado. This drives the Palmer Index down to drought severity rarely witnessed during the 20th century.

Past Peak Water

What are the implications of intensified aridity for Colorado River flow? Downscaling the simulated PDSI to Lees Ferry flow yields an average rate of 10 maf for the next 25 years. As drought conditions further intensify due to heat, Colorado River flows would decline further (see charts below), averaging 7 maf during 2035-2060, values equivalent to the observed lowest flow at our recent drought's nadir.

Are such low flows realistic on a year-by-year sustained level? First, virtually all simulations point to sufficient drought to reduce flow below current consumptive uses on the river within 20 years, although the range of model outcomes indicates that we don't know precisely how low the flow will be. Second, whereas the 21st century climate change signal is one of low Colorado River flow, the superimposed natural variability in precipitation is still capable of producing "normal" flow (by 20th century standards) for a year or two within an otherwise drought epoch. Finally, it is unclear whether the historical Lees Ferry flow-PDSI relation used in this study is strictly applicable to the substantial change in climate that is projected.

Nonetheless, a robust physical relation underpins the projected reduction in Colorado River flow. Evapotranspiration exceeds precipitation throughout the basin, implying less runoff as dictated by water balance requirements. Also, the Lees Ferry flow estimated from the climate simulations for 1990-2005 is 13 maf, an already substantial decline from higher simulated flows in the early 20th century. This change is remarkably consistent with observations and suggests an emerging warming effect on streamflow.

Relative to the 1990-2005 mean flow of 13 maf, the 42-run average predicts a 25 percent decline in streamflow during 2006-2030, and a 45 percent decline during 2035-2060. This scenario is consistent with several independent estimates using different approaches. Revelle and Waggoner (1983) used empirical methods to predict a 29 percent reduction in Lees Ferry flow under a scenario of 2°C warming. Christensen and others (2004) used a sophisticated hydrology model to predict an 18 percent reduction in Colorado River streamflow by 2050 under a change scenario derived from a climate model that is now recognized to be on the low range of climate change sensitivity. Milly and others (2005) diagnosed annual runoff in 12 different AR4 models and discovered a near 20 percent decline in runoff for the Colorado River headwaters by 2050.

Our study reveals that a sustained change in moisture conditions is unfolding within the broad range of natural variations. The Southwest is likely past the peak water experienced in the 20th century preceding the signing of the 1922 Colorado Compact: a decline in Lees Ferry flow will reduce water availability below current consumptive demands within a mere 20 years. These projections further expose the risky reliance by Colorado River water users upon the Compact as a guarantee that streamflows will always materialize to match legislated requirements.

Contact Martin Hoerling at martin.hoerling@noaa.gov.

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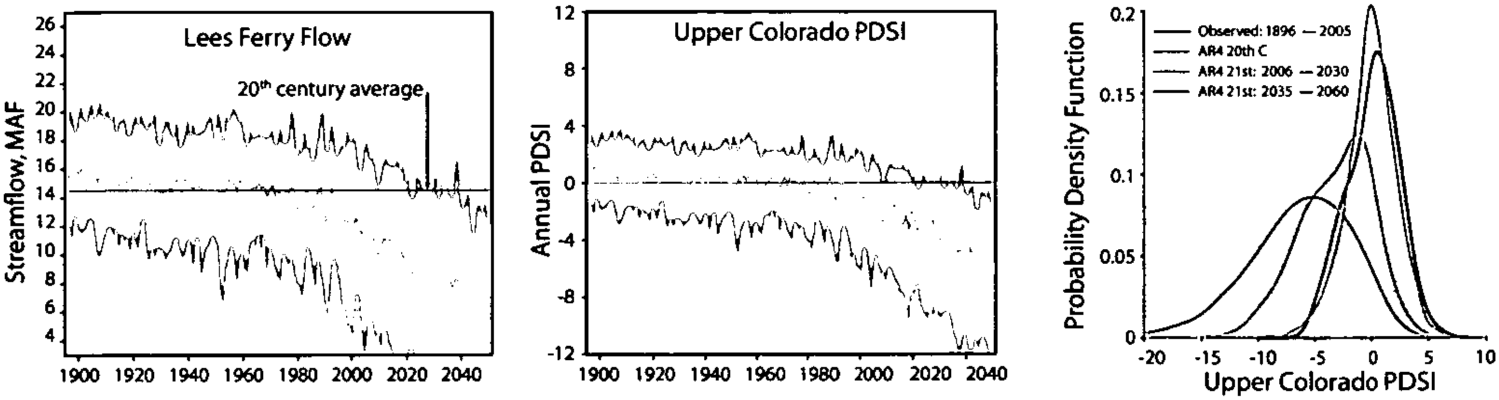

The 1895-2050 Lees Ferry annual streamflow (left) was derived from the AR4 simulations of PDSI (middle) using the downscaling formula that relates observed Lees Ferry flow to observed PDSI during the 20th century. The dark red curve denotes the 42-run average, and the cloud describes the 10 to 90 percent range of individual simulations. The right panel summarizes the probability distribution function of PDSI averaged over the Upper Colorado Drainage Basin for individual years of observations 1895-2005 (black), for the 42 models for 1895-2005 (green), and for the 42-model projections of the average PDSI during 2006-2030 (orange) and 2035-2060 (red). Note that the models produce a realistic range of PDSI drought events during the 20th century, and for the future they produce surface moisture conditions that denote progressive aridification and severe drought conditions.

From: James White [James.White@Colorado.EDU]
Sent: Friday, April 11, 2008 11:41 AM
To: PUCConsumer.complaints@dora.state.co.us
Subject: climate change scientist weighs in

Attachment 21
Docket 07A-447E
Glustrom Answer Testimony

Raupach CO2 Meehl Science
icrease PNAS 2007.2008.pdf (538 KB...

Good morning,

I understand that the PUC is holding a public hearing on April 14. As I cannot attend, I wanted to write in support of Xcel's plan to reduce CO2 emissions and to encourage the PUC to keep taking a leadership role in moving Colorado more towards renewable energy.

I am a climate scientist on the faculty at the University of Colorado at Boulder. My research includes the fate of modern greenhouse gases, and the study of past climates and the role of greenhouse gases in warming and cooling the Earth in the past. Our understanding of Earth's climate system makes it clear that if we increase CO2 and other greenhouse gases in the atmosphere, climate will change, ecosystems will change, and the sea will rise. The more CO2 we add, the bigger these effects will be.

I want to briefly stress three points that occasionally wake me at 3am (its not easy being a climate scientist these days!):

- Despite all the research and occasional uproar over climate change in the past decade or so, CO2 levels are increasing faster now in the first decade of the 2000's than they were in the 1990's. (see attached paper in the Proceedings of the National Academy of Sciences). It is time for action and leadership on this issue.

- CO2 levels are now 100 ppm above the preindustrial baseline. This is the same amount of CO2 change that we see in ice cores between the huge climate changes of glacial to interglacial periods. It is clear that we are already at a point of "locking in" climate change (see attached paper in Science). Again, action is needed now.

- The Earth's climate system contains feedbacks, some negative (such as the removal of 50% of fossil fuel CO2 by the ocean and land plants) and some positive. One big positive feedback is carbon currently locked up in permafrost soils which has been accumulating for hundreds of thousands of years.. There is as much carbon there as there is in all fossil fuels. As the Arctic warms, permafrost melts, and carbon dioxide and methane is released. In short, our actions can be multiplied by natural changes that occur because of our actions. Once again, the time for action is now.

I appreciate your taking the time to read this. I am proud that Colorado has chosen to be a leader in addressing our energy needs for the future, and encourage you to keep going in that direction.

Sincerely,

Jim White

--
Jim White
Interim Director, Institute of Arctic and Alpine Research Professor, Geological Sciences

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BREVIA

The Movement of Aquatic Mercury Through Terrestrial Food Webs

Daniel A. Cristol,* Rebecka L. Brasso, Anne M. Condon, Rachel E. Fovargue, Scott L. Friedman, Kelly K. Hallinger, Adrian P. Monroe, Ariel E. White

Mercury has contaminated rivers worldwide, with health consequences for aquatic organisms and humans who consume them. Researchers have focused on aquatic birds as sentinels for mercury. However, trophic transfer between adjacent ecosystems could lead to the export of aquatic mercury to terrestrial habitats. Along a mercury-contaminated river in Virginia, United States, terrestrial birds had significantly elevated levels of mercury in their blood, similar to their aquatic-feeding counterparts. Diet analysis revealed that spiders delivered much of the dietary mercury. We conclude that aquatic mercury pollution can move into terrestrial habitats, where it biomagnifies to levels in songbirds that may cause adverse effects. Rivers contaminated with mercury may pose a threat to the many bird species that feed on predatory invertebrates in adjacent riparian habitats.

Institute for Integrative Bird Behavior Studies, Department of Biology, College of William and Mary, Williamsburg, VA 23185, USA.

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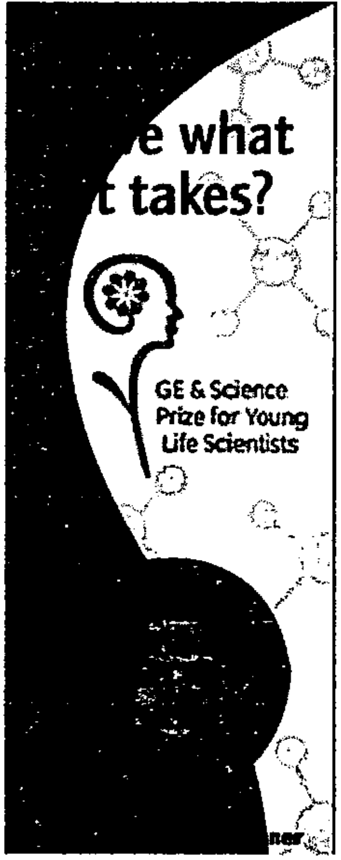

The editors suggest the following Related Resources on *Science* sites:

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(18 April 2008)
Science **320** (5874), 389b. [DOI: 10.1126/science.320.5874.389b]
Summary » Transcript »

STATE OF COLORADO

OFFICE OF THE GOVERNOR
136 State Capitol Building
Denver, Colorado 80203
(303) 866 - 2471
(303) 866 - 2003 fax

Attachment 23
Docket 07A-447E
Glustrom Answer Testimony

1876

Bill Ritter, Jr.
Governor

D 004 08

EXECUTIVE ORDER

Reducing Greenhouse Gas Emissions in Colorado

Pursuant to Article IV, Section 2 of the Colorado Constitution and the authority vested in the Office of the Governor of the State of Colorado, I, Bill Ritter, Jr., Governor of the State of Colorado, hereby issue this Executive Order declaring the state's greenhouse gas reduction goals, directing the Colorado Department of Public Health and Environment ("CDPHE") to develop regulations mandating the reporting of greenhouse gas emissions for major emitters, requesting the Public Utilities Commission to require utilities to submit electric resource plans for meeting greenhouse gas reduction goals, and directing CDPHE to propose, after a full vetting process and within 24 months, regulations requiring reduced greenhouse gas emissions from passenger motor vehicles.

I. Background and Need

Scientists tell us that to head off disruptions to our economy, environment and society by the second half of this century, we must reduce greenhouse gas emissions by at least 80% below 2005 levels by 2050. Many sectors of Colorado's economy, including agriculture, recreation, skiing, and tourism, could experience significant changes and impacts if emissions are not reduced. Because long term planning to address climate change is essential, this Executive Order establishes a goal of achieving an 80% reduction from 2005 levels by 2050. To meet this long term goal, we must first strive toward an interim goal, and this Executive Order establishes a goal of a 20% reduction from 2005 levels by 2020.

To achieve even our interim goal as efficiently as possible, we must have accurate data regarding the sources of greenhouse gas emissions within the state. Colorado, together with 38 other states, seven Canadian provinces, six Mexican states, and three tribal nations, has joined The Climate Registry, a voluntary greenhouse gas emissions reporting system. This voluntary registry provides a mechanism through which businesses, state agencies, local governments, and others can measure and report their greenhouse gas emissions. This voluntary system, however, will not provide the comprehensive data necessary to enable policy makers and business leaders to determine how best to meet our state's emissions reduction goal. This Executive Order directs CDPHE to draft, within 18-24 months, regulations to mandate reporting of greenhouse gas emissions from major sources.

In 2005, emissions from electricity production accounted for 36% of carbon dioxide emissions in Colorado. We must work with utilities, which provide a vital service to the state, to reduce their greenhouse gas emissions. The Public Utilities Commission ("PUC") requires the state's investor-owned utilities to periodically file an electric resource plan ("ERP") that shows how they will meet their customers' energy needs well into the future. This Executive Order requests the PUC to seek from each utility within its jurisdiction an ERP that includes an analysis that shows how the utility could achieve a 20% reduction in its greenhouse gas emissions from 2005 levels by the year 2020. We recognize that large utilities will have to weigh many approaches to achieve a 20% cut in emissions, including significant expansion of renewable energy sources and energy efficiency, investments in new clean coal technologies, retirement of old, inefficient coal-fired generating stations, purchases of carbon credits to offset emissions, and other strategies. The benefits to the state from such reductions include reduced air pollution, new jobs, as well as a more diverse, and therefore less volatile, energy supply portfolio.

To ensure that such plans can be achieved in the most efficient manner, this Executive Order also directs the Governor's Energy Office ("GEO") to work with the Department of Regulatory Agencies and other relevant agencies to identify regulatory and legislative changes that may be needed to provide investor-owned utilities with the appropriate incentives to invest in renewable energy sources, energy efficiency, carbon credits, and clean coal technologies.

Whether to allow the construction of new, conventional pulverized coal plants is an important decision that requires careful study and outreach to many key stakeholders. This Executive Order directs CDPHE and GEO to evaluate alternatives for addressing greenhouse gas emissions from new coal-fired power plants in consultation with affected parties and to make a recommendation within 12 months.

Emissions in the transportation sector account for 23% of greenhouse gas emissions in Colorado. In the absence of federal action, state governments are taking direct action to ensure that automakers reduce emissions of both greenhouse gases and pollutants that cause high ozone levels. These standards must be thoughtfully and deliberately examined to determine if they make sense for Colorado. This Executive Order directs CDPHE to propose regulations, after a full vetting process and within the next 24 months, to the Air Quality Control Commission that will achieve maximum feasible and cost effective reductions of greenhouse gas emissions from passenger motor vehicles. This timeframe will allow CDPHE to engage in a stakeholder process to analyze issues associated with consumer choice, vehicle costs, driving performance at high altitude, and other issues that arise during the stakeholder process.

2. Declaration and Directive

A. State of Colorado Greenhouse Reduction Goal

1. I hereby declare that it shall be the goal of the State of Colorado to achieve the following greenhouse gas emissions reduction goals:
    i. By 2020, to reduce greenhouse gas emissions in Colorado to 20% below its 2005 levels.

   ii. By 2050, to reduce greenhouse gas emissions in Colorado to 80% below its 2005 levels.

2. State agencies are directed to join in a statewide effort, coordinated by CDPHE, the Department of Natural Resources, the Department of Agriculture, GEO, and the Governor's Office of Policy and Initiatives, to achieve these goals. This effort should consider, and where appropriate coordinate with, greenhouse gas reduction efforts occurring within local governments.

B. Reporting of Greenhouse Gas Emissions and State Inventory

1. I hereby direct CDPHE to develop and propose regulations, by no later than 24 months from the date of this Executive Order, to the Air Quality Control Commission mandating reporting of greenhouse gas emissions for all major sources. The reporting requirements should be phased in as standardized quantification protocols, baseline data, and other tools become available.
2. CDPHE is directed to plan for performing updates to the state's greenhouse gas emissions inventory, with the first update scheduled to be completed no later than 2012 and repeated every five years thereafter.

C. Greenhouse Gas Emissions from the Utility Sector

1. I hereby request that the PUC require from each utility within its jurisdiction an ERP for achieving a 20% reduction in its greenhouse gas emissions from 2005 levels by 2020.
2. I hereby direct GEO and the Department of Regulatory Agencies to identify regulatory and legislative changes that may be needed to provide investor-owned utilities with the appropriate incentives to reduce greenhouse gas emissions, and to reduce financial barriers to investments in renewable energy sources, energy efficiency, carbon credits, and clean coal technologies. The Executive Directors of these agencies will provide their suggestions to my office within 12 months of the date of this Executive Order.
3. I hereby direct CDPHE and GEO to evaluate policy options to address future demand for new coal-fired power plants. This effort shall consider, at a minimum, development of alternate sources of energy and options for reducing or mitigating greenhouse gas emissions from new plants. CDPHE and GEO shall evaluate these options in consultation with affected parties and make a recommendation to my office within 12 months of the date of this Executive Order.

D. Greenhouse Gas Emissions from the Transportation Sector

1. I hereby direct CDPHE to develop and implement a process for identifying and evaluating the benefits as well as potential impediments to measures designed to reduce tailpipe emissions of greenhouse gases from passenger cars and light duty trucks, including protection of consumer choice, vehicle costs, driving performance at high altitude, the utility and availability of alternative-fuel vehicles (including positive and negative effects on air quality), projected reduction in gasoline demand and consumption, and potential short- and long-term cost savings for consumers. As part of this effort, CDPHE shall develop a process for seeking the participation of all affected stakeholders and for periodically briefing the Air Quality Control Commission on these matters.
2. I further direct CDPHE, upon the completion of this process but in no case longer than 24 months from the date of this Executive Order, to propose to the Air Quality Control Commission a comprehensive proposal for reducing net emissions of greenhouse gases from the state's transportation sector, including measures to achieve the maximum feasible and cost-effective reductions of greenhouse gases from passenger cars and light duty trucks. This proposal should reflect the evaluation of costs and benefits achieved through the process outlined in D.1 and be tailored to the specific needs of Colorado.

3. Duration

This Executive Order shall remain in force until modified or rescinded by a subsequent Executive Order.

Given under my hand and
the Executive Seal of the
State of Colorado this 22nd
day of April, 2008.

Bill Ritter, Jr.
Governor

Attachment 24
Docket 07A-447E
Glustrom Answer Testimony

Final Colorado Greenhouse Gas Inventory and Reference Case Projections 1990-2020

Center for Climate Strategies
October 2007

Principal Authors: Randy Strait, Steve Roe, Alison Bailie, Holly Lindquist, Alison Jamison, Ezra Hausman, Alice Napoleon

CCS
CENTER FOR CLIMATE STRATEGIES

Executive Summary

This report presents a summary of Colorado's anthropogenic greenhouse gas (GHG) emissions and sinks (carbon storage) from 1990 to 2020. The Center for Climate Strategies (CCS) prepared a preliminary draft GHG emissions inventory and reference case projection for the Colorado Department of Public Health and Environment (CDPHE) through an effort of the Western Regional Air Partnership (WRAP).[1] The preliminary draft report was provided to the Climate Action Panel (CAP) (and its Policy Work Groups [PWGs]) of the Colorado Climate Project to assist the CAP in understanding past, current, and possible future GHG emissions in Colorado, and thereby inform the policy option development process. The CAP and the PWGs provided comments for improving the reference case projections. This report documents the revised inventory and reference case projections incorporating comments as approved by the CAP.[2]

Colorado's anthropogenic GHG emissions and anthropogenic/natural sinks (carbon storage) were estimated for the period from 1990 to 2020. Historical GHG emissions estimates (1990 through 2005)[3] were developed using a set of generally accepted principles and guidelines for state GHG emissions inventories, relying to the extent possible on Colorado-specific data and inputs. The reference case projections (2006–2020) are based on a compilation of various existing Colorado and regional projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions described in Appendixes A through I of this report.

Table ES-1 provides a summary of historical (1990 to 2005) and reference case projection (2010 and 2020) GHG emissions for Colorado. In 2005, on a gross emissions consumption basis (i.e., excluding carbon sinks), Colorado accounted for approximately 116 million metric tons (MMt) of CO_2e emissions, an amount equal to 1.6% of total United States (US) gross GHG emissions. On a net emissions basis (i.e., including carbon sinks), Colorado accounted for approximately 89 $MMtCO_2e$ of emissions in 2005, an amount equal to 1.4% of total US net GHG emissions.[4] Colorado's GHG emissions are rising more quickly than those of the nation as a whole.[5]

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[1] *Draft Colorado Greenhouse Gas Inventory and Reference Case Projections, 1990–2020*, prepared by the Center for Climate Strategies for the Colorado Department of Public Health and Environment (CDPHE) through an effort of the Western Regional Air Partnership, January 2007.

[2] *Final Colorado Greenhouse Gas Inventory and Reference Case Projections, 1990–2020*, prepared by the Center for Climate Strategies for the Climate Action Panel of the Colorado Climate Project, October 2007.

[3] The last year of available historical data varies by sector; ranging from 2000 to 2005.

[4] National emissions from *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005*, April 2007, US EPA #430-R-07-002, (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

[5] *Gross* emissions estimates only include those sources with positive emissions. Carbon sequestration in soils and vegetation is included in *net* emissions estimates. All emissions reported in this section for Colorado reflect consumption-based accounting (including emissions from electricity imports). On a national basis, little difference exists between *production-based* and *consumption-based* accounting for GHG emissions because net electricity imports are less than 1% of national electricity generation.

Table ES-1. Colorado Historical and Reference Case GHG Emissions, by Sector[a]

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Energy	**75.4**	**96.0**	**102.2**	**114.1**	**129.1**	
Electricity Production	**31.6**	**38.7**	**39.8**	**45.3**	**50.0**	
Coal	30.9	35.1	34.9	40.0	44.2	See electric sector assumptions
Natural Gas	0.71	3.5	4.9	5.2	5.8	in Appendix A
Oil	0.02	0.08	0.02	0.02	0.02	
Wood	0.00	0.00	0.00	0.00	0.01	
Net Imported Electricity	1.0	2.2	3.1	2.9	2.6	
Electricity Consumption Based	**32.7**	**40.9**	**42.9**	**48.2**	**52.6**	
Residential/Commercial/Industrial (RCI) Fuel Use	**16.3**	**20.2**	**21.2**	**23.6**	**27.9**	
Coal	1.6	1.0	1.2	1.3	1.5	Based on US DOE regional projections
Natural Gas	11.8	15.4	16.5	18.8	23.7	Based on US DOE regional projections
Oil	2.8	3.7	3.5	4.1	5.2	Based on US DOE regional projections
Wood (CH_4 and N_2O)	0.06	0.07	0.04	0.05	0.05	Based on US DOE regional projections
Avoided emissions from recent building code and demand-side management (DSM) initiatives	0.00	0.00	0.00	-0.64	-2.5	Based on analysis of Colorado House Bill (HB) 07-1037 for avoided electricity and natural gas, HB 07-1146 for avoided natural gas, and Xcel settlement electric DSM
Transportation	**19.0**	**25.5**	**28.0**	**30.6**	**36.2**	
Motor Gasoline	13.3	17.4	18.1	19.2	22.1	Based on US DOE regional projections
Diesel	2.9	4.8	6.5	7.7	9.8	Based on US DOE regional projections
Natural Gas, LPG, other	0.19	0.22	0.22	0.28	0.39	Based on US DOE regional projections
Jet Fuel and Aviation Gasoline	2.5	3.1	3.2	3.4	3.9	Based on US DOE regional projections
Fossil Fuel Industry	**7.5**	**9.3**	**10.1**	**11.8**	**12.3**	
Natural Gas Industry	3.1	4.8	5.0	6.5	7.3	Increase based on current trend to 2009, then US DOE to 2020
Oil Industry	0.22	0.15	0.16	0.18	0.20	Increase based on current trend to 2009, then US DOE to 2020
Coal Mining (Methane)	4.2	4.3	4.9	5.1	4.8	Assumes no change after 2003
Industrial Processes	**0.76**	**2.1**	**2.9**	**3.8**	**5.9**	
Cement Manufacture (CO_2)	0.32	0.56	0.52	0.55	0.62	Based on state's Nonmetallic Minerals employment projections (2004-2014)
Lime Manufacture (CO_2)	0.01	0.01	0.01	0.01	0.01	Ditto
Limestone & Dolomite Use (CO_2)	0.00	0.03	0.04	0.04	0.04	Ditto
Soda Ash (CO_2)	0.04	0.04	0.04	0.04	0.05	Based on 2004 and 2009 projections for US production
ODS Substitutes (HFC, PFC, and SF_6)	0.004	1.2	2.1	3.0	5.1	Based on national projections (US State Dept.)
Semiconductor Manufacturing (HFC, PFC, and SF_6)	0.05	0.14	0.08	0.06	0.03	Based on national projections (US EPA)
Electric Power T & D (SF_6)	0.35	0.20	0.19	0.14	0.08	Based on national projections (US EPA)
Waste Management	**1.2**	**1.9**	**2.1**	**2.5**	**3.5**	
Solid Waste Management	0.79	1.3	1.5	1.8	2.7	Projections primarily based on population
Wastewater Management	0.39	0.57	0.59	0.66	0.84	Projections based on population
Agriculture (Ag)	**8.7**	**9.6**	**8.9**	**8.9**	**9.1**	
Enteric Fermentation	3.0	3.2	3.2	3.2	3.2	Projections held constant at 2003 levels except for dairy cattle (see Appendix F)
Manure Management	0.83	1.2	1.2	1.2	1.3	Ditto
Ag. Soils and Residue Burning	4.9	5.2	4.5	4.5	4.5	Projections held constant at 2005 levels
Total Gross Emissions	**86.1**	**109.6**	**116.1**	**129.3**	**147.5**	
increase relative to 1990		*27%*	*35%*	*50%*	*71%*	
Forestry and Land Use	**-24.7**	**-24.7**	**-24.7**	**-24.7**	**-24.7**	Historical and projected emissions held constant at 2004 levels.
Agricultural Soils	**-2.0**	**-2.0**	**-2.0**	**-2.0**	**-2.0**	Historical and projected emissions held constant at 1997 levels.
Net Emissions (including sinks)	**59.4**	**82.9**	**89.4**	**102.6**	**120.8**	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

From 1990 to 2005, Colorado's gross GHG emissions were up 35% while national gross emissions rose by 16% during this period. Much of Colorado's emissions growth can be attributed to its population growth. From 1990 to 2005, Colorado's population grew by 43% as compared with a national population growth of 19%.

Figure ES-1 illustrates the state's emissions per capita and per unit of economic output. Colorado's per capita emission rate is slightly more than the national average of 25 $MtCO_2e$/year. Between 1990 and 2005, per capita emissions in Colorado and national per capita emissions have changed relatively little. Economic growth exceeded emissions growth in Colorado throughout the 1990–2005 period. From 1990 to 2005, emissions per unit of gross product dropped by 40% nationally, and by 54% in Colorado.[6]

Electricity use and transportation are the state's principal GHG emissions sources. Together, the combustion of fossil fuels for electricity generation and in the transportation sector accounted for 61% of Colorado's *gross* GHG emissions in 2005. The remaining use of fossil fuels—natural gas, oil products, and coal—in the residential, commercial, and industrial (RCI) sectors, plus the emissions from fossil fuel production, constituted another 27% of total state emissions in 2005.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Colorado's gross GHG emissions continue to grow, and are projected to climb to 148 $MMtCO_2e$ by 2020, reaching 71% above 1990 levels. Overall, the average annual projected rate of emissions growth in Colorado is 1.6% per year from 2005 to 2020. As shown in Figure ES-3, demand for electricity is projected to be the largest contributor to future emissions growth accounting for about 36% of total gross GHG emissions in 2020, followed by emissions associated with transportation (25%), RCI fossil fuel use (19%), and fossil fuel production (8%)

Some data uncertainties exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of the inventory and projections include review and revision of key drivers (such as electricity, fossil fuel production, and transportation fuel use growth rates) that will be major determinants of Colorado's future GHG emissions. These growth rates are driven by uncertain economic, demographic, and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion.

Perhaps the variable with the most important implications for GHG emissions is the type and number of power plants that will be built in Colorado between now and 2020. The assumptions on VMT and air travel growth also have large impacts on projected GHG emissions growth in the state. Finally, uncertainty remains on estimates for historic and projected GHG sinks from forestry, which can greatly affect the net GHG emissions attributed to Colorado.

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[6] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis, http://www.bea.gov/regional/gsp/. The national emissions used for these comparisons are based on 2005 emissions, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Figure ES-1. Historical Colorado and US Gross GHG Emissions, Per Capita and Per Unit Gross Product

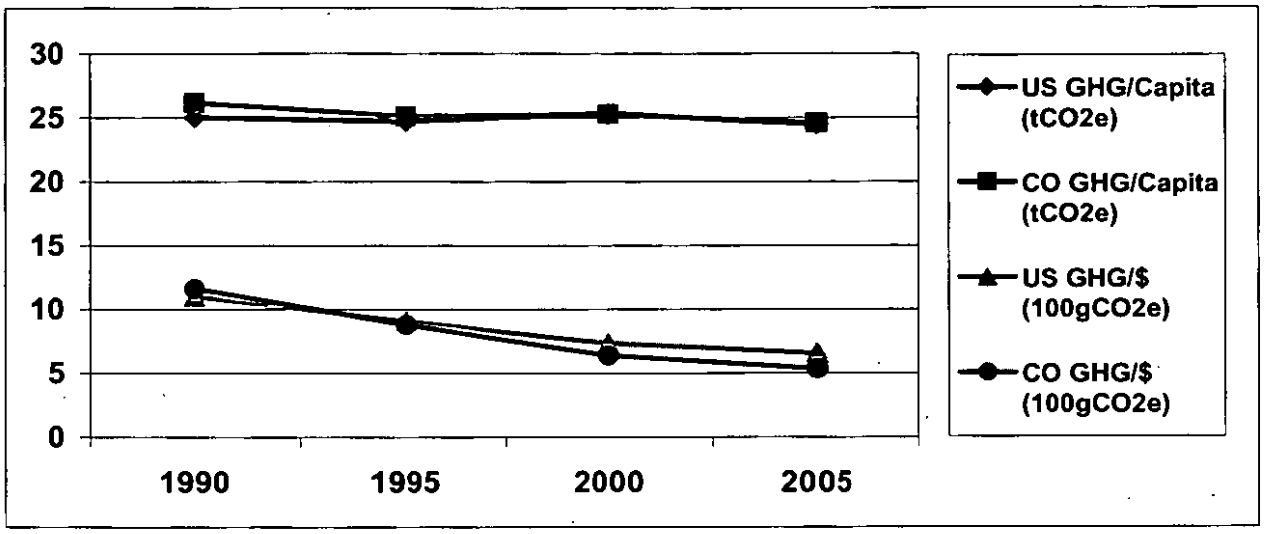
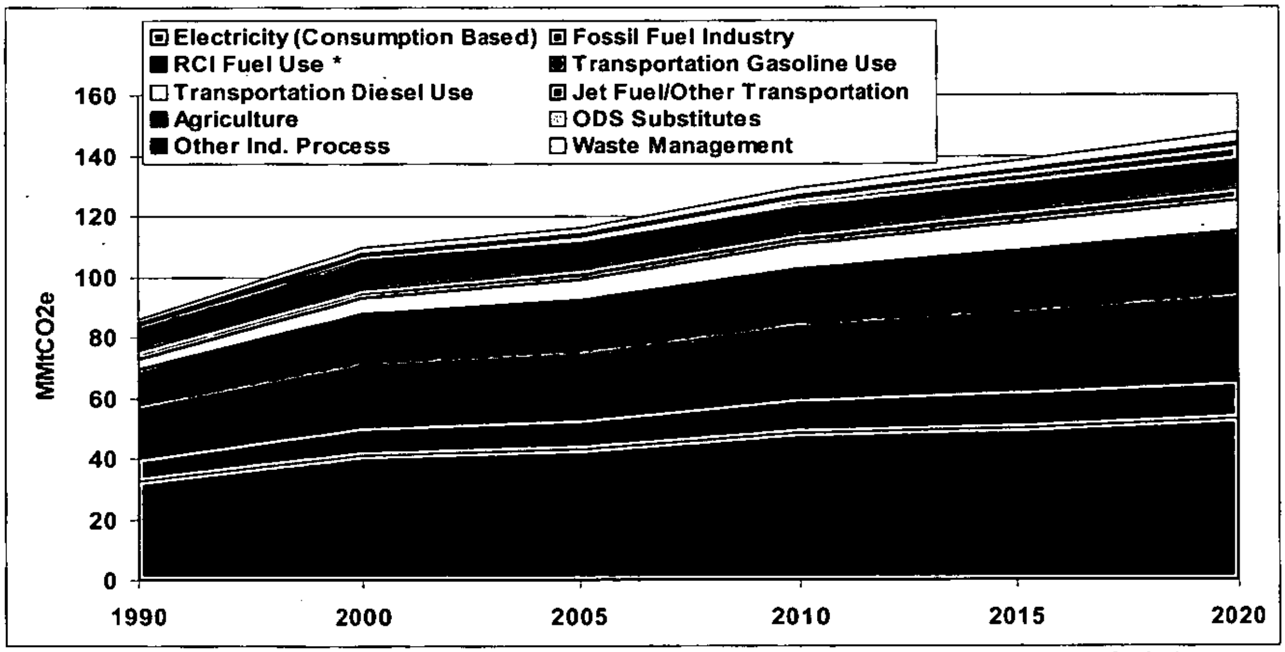
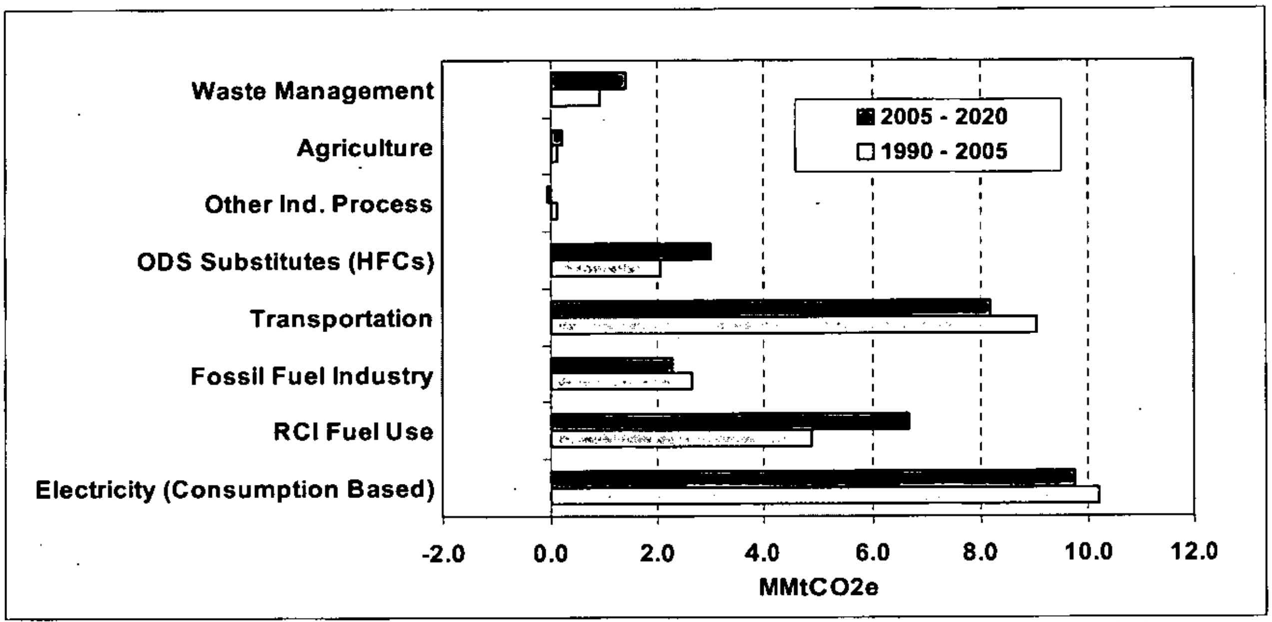


Figure ES-2. Colorado Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



* RCI = direct fuel use in residential, commercial, and industrial sectors; ODS Substitutes = ozone depleting substances substitutes. Other Industrial Processes include process-related GHG emissions from cement and lime manufacturing; semiconductor manufacture; soda ash, limestone, and dolomite use; and electricity transmission and distribution systems.

Figure ES-3. Sector Contributions to Gross Emissions Growth in Colorado, 1990-2020: Reference Case Projections (MMtCO$_2$e Basis)



RCI = direct fuel use in residential, commercial, and industrial sectors; ODS Substitutes = ozone depleting substances substitutes; HFC = hydrofluorocarbons.

Emissions of aerosols, particularly "black carbon" (BC) from fossil fuel combustion, could have significant climate impacts through their effects on radiative forcing.[7] Estimates of these aerosol emissions on a CO$_2$e basis were developed for Colorado based on 2002 and 2018 data from the WRAP. The results were a total of 6.75 MMtCO$_2$e, which is the mid-point of a range of estimated emissions (4.3–9.2 MMtCO$_2$e) in 2002. Based on an assessment of the primary contributors, it is estimated that BC emissions will decrease substantially by 2018 after new engine and fuel standards take effect in the onroad and nonroad diesel engine sectors (decrease of about 4.0 MMtCO$_2$e). These estimates are not incorporated into the totals shown in Table 2-1 because a global warming potential for BC has not yet been assigned by the Intergovernmental Panel on Climate Change (IPCC). By including BC emission estimates in the inventory, however, additional opportunities for reducing climate impacts can be identified as the scientific knowledge related to BC emissions improves.

The following identifies the revisions that the CAP made to the inventory and reference case projections thus explaining the differences between the information presented in this report and the preliminary information presented in the January 2007 report:

- Energy Supply: Lowered emissions to account for changes in reference case assumptions associated with Colorado's Renewable Portfolio Standard (RPS), which was amended

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[7] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 1996). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm.

upward in 2007 by the state legislature's passage of House Bill (HB) 07-1281 (Renewable Energy Standards):

  - Investor-Owned Utilities (IOUs) to provide 20% renewable energy by 2020
  - Non-IOUs (e.g., municipal utilities and rural electric cooperatives) to provide 10% renewable energy by 2020
  - Incentives for in-state generation, community-based projects, and solar energy

- RCI: Reduced energy consumption in the reference case projections associated with the passage of HB 07-1146 (Energy Conservation Building Codes) in 2007. This bill requires local governments who have building codes to adopt energy efficiency codes for certain buildings.[8] Reduction in emissions is accounted for under the RPS adjustment to avoid double counting of emission reductions.

- RCI: Reduced energy consumption in the reference case projections associated with the passage of HB 07-1037 (legislation recently passed requiring that public electric and gas utilities implement demand-side management programs)[9] and Xcel's demand side management commitments under a recent legal settlement, both of which have the effect of limiting demand growth relative to what it would have been in the absence of these factors.[10]

- Waste Management: Revisions to municipal solid waste (MSW) to reflect revisions the US Environmental Protection Agency made to the methods for calculating emissions in US EPA's State Greenhouse Gas Inventory Tool (SGIT; i.e., change was from use of regression equations to LANDGEM model equation):

  - 1990 emissions decrease from 1.6 to 0.8 $MMtCO_2e$
  - 2020 emissions decrease from 5.7 to 2.7 $MMtCO_2e$

- Forestry: Removed forest soil organic carbon emissions sink as recommended by the United States Forest Service (USFS). Relative to the January 2007 report, this change removed 7.1 $MMtCO_2e$ of emissions from the forest sink pool for 1990 through 2020.

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[8] http://www.statebillinfo.com/sbi/index.cfm?fuseaction=Bills.View&billnum=HB07-1146.

[9] http://www.statebillinfo.com/sbi/index.cfm?fuseaction=Bills.View&billnum=HB07-1037.

[10] Comprehensive Settlement Agreement, docket 04A-214E, 04A-215E, and 04A-216E, issued December 3, 2004, available at http://www.xcelenergy.com/docs/corpcomm/SettlementAgreementFinalDraftclean20041203.pdf.

Table of Contents

Appendix A. Electricity Use and Supply

Overview

Colorado's electric sector has experienced strong growth in the last 15 years, mostly driven by population and economic growth in the state. These drivers, and the state's electric sector, appear likely to experience continued growth for some time. Greenhouse gas (GHG) emissions associated with electricity production and consumption accounted for about 36% of Colorado's gross GHG emissions in 2005.

As noted in the main report, one of the key questions for the state to consider is how to treat GHG emissions that result from generation of electricity that is produced outside Colorado to meet electricity needs in the state. In other words, should the state consider the GHG emissions associated with the state's electricity consumption, with its electricity production, or with some combination of the two? This appendix describes GHG emissions from Colorado's electricity sector in terms of emissions from both electricity consumption and production, including the assumptions used to develop the reference case projections. It then describes Colorado's electricity trade and potential approaches for allocating GHG emissions for the purpose of determining the state's inventory and reference case projections. In addition, as discussed at the end of this appendix, the reference case projections were updated to reflect recent legislation that increased requirements for renewable fuels in Colorado's Renewable Portfolio Standard (RPS), which was amended by the Colorado State Legislature in 2007 by House Bill (HB) 07-1281 (Renewable Energy Standards), and requirements for demand-side management programs (DSM). Finally, key assumptions and results are summarized.

Electricity Consumption

At about 10,000 kilowatt-hour (kWh) per capita (2004 data), Colorado has relatively low electricity consumption per capita. By way of comparison, the annual per capita consumption for the US was about 12,000 kWh/capita.[28] Figure A1 shows Colorado's rank compared to other western states from 1960-1999; while showing stronger increases during this time period than most states, Colorado's per capita consumption has been relatively low (2nd lowest, effectively tied with Utah and New Mexico for much of 1985 to 1999). Many factors influence a state's per capita electricity consumption, including the impact of weather on demand for cooling and heating, the size and type of industries in the state, and the type and efficiency of equipment in use in the residential, commercial and industrial sectors.

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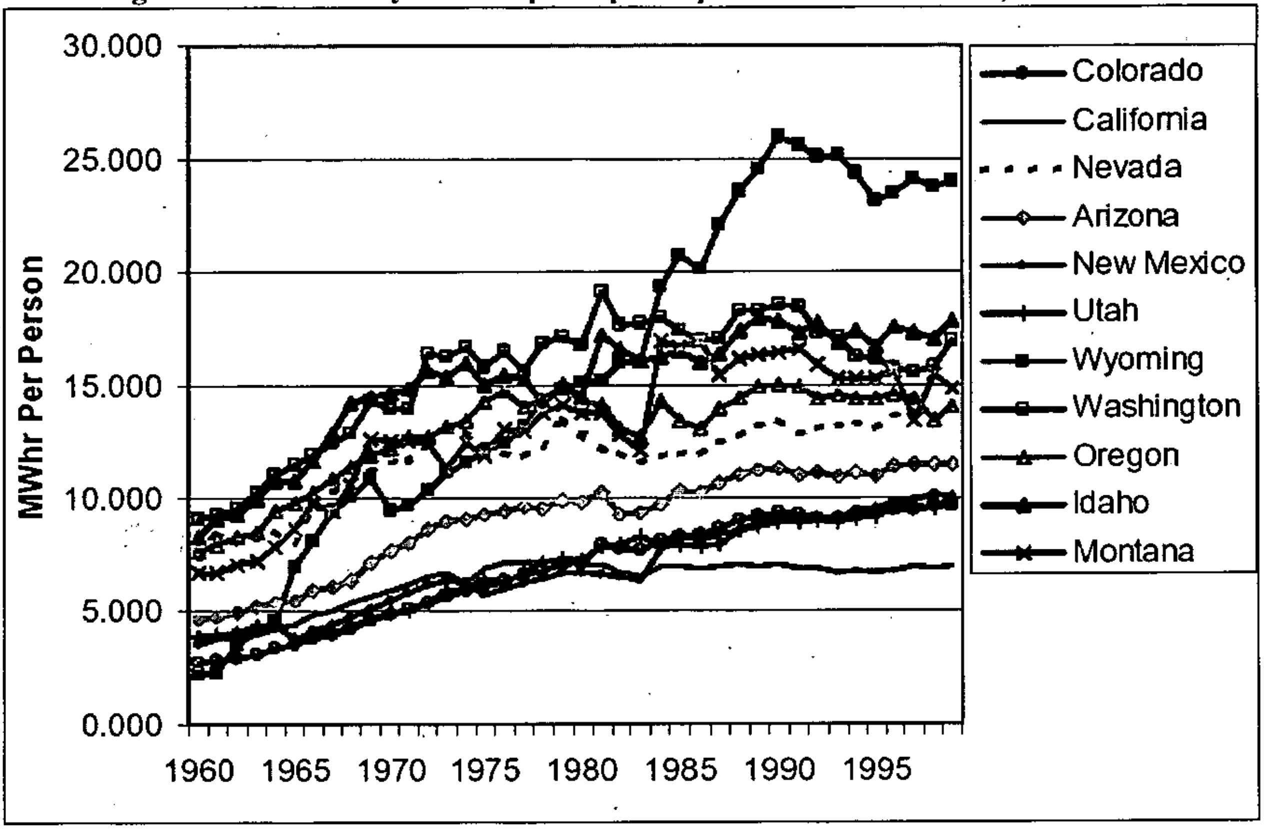
[28] Census bureau for U.S. population, Energy Information Administration for electricity sales.

Figure A1. Electricity Consumption per capita in Western States, 1960-1999



Source: Northwest Power Council, 5th Power Plan, Appendix A Note: MWhr is Megawatt-hours.

As shown in Figure A2, electricity sales in the Colorado have generally increased steadily from 1990 through 2004. Overall, total electricity consumption increased at an average annual rate of 3% from 1990 to 2004, which can be compared with population growth at a rate of 2.5% per year and gross state product increases averaging of 4.3%/yr over the same period.[29] During this period, residential sector consumption grew by an average of 3.4% per year, commercial sector use grew by 2.2% per year, and industrial sector consumption increased at 4.2% per year. The industrial sector electricity sales increases in Colorado have not been uniform over this period – total industrial sector sales increased by 37% from 1993 to 1994, then by less than 4% from 1994 through 2000.[30]

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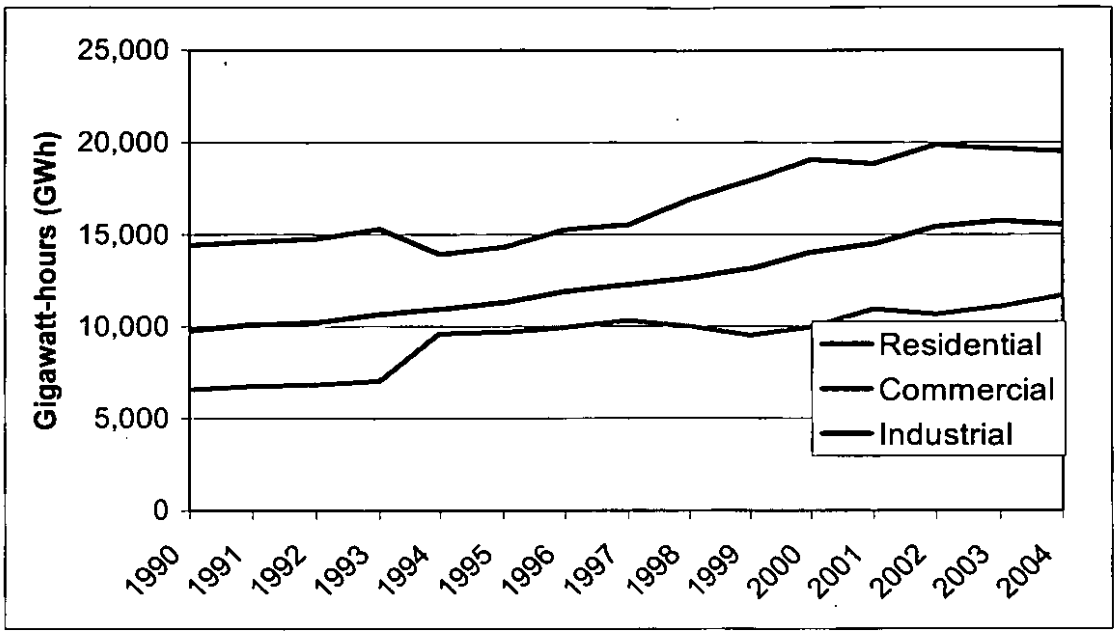
[29] Populations from Colorado's Databook. Gross State Production from Bureau of Economic analysis. Available as http://bea.gov/bea/newsrelarchive/2006/gsp1006.xls

[30] CCS checked this value with EIA who were unable to determine the exact source of the increase. The data are reported directly by utilities to EIA.

Figure A2. Electricity Consumption by Sector in Colorado, 1990-2004[31]



Source: EIA State Energy Data (SED) (1990-2002) and EIA Electric Power Annual (2003-2004)

The Colorado Energy Forum recently released a report, *Colorado's Electricity Future*.[32] This report provides projections for electricity sales in Colorado, excluding the impacts of any additional investments in energy efficiency programs. These projections were developed by RW Beck by compiling forecasts from the largest utility providers in Colorado and extrapolating these forecasts to smaller electricity suppliers in similar regions. The RW Beck analysis included a base case forecast, plus high- and low-case sensitivities. The base case projection was used for the current analysis. Table A1 reports historic and projected annual average growth rates for electricity use in Colorado.

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[31] Note that from 1990-2002, the US Department of Energy (US DOE) Energy Information Administration (EIA) data includes a category referred to as "other," which included lighting for public buildings, streets, and highways, interdepartmental sales, and other sales to public authorities, agricultural and irrigation sales where separately identified, electrified rail and various urban transit systems (such as automated guideway, trolley, and cable systems). To report total electricity in Figure A2, the sales from the "other" category are included with commercial sector sales. The decision to include sales listed as "other" with commercial rather than the residential or industrial sector sales data was based on a comparison of the trends of electricity sales from 2000-2002 with sales are categorized in 2003 EIA data.

[32] *Colorado's Electricity Future: An Analysis by the Colorado Energy Forum Incorporating Three Separate Reports by:* R.W. Beck Inc., Schmitz Consulting LLC, and The Colorado School of Mines (September 2006)

Table A1. Electricity Growth Rates, historic and projected

	Historic		Projections	
	1990-2000	2000-2004	2004-2010	2010-2020
Residential	3.7%	2.6%	Not Available	
Commercial	2.8%	0.6%		
Industrial	4.2%	4.1%		
Total	**3.4%**	**2.1%**	**2.9%**	**2.1%**

Source: Historic from EIA data, projections from *Colorado's Electricity Future (*2006).

Electricity Generation – Colorado's Power Plants

The following section provides information on GHG emissions and other activity associated with power plants *located in Colorado*. Note that GHG emissions are reported in this document as metric tons of CO_2 equivalents ($MTCO_2$) or as million metric tons of CO_2 equivalents ($MMtCO_2$). Since Colorado is part of the interconnected Western Electricity Coordinating Council (WECC) region – electricity generated in Colorado can be exported to serve needs in other states, and electricity used in Colorado can be generated by plants outside the state. For this analysis, we estimate emissions on both a *production-basis* (emissions associated with electricity produced in Colorado, regardless of where it is consumed) and a *consumption-basis* (emissions associated with electricity consumed in Colorado). The following section describes production-based emissions while the subsequent section, *Electricity trade and the allocation of GHG emissions*, reports consumption-based emissions.

As mentioned the main report and as displayed in Figure A3, coal figures prominently in electricity generation and accounts for 88% of the GHG emissions from power plants in Colorado. Table A2 reports the carbon dioxide (CO_2) emissions from the eight plants in Colorado with the highest emissions. The plant with the highest emissions, Craig, accounts for 24%-27% of Colorado's GHG emissions. Craig is a large facility with three generator units having a combined capacity of over 1,300 megawatts (MW). It runs primarily on coal (over 99.5% of energy consumption) but also consumes small amounts of natural gas and oil. As will be discussed further in the *Electricity Trade and Allocation of GHG emissions* section, the Craig Power Plant is owned by Tri-State (49%), Salt River Project (19%), Pacific-Corp West (13%), Platte River Power Authority (12%) and Xcel Energy (7%). The contracts associated with these ownership shares lead to a significant level of electricity from these plants being exported outside the state – the Salt River Project serves customers in central Arizona; Tri-State provides power to cooperatives in Wyoming and Nebraska, as well at Colorado; and Pacific-Corp West serves customers in Oregon, Washington and California. The Hayden power plant is also owned by a mix of Salt River Project (29%), Pacific-Corp West (18%), and Xcel Energy (53%). Comanche and Cherokee are 100% owned by Xcel Energy. [33] Electricity trade and its impact on GHG allocation in Colorado are discussed in the section below.

We considered two sources of data in developing the historic inventory of GHG emissions from Colorado power plants – EIA State Energy Data (SED), which need to be multiplied by GHG

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[33] Data from US EPA's Emissions & Generation Resource Integrated Database (eGRID) database, reflecting ownership levels in 2000.

emission factors for each type of fuel consumed, and United States Environmental Protection Agency (US EPA) data on CO_2 emissions by power plant. For total electric sector GHG emissions, we used the EIA's State Energy Data (SED) rather than US EPA data because of the comprehensiveness of the EIA-based data. The US EPA data are limited to plants over 25 MW and include only CO_2 emissions (US EPA does not collect data on methane (CH_4) or nitrous oxide (N_2O) emissions). Through discussions with staff at the US EPA we also learned that US EPA data tend to be conservative (that is, overestimate emissions) because the data are reported as part of a regulatory program, and that during early years of the data collection program, missing data points were sometimes assigned a large value as a placeholder. However, the US EPA provides easily accessible data for each power plant (over 25 MW), which would be much more difficult to extract from EIA data, and the CO_2 emissions from the two sources differ by less than 2% in most years. Based on this information, we chose to report information from both data sources, but rely on the EIA data for the inventory values. For total GHG emissions from electricity production in Colorado, we applied State Greenhouse Gas Inventory Tool (SGIT) emission factors[34] to EIA's SED. For CO_2 emissions from individual plants, we used the EPA database.

Table A2. CO_2 Emissions from Individual Colorado Power Plants, 2000-2005

(Million metric tons CO2)	2000	2001	2002	2003	2004	2005
Cherokee	*4.9*	*4.8*	*4.3*	*5.0*	*4.9*	*5.2*
Comanche	*4.4*	*4.7*	*5.2*	*5.4*	*4.8*	*4.8*
Craig	*9.5*	*9.7*	*9.7*	*9.7*	*10.4*	*10.5*
Hayden	*3.6*	*3.8*	*4.0*	*3.6*	*3.8*	*4.1*
Martin Drake	*2.0*	*2.1*	*2.0*	*2.1*	*1.8*	*2.2*
Pawnee	*4.3*	*4.8*	*3.6*	*4.2*	*3.8*	*3.2*
Rawhide Energy Station	*2.2*	*2.4*	*2.3*	*2.5*	*2.5*	*2.1*
Ray D Nixon	*1.6*	*1.7*	*1.7*	*1.7*	*1.8*	*1.6*
Other Plants	*6.0*	*6.8*	*6.7*	*5.4*	*5.5*	*6.0*
Total CO2 emissions	**38.5**	**40.7**	**39.5**	**39.6**	**39.3**	**39.6**

Source: US EPA Clean Air Markets database for named plants (http://cfpub.epa.gov/index.cfm). Total emissions calculated from fuel use data provided by SED (EIA). Note: The emissions reported in the above table are CO_2 only. CH_4 and N_2O emissions were not included in the power plant data available from the US EPA.

Table A3 shows the growth in generation by fuel type for all power plants in Colorado between 1990 and 2004. Overall generation grew by 47% over the 15 years, while electricity consumption grew by 52%. Natural gas-fired generation has been particularly strong, increasing by more than 8-fold from 1994 through 2004. Renewable generation (biomass, solar and wind) grew by a similar relative amount over the time period, but as of 2004 these resources accounted for only 0.5% of total generation. Coal generation grew more slowly but remains the dominant source of electricity in the state. Imports grew from an estimated 1,500 Gigawatt-hour (GWh) (4.6% of state generation) in 1990 to 3,500 GWh (7.6% of state generation) in 2004.

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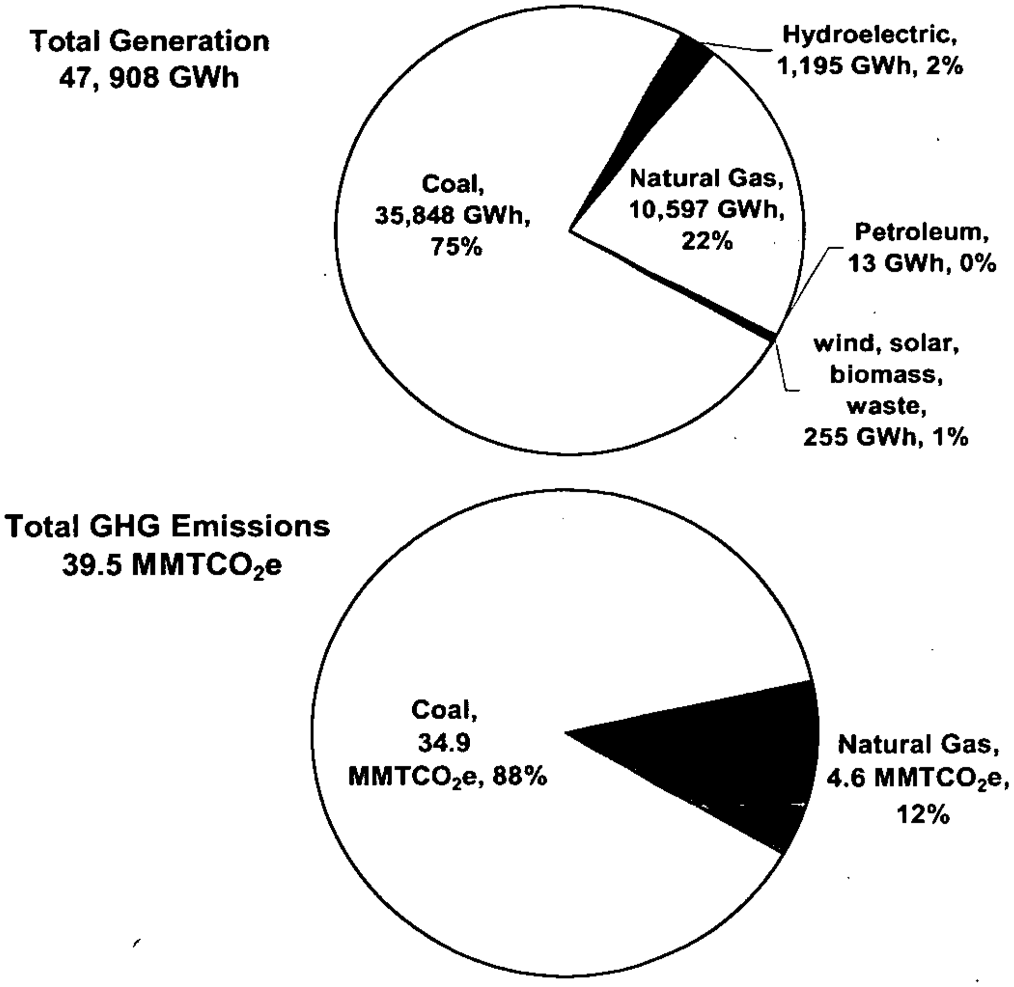
[34] SGIT http://www.epa.gov/climatechange/emissions/state_guidance.html, National GHG inventory http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Figure A3. Electricity Generation and CO$_2$ Emissions from Colorado Power Plants, 2004



Source: Generation data from EIA Electric Power Annual spreadsheets, GHG emissions figures calculated from EIA data on consumption and SGIT GHG emission factors.

Table A3. Growth in Electricity Generation in Colorado 1990-2004

	Generation (GWh)		Growth
	1990	2004	
Coal	29,815	35,848	20%
Hydroelectric	1,420	1,195	-16%
Natural Gas	1,238	10,597	756%
biomass, solar, wind	4	255	723%
Petroleum	25	13	-49%
Total	32,502	47,908	47%

Source: EIA Electric Power Annual Data

Future Generation and Emissions

Estimating future generation and GHG emissions from Colorado power plants requires estimation of new power plant additions and production levels from new and existing power plants. There are, of course, large uncertainties, especially related to the timing and nature of new power plant construction.

The future mix of generating plants in Colorado remains uncertain, as the trends in type of new builds are influenced by many factors. Since 1982, new fossil-fueled plants in Colorado have been natural gas-fired; however, concerns about the cost and availability of natural gas seem to have led to a trend towards a more coal-dominated mix. Recent announcements by several utilities indicate that coal-fired units will dominate new power plant builds. Xcel Energy has started construction on the Pueblo unit, an expansion of the Comanche power plant. Additionally, according a recent Denver Post article, Xcel has proposed to build a separate new plant, which would be "the nation's first power plant that converts coal to clean-burning gas and captures carbon emissions - viewed as an environmental breakthrough that will change coal's image from a belching polluter to an abundant, clean and relatively affordable resource. The plant could cost from $500 million to $1 billion or more, with a possible construction start in 2009."[35]

In 2004, Colorado became the first state in the country to have voters directly approve a RPS, rather than have it processed through a state's legislature.[36] Colorado voters approved Amendment 37 and the state has recently begun implementation. The RPS requires utilities with over 40,000 customers to generate (or purchase) a minimum amount of electricity from renewable sources. Colorado's RPS requires minimum annual contributions of renewable electricity of 3% from 2007 through 2010, 6% from 2011 through 2014; and 10% by 2015 and thereafter. Of the electricity generated each year from renewable sources, at least 4% must come from solar electric technologies. At least one-half of this percentage must come from solar electric systems located on-site at customers' facilities. Other eligible technologies include wind, geothermal heat, biomass facilities that burn nontoxic plants, landfill gas, animal waste, small hydroelectric, and hydrogen fuel cells. Energy generated in Colorado is favored; each kWh of renewable electricity generated in-state will be counted as 1.25 kWh for the purposes of meeting this standard. The RPS will likely spur additional new wind and solar projects in the state. Xcel Energy's Spring Canyon wind farm came on-line in 2006, and three other wind plants have been proposed for Colorado. Xcel has also announced a project to build and operate an 8 MW solar central solar power plant in Alamosa, Colorado, that will house two technologies: concentrating photovoltaic (PV) and advanced flat-plate solar panel units. The plant is expected to be on-line at the end of 2007, pending regulatory approval, and will be the largest PV central solar station in the United States.[37] Table A4 presents data on new and proposed plants in Colorado.

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[35] http://www.denverpost.com/business/ci_4421583

[36] Database of State Incentives for Renewables and Efficiency http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=CO24R&state=CO&CurrentPageID=1&RE=1&EE=1

[37] http://www.renewableenergyaccess.com/rea/news/story?id=46072

Note that proposals for individual plants cover the period through 2010. Beyond this time period it is necessary to make assumptions about expected growth. Given the many factors affecting electricity-related emissions and a diversity of assumptions by stakeholders within the electricity sector, developing a "reference case" projection for the most likely development of Colorado's electricity sector is particularly challenging. Therefore, to develop an initial projection, simple assumptions were made, relying to the extent possible on widely-reviewed and accepted modeling assessments.

Table A4. New and Proposed Power Plants in Colorado

	Plant Name	Fuel	Status	Capacity MW	Expected Annual generation GWh	Expected Annual Emissions MMTCO2e	Notes
Wind and Solar Plants	Colorado Green	wind	On-line 2003	162	500	0	All power will be sold to Xcel Energy under a long term Power Purchase Agreement
	Spring Canyon	wind	On-line 2006	60	190	0	All power will be sold to Xcel Energy under a long term Power Purchase Agreement
	Solar plant in Alamosa, Colorado	solar	Proposed - end of 2007	8	13	0	Xcel Energy selected an affiliate of SunEdison, LLC, to build, own and operate this plant, PSCo will purchase the power and renewable energy credits
	Xcel Wind Plants	wind	Proposed - end of 2007	775	1697	0	Xcel Energy announced its intent to acquire 775 MW of new wind, to be in service by end of 2007. Xcel signed contracts with FPL and Invenergy for 400 MW of capacity.
Non-Renewable Plants	Blue Spruce Energy Center	gas	On-line 2003	280	255	0.16	Generation and Emissions from US EPA Clean Air Database for 2005
	Rawhide expansion-Unit D	gas	On-line 2004	74	3	less than 0.005	Generation and Emissions from US EPA Clean Air Database for 2005
	Rocky Montain Energy Center	gas	On-line 2004	478	3,261	1.32	Generation and Emissions from US EPA Clean Air Database for 2005
	Xcel Natural Gas Plants	gas	2007/2012	608 for 2007 193 for 2012	1050 by 2012	0.54	Plants reported in Xcel Bid Evaluation report, generation based on 15% capacity factor (peaking plants)
	Lamar Expansion	coal	Application Pending - 2008	37	259	0.22	Generation based on 0.80 capacity factor, GHG emissions based on heatrate of 9000 british thermal unit per kWh (BTU/kWh)
	Comanche Expansion	coal	Under Construction - Oct 2009	750	5,256	4.38	Generation based on 0.80 capacity factor, GHG emissions based on heatrate of 9000 BTU/kWh

Sources: Colorado Green – E-mail from Tim Oleary, Shell Renewables, November 10, 2006
Spring Canyon – E-mail from Phil Stiles, InvEnergy, October 18, 2006
Solar Plant – Xcel Energy press release, capacity factor from Wiser and Bolinger powerpoint presentation 2006, newrules.org
Xcel Wind Plants – Xcel press release, http://www.xcelenergy.com/XLWEB/CDA/0,3080,1-1-1_15531_26314-28906-0_0_0-0,00.html
Blue Spruce, Rawhide, Rocky Mountain – *Colorado's Electricity Future*
Xcel Natural Gas – Xcel Bid Evaluation report
Lamar and Comanche expansion – *Colorado's Electricity Future*

The reference case projections are based on CCS's review of the analyses discussed below and assume:

- Generation from plants in Colorado grows at 2.8% per year from 2006-2010 – this growth reflects the estimated generation from the new plants that came on-line in 2006 or are under-construction in the state (as reported in Table A3 above) and additional renewable generation that is required to meet the RPS.

- Generation from plants in Colorado grows at 2.5% per year from 2010 to 2015 and 2.0% from 2015 to 2020. This reflects the generation growth rate for the Rocky Mountain region in EIA's Annual Energy Outlook 2006 (AEO2006). These assumptions lead to about 4300 MW of new power plant capacity by 2020 (excluding Comanche expansion).
- Generation from existing non-hydro plants is based on holding generation at 2004 levels. Generation from existing hydro-electric plants is assumed to be 1,597 GWh per year, the average generation from the last ten years. New plants and changes to existing plants due to plant renovations and overhauls that result in higher capacity factors are counted as new generation.
- The RPS requirements are assumed to be met by Xcel Energy and Aquila, the state's investor-owned utilities. From 2007 to 2010, three of the public utilities (Colorado Spring, Holy Cross and Fort Collins) are expected to meet the RPS minimum requirements. From 2011 onwards, Longmont is also assumed to meet the RPS requirements. These utilities are expected to meet the requirements through self-certification and are assumed to meet the total renewable requirements, but not necessarily the solar requirements.[38] The 2 investor-owned utilities and the 4 "publics" are estimated to account for 65% of electricity sales.[39] This analysis assumes that 95% of the renewables will be located in-state and will receive an additional 25% credit toward the RPS requirements.[40]
- New fossil fuel plants built between 2010 and 2020 will be a mix of 80% coal and 20% natural gas, based on the mix projected for the Rocky Mountain region of WECC in the AEO2006.
- Following the definition of *reference case* that CCS is using – i.e., based on existing or soon-to-be enacted policies – the projections for the electric sector assume that the state does not enact rules designed to limit GHG emissions.

Electricity Trade and Allocation of GHG Emissions

Colorado is part of the interconnected WECC region - a vast and diverse area covering 1.8 million square miles and extending from Canada through Mexico, including all or portions of 14 western states. The inter-connected region allows electricity generators and consumers to buy and sell electricity across regions, taking advantage of the range of resources and markets. Electricity generated by any single plant enters the interconnected grid and may contribute to meeting demand throughout much of the region, depending on sufficient transmission capacity. Thus, it is challenging to define, first, which emissions should be allocated to Colorado, and secondly, to estimate these allocated emissions both historically and into the future. Some

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[38] Information on utility plans for meeting RPS based on personal communication, Richard Mignogna, Colorado Department of Regulatory Agencies, October 23, 2006.

[39] Based on utility sales data in 2004, from EIA.

[40] CCS assumptions, needs verification

utilities track and report electricity sales to meet consumer demand by fuel source and plant type; however, tracing sales to individual power plants may not be possible.

In 2004, Colorado had 62 entities involved in providing electricity to state customers. The state's two investor-owned utilities serve approximately 60% of the customers, and provide 58% of the electricity sales. The state's 28 electric cooperatives serve 23% of the customers and provide the same fraction of sales. One federal and 29 municipal utilities account for the remaining 18.5% of sales and 17% of customers. The top 5 providers of retail electricity in the state are reported in Table A5; Xcel Energy provided about 55% of retail electricity sales in 2004.[41]

Table A5. Retail Electricity Providers in Colorado (2004)

Entity	Ownership Type	2004 GWh
Xcel Energy	Investor-Owned	25,748
City of Colorado Springs	Public	4,312
Intermountain Rural Elec Assn	Cooperative	1,784
Aquila Inc	Investor-Owned	1,735
City of Fort Collins	Public	1,350
Total Sales, Top Five Providers		34,928
Total, All Colorado		**46,724**

Source: EIA state electricity profiles.

Most of the municipal systems and rural electric cooperatives purchase power from other utilities, including the Western Area Power Administration (WAPA), Xcel Energy, Tri-State Generation and Transmission Association (Tri-State), or from a municipal joint-action power authority. Tri-State, Colorado's one generation and transmission cooperative, has 1300 MW of generation capacity and supplies power to rural electricity cooperatives in Colorado, Wyoming and Nebraska. Three municipal power authorities operate within Colorado – the Arkansas River Power Authority, the Platte River Power Authority, and the Nebraska Municipal Power Pool. The Platte River Power Authority is the largest of the three and provides electricity to four cities (Estes Park, Fort Collins, Longmont, and Loveland) in Colorado with 425 MW of installed generation – including about 6 MW of wind generation in Wyoming.[42] The largest municipal generator is Colorado Springs Utilities, which owns and operates 633 MW.[43]

In 2004, electricity demand (sales + losses[44]) in Colorado was about 51,500 GWh, while electricity generation in the state was 47,900 GWh. Net imported electricity from other states provided the additional 3,400 GWh. Also as mentioned above, 620 MW of the capacity at the Craig and Hayden power plants is owned by out-of-state utilities. Similarly Colorado utilities own or have long term contracts for 500 MW of hydro capacity and 340 MW of coal capacity

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[41] EIA state electricity profiles

[42] http://www.awea.org/projects/wyoming.html,
http://www.dora.state.co.us/PUC/projects/euir/FinalRpt/Sctn3Rpt.pdf

[43] Colorado Springs *Fact Book 2004-2005.* http://www.csu.org/about/library/2191.pdf

[44] Colorado's electricity losses are assumed to be 10% of total generation, based on information from eGRID, http://www.epa.gov/cleanenergy/egrid/index.htm. 10% is the average rate of losses, according to this dataset, over the period 1994-2000.

from outside of the state. Thus, electricity trade counts for a significant portion of the electric power associated with Colorado.

Since almost all states are part of regional trading grids, many states that have developed GHG inventories have grappled with the problem of how to account for electric sector emissions, when electricity flows across state borders. Several approaches have been developed to allocate GHG emissions from the electricity sector to individual states for inventories.

In many ways the simplest approach is *production-based* – emissions from power plants within the state are included in the state's inventory. The data for this estimate are publicly available and unambiguous. However, this approach is problematic for states that import or export significant amounts of electricity. Under a production-based approach, characteristics of Colorado electricity consumption would not be fully captured since only emissions from in-state generation would be considered.

An alternative is to estimate *consumption-based* or *load-based* GHG emissions, corresponding to the emissions associated with electricity consumed in the state. The load-based approach is currently being considered by states that import significant amounts of electricity, such as California, Oregon, and Washington.[45] By accounting for emissions from imported electricity, states can account for increases or decreases in fossil fuel consumed in power plants outside of the state, due to demand growth, efficiency programs, and other actions in the state. The difficulty with this approach is properly accounting for the emissions from imports and exports. Since the electricity flowing into or out of Colorado is a mix of all plants generating on the inter-connected grid, it is impossible to physically track the sources of the electrons.

The approach taken in this initial inventory is a simplification of the consumption-based approach. This approach, which one could term "*Net-Consumption-based,*" estimates consumption-based emissions as in-state (production-based) emissions plus the emissions from the net imports. Emissions for net imports are calculated as net electricity imports (in GWh) multiplied by the average emission intensity for imports (in $MtCO_2e/GWh$). Estimating the mix of electricity generation for the imports/export of a state is possible and several states are developing data collection approaches to do this. Washington State has developed regular fuel disclosure reporting.[46] Colorado enacted legislation in 1999 that requires investor-owned utilities to disclose information on their fuel mix to retail customers.[47] While this information would be helpful in estimating the fuel mix of electricity that is imported into Colorado by Xcel and Aquila, the information was not readily available.[48] As a proxy for estimating the mix of historic

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[45] See for example, the reports of the Puget Sound Climate Protection Advisory Committee (http://www.pscleanair.org/specprog/globclim/), the Oregon Governor's Advisory Group On Global Warming (http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml), and the California Climate Change Advisory Committee, Policy Options for Reducing Greenhouse Gas Emissions From Power Imports - Draft Consultant Report (http://www.energy.ca.gov/2005publications/CEC-600-2005-010/CEC-600-2005-010-D.PDF).

[46] http://www.cted.wa.gov/site/539/default.aspx

[47] Code of Colorado Regulations Rule 723-3-10(f) et seq. Information from Database of State Incentives for Renewables and Efficiency http://www.dsireusa.org/documents/Incentives/CO17R.htm

[48] The fuel mix provided on Xcel Energy's bills included a breakdown by fuel for electricity provided by plants in Colorado but did not include the fuel mix of imported electricity. Information on the legislation is listed at: http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=CO17R&state=CO&CurrentPageID=1&RE=1&EE=0

and future GHG for Colorado's electricity imports, emission intensities that reflect the regional fuel mix were used. Emissions from the Rocky Mountain region of the WECC (excluding Colorado's emissions) were used to calculate GHG emission intensity for imports, with estimates of future Rocky Mountain emissions provided by the AEO2006. These regional emission factors were 0.61 $MtCO_2e/MWh$ in 2004, increasing to 0.68 $MtCO_2e/MWh$ in 2020, reflecting an increasing domination of coal generation. To estimate GHG emissions for imports, the amount of net imports to the state (electricity sales + losses – electricity generation) was multiplied by the regional emission factors.

This method does not account for differences in the type of electricity that is imported or exported from the state, and as such, it provides a simple method for reflecting the emissions impacts of electricity consumption in the state. The calculation also ignores "gross" imports – since Colorado plants have contracts to out-of-state entities, some of the in-state electricity generation will be exported and gross imports will be greater than net imports. More sophisticated methods – for example, based on individual utility information on resources used to meet loads – can be considered for further improvements to this approach.

Summary of Assumptions and Reference Case Projections

As noted, projecting generation sources, sales, and emissions for the electric sector out to 2020 requires a number of key assumptions, including assumptions regarding future economic and demographic activity, changes in electricity-using technologies, regional markets for electricity (and competitiveness of various technologies and locations), access to transmission and distribution, the retirement of existing generation plants, the response to changing fuel prices, and the fuel/technology mix of new generation plants. The key assumptions described above are summarized in Table A6.

Figure A4 shows historical sources of electricity generation in the state by fuel source, along with projections to the year 2020 based on the assumptions described above.

Based on the above assumptions for new generation, coal continues to dominate new generation throughout the forecast period (2005-2020). Renewable generation shows the highest relative growth due to the RPS, growing to 5% of total Colorado generation in 2020.[49] Net imports increase to a maximum of 6,800 GWh in 2008 (13% of Colorado's generation) then decrease sharply as the Comanche coal plant expansion comes on-line (imports are 4,500 GWh or 8.0% in 2010) and continue to decrease, relative to total state generation, to 6% in 2020.

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[49] This level is lower than the 10% RPS due to assumptions on 1) not all utilities will opt to meet the RPS and 2) in-state renewable generation receives a credit of 1.25 kWh for each kWh generated so a lower amount of total renewable generation is required. See assumptions in table A5 for more details.

Table A6. Key Assumptions and Methods for Electricity Projections for Colorado

Electricity sales	Average annual growth of 2.8% from 2005 to 2010 and 2.2% per year from 2010 to 2020, based on regional growth rates in *Colorado's Electricity Future*, which are based on rates in utilities' integrated resource plans.
Electricity generation	2.9% per year growth from 2005-2010, based on plants under construction and RPS requirements and 2.2% per year from 2010 to 2020, based on regional growth rates in AEO2006.
Transmission and Distribution losses	10% losses are assumed, based on average statewide losses, 1994-2000, (data from eGRID[50])
New Renewable Generation Sources	Colorado's RPS will be met by 2 investor-owned utilities and 4 public owned utilities (65% of electricity sales), 6% of the utilities' sales met by renewable generation by 2011, 10% by 2015 and in subsequent years. 95% of the renewable requirements will be met by in-state sources. New renewable power plants are assumed to be wind except for the solar set-aside (4% of the renewable requirements).
New Non-Renewable Generation Sources (2006-2010)	New generation in this period assumes the Comanche coal plant expansion will be on-line by 2010 and new natural gas peaking plants will be built, following Xcel's Bid Evaluation. Additional electricity requirements for Colorado will be met through net electricity imports.
New Non-Renewable Generation Sources (2010-2020)	75% coal 25% natural gas based on mix of new generation projected in AEO2006 for the Rocky Mountain region of the WECC.
Heat Rates	The assumed heat rates for new gas and coal generation are 7000 BTU/kWh and 9000 BTU/kWh, respectively, based on estimates used in similar analyses.[51]
Operation of Existing Facilities	Existing facilities are assumed to continue to operate as they were in 2004. Improvements in existing facilities that lead to higher capacity factors and more generation are captured under the new non-renewable generation sources.

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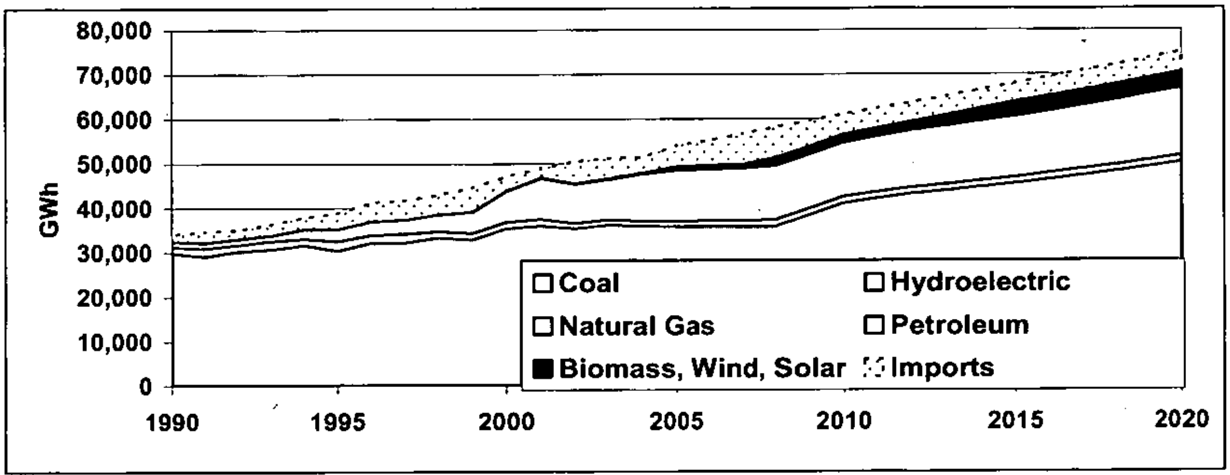
[50] http://www.epa.gov/cleanenergy/egrid/index.htm.

[51] See, for instance, the Oregon Governor's Advisory Group On Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml.

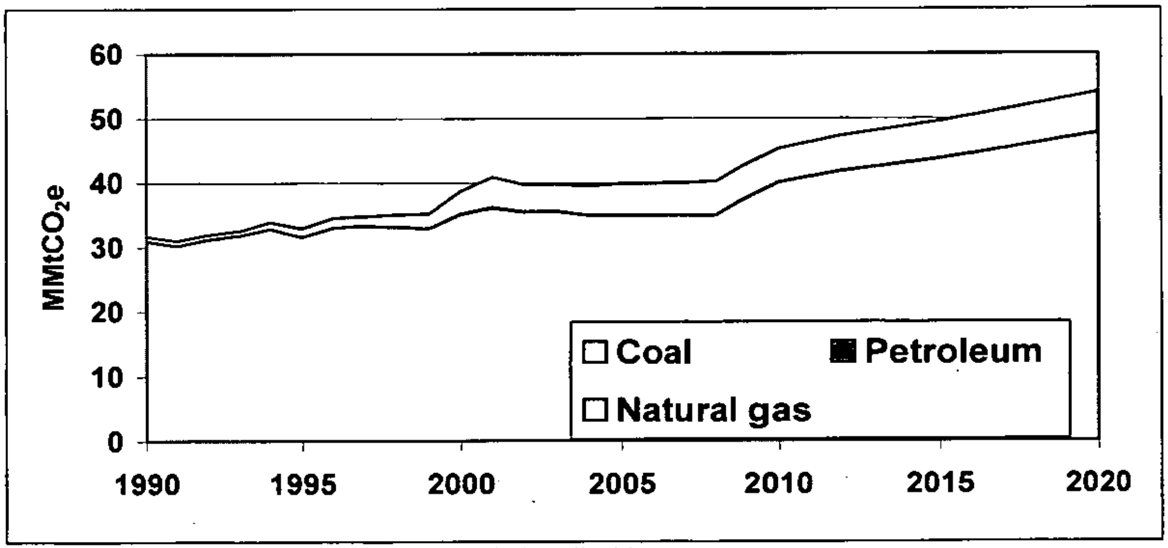
Figure A4. Electricity Generated by Colorado Power Plants plus Estimated Net Imports, 1990-2020



Source: 1990-2004 EIA data, 2005-2020 CCS calculations based on assumptions described above, generation from petroleum resources is too small to be visible in the chart

Figure A5 illustrates the GHG emissions associated with the mix of electricity generation shown in Figure A4. From 2005 to 2020, the emissions from Colorado electricity generation are projected to grow at 2.0% per year, slightly lower than the growth in electricity generation, due to an increased fraction of generation from renewables. As a result, the average emission intensity (emissions per MWh) of Colorado's electricity is expected to decrease from 0.82 $MtCO_2/MWh$ in 2004 to 0.76 $MtCO_2/MWh$ in 2020.

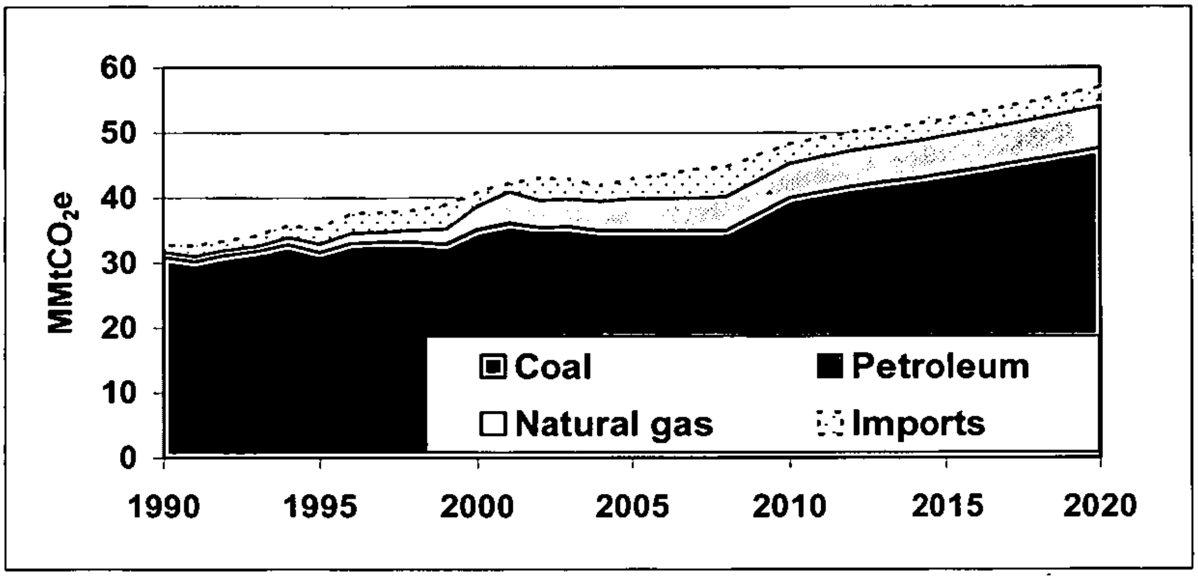
Figure A5. Colorado GHG Emissions Associated with Electricity Production (Production-Basis), excludes Imports



Source: CCS calculations based on approach described in text.
Note: Colorado's electric generation GHG emissions from petroleum sources are less than 0.1 $MMtCO_2e$ and too small to be visible in the chart.

Figure A6 shows the "net-consumption-based" emissions from 1990 to 2020. Total emissions are greater than the production-based emissions due to the GHG emissions associated with electricity imports. These GHG emissions are based on the mix of fuels forecast to generate electricity in the Rocky Mountain region of the WECC, based on results of the AEO2006. The estimated regional emission factor is about 0.61 $MtCO_2e/MWh$ in 2004, increasing to 0.68 $MtCO_2e/MWh$ in 2020, which is lower than Colorado's GHG emission rate (see *Electricity Trade* section above for further information on this factor).

Figure A6. Colorado GHG Emissions Associated with Electricity Use (Consumption-Basis), including Imports



Source: CCS calculations based on approach described in text.
Note: GHG emissions from imports are estimated using the mix of fuels in the Rocky Mountain region of WECC (as defined in the AEO2006). Colorado's electric generation GHG emissions from petroleum sources are less than 0.1 $MMtCO_2e$ and too small to be visible in the chart.

Table A7 summarizes the GHG emissions for Colorado's electric sector from 1990 to 2020. During this time period, emissions are projected to increase by 71% on a production-basis and 74% on a consumption-basis.

Comparison to Previous State GHG Inventory

The Colorado Department of Public Health and Environment's (CDPHE) inventory provided estimates of production-based electric sector GHG emissions. The production-based GHG emissions that CCS has estimated for this analysis are about 14% higher than the CDPHE estimates for 1990 and 12% higher than CDPHE for 1997. These differences appear to result from differences in energy consumption data, although both analyses relied on EIA data. We discussed the differences with EIA but were unable to determine the cause for changes in energy consumption data. However, we verified that the energy consumption values used in this analysis reflect EIA's current best estimates. The CDPHE analysis also included projections to 2015, based on AEO1995 projections for energy consumption in the electric sector. The 2015 emissions estimates from the CDPHE analysis were 50.2 MMtCO_2e, only 1.6% larger than the estimates from this analysis, 49.5 MMtCO_2e.

Table A7. Colorado GHG Emissions from Electric Sector, Production and Consumption-based estimates, 1990-2020 (MMtCO_2e).

	1990	1995	2000	2005	2010	2015	2020
Electricity Production Based	**31.6**	**32.9**	**38.7**	**39.8**	**45.3**	**49.5**	**54.0**
Coal	30.9	31.6	35.1	34.9	40.0	43.7	47.6
CO2	*30.8*	*31.5*	*34.9*	*34.7*	*39.8*	*43.5*	*47.4*
CH4 and N2O	*0.15*	*0.15*	*0.17*	*0.17*	*0.20*	*0.21*	*0.23*
Natural Gas	0.71	1.3	3.5	4.9	5.2	5.8	6.3
CO2	*0.71*	*1.27*	*3.53*	*4.88*	*5.22*	*5.76*	*6.34*
CH4 and N2O	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*
Oil	0.02	0.02	0.08	0.02	0.02	0.02	0.02
CO2	*0.02*	*0.02*	*0.08*	*0.02*	*0.02*	*0.02*	*0.02*
CH4 and N2O	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Wood (CH4 and N2O)	0.000	0.000	0.000	0.001	0.001	0.001	0.001
Net Imported Electricity	1.0	2.5	2.2	3.1	3.0	4.5	3.0
Electricity Consumption Based	32.7	35.4	40.9	42.9	48.2	54.0	57.0

Note: Assumes electricity production from renewable fuels are based on 2004 RPS requirements.

Updates to the Reference Case Projection

At the request of the Climate Action Panel (CAP), the reference case projections for the Electricity Supply sector were modified to include the effects of Colorado's 2007 RPS law that increased requirements (relative to the state's 2004 RPS) for IOUs to use renewable fuel resources. The reference case was also modified to incorporate the effects for House Bill (HB) 1146 to increase demand-side management (DSM) requirements for electricity. It was assumed that the fuel resource mix meeting the RPS is the same as that assumed in the 30% RPS policy developed by the CAP's Policy Work Group (PWG). In 2020, wind energy is approximately 85% of RPS generation, and photovoltaic (PV), solar thermal, small hydro, biomass and geothermal are about 3% each.

In addition, total electricity demand was reduced relative to the original reference case in response to certain DSM activities as discussed for the RCI sector. The effect of this is a reduction in the overall emissions associated with energy use, and also a reduction of the direct impact of the RPS program as this is based on a percentage of total electricity sales in the state.

The RPS law requires Investor-Owned Utilities (IOUs) to provide 20% renewable energy by 2020 and non-IOUs (e.g., municipal utilities and rural electric cooperatives) to provide 10%. The law also includes incentive clauses for in-state generation, community-based projects and solar energy. The following assumptions were made for the purpose of revising the emissions projections under the 2007 RPS law:

- In-state generation constitutes 80% of the RPS generation for IOUs; and this energy receives 125% credit.

- Community-based projects constitute 10% of non-IOU RPS generation; and this energy receives 150% credit.
- Pre-2015 solar energy constitutes 5% of non-IOU RPS generation; and this energy receives 300% credit.
- 10% of energy from existing hydro facilities in Colorado is eligible to meet the RPS.
- New RPS generation and reduced electricity demand displace fossil generation in the same ratio at which fossil generation is being added to the Colorado system over the study period: 75% coal and 25% gas.
- While the new law goes into effect in 2008, it has no effect until 2011 as there is sufficient existing renewable generation to meet the requirement prior to that date.

Table A8 shows the revised contributions to electric sector emissions by fuel after incorporating the effects of the 2007 RPS requirements and the electricity DSM requirements of HB 1146. Table A9 shows the total emissions in the initial and the revised reference case projections and the GHG reductions resulting from the revisions.

Table A8. Colorado GHG Emissions from Electric Sector with 2007 RPS, Production and Consumption-based estimates, 1990-2020 (MMtCO_2e).

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Electricity Production Based	**31.6**	**32.9**	**38.7**	**39.8**	**45.3**	**47.6**	**50.0**
Coal	30.9	31.6	35.1	34.9	40.0	42.1	44.2
CO2	*30.8*	*31.5*	*34.9*	*34.7*	*39.8*	*41.9*	*43.9*
CH4 and N2O	*0.15*	*0.15*	*0.17*	*0.17*	*0.20*	*0.2*	*0.2*
Natural Gas	0.71	1.3	3.5	4.9	5.2	5.5	5.8
CO2	*0.71*	*1.27*	*3.53*	*4.88*	*5.22*	*5.5*	*5.8*
CH4 and N2O	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.0*	*0.0*
Oil	0.02	0.02	0.08	0.02	0.02	0.02	0.02
CO2	*0.02*	*0.02*	*0.08*	*0.02*	*0.02*	*0.0*	*0.0*
CH4 and N2O	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.0*	*0.0*
Wood (CH4 and N2O)	0.000	0.000	0.000	0.001	0.001	0.004	0.006
Net Imported Electricity	1.0	2.5	2.2	3.1	2.9	2.4	2.6
Electricity Consumption Based	32.7	35.4	40.9	42.9	48.1	50.0	52.6

Note: Assumes electricity production from renewable fuels are based on 2007 RPS requirements.

Table A9. Comparison of Colorado GHG Emissions from Electric Sector for Original and Revised Forecast (Consumption-Based), 2007-2020

	2007	**2010**	**2015**	**2020**
Original GHG Emissions (MMtCO_2e)	**44.4**	**48.2**	**52.0**	**57.0**
Revised GHG Emissions (MMtCO_2e)	**44.4**	**48.2**	**50.0**	**52.6**
Difference (MMtCO_2e)	**-**	**0.1**	**2.0**	**4.3**
Difference (%)	**0.00**	**0.15**	**3.91**	**7.60**

Clean Energy

You are here: EPA Home Climate Change Clean Energy
Greenhouse Gas Equivalencies Calculator

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Greenhouse Gas Equivalencies Calculator

Did you ever wonder what reducing carbon dioxide (CO_2) emissions by 1 million metric tons means in everyday terms? The following equivalency calculator can help you understand just that.

For example, it can be difficult to visualize what a "metric ton of carbon dioxide" really is. This calculator will translate rather difficult to understand statements into more commonplace terms, such as "is equivalent to avoiding the carbon dioxide emissions of X number of cars annually."

This equivalency calculator may be useful in communicating your greenhouse gas reduction strategy, reduction targets, or other initiatives aimed at reducing GHG emissions.

Other Calculators

There are a number of other web-based calculators that can estimate greenhouse gas emission reductions for

- individuals and households
- waste, and
- transportation.

For basic information and details on greenhouse gas emissions, visit the Emissions section of EPA's climate change site.

Enter Your Data Below

There are two options for entering data into this calculator.

Option 1:

1. If you are starting with data in units of "gallons of gasoline consumed," "kilowatt-hours of electricity," "therms of natural gas," or "passenger vehicles per year", use this option.
2. Enter a quantity and pick the desired unit below; and
3. Click on the "Calculate Equivalent**" button to convert your value to Carbon Dioxide Equivalent.

- choose a unit - ▾ Calculate Equivalent**

? Click Here for Calculations and References

**This calculator uses an eGRID non-baseload national average emissions rate when calculating "kilowatt-hours of electricity" to "carbon dioxide equivalent".

Option 2:

If you have already estimated the quantity of avoided emissions reductions (e.g., metric tons of carbon dioxide equivalent), you can input the amount of avoided emissions and select the appropriate units for the corresponding greenhouse gas type.

Amount	Unit	Gas
1,000,000	Tons ▾	CO_2 - Carbon Dioxide
	Tons ▾	CH_4 - Methane

Amount	Unit	Gas
	Tons	N_2O - Nitrous Oxide
	Tons	HFC-23 - Hydrofluorocarbon gases
	Tons	CF4 - Perfluorocarbon gases
	Tons	SF_6 - Sulfur Hexafluoride
	Tons	Carbon Equivalent

Calculate Equivalencies | Clear Fields

*If your estimated emissions of methane, nitrous oxide, or other non-CO_2 gases are already expressed in CO_2 or carbon equivalents, please enter your figures in the row for CO_2 or carbon equivalent.

The sum of the greenhouse gas emissions you entered above is 907,185 Metric Tons of Carbon Dioxide Equivalent.

This is equivalent to one of the following:

Equivalency Results

Click on the question mark **?** link to read the explanation of that particular calculation. Read about all calculations.

The information you entered above is equivalent to one of the following statements:

→ Annual greenhouse gas emissions from 166,151 passenger vehicles **?** *(click to read more about this calculation)*

CO_2 emissions from 102,972,157 gallons of gasoline consumed **?**

CO_2 emissions from 2,109,732 barrels of oil consumed **?**

CO_2 emissions from 12,115 tanker trucks' worth of gasoline **?**

→ CO_2 emissions from the *electricity* use of 120,157 homes for one year **?**

CO_2 emissions from the *energy* use of 80,069 homes for one year **?**

→ Carbon sequestered by 23,261,146 tree seedlings grown for 10 years **?**

Carbon sequestered annually by 206,178 acres of pine or fir forests **?**

Carbon sequestered annually by 6,328 acres of forest preserved from deforestation **?**

CO_2 emissions from 37,799,363 propane cylinders used for home barbeques **?**

CO_2 emissions from burning 4,737 railcars' worth of coal **?**

Greenhouse gas emissions avoided by recycling 312,822 tons of waste instead of sending it to the landfill **?**

Annual CO_2 emissions of 0.2 coal fired power plants **?**

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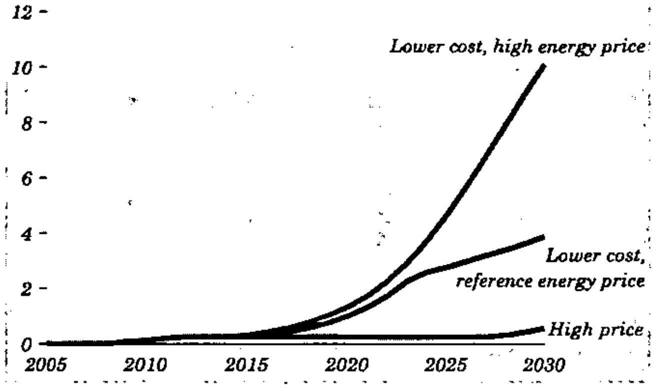
Lower Costs, Greater Demand Could Spur Cellulose Ethanol Production

Figure 85. Cellulose ethanol production, 2005-2030 (billion gallons per year)

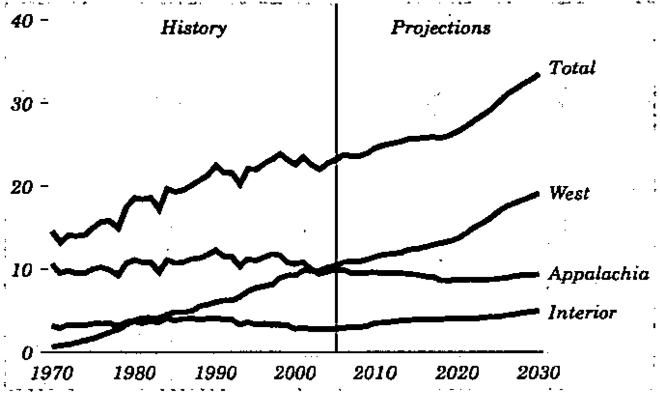


For *AEO2007*, two alternative ethanol cases examine the potential impact on ethanol demand of lower costs for cellulosic ethanol production, in combination with policies that increase sales of FFVs [*170*]. The reference case projects that 10.5 percent of new light-duty vehicles will be capable of burning E85 in 2016. The lower cost ethanol case using reference energy prices assumes that capital and operating costs for cellulose ethanol plants in 2018 are 20 percent lower than projected in the reference case, that at least 80 percent of new light-duty vehicles in 2016 can run on E85, and that energy prices will be the same as projected in the reference case. The lower cost ethanol case using high energy prices is based on the same assumptions for cellulose ethanol plant costs and FFV sales but with energy prices from the high price case.

E85 is projected to be competitive with gasoline in both alternative ethanol cases, and projected demand for ethanol fuels increases accordingly. In the lower cost ethanol case with reference prices, E85 demand in 2030 is projected to be 1.9 billion gallons, or 1.7 billion gallon higher than in the reference case. In the lower cost ethanol case with high energy prices, E85 demand in 2030 is projected to be 27.9 billion gallons, or 24.7 billion gallons higher than in the high price case. Increased demand for E85 and reduced production costs in the alternative ethanol cases result in increased production of cellulosic ethanol, which exceeds the mandated level in 2015 in both cases, growing to 3.9 billion gallons per year in 2030 in the lower cost ethanol case with reference prices and to 10.1 billion gallons per year in 2030 in the lower cost ethanol case with high energy prices (Figure 85).

Western Coal Production Continues To Increase Through 2030

Figure 86. Coal production by region, 1970-2030 (quadrillion Btu)



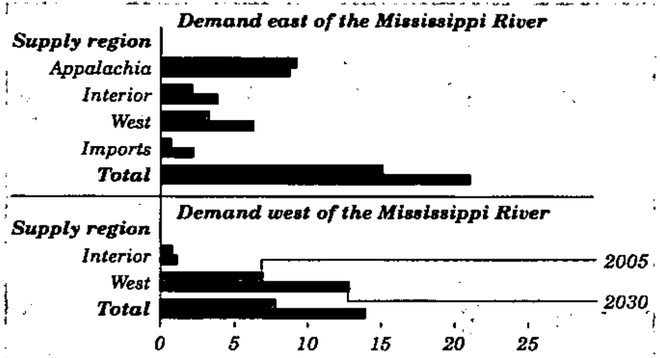
In the *AEO2007* reference case, increasing coal use for electricity generation at existing plants and construction of a few new coal-fired plants lead to annual production increases that average 1.1 percent per year from 2005 to 2015, when total production is 25.7 quadrillion Btu. The growth in coal production is even stronger from 2015 to 2030, averaging 1.8 percent per year, as substantial amounts of new coal-fired generating capacity are added and several CTL plants are brought on line.

Western coal production, which has grown steadily since 1970, continues to increase through 2030 (Figure 86). Much of the projected growth is in output from the Powder River Basin, where producers are well positioned to increase production from the vast remaining surface-minable reserves. Constraints on rail capacity limited growth in coal production from the Basin during 2005 and 2006, but recent and planned maintenance and investment in the rail infrastructure serving the region should allow for substantial growth in future production.

Appalachian coal production declines slightly in the reference case. Although producers in Central Appalachia are well situated to supply coal to new generating capacity in the Southeast, the Appalachian basin has been mined extensively, and production costs have been increasing more rapidly than in other regions. The eastern portion of the Interior coal basin (Illinois, Indiana, and western Kentucky), with extensive reserves of mid- and high-sulfur bituminous coals, benefits from the new coal-fired generating capacity in the Southeast.

Eastern Power Plants Are Expected To Use More Western Coal

Figure 87. Distribution of coal to domestic markets by supply and demand regions, including imports, 2005 and 2030 (quadrillion Btu)



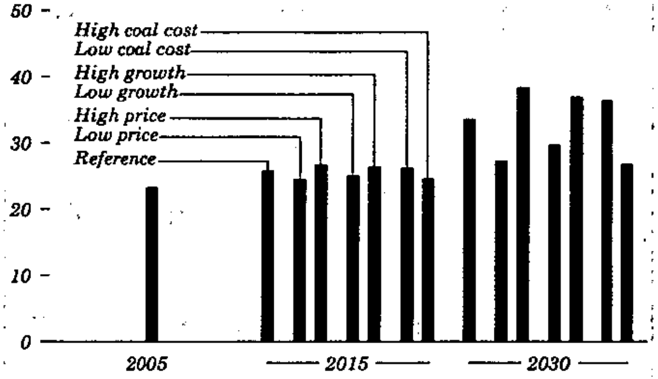
In the reference case, coal use is expected to grow substantially throughout the United States. For States east of the Mississippi River, coal demand is projected to increase by 5.9 quadrillion Btu, or 39 percent, from 2005 to 2030. Much of that increase is expected to be met by western coal—particularly in those States that are relatively close to the Powder River Basin supply region. Coal supply from Appalachian producers to markets east of the Mississippi River remains close to current levels, but increases in shipments from mines in the Eastern Interior region and in coal imports contribute to the overall decline in Appalachia's share of the market east of the Mississippi, from 61 percent in 2005 to 42 percent in 2030.

West of the Mississippi River, coal demand is projected to increase by 6.1 quadrillion Btu, or 79 percent, from 2005 to 2030, with western coal producers as the primary source of supply (Figure 87). Most of the remainder is expected to be supplied from lignite mines in the Gulf Coast area, primarily in Texas.

East of the Mississippi River, an increase in utilization rates for existing coal-fired power plants—from 71 percent in 2005 to 82 percent in 2030—accounts for approximately 30 percent of the projected increase in coal demand for the electric power sector. In contrast, west of the Mississippi, existing coal-fired plants already are operating at an average utilization rate of 80 percent. Therefore, increased utilization accounts for only a small amount of the projected increase in the region's coal demand over the projection period.

Long-Term Production Outlook Varies Considerably Across Cases

Figure 88. U.S. coal production, 2005, 2015, and 2030 (quadrillion Btu)



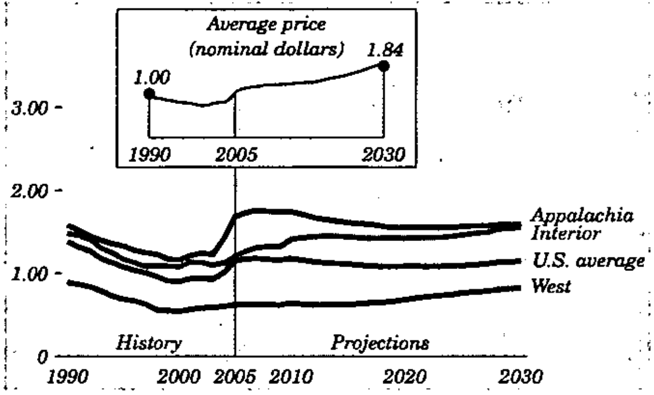
In all the *AEO2007* cases, U.S. coal production is projected to increase from 2005 to 2030; however, different assumptions about economic growth and the costs of producing fossil fuels lead to different results. The reference case projects a 44-percent increase from 2005 to 2030, whereas the alternative cases show increases ranging from as little as 15 percent to as much as 65 percent (Figure 88). Because the level of uncertainty is higher in the longer term, the projected increases in coal production from 2005 to 2015 show significantly less variation, ranging from 6 percent to 15 percent.

Regional coal production trends generally follow the national trend. For example, production of subbituminous coal in Wyoming's Powder River Basin is projected to increase by 73 percent from 2005 to 2030 in the reference case, as compared with 45 percent in the low price case and 95 percent in the high price case. The projected regional shares of total coal production in 2030 (from the Appalachian, Interior, and Western supply regions) do not vary by much among the reference, high and low price, and high and low economic growth cases.

In the high coal cost case, higher mining and transportation costs for coal from the Powder River Basin hold the projected increase in the region's annual coal production from 2005 to 2030 to a relatively small 0.2 quadrillion Btu, or 2 percent. As a result, the Wyoming Powder River Basin share of total U.S. coal production in 2030 is 26 percent in the high coal cost case, as compared with 33 percent to 36 percent in the other cases.

Minemouth Coal Prices in the Western and Interior Regions Increase Slowly

Figure 89. Average minemouth price of coal by region, 1990-2030 (2005 dollars per million Btu)



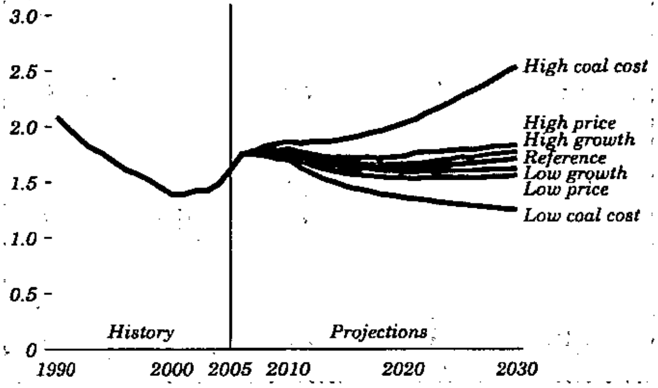
From 1990 to 1999, the average minemouth price of coal declined by 4.5 percent per year, from $1.38 per million Btu (2005 dollars) to $0.91 per million Btu (Figure 89). Increases in U.S. coal mining productivity of 6.3 percent per year helped to reduce mining costs and contributed to the price decline. Since 1999, U.S. coal mining productivity has declined by 0.6 percent per year, and the average minemouth coal price has increased by 3.9 percent per year, to $1.15 per million Btu in 2005.

In the reference case, the average minemouth coal price drops slightly from 2010 to 2019, as mine capacity utilization declines and production shifts away from higher cost Central Appalachian mines. After 2019, rising natural gas prices and the need for additional generating capacity result in the construction of 119 gigawatts of new coal-fired generating plants. The substantial investment in new mining capacity required to meet increasing demand during the period, combined with low productivity growth and rising utilization of mining capacity, leads to an increase in the average minemouth price, from $1.08 per million Btu in 2019 to $1.15 per million Btu in 2030. In the projection, the increasing share of lower rank coals (subbituminous and lignite) in the U.S. production mix tempers the price increase.

Strong growth in production in the Interior and Western supply regions, combined with limited improvement in coal mining productivity, results in minemouth price increases of 1.0 and 1.1 percent per year, respectively, for the two regions from 2005 through 2030. Average minemouth prices in Appalachia decline by 0.2 percent per year over the same period.

Higher Mining and Transportation Costs Raise Delivered Coal Prices

Figure 90. Average delivered coal prices, 1980-2030 (2005 dollars per million Btu)



Alternative assumptions for coal mining and transportation costs affect coal prices and demand. Two alternative coal cost cases developed for *AEO2007* examine the impacts on U.S. coal markets of alternative assumptions about mining productivity, labor costs, and mine equipment costs on the production side, and about railroad productivity and rail equipment costs on the transportation side.

In the high coal cost case, the average delivered coal price in 2005 dollars is $2.54 per million Btu in 2030—49 percent higher than in the reference case (Figure 90). As a result, U.S. coal consumption is 6.4 quadrillion Btu (18 percent) lower than in the reference case in 2030, reflecting both a switch from coal to natural gas, nuclear, and renewables in the electricity sector and reduced CTL production. In the low coal cost case, the average delivered coal price in 2030 is $1.25 per million Btu—27 percent lower than in the reference case—and total coal consumption is 2.3 quadrillion Btu (9 percent) higher than in the reference case.

Because the high and low economic growth and high and low price cases use the reference case assumptions for coal mining and rail transportation productivity and equipment costs, they show smaller variations in average delivered coal prices than do the two coal cost cases. Different coal price projections in the high and low economic growth cases and high and low price cases result mainly from higher and lower projected levels of demand for coal. In the price cases, higher and lower fuel costs for both coal producers and railroads contribute to the variations in projected coal prices.

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Table 28. Average Open Market Sales Price of Coal by State and Mine Type, 2006, 2005
(Dollars per Short Ton)

Coal-Producing State	2006			2005			Percent Change		
	Underground	Surface	Total	Underground	Surface	Total	Underground	Surface	Total
Alabama	43.13	55.32	48.39	54.75	51.74	53.63	-21.2	6.9	-9.8
Alaska	-	W	W	-	W	W	-	W	W
Arizona	-	W	W	-	W	W	-	W	W
Arkansas	W	-	W	-	-	-	W	-	W
Colorado	24.10	24.70	24.27	21.69	21.45	21.63	11.1	15.1	12.2
Illinois	30.86	32.78	31.17	29.18	31.63	29.67	5.8	3.7	5.1
Indiana	33.70	24.66	27.27	33.17	22.01	25.31	1.6	12.0	7.7
Kansas	-	W	W	-	W	W	-	W	W
Kentucky Total	41.42	44.82	42.73	38.70	41.24	39.68	7.0	8.7	7.7
Eastern	46.88	46.46	46.68	43.55	43.05	43.33	7.6	7.9	7.7
Western	30.52	24.29	29.76	27.48	25.87	27.19	11.1	-6.1	9.5
Louisiana	-	W	W	-	W	W	-	W	W
Maryland	W	W	30.63	W	W	28.55	W	W	7.3
Mississippi	-	W	W	-	W	W	-	W	W
Missouri	-	W	W	-	W	W	-	W	W
Montana	W	W	10.42	W	W	9.74	W	W	7.0
New Mexico	W	W	29.15	W	W	25.82	W	W	12.9
North Dakota	-	10.70	10.70	-	10.45	10.45	-	2.4	2.4
Ohio	26.72	28.93	27.40	25.25	30.06	26.88	5.8	-3.7	1.9
Oklahoma	W	W	30.75	W	W	28.24	W	W	8.9
Pennsylvania Total	37.12	38.81	37.42	36.23	37.05	36.39	2.5	4.8	2.8
Anthracite	72.79	37.89	43.61	46.74	39.71	41.00	55.7	-4.6	6.4
Bituminous	36.99	38.90	37.30	36.18	36.76	36.28	2.2	5.8	2.8
Tennessee	49.07	35.65	41.37	49.89	37.91	42.50	-1.7	-5.9	-2.6
Texas	-	18.61	18.61	-	17.39	17.39	-	7.0	7.0
Utah	24.98	-	24.98	21.45	-	21.45	16.4	-	16.4
Virginia	53.57	52.16	52.99	48.01	47.93	47.97	11.6	8.8	10.5
West Virginia Total	45.53	46.44	45.94	41.99	42.33	42.14	8.4	9.7	9.0
Northern	35.26	36.95	35.48	32.52	38.10	33.16	8.4	-3.0	7.0
Southern	53.44	47.30	49.94	49.06	42.66	45.50	8.9	10.9	9.8
Wyoming	-	9.03	9.03	-	7.71	7.71	-	17.2	17.2
U.S. Total	**38.28**	**18.88**	**25.16**	**36.42**	**17.37**	**23.59**	**5.1**	**8.7**	**6.7**

- = No data are reported.

W = Data withheld to avoid disclosure.

Note: • Open market includes all coal sold on the open market to other coal companies or consumers. An average open market sales price is calculated by dividing the total free on board (f.o.b) rail/barge value of the open market coal sold by the total open market coal sold. Excludes mines producing less than 10,000 short tons, which are not required to provide data. Excludes silt, culm, refuse bank, slurry dam, and dredge operations. Totals may not equal sum of components because of independent rounding.

Source: • Energy Information Administration Form EIA-7A, "Coal Production Report," and U.S. Department of Labor, Mine Safety and Health Administration, Form 7000-2, "Quarterly Mine Employment and Coal Production Report."

Attachment 28
Docket 07A-447E
Glustrom Answer Testimony

Inventory of Assessed Federal Coal Resources and Restrictions to Their Development

IN COMPLIANCE WITH THE ENERGY POLICY ACT OF 2005, P.L. 109-58 §437

Prepared by the
U.S. Departments of Energy, Interior and Agriculture

August 2007

MARCH 3, 1849

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Executive Summary

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EXECUTIVE SUMMARY

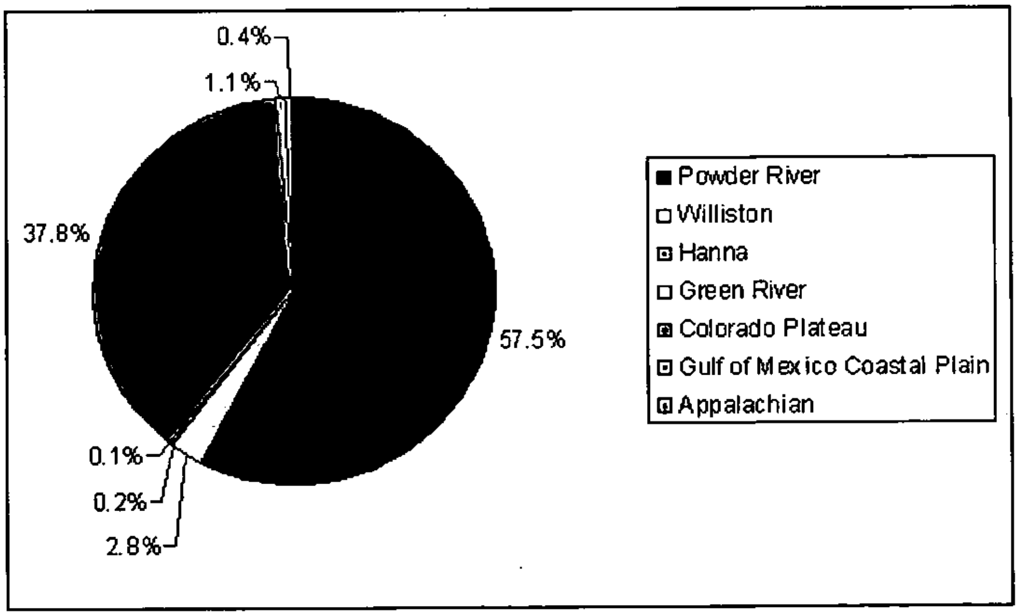
Section 437 of the Energy Policy Act of 2005 (EPAct) directs the Secretary of the Interior, in consultation with the Secretaries of Energy and Agriculture to conduct an inventory of coal resources underlying Federal lands. Further, EPAct directs the Secretary of Energy to submit a report to Congress containing the inventory and update it as the availability of data and developments in technology warrant.

Under Section 437, the Inventory shall identify Federal lands that are presently available for coal development and the extent and nature of any restrictions on the development of coal resources on those lands. Section 437 of EPAct also calls for the identification of compliant and supercompliant coal resources where sufficient data exist. Compliant and supercompliant coal resources are defined in terms of sulfur dioxide content per million British thermal units (BTU). Analysis of existing information indicates that data are either lacking or of insufficient density to facilitate a scientifically robust spatial analysis/allocation of this parameter.

Additionally, assessments in Alaska are not included in this Inventory. While Alaska has vast coal resources, much of which are Federally owned, digital data for Alaskan coal ownership are not currently available, a small fraction of the basins and fields are assessed, and planning has either not been done or coal leasing planning deferred until leasing interests are provided.

Based on recent United States Geological Survey (USGS) assessments, Federal coal resources in the United States total 957,000 million short tons (MST), as shown in Figure ES-1. The Powder River Basin (PRB or Basin) is the location of the most complete datasets needed for determining the restrictions on the development of Federal coal assessed and, as a consequence, is the focus of the effort reported herein. The Inventory will be updated as additional information from other areas becomes as complete as that of the PRB.

Figure ES-1. United States Federal Coal in USGS Assessments by Basin



The PRB contains nearly 58 percent (over 550,000 million short tons) of the total Federal resources currently assessed. In recent years, of the coal produced from Federal lands, 88 percent comes from the PRB, and the Basin is also the most active location for Federal leasing. The Bureau of Land Management received eight lease applications for 26,050 acres containing 3,400 million short tons of coal in the PRB alone in 2006 (more than three years of the national annual average consumption). A map of the PRB study area is depicted in Figure ES-2 showing Bureau of Land Management (BLM) Field Office (FO) boundaries and Forest Service (FS), Department of Agriculture areas.

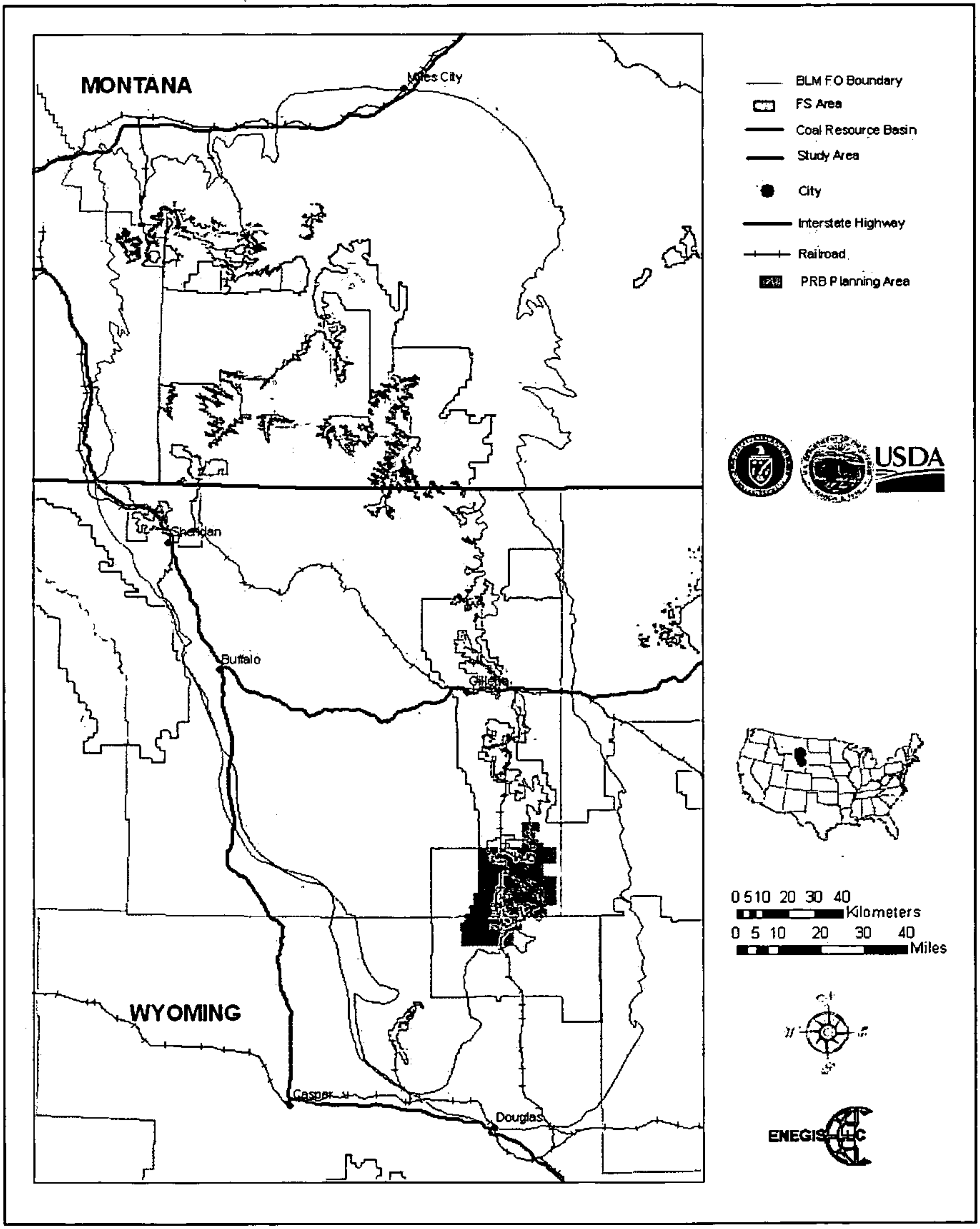
This Inventory provides information regarding the geographic relationship between coal resources and the constraints that govern their development in the Powder River Basin. It is not a reassessment of any restrictions themselves on the development of coal resources. The public's opportunity to participate in any change of restrictions on coal development activities will occur during the land use planning or legislative process. This Inventory provides some basic information for any such process. Additional information may be available from monitoring and scientific studies incorporated into adaptive management processes.

All Federal coal must be included in a land use plan prior to leasing. These coal leases, including those issued with only the standard lease terms, are subject to full compliance with all laws and regulations. These laws establish the restrictions and impediments encompassed in this Inventory and include, but are not limited to, the National Environmental Policy Act, Clean Water Act, Clean Air Act, Endangered Species Act, Surface Mining Control and Reclamation Act, Federal Coal Leasing Amendments Act of 1976, Mineral Leasing Act of 1920, and National Historic Preservation Act.

This Inventory was prepared under the lead of the Department of Energy (DOE). Senior professionals from the DOE Office of Fossil Energy (National Energy Technology Laboratory) and Energy Information Administration, Department of the Interior's Bureau of Land Management and USGS, and the Forest Service were the major contributors. The DOE provided technical expertise to guide the design and analysis process for the Inventory. USGS provided the assessment of coal resources beneath Federal lands. Field offices of the BLM and the FS contributed their land use planning information regarding coal availability and leasing requirements for the lands under their respective jurisdictions.

This Inventory is based on information that has been previously developed through the scientific and planning processes of the contributing Federal agencies. This information has in large part been provided to the public for its review and use and is the best that is commercially and scientifically available. It has been compiled and analyzed by experts from the contributing agencies. The analytical methods and protocols used in this study have been subjected to rigorous review. The study necessarily incorporates the assumptions, conditions, and limitations of the supporting scientific information as discussed in this report.

Figure ES-2. Powder River Basin Study Area



The Inventory examines the Powder River Basin, the major producing area of Federal coal in the United States. The Inventory encompasses almost 7 million acres (10,900 sq. mi.) of land in the PRB. Of this, the Federal mineral estates (Federal coal ownership) total 5.4 million acres (8,400 sq. mi.), of which 4.5 million acres (7,030 sq. mi.) underlie non-Federal surface (split estates lands).

This analysis of constraints to development centers on three factors that affect the development of coal resources on Federal lands. These factors are (1) whether the lands are statutorily available for leasing, (2) whether there has been land use planning to determine future leasing of the area, and (3) the degree of access afforded by leasing restrictions and other conditions on lands where land use planning has been completed. All coal leases are subject to a baseline level of constraint governed by statutory and regulatory requirements. These restrictions serve many purposes, ranging from the protection of environmental, mineral, social, historical, or cultural resources or values, to the payment of rentals and royalties.

To focus the analysis of constraints on coal development, the Inventory evaluates the Federal lands where: (1) leasing and development is permitted under standard lease terms and conditions; (2) leasing is permitted with varying limitations on access, from required surface mitigation to no surface operations; and (3) coal leasing and development is precluded or prohibited. The Inventory considers exceptions that may be granted to restrictions after a review of on-the-ground conditions. It also considers the potential for surface mining utilizing current technology, then designates the remaining coal resources as beyond conventional surface mining technology.

The results of this Inventory for the Powder River Basin (Table ES-1, Figure ES-3, and Figure ES-4) are summarized below. The results below exclude areas containing unmined coal currently under development (leased coal or coal resources under Lease by Application (LBA)), which comprise an estimated 11,600 million short tons, as shown in Table ES-2. The environmental work for that portion of the resource has already been performed or is under administrative review. As such, the remainder of the Inventory examines the subset of the resource base for which the final environmental work has yet to be performed.

- Total assessed Federal coal resource acreage, including split estates, total 5.4 million acres (8,400 sq. mi.).
- Undeveloped assessed coal resources total 550,000 MST.
- Approximately 1.5 percent (82,000 acres (128 sq. mi.)) of assessed Federal coal resource acreage is available for mining under standard lease terms (Figures ES-3 and ES-4, Category 7). Based on resource estimates, these lands contain 5 percent (27,000 MST) of the Federal coal.
- Less than 1 percent (12,000 acres (19 sq. mi.)) of Federal mineral estate is available for mining with mitigation measures (Figures ES-3 and ES-4, Category 6). Based on resource estimates, these lands contain 1 percent (3,000 MST) of the Federal coal.

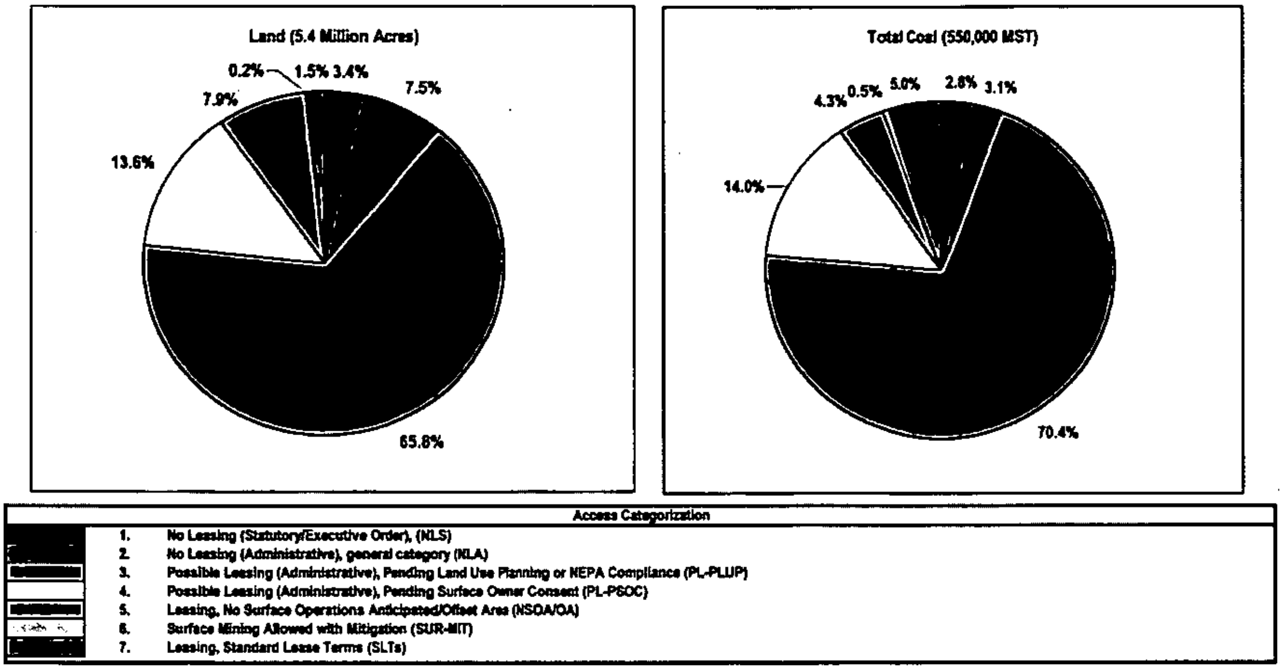
Table ES-1. Summary of Inventory Study Area—Powder River Basin Federal Land and Coal Resources by Access Category

Access Category	Area		Coal Types				Total Coal	
			Hypothetical	Inferred	Indicated	Measured		
	(Acres)	Percent of Federal	(MST)*	(MST)	(MST)	(MST)	(MST)	Percent of Federal
1. No Leasing (Statutory/Executive Order), (NLS)	184,385	3.4	245	9,636	4,524	872	15,277	2.8
2. No Leasing (Administrative), general category (NLA)	406,172	7.5	280	10,494	5,064	1,043	16,880	3.1
3. Possible Leasing (Administrative), Pending Land Use Planning or NEPA Compliance (PL-PLUP)	3,571,162	65.8	28,875	243,230	93,926	21,435	387,466	70.4
4. Possible Leasing (Administrative), Pending Surface Owner Consent (PL-PSOC)	738,827	13.6	–	29,919	37,471	9,128	77,045	14.0
5. Leasing, No Surface Operations Anticipated/Offset Area (NSOA/OA)	430,941	7.9	515	12,506	8,756	1,864	23,640	4.3
6. Surface Mining Allowed with Mitigation (SUR-MIT)	12,208	0.2	–	179	1,744	739	2,662	0.5
7. Leasing, Standard Lease Terms (SLTs)	81,962	1.5	255	9,148	14,156	3,676	27,235	5.0
Total Federal	**5,425,657**	**100**	**30,696**	**315,113**	**165,641**	**38,757**	**550,206**	**100.0**
NonFederal	**1,403,858**		**10,589**	**52,881**	**28,135**	**5,875**	**97,480**	
Total	**6,829,515**		**41,285**	**367,994**	**193,775**	**44,633**	**647,686**	

* Million Short Tons

- Approximately 8 percent (431,000 acres (673 sq. mi.)) of Federal land is accessible in areas with no surface mining anticipated or under offsets (Figures ES-3 and ES-4, Category 5). Based on resource estimates, these lands contain 4 percent (24,000 MST) of the Federal coal in the basin.
- Approximately 14 percent (739,000 acres (1,154 sq. mi.)) of Federal land is not available for leasing without Federal surface management agency or qualified surface owner consent (Figures ES-3 and ES-4, Category 4). Based on resource estimates, these lands contain 14 percent (77,000 MST) of the Federal coal in the basin.
- Land use planning screens have not been applied to approximately 66 percent (3.6 million acres (5,600 sq. mi.)) of Federal coal estate (Figures ES-3 and ES-4, Category 3). Based on resource estimates, these low current development interest (coals deeper than a 10:1 strip ratio) lands contain about 70 percent (387,000 MST) of the Federal coal assessed by the USGS.

Figure ES-3. Chart of Results, Powder River Basin Study Area—Total Federal Land and Coal Resources by Access Category

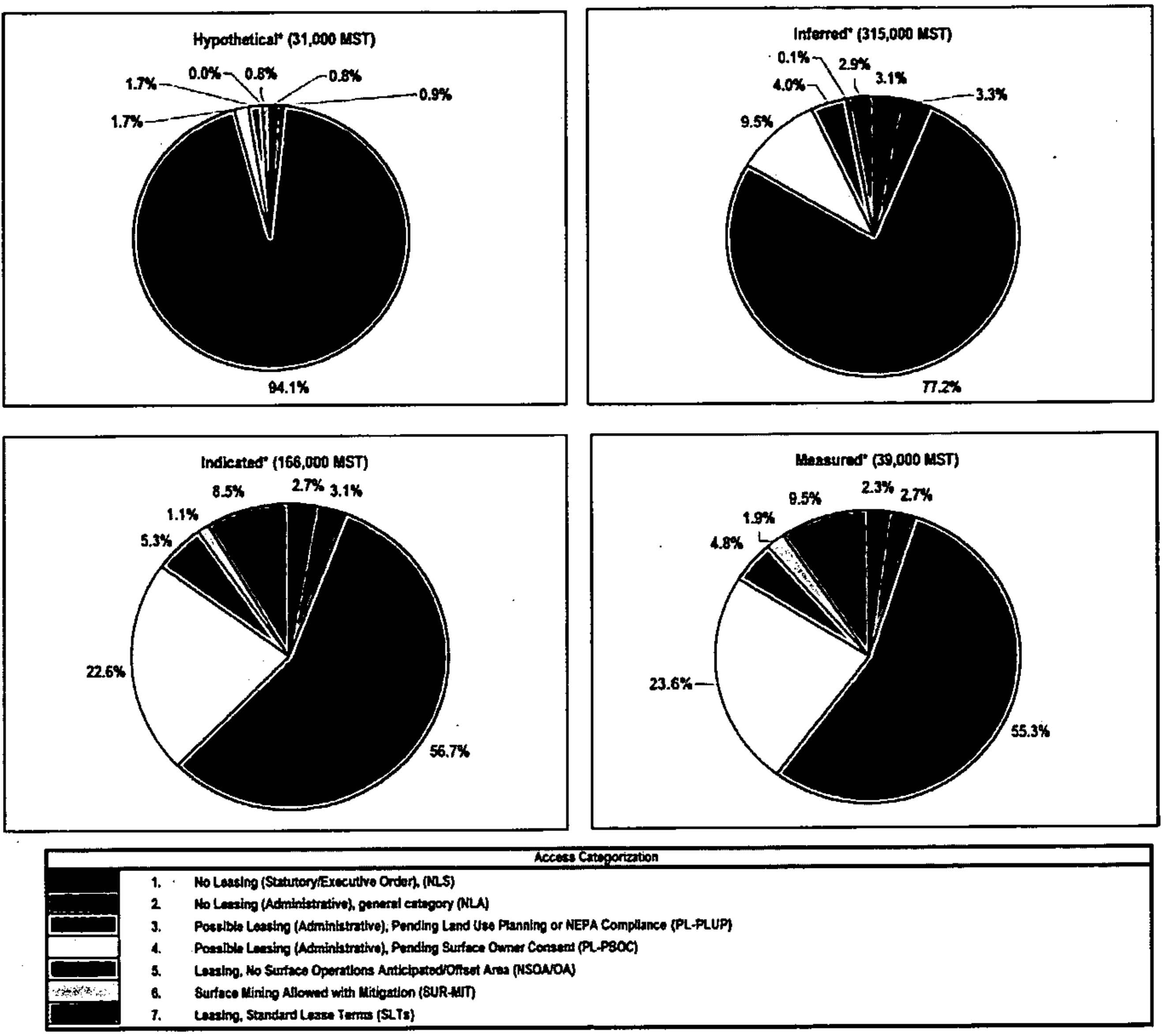


- Approximately 8 percent (406,000 acres (635 sq. mi.)) of Federal land is not being leased as a result of local land use planning decisions (Figures ES-3 and ES-4, Category 2). Based on resource estimates, these lands contain about 3 percent (17,000 MST) of the Federal coal.
- Approximately 3 percent (184,000 acres (288 sq. mi.)) of Federal land is statutorily not leasable (Figures ES-3 and ES-4, Category 1). Based on resource estimates, these lands contain about 3 percent (15,000 MST) of the Federal coal.

Table ES-2. Coal Reserves Under Lease By Application and Leased Coal Reserves Remaining to be Mined in the PRB as of September 30, 2006

Coal Development Status	Wyoming (MST)	Montana (MST)	Total (MST)
Unmined Coal Under Lease	6,476	458	6,934
Lease by Application	4,513	109	4,622
Total Unmined Coal Under Development	10,989	566	11,555

Figure ES-4. Chart of Results, Powder River Basin Study Area—Federal Coal Resources by Coal Reliability Type



* *For an explanation of Hypothetical, Inferred, Indicated, and Measured resources, see Section 2.2.1*

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1.0 INTRODUCTION

As the energy demand of the nation continues to grow, the coal resources of the United States are expected to continue to help meet these needs. According to the Energy Information Administration (EIA), the United States produced approximately 1,161 MST of coal and consumed about 1,114 MST during 2006. Approximately 92 percent of the total coal consumption was used in electricity generation accounting for almost half of the nation's electricity. The Western Coal Region,[1] comprising predominately Federal resources, produced 672 MST, over half of the total coal production for the entire U.S. in 2006.[2] Production from the Western Coal Region is forecasted to increase by over 460 MST over the next 23 years (2030).[3]

Based on recent USGS assessments, Federal coal resources in the United States total 957,000 MST.[4] The Powder River Basin contains 58 percent of total Federal coal, or over 550,000 MST (Table 1-1).

Table 1-1. Assessed Federal Coal Resources

Basin/Region	Federal Coal	
	(MST)*	Percent
Powder River	550,206	57.5
Williston	27,200	2.8
Hanna	2,350	0.2
Green River	1,200	0.1
Colorado Plateau	361,860	37.8
Gulf of Mexico Coastal Plain	10,350	1.1
Appalachian	4,051	0.4
Total Coal	**957,217**	**100**

* Million Short Tons

Source: USGS (http://energy.cr.usgs.gov/regional_studies/fedlands/index.html) and BLM

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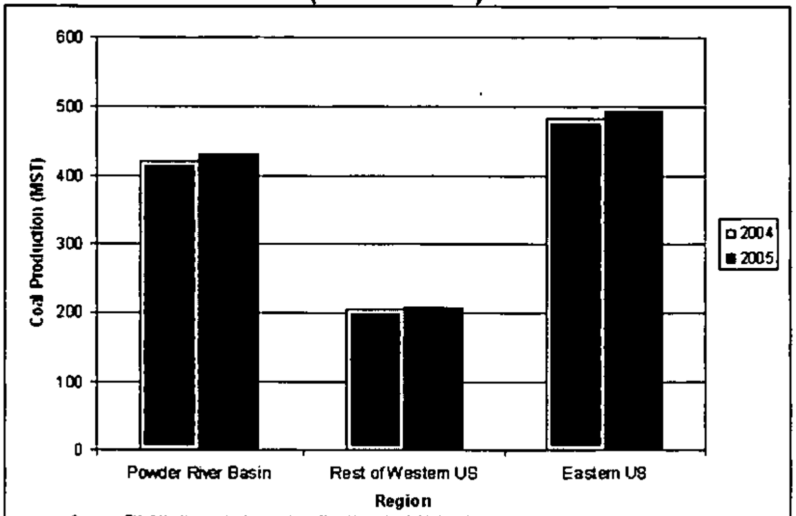
[1] Defined by EIA as Alaska, Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming. The Eastern Region is defined as Alabama, Arkansas, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Missouri, Ohio, Oklahoma, Pennsylvania, Tennessee, Texas, Virginia and West Virginia.

[2] Available on the EIA website: http://www.eia.doe.gov/fuelcoal.html.

[3] *Ibid.*

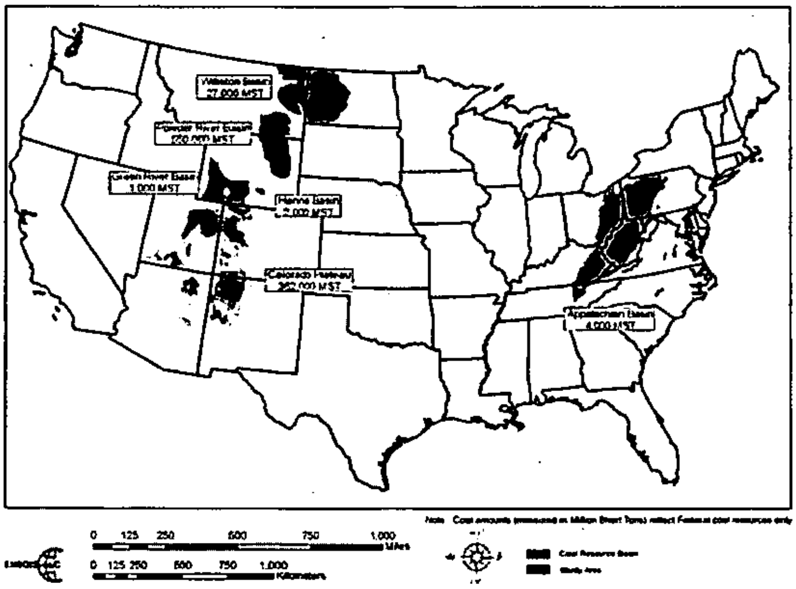
[4] Available on the USGS website: http://energy.cr.usgs.gov/regional_studies/fedlands/index.html. Note that the figures cited exclude unmined coal currently under development in the Powder River Basin.

Figure 1-1. United States Coal Production (2004-2005)



Source: EIA (http://www.eia.doe.gov/cneaf/coal/page/acr/table1.html)

Figure 1-2. USGS Assessed Coal Basins



It is clear that Federal lands will be an important future source of energy. According to EIA data, the Powder River Basin is currently supplying 38 percent of the United States coal production (Figure 1-1), and, in recent years, 88 percent of coal production from Federal lands.

The Inventory examines the Powder River Basin, the largest producing area of Federal coal. The Inventory encompasses almost 7 million acres of land. Of this, 5.4 million acres are under Federal management, of which 4.5 million underlie non-Federal surface (split estates lands).

The coal basins assessed by the USGS are shown in Figure 1-2. The PRB study area is shown in Figure 1-3a and the PRB planning areas are shown in Figure 1-3b.

A full set of acronyms used in this report, as well as a glossary, can be found in Appendices 1 and 2, respectively.

1.1 Background

With the increasing demand for cleaner burning coals, the low-sulfur coals of the Powder River Basin in Wyoming and Montana are expected to continue to be in high demand for the foreseeable future. Developing these coal resources, while mitigating the environmental impacts and maintaining the BLM and FS's multiple use land management goals, continues to be a unique challenge.

The restrictions that constrain access to Federal lands are frequently a complex set of requirements that can preclude mining or increase costs and delay activity in order to achieve other important policy objectives, such as environmental protection and maximizing public benefit from revenues in return for rights to extract resources from Federal lands. Restrictions and impediments include areas unavailable for leasing and areas where the coal can be leased, but with no surface mining allowed. There are also limitations on activities due to a variety of environmental considerations, typically manifested as leasing restrictions.

Figure 1-3a. Powder River Basin Study Area

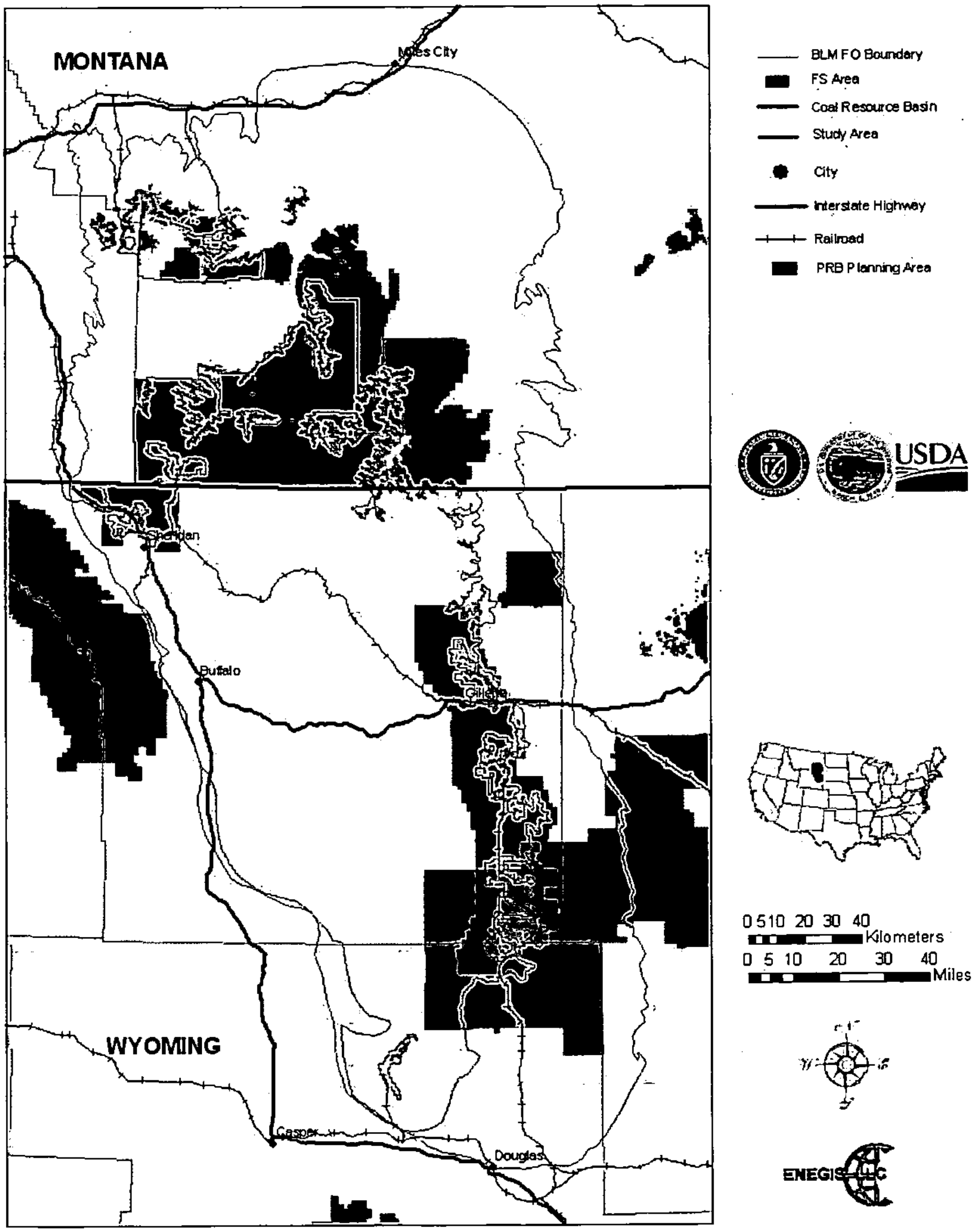
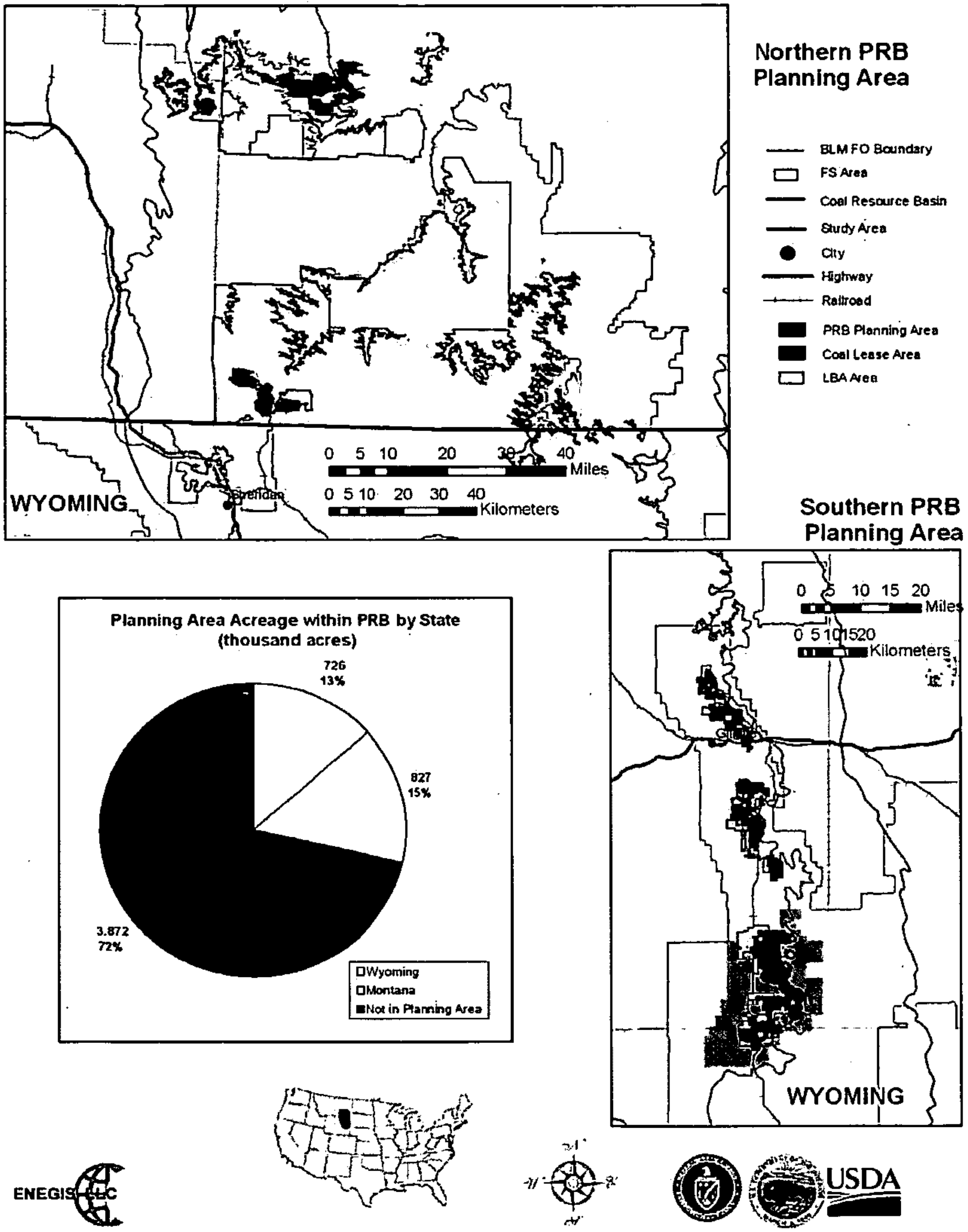


Figure 1-3b. Powder River Basin Planning Areas



Section 437 of the Energy Policy Act of 2005 required a study, as a cooperative effort between Department of Energy, Department of the Interior (DOI), and Department of Agriculture (USDA), which was to include an analysis of coal resources for Federal lands in the United States. The text of Section 437 is set forth below.

1.2 The EPAct 437 Coal Inventory

SEC. 437. INVENTORY REQUIREMENT

(a) REVIEW OF ASSESSMENTS—

(1) IN GENERAL—The Secretary of the Interior, in consultation

with the Secretary of Agriculture and the Secretary [of Energy], shall review coal assessments and other available data to identify—

(A) Federal lands with coal resources that are available for development

(B) the extent and nature of any restrictions on the development of coal resources on Federal lands identified under paragraph (1); and

(C) with respect to areas of such lands for which sufficient data exists, resources of compliant coal and supercompliant coal.

(2) DEFINITIONS—For purposes of this subsection—

(A) the term "compliant coal" means coal that contains not less than 1.0 and not more than 1.2 pounds of sulfur dioxide per million BTU; and

(B) the term "supercompliant coal" means coal that contains less than 1.0 pounds of sulfur dioxide per million BTU.

(b) COMPLETION AND UPDATING OF THE INVENTORY—The Secretary [of Energy]—

(1) shall complete the inventory under subsection (a) by not later than 2 years after the date of enactment of this Act; and

(2) shall update the inventory as the availability of data and developments in technology warrant.

(c) REPORT—The Secretary [of Energy] shall submit to the Committee on Resources of the House of Representatives and to the Committee on Energy and Natural Resources of the Senate and make publicly available—

(1) a report containing the inventory under this section, by not later than 2 years after the effective date of this section; and

(2) each update of such inventory.

1.3 Approach

A Steering Committee, comprising representatives from the participating agencies, was responsible for designing and overseeing the completion of the Inventory. The EPAct Section 437 Coal Inventory is a review of Federal coal resource assessments and the constraints on their development. This Inventory reviews coal resources within the Powder River Basin in northeast Wyoming and southeast Montana. The Powder River Basin represents 58 percent of the total Federal resources currently assessed. Further, of coal production from Federal lands, 88 percent comes from the PRB, and the Basin is also the most active location for Federal leasing. The Bureau of Land Management received eight lease applications for 26,050 acres containing 3,400 MST of coal in the PRB alone in 2006 (more than three years of the national annual average consumption). Finally, because of the focus on its coal and coalbed methane development, the PRB is the location of the most complete datasets for surface and resources information.

The study area is defined primarily by the aggregation of the USGS coal resource assessment units within the Powder River Basin (see Figure 1-3a). In this study, the coal resource, Federal land status, and coal access constraints data for this area have been incorporated into a Geographic Information System (GIS) that allows derivative mapping and statistical analysis. The results are presented in this report.

A fundamental product of this Inventory is the GIS database containing numerous layers of geographic data. While the surface data used in the Inventory are accurate, an important caution applies to the use and interpretation of the undeveloped resources data: the *precise* locations and sizes of recoverable accumulations of undeveloped coal resources on Federal lands are unknown.

The National Coal Resource Assessment (NCRA) project is a multi-year effort by the USGS Energy Resources Program to identify, characterize, and assess the coal resources that will supply a major part of the Nation's energy needs during the next few decades. Assessment results are based on known or estimated geologic input parameters provided by knowledgeable geologists. Because of the uncertainty associated with input parameters, the assessment result is reported within coal reliability categories within the assessment unit. For these reasons, this Inventory does not imply that the locations and sizes of accumulations of undeveloped coal resources are known to occur under specific land parcels.

Section 437 of EPAct calls for the identification of compliant and supercompliant coal resources where sufficient data exist. Compliant and supercompliant coal resources are defined in terms of sulfur dioxide content per million BTU. USGS information indicates that sufficient data do not exist to categorize the resources in such a manner. Where sulfur dioxide information exists, the data are highly variable. Moreover, sulfur dioxide data are sparse with respect to the undeveloped coal resources. For coal resources in the PRB, these circumstances are clearly evidenced by the data published by the USGS.[5] Given these constraints, the coal resources were not analyzed in terms of compliant and super-compliant categories.

1.4 Roles of the Agencies Pertaining to This Inventory

Section 437 of EPAct designated responsibility for preparing the Inventory as a cooperative effort between the DOE, DOI and USDA. The Interagency Steering Committee is responsible for providing guidance for conducting the studies, recommending direction to the consulting firm retained to support the Inventory,[6] making decisions concerning critical parameters, reviewing the methods and results, and publishing the report.

The DOE is the lead agency for the Inventory and contributes its expertise and experience in guiding the design and analysis process for the Inventory.

The BLM, part of the DOI, manages all Federal leasable minerals (e.g., oil, gas and coal) and maintains the coal lease restriction information developed during land use planning for lands under its jurisdiction, and land status data for all Federally owned lands within the United States.

The USGS, also a bureau of the DOI, conducts assessments of undeveloped coal resources. The primary source of the coal resource information used in this study is the NCRA.

The Secretary of Agriculture, through the FS, provides coal restriction information developed during broad-scale analysis for leasing of lands within the National Forest System.

During the course of this study, members of the Steering Committee and personnel from the firm contracted to support the Inventory visited field offices within the Powder River Basin. BLM and FS personnel from four offices (Buffalo, WY BLM FO, Casper, WY BLM FO, Miles City, MT BLM FO, and Thunder Basin National Grassland) participated in these visits.[7] The purpose of the site visits was to inform BLM and FS officials about the study, to solicit input concerning coal leasing restrictions and other issues of concern regarding coal development, and to collect requisite information and data. As described in Section 2, parameter input from these officials was critical to the study. Data were collected before, during, and following the field visits.

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[5] For more information on Coal Quality in the PRB, consult USGS's Professional Paper 1625-A Resource Assessment of Selected Tertiary Coal Beds and Zones in the Northern Rocky Mountain and Great Plains Region (1999), Chapter PQ.

[6] The contractor is Enegis, LLC, of Fairfax, VA. They have engaged Premier Data Services of Englewood, CO as a subcontractor.

[7] Officials at Custer National Forest were consulted to verify the status of their coal leasing prior to field visits. Based on their input, a visit to the Forest office was not necessary.

1.5 Intended Use

This Inventory is designed to be useful to a wide range of interests. In a broad sense, it gives a picture of where coal resources in the Powder River Basin are estimated to occur and a quantification of statutory and administrative constraints on development.

The highly detailed Federal land status data, along with the coal resource data, are available for additional analyses by Congress, industry, environmental organizations, and other interested parties. Land withdrawals and coal lease requirements protect or mitigate adverse impacts to other valuable land resources.

2.0 METHODS

The EPAct Section 437 Coal Inventory assesses the issue of access to Federal coal by calculating the areas and coal tonnages associated with Federal lands (including non-Federal surface interests overlying Federal coal mineral estates [split estates]) in each of several access categories in an access constraint hierarchy. The Inventory quantifies coal resources underlying the Federal lands in each access category, while at the same time accounting for restriction exceptions and the accessibility of resources utilizing underground extraction techniques. A complex geospatial model, termed the EPAct coal model, has been created to support the DOE, BLM, USGS, and FS in their efforts to fulfill Public Law (P.L.) 109-58, Section 437 (Energy Policy Act of 2005), Inventory Requirement.

The study area of the Inventory is delineated by aggregating the areas of the three USGS coal assessment units located within the PRB of Wyoming and Montana. The Inventory involves the compilation and geographic analysis of three independent datasets:

1. Federal surface and coal mineral estates;

2. Coal leasing and mining access restraints, as defined at 43 Code of Federal Regulations (CFR) 3420.1-4, and coal planning screens in applicable BLM and FS land use plans, and discussions in Environmental Assessments (EAs) and Environmental Impact Statements (EISs); and

3. Coal resource data published in the NCRA—Rocky Mountains and Great Plains.[8]

It should be noted that this Inventory is a "snapshot" in time and depicts the regulatory status at the time the study was completed. For example, it is recognized that wildlife habitat patterns continually change, and that restrictions may have to be reevaluated at the time site-specific National Environmental Policy Act (NEPA) analysis is conducted for a coal lease application. As planning efforts continue and new data become available, the PRB can be updated in future assessments.

2.1 Procedures for Collecting and Preparing Land Status and Coal Development Restrictions

2.1.1 Federal Land Status

2.1.1.1 Sources of Land Status Data

The primary source of Federal land status data is the BLM's Legacy Rehost-2000 (LR 2000) Status Dataset.

2.1.1.2 Land Status Data Preparation

These data, which can be stored in alphanumeric format, were converted for this Inventory into a GIS theme by using commercially available CarteView software. The software inter-

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[8] USGS Professional Paper 1625-A. 1999 Resource Assessment of Selected Tertiary Coal Beds and Zones in the Northern Rocky Mountains and Great Plains Region.

polates the legal descriptions contained in the Status Dataset against a public land survey GIS theme derived from either the BLM's Geographic Coordinate Database (GCDB) or other sources such as digitized USGS 7-1/2 minute quadrangle maps.

- In this effort, assisted by Premier Data Services of Denver, Colorado, data obtained from the Federal government covering the geography of Federal lands and Federal coal estates in the defined extent of the PRB were collected, converted and incorporated with ownership data into up-to-date maps. Where possible, the Federal lands status was converted from the BLM LR-2000 Data Bases. Federal mineral estate data includes split estates, where available, and all land patents, exchanges or acquired lands where the U.S. retained all minerals and coal only.

A map of the Federal land status for the study area is presented in Figure 2-1.

2.1.1.3 Land Status Data – Related Caveats

The following precautions are advised when reviewing this Inventory:

- The land status data are generally spatially accurate down to 40 acres.
- The GIS files, created using the processes described in detail in Appendix 3, were interpolated from the legal land descriptions contained in the BLM's LR-2000 database. If a legal description referenced a small survey lot or tract by number, a nominal location was mapped through a process that referenced the Legal Land Description dataset. This dataset is limited to a 40-acre description and therefore carries a minor degree of generalization in complex areas. Isolated parcels of less than 40 acres were not included in the Inventory.
- This mapping process uses public land survey data derived from various sources. The spatial location of the land status parcels so derived matches the accuracy of the survey data.
- Some land status GIS data are restricted from the public domain by agency request. Such data were used in the analyses presented in this report, but are not contained in the public datasets.

For purposes of this Inventory, Federal lands include split estates. This Inventory includes over 4.5 million acres of split estate land. In cases of split estates where the Federal government holds a partial interest in the mineral estate, the Federal government was assumed to hold the total mineral interest for purposes of the analysis.[9]

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[9] Note that areas do exist within PRB that have Federal surface with private mineral ownership. Although these areas are included in the analysis, they are very small in area and cannot be seen in Figure 2-1.

Figure 2-1. Federal Land Status Map, Powder River Basin Study Area

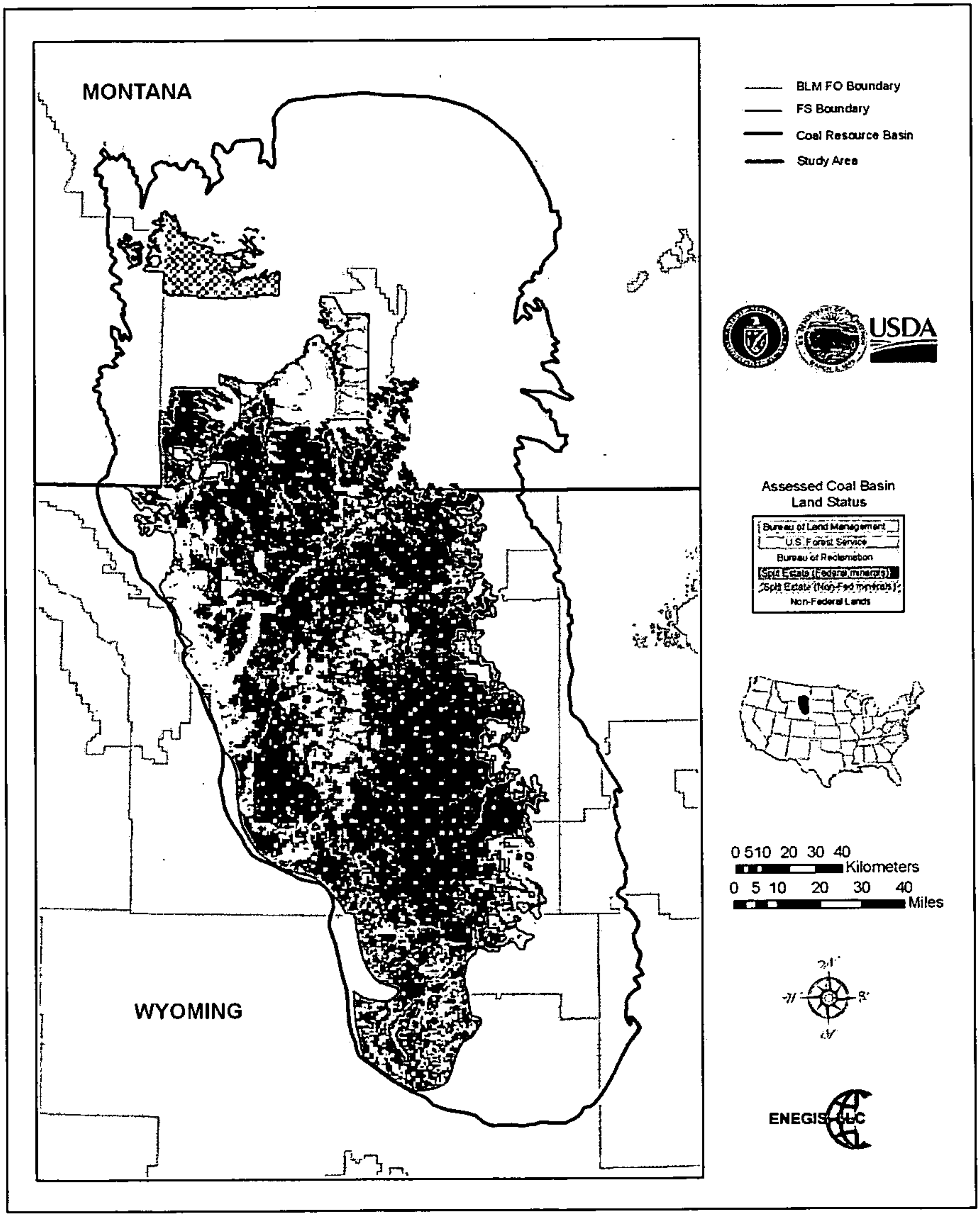


Table 2-1. Federal Land Acreage by Management Agency

Federal Surface Management Agency	Inventory Acreage
Bureau of Land Management	4,815,192
Federal surface/Federal mineral ownership	*628,425*
Non-Federal surface/Federal mineral ownership	*4,186,679*
Federal surface/Non-Federal mineral ownership	*88*
USDA Forest Service	610,395
Federal surface/Federal mineral ownership	*347,536*
Non-Federal surface/Federal mineral ownership	*259,532*
Federal surface/Non-Federal mineral ownership	*3,327*
Bureau of Reclamation	70
Federal surface/Federal mineral ownership	*70*
Total Federal Land	**5,425,657**

2.1.2 Federal Coal Lease Requirements

2.1.2.1 Coal Leasing Decisions

Leasing decisions for Federal coal are guided by Resource Management Plans (RMPs) and Forest Plans (FPs), where the goal is to determine areas acceptable for further consideration for coal leasing.

The regulations that govern land use planning for coal are found in 43 CFR 3420.1-4(e), which state: "The major land use planning decision concerning the coal resource shall be the identification of areas acceptable for further consideration for leasing, which shall be identified by the screening process..."

There are four planning screens that must be applied as described below.

1. <u>Determine areas of Federal coal with development potential</u> (43 CFR 3420.1-4(e)(1)). A *Call for Coal Resource and Other Resource Information* is issued to encourage companies, State and local governments, and general public to submit data (43 CFR 3420.1-2). Ideally, this occurs early in the scoping process for the land use plan and can be combined with a *Notice of Intent* to conduct land use planning or issue identification. Based on the response to the call and other available coal publications, and exploration and development data, the BLM defines the area considered to have development potential within the life of the land use plan. The BLM uses economics in its decision to focus in on the areas with most potential for development. The BLM is not required to include all areas with Federal coal simply because they meet USGS classification criteria as a coal resource.

2. <u>Apply unsuitability criteria</u> (43 CFR 3420.1-4 (e)(2) and 43 CFR 3461). There are 20 unsuitability criteria as listed in 43 CFR 3461. The criteria mostly come from Sec. 522 (a, b, and e) of the Surface Mining Control and Reclamation Act (SMCRA),

which prohibits or conditions mining of certain lands in order to protect other resources. The 20 unsuitability criteria are listed in Table 2-2. The criteria have specific exemptions and exceptions that may allow for leasing while still stipulating protection of the resource (see Section 2.6). Some resources, however, remain unsuitable for leasing by law. The criteria only apply to "surface coal mining operations" as defined in 43 CFR 3400.0-5 (mm) and 43 CFR 3461.1, which defines surface coal mining operations as "activities conducted on the surface of lands in connection with a surface coal mine or surface operations and surface impacts incident to an underground mine". The criteria either can be applied during the general land use plan or the National Environmental Policy Act assessment for a specific lease application.

3. Apply multiple use conflict analysis (43 CFR 3420.1-4 (e)(3)). The regulations state that this screen "shall place particular emphasis on protecting" air and water quality, wetlands, riparian areas, sole source aquifers, units of National Park System, National Wildlife Refuge System, National System of Trails, National Wild and Scenic Rivers System, and other important or unique resource values. Examples may include: oil and gas conflicts (such as stipulations for Coalbed Natural Gas conflict administration zones), values identified in Sec. 522(a)(3) of SMCRA, areas incompatible with State or local land use plans, and fragile or historic lands where operations could significantly damage important historic, cultural, scientific, and esthetic values (e.g., paleontological sites).

4. Consult with qualified surface owners (43 CFR 3420.1-4 (e)(4)). This regulation applies only to surface mining associated with split estates. Criteria in 43 CFR 3400.0-5 are used to determine if surface owners are qualified (i.e., hold title to surface, have their principal place of residence on the land, personally conduct farm or ranching operations on the land or receive directly a significant portion of income from those operations, and have met these conditions for at least three years). If a "significant" number of surface owners in an area express preference against mining, the area will be considered unacceptable for surface mining and only minable by underground techniques, unless no acceptable alternative areas are available to meet a regional leasing level (there are currently no regional leasing levels in the Powder River Basin and leasing is conducted under the lease-by-application process). It should be noted that the consultation process is not the same as surface owner consent, which provides a qualified surface owner over a split estate with a veto power over whether or not to allow a surface coal mining operations lease (43 CFR 3427) be issued; in effect, consultation is a "pre-screen."

After the unsuitability, multiple use, and surface owner consultation screens are applied to the Federal coal with development potential and affected areas are deleted, the remaining Federal coal lands are carried forward in the land use plan as "acceptable for further consideration for leasing" in accordance with 43 CFR 3420.1-8 (a).

Figure 2-3. Overburden Thickness above Assessed Coal Zones in the Powder River Basin

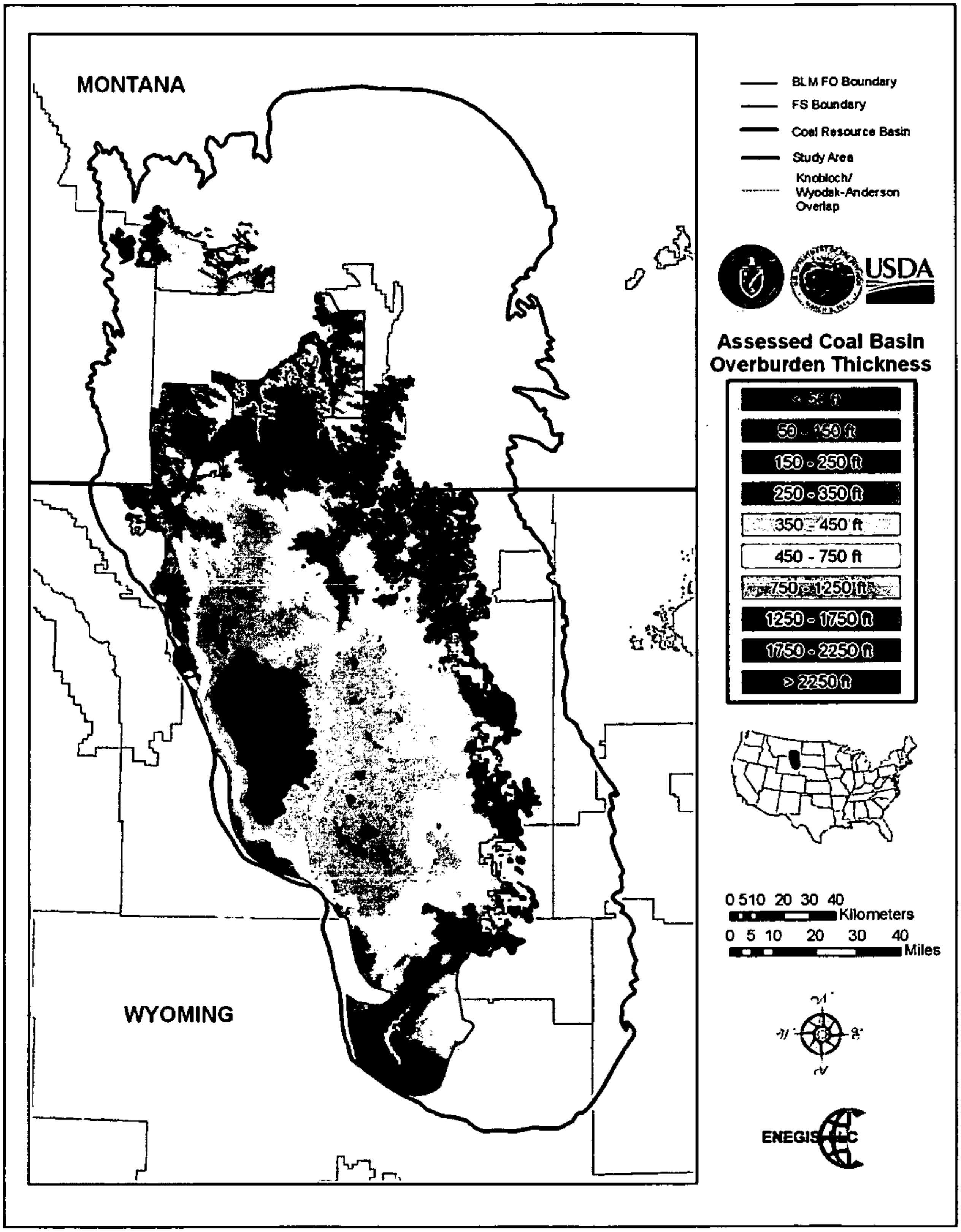


Figure 2-6. Resources beyond Conventional Surface Mining Technology in the Powder River Basin

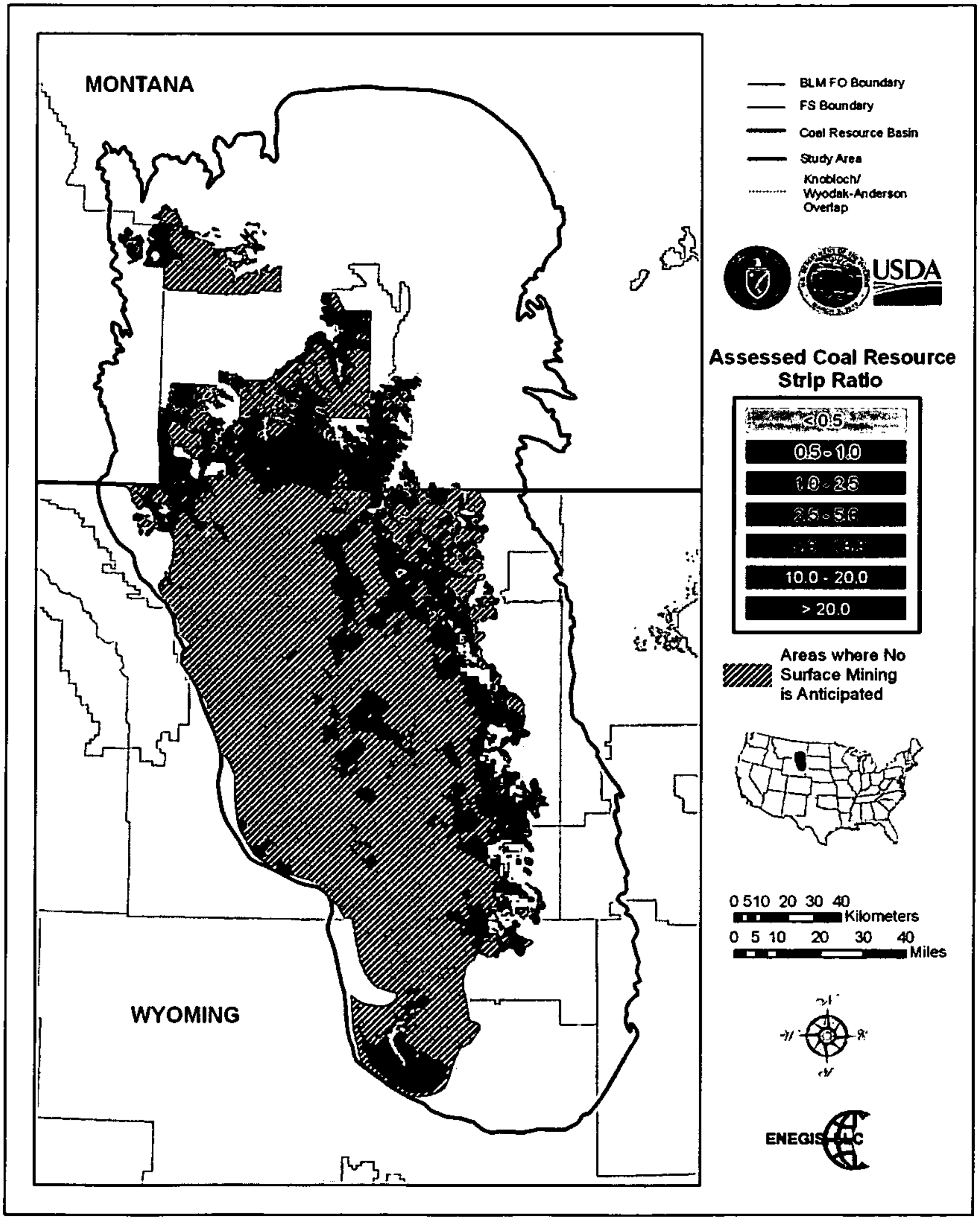
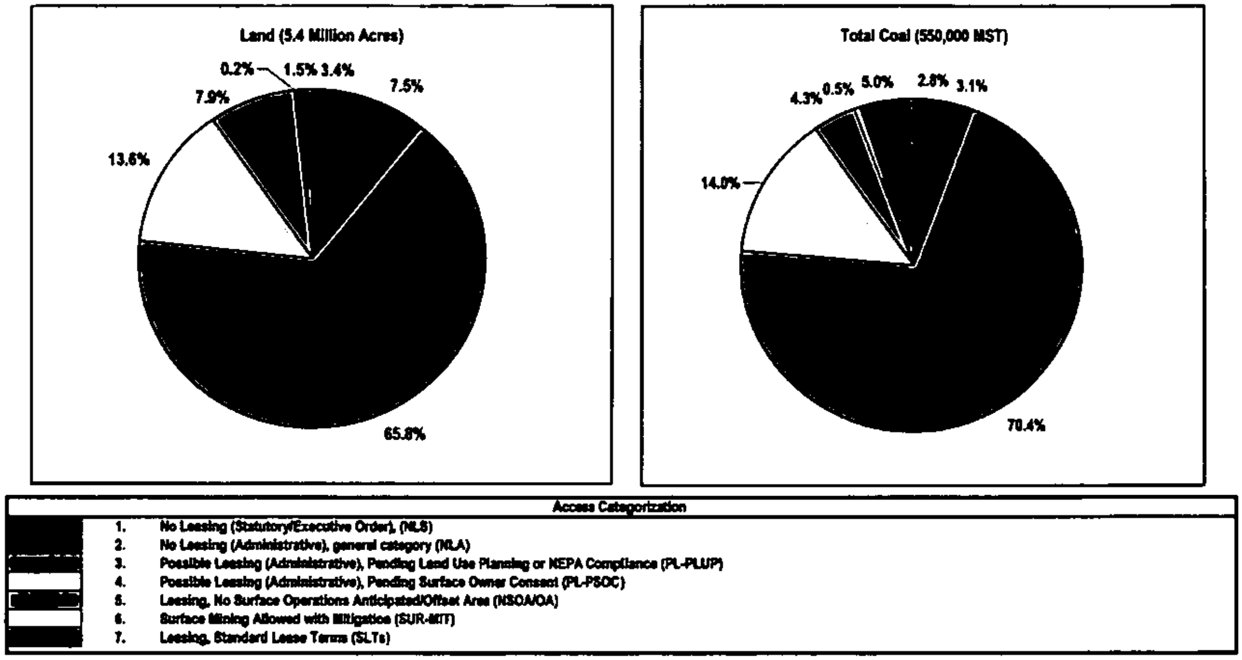


Figure ES-3. Chart of Results, Powder River Basin Study Area—Total Federal Land and Coal Resources by Access Category

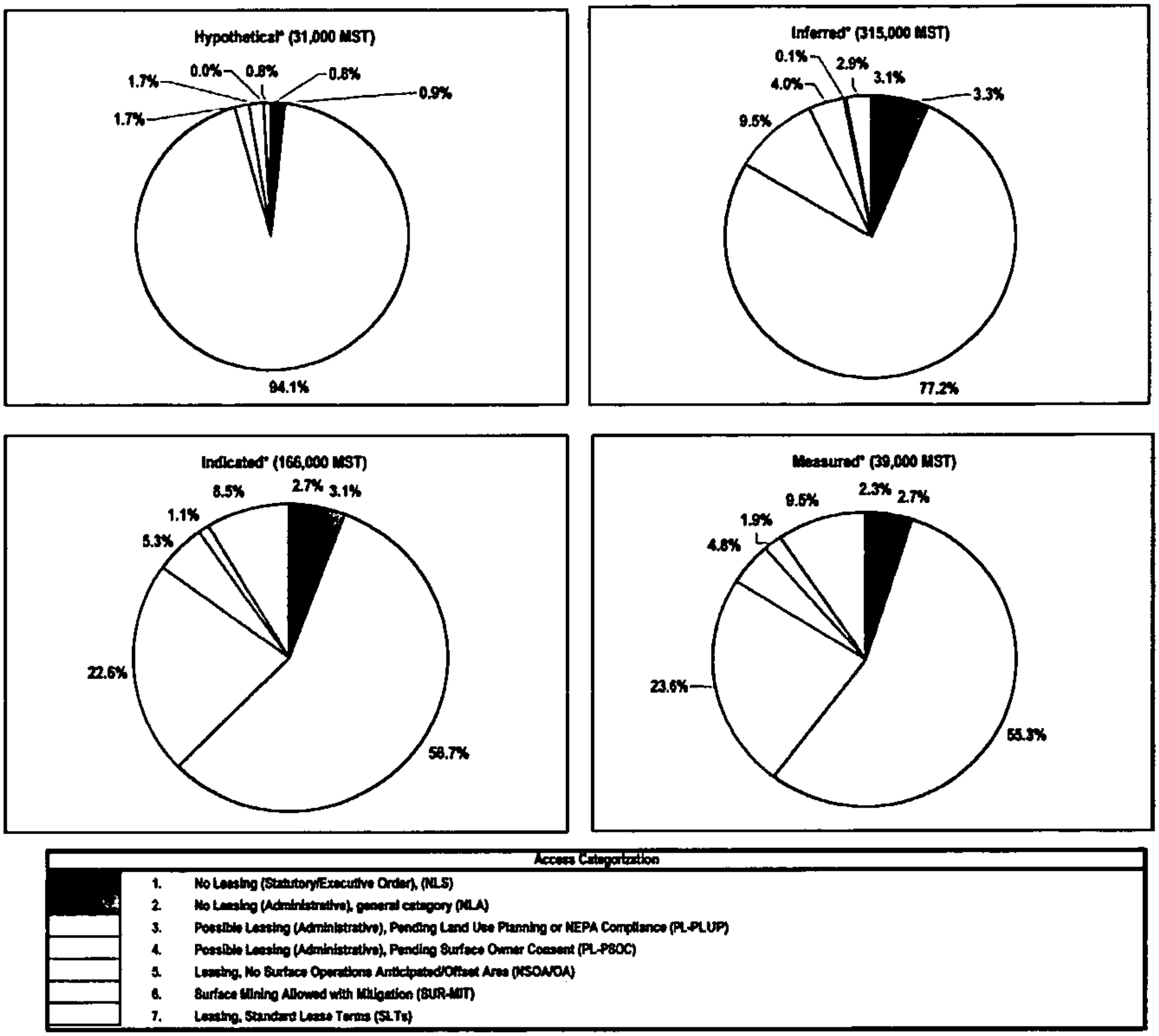


- Approximately 8 percent (406,000 acres (635 sq. mi.)) of Federal land is not being leased as a result of local land use planning decisions (Figures ES-3 and ES-4, Category 2). Based on resource estimates, these lands contain about 3 percent (17,000 MST) of the Federal coal.
- Approximately 3 percent (184,000 acres (288 sq. mi.)) of Federal land is statutorily not leasable (Figures ES-3 and ES-4, Category 1). Based on resource estimates, these lands contain about 3 percent (15,000 MST) of the Federal coal.

Table ES-2. Coal Reserves Under Lease By Application and Leased Coal Reserves Remaining to be Mined in the PRB as of September 30, 2006

Coal Development Status	Wyoming (MST)	Montana (MST)	Total (MST)
Unmined Coal Under Lease	6,476	458	6,934
Lease by Application	4,513	109	4,622
Total Unmined Coal Under Development	10,989	566	11,555

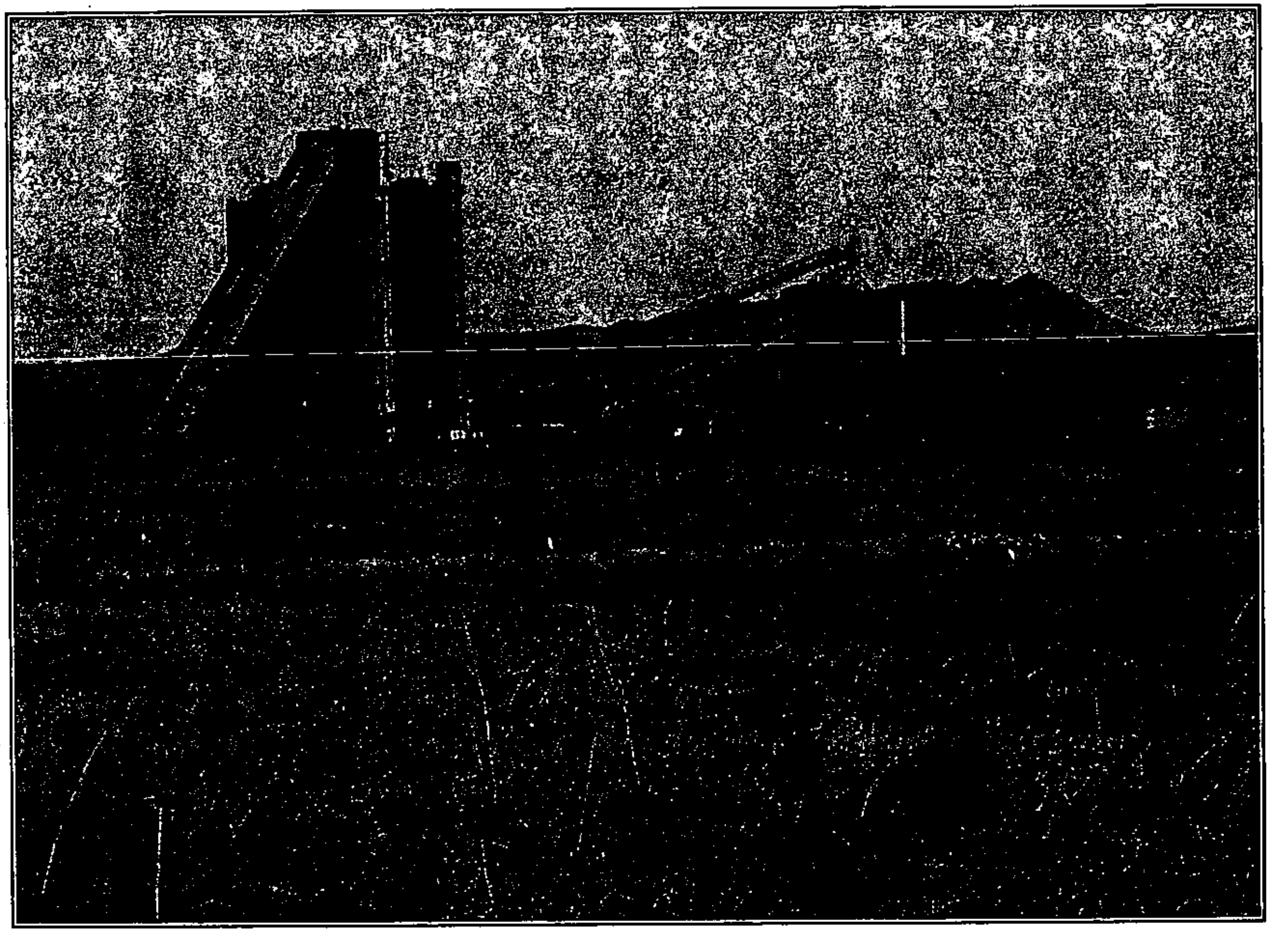
Figure ES-4. Chart of Results, Powder River Basin Study Area—Federal Coal Resources by Coal Reliability Type



** For an explanation of Hypothetical, Inferred, Indicated, and Measured resources, see Section 2.2.1*

Attachment 29
Docket 07A-447E
Glustrom Answer Testimony

FINAL
Environmental Impact Statement for the Eagle Butte West Coal Lease Application
WYW155132



August 2007

BLM

Casper Field Office

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

EXECUTIVE SUMMARY

On December 28, 2001, RAG[1] filed an application with the BLM for federal coal reserves in a tract located west of and immediately adjacent to the Eagle Butte Mine in Campbell County, Wyoming, approximately three miles north of Gillette, Wyoming (Figures ES-1 and ES-2). The application, which was assigned case file number WYW155132, is referred to as the Eagle Butte West coal lease application. RAG submitted a modification to the application to the BLM, effective October 20, 2003, which decreased the size of the lease application area and increased the coal volume. As currently applied for, the Eagle Butte West LBA Tract includes approximately 1,397.64 acres and FCW estimates that it includes 238 million tons of mineable federal coal reserves.

In August 2004, RAG finalized the sale of the Eagle Butte Mine to FCW, a directly held subsidiary of Foundation Coal Corporation. In this EIS, the applicant for the Eagle Butte West LBA Tract is referred to as FCW.

This lease application was reviewed by Division of Mineral and Lands at the BLM Wyoming State Office, who determined that the application and the lands involved met the requirements of the regulations governing coal leasing on application at 43 CFR 3425.1. The PRRCT reviewed this lease application at public meetings held on May 30, 2002, in Casper, Wyoming and on April 27, 2005, in Gillette, Wyoming. At those meetings, the PRRCT recommended that the BLM continue to process the lease application.

In order to process an LBA, the BLM must evaluate the quantity, quality, maximum economic recovery, and fair market value of the federal coal and fulfill the requirements of the NEPA by evaluating the environmental consequences of leasing the federal coal.

To evaluate the environmental impacts of leasing the coal, the BLM must prepare an EA or an EIS to evaluate the site-specific and cumulative environmental and socioeconomic impacts of leasing and developing the federal coal in the application area. The BLM made a decision to prepare an EIS for this lease application. BLM does not authorize mining by issuing a lease for federal coal, but the impacts of mining the coal are considered in this EIS because it is a logical consequence of issuing a maintenance lease to an existing mine.

The EPA published a notice announcing the availability of the Draft EIS in the *Federal Register* on October 20, 2006. BLM published a Notice of Availability and Notice of Public Hearing in the *Federal Register*, also on October 20, 2006. The 60-day comment period on the Draft EIS ended on December 19, 2006. The public hearing was held on November 14, 2006, in Gillette, Wyoming. The applicant and one member of the public made statements during the hearing and eight written comments were received on the Draft EIS. The written comments are included, with agency responses, as Appendix I of the Final EIS.

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[1] Refer to page xv for a list of abbreviations and acronyms used in this document.

Table ES-1. Summary Comparison of Coal Production, Surface Disturbance, Mine Life, and Revenues for Eagle Butte West LBA Tract and Eagle Butte Mine – Assuming Highway 14-16 is Moved and the Underlying Coal is Recovered.

Item	No Action Alternative (Existing Eagle Butte Mine)	Added by Proposed Action	Added by Alternative 1 (Preferred Tract Configuration)
In-Place Coal (as of 1/1/06)	374.0 mmt	238.0 mmt	243.7 mmt
Mineable Coal (as of 1/1/06)	354.0 mmt	238.0 mmt	241.2 mmt
Recoverable Coal (as of 1/1/06)[1]	340.0 mmt	228.0 mmt	231.1 mmt
Coal Mined Through 2005	420.4 mmt	--	--
Lease Area[2]	4,884.0 ac	1,397.6 ac	1,427.8 ac
Total Area To Be Disturbed[2]	6,076.0 ac	2,460.0 ac	2,460.0 ac
Permit Area[2]	7,471.0 ac	2,460.0 ac	2,460.0 ac
Average Annual Post-2005 Coal Production	25.0 mmt	0 mmt	0 mmt
Remaining Life of Mine (post-2005)	13.6 yrs	9.1 yrs	9.2 yrs
Average Number of Employees	223	0	0
Total Projected State Revenues (post-2005)[3]	$ 384.4 million	$ 293.5 – $ 373.2 million	$ 297.4 – $ 378.2 million
Total Projected Federal Revenues (post-2005)[4]	$ 261.6 million	$ 211.1 – $ 290.9 million	$ 214.0 – $ 294.8 million

[1] Assumes 96 percent recovery of mineable coal. The estimated tons of recoverable coal added under the Proposed Action and Alternative 1 are based on the assumptions that the coal beneath the north half of Section 20 (under Alternative 1) would not be mined, and that the coal beneath U.S. Highway 14-16 ROW and associated buffer zone would be mined.

[2] The lease area includes federal coal leases only and does not include state coal within the permit boundary. The disturbed area exceeds the leased area (total federal and state) because of the need for highwall reduction, topsoil removal, and other mine support activities outside the lease boundaries. The permit area is larger than the leased or disturbed area to assure that all disturbed lands are within the permit boundary and to allow an easily defined legal land description.

[3] Revenues to the State of Wyoming include income from severance tax, property and production taxes, sales and use taxes, and Wyoming's share of federal royalty payments, bonus bids, and AML fees. State revenues are based on $5.80 per ton (projected for 8,400-Btu coal) price × amount of recoverable coal × federal royalty of 12.5 percent minus federal's 50 percent share, plus $0.35 per ton for AML fees × amount of recoverable coal minus federal's 50 percent share, plus bonus payment on LBA leased coal of $0.30 to $0.97 per ton (based on the range of bonus payments for the last 6 LBAs sold in 2004 and 2005) × amount of mineable coal minus federal's 50 percent share, plus $0.023 per ton estimate for sales and use taxes × amount of recoverable coal, plus $0.26 per ton estimate for Ad Valorem taxes × amount of recoverable coal, plus $0.31 per ton estimate for severance taxes × amount of recoverable coal.

[4] Federal revenues are based on $5.80 per ton (projected for 8,400-Btu coal) price × amount of recoverable coal × federal royalty of 12.5 percent minus state's 50 percent share, plus $0.35 per ton for AML fees × amount of recoverable coal minus state's 50 percent share, plus $5.80 per ton (for 8,400-Btu coal) price × amount of recoverable coal × black lung tax of 4.0 percent, plus bonus payment on LBA leased coal of $0.30 to $0.97 per ton (based on the range of bonus payments for the last 6 LBAs sold in 2004 and 2005) × amount of mineable coal minus state's 50 percent share.

Table 3-2. Comparison of Average Overburden and Coal Thicknesses and Approximate Postmining Surface Elevation Changes Under the No Action and Action Alternatives.

	No Action Alternative (Existing Leases)	**Proposed Action (As Applied For LBA Tract)**	**Alternative 1 Preferred Tract Configuration**
Average Overburden Thickness (ft)	200.0	325.0	325.0
Average Interburden Thickness (ft)	5.3	8.0	8.0
Average Coal Thickness (ft)	100.0	110.0	110.0
Swell Factor (percent)	11	11	11
Coal Recovery Factor (percent)	96	96	96
Postmining Elevation Change[1]	73.4 ft lower	69.0 ft lower	69.0 ft lower

[1] Reclaimed (postmining) elevation surface change calculated as: (overburden + interburden thickness) + (overburden swell) – (coal thickness x coal recovery factor).

surface bulk density of the reclaimed soils (Section 3.8.2). It may also increase vegetative productivity, and potentially accelerate recharge of groundwater.

The approximate original drainage pattern would be restored, and stock ponds would be replaced to provide livestock and wildlife watering sources. These topographic changes would not conflict with regional land use, and the postmining topography would be designed to adequately support anticipated land use.

These impacts are occurring on the existing Eagle Butte Mine coal leases as coal is mined and mined-out areas are reclaimed. For the Proposed Action and for the BLM's preferred tract configuration under Alternative 1, the areas that would be permanently topographically changed would increase as shown in Table 3-1. As discussed in Section 3.0, the estimated recoverable coal, associated disturbance, and mine life shown in Table 3-1 assume that Highway 14-16 is not moved.

3.2.2.2 No Action Alternative

Under the No Action Alternative, the Eagle Butte West coal lease application would be rejected and coal removal would not occur on the LBA tract. Mining operations and the associated impacts to topography and physiography would continue as permitted on the existing Eagle Butte Mine leases. Table 3-2 presents the approximate postmining surface elevation change for the existing mine. The portion of the Eagle Butte West LBA Tract lying west of U.S. Highway 14-16 would not be disturbed to recover the coal in the existing leases, which are east of the highway.

As discussed in Section 2.2, a decision to reject the Eagle Butte West lease application at this time would not preclude an application to lease the tract in the future.

ttachment 30
ocket 07A-447E
lustrom Answer Testimony

Lehman Brothers CEO Energy / Power Conference

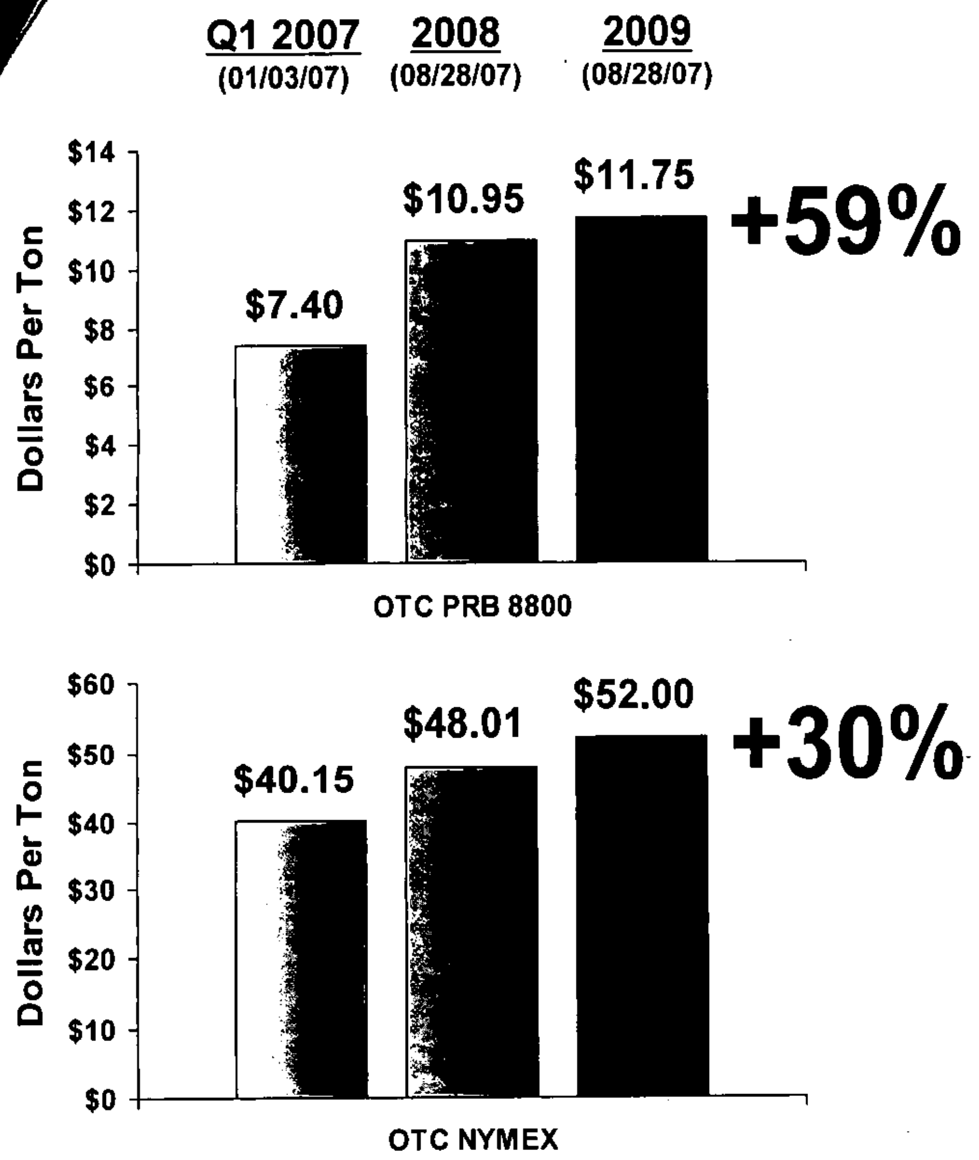
September 6, 2007

$$E=mc^2$$

Peabody Energy
NYSE: BTU

U.S. Markets Continue to Show Improvement in 2007

Published Prices



Source: [illegible]al and Energy Price Report (CEPR), January 3, 2007 and August 28[illegible]007.

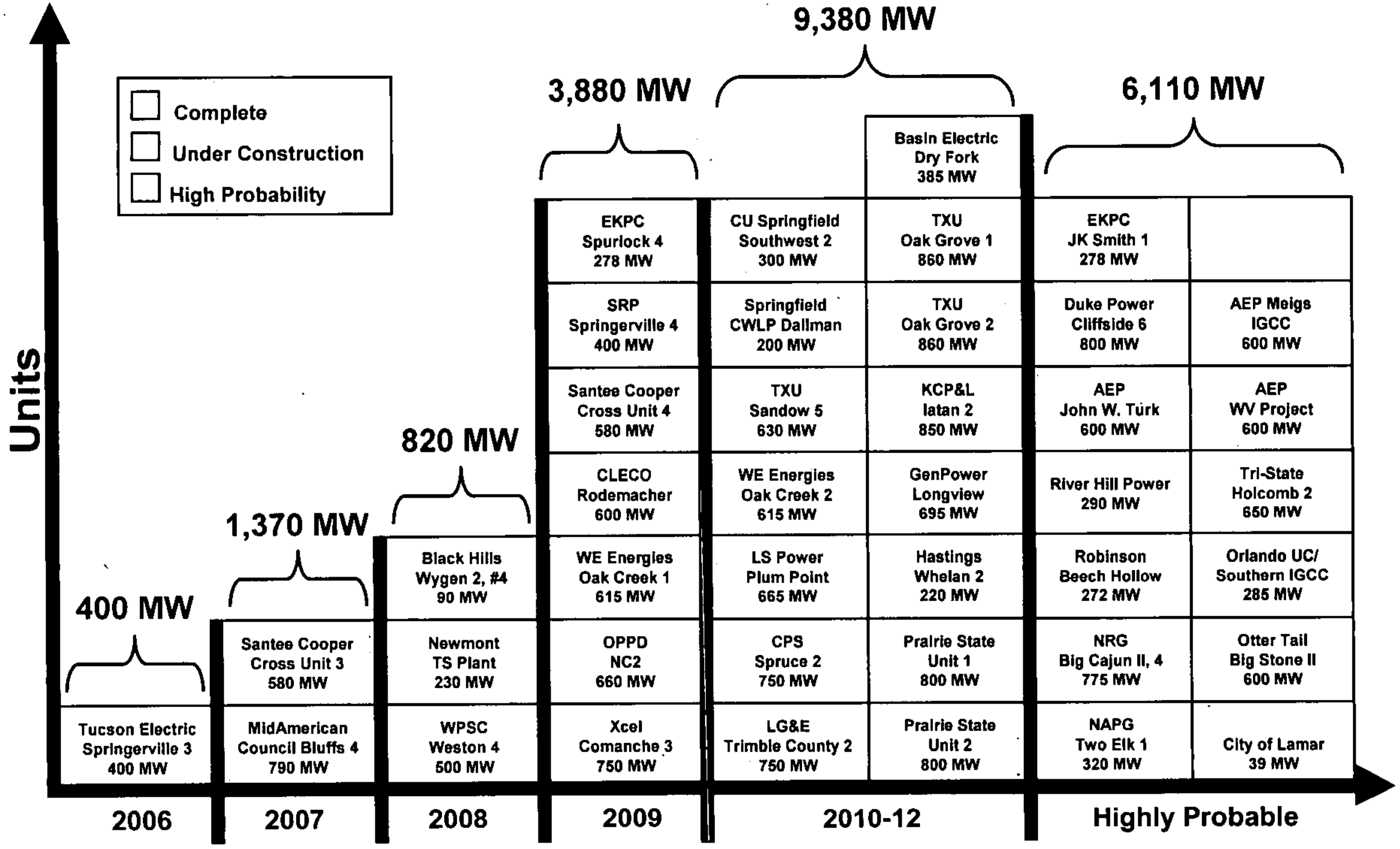
Peabody's
Unpriced U.S. Tons

2008: 50 – 60 Million
2009: 130 – 140 Million

- Peabody's realized PRB prices 25% higher than second quarter 2006
- 38 million tons of premium PRB product priced 49% above average 2006 realized price
- Higher second half 2007 PRB shipments required to meet sales contracts

Increased Long-Term Coal Demand Due to Increased Coal Generation

41 Units in 21 States Represent More Than 90 MTPY of Coal Use



2006 — 400 MW
- Tucson Electric Springerville 3 400 MW

2007 — 1,370 MW
- MidAmerican Council Bluffs 4 790 MW
- Santee Cooper Cross Unit 3 580 MW

2008 — 820 MW
- WPSC Weston 4 500 MW
- Newmont TS Plant 230 MW
- Black Hills Wygen 2, #4 90 MW

2009 — 3,880 MW
- Xcel Comanche 3 750 MW
- OPPD NC2 660 MW
- WE Energies Oak Creek 1 615 MW
- CLECO Rodemacher 600 MW
- Santee Cooper Cross Unit 4 580 MW
- SRP Springerville 4 400 MW
- EKPC Spurlock 4 278 MW

2010-12 — 9,380 MW
- LG&E Trimble County 2 750 MW
- CPS Spruce 2 750 MW
- LS Power Plum Point 665 MW
- WE Energies Oak Creek 2 615 MW
- TXU Sandow 5 630 MW
- Springfield CWLP Dallman 200 MW
- CU Springfield Southwest 2 300 MW
- Prairie State Unit 2 800 MW
- Prairie State Unit 1 800 MW
- Hastings Whelan 2 220 MW
- GenPower Longview 695 MW
- KCP&L Iatan 2 850 MW
- TXU Oak Grove 2 860 MW
- TXU Oak Grove 1 860 MW
- Basin Electric Dry Fork 385 MW

Highly Probable — 6,110 MW
- NAPG Two Elk 1 320 MW
- NRG Big Cajun II, 4 775 MW
- Robinson Beech Hollow 272 MW
- River Hill Power 290 MW
- AEP John W. Turk 600 MW
- Duke Power Cliffside 6 800 MW
- EKPC JK Smith 1 278 MW
- City of Lamar 39 MW
- Otter Tail Big Stone II 600 MW
- Orlando UC/ Southern IGCC 285 MW
- Tri-State Holcomb 2 650 MW
- AEP WV Project 600 MW
- AEP Meigs IGCC 600 MW

Source: DOE NETL, "Tracking New Coal-fired Power Plants" May 2007; Public filings; Peabody analysis.

Peabody

Near-Term U.S. Markets: Supply / Demand Indicators to Watch Entering 2008

	Item	*Effects*	*Implication*
Supply	**Challenging Geology**	↑	Thinning Eastern seams drive production declines and cost increases
	Permitting Issues	↑	Uncertainty and delays challenge production at many Eastern surface mines
	New Safety Regulations	↑	Production and costs affected as upgrades occur at many mines
	Loss of Synfuels Credit	↑	Likely to lead to lower production due to marginal high-cost operations
Demand	**Economic Growth**	↗	Continued increases tempered by changes to off-peak demand
	Growing Net Exports	↑	Strong global met and steam demand and limited South America growth
	Natural Gas Pricing	→	No dispatch effects at $5.00/mmBtu; some minor regional effects
	Inventory Levels	↓	Higher-than-normal customer stockpiles carried over from lighter burns
	Inventory Direction	↑	Stockpiles declining with strong seasonal burns and production cutbacks

Attachment 31
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	**First Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	**January 22, 2008**

<u>DISCOVERY REQUEST LWG1-4:</u>

Please provide a graph like the one in Figure 1.7-1 going from 1998 to 2007 and on the graph please show:

a) The average price of natural gas paid by PSCo
b) The average price of coal paid by PSCo
c) The range of projected prices for natural gas for the planning document in place at the time (e.g. 1999 Integrated Resource Plan, 2003 Least Cost Plan etc.)
d) The projected price for coal for the planning document in place at the time (e.g. 1999 Integrated Resource Plan, 2003 Least Cost Plan etc.)
e) Please also provide all the data used for parts a) through d) above in a table format.
f) Please provide the data used to produce Figure 1.7-1 in a table format.
g) What data were used as the foundation for the assumption on page 1-55 that coal prices would increase at a rate of 2.33% per year after 2030? Please provide copies of all data used to develop this projection

RESPONSE:

a)

Year	Avg. Price of Natural Gas (per Mcf)
2007	$ 4.34
2006	$ 6.22
2005	$ 7.55
2004	$ 5.58
2003	$ 4.45
2002	$ 2.93
2001	$ 4.31
2000	$ 4.06
1999	$ 2.61
1998	$ 2.52

RESPONSE TO DISCOVERY REQUEST LWG1-4 continued:

b)

WEIGHTED AVERAGE PRICE PER MMBTU	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
COAL	$ 0.52	$ 0.52	$ 0.52	$ 0.54	$ 0.57	$ 0.57	$ 0.59	$ 0.58	$ 0.82	$ 0.73
FREIGHT	$ 0.39	$ 0.38	$ 0.39	$ 0.33	$ 0.33	$ 0.33	$ 0.33	$ 0.38	$ 0.43	$ 0.47
TOTAL	$ 0.91	$ 0.90	$ 0.91	$ 0.87	$ 0.90	$ 0.90	$ 0.92	$ 0.96	$ 1.25	$ 1.20

c) Gas price projections from the 1999 IRP were provided to the Commission in Docket No. 99A-549E. This docket is over seven years old. For the Company to ensure that we provide the gas prices actually used in the 1999 IRP resource selection processes, it would be necessary for Public Service to retrieve information that the Company provided to Commission Staff, and other intervening parties to that docket. This would entail a considerable amount of time and effort on the Company's behalf. Ms. Glustrum is free to retrieve this information from the Commission record in the CPUC Docket No. 99A-549E proceedings.

For gas price forecast information used in the 2003 LCP see Table 1.10-1 (page 1-80), Figure 1.10-3 (page 1-81), and the corresponding discussions from Volume 1 of the 2003 Least-Cost Plan. This plan was filed in cumulative CPUC Docket No. 04A-214E, 215E, 216E.

d) See response to LWG1-4(c) regarding information requested for the 1999 IRP.

Coal prices used in the 2003 Least Cost Plan were provided in response to Staff discovery response CPUC18-5 in CPUC Docket No. 05A-543E. The information was provided in Highly Confidential Attachment CPUC18-5.xls

e) The information is provided or directions are given to find the information in each of the subparts, Ms. Glustrom can accumulate all the required information and create the table.

f) See Attachment LWG1-4(f).

g) See response to LWG1-9d.

Sponsor: a)Heather Cellini, b-g Kathryn Valedez, Jim Hill **Response Date:** February 12, 2008

Attachment LWG1-4(f)

Year	Nuclear	Coal - Delivered	Natural Gas
2007	$0.50	$1.02	$6.97
2008	$0.57	$1.02	$7.31
2009	$0.74	$1.03	$7.24
2010	$0.95	$1.08	$7.12
2011	$1.14	$1.04	$6.87
2012	$1.24	$1.06	$6.78
2013	$1.30	$1.07	$6.45
2014	$1.27	$1.08	$6.56
2015	$1.20	$1.08	$6.97
2016	$1.14	$1.10	$7.24
2017	$1.09	$1.13	$7.27
2018	$1.07	$1.15	$7.40
2019	$1.07	$1.17	$7.64
2020	$1.08	$1.19	$7.96
2021	$1.11	$1.21	$8.19
2022	$1.13	$1.23	$8.50
2023	$1.17	$1.24	$8.84
2024	$1.20	$1.26	$9.14
2025	$1.23	$1.28	$9.37
2026	$1.27	$1.29	$9.63
2027	$1.30	$1.31	$9.96
2028	$1.34	$1.33	$10.35
2029	$1.39	$1.35	$10.69
2030	$1.42	$1.37	$11.02
2031	$1.46	$1.40	$11.28
2032	$1.51	$1.43	$11.54
2033	$1.55	$1.47	$11.81
2034	$1.56	$1.50	$12.09
2035	$1.61	$1.54	$12.37
2036	$1.66	$1.57	$12.66
2037	$1.71	$1.61	$12.95
2038	$1.75	$1.65	$13.25
2039	$1.80	$1.68	$13.56
2040	$1.85	$1.72	$13.88
2041	$1.90	$1.76	$14.20
2042	$1.95	$1.81	$14.53
2043	$2.01	$1.85	$14.87
2044	$2.06	$1.89	$15.22
2045	$2.12	$1.93	$15.57
2046	$2.18	$1.98	$15.94

Attachment 32
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of)
Public Service Company of Colorado)
For Approval of its 2007 Colorado)
Resource Plan)
)
Docket No. 07A-447E)

First Set of Discovery Requests
Of Ms. Glustrom
Served On Public Service Company

January 22, 2008

DISCOVERY REQUEST LWG1-5:

In response to discovery question LWG 2-11 in Docket 07A-107E, you provided the following information on coal contracts to me:

LWG 2-11b. And LWG 2-11c.

Supplier	Mine	Plant(s)	Expiration	Quantity	% Plant(s) Req
Arch Coal Sales	Black Thunder	Arapahoe	12/31/2008	400,000	58%
Arch Coal Sales	Black Thunder	Arapahoe	12/31/2007	42,300	6%
Arch Coal Sales	Black Thunder	Arapahoe	12/31/2007	250,000	36%
Foundation	Belle Ayr	Comanche	12/31/2009	Requirements	100%
Foundation	Eagle Butte	Pawnee	12/31/2009	Requirements	100%
Bowie Resources	Bowie	Cherokee/Valmont	12/31/2007	400,000	14%
Rio Tinto	Colowyo	Cherokee/Valmont	12/31/2007	250,000	8%
Twentymile Coal Co.	Foidel Creek	Cherokee/Valmont	12/31/2007	2,000,000	68%
Twentymile Coal Co.	Foidel Creek	Cherokee/Valmont	12/31/2007	300,000	10%
CoalSales Co.	Twentymile	Hayden	12/31/2011	Requirements	100%
Central Appalachia	McClane Canyon	Cameo	12/31/2008	250,000	100%
Colowyo Coal Co.	Colowyo	Craig	12/31/2017		
Trapper Mining	Trapper	Craig	12/31/2014		

a) Is this information still correct?

b) For each contract that expired in 2007, please indicate the number of tons of coal in the expired contract and its price and the number of tons of coal and its price in the new contract. Please express all prices in both $/ton and $/ MMBtu. Please provide the expiration dates of the new contracts negotiated in 2007. [question continued on next page]

DISCOVERY REQUEST LWG1-5 continued:

c) For each contract that will expire in 2008, please provide the existing price in both $ per ton and $ per MMBtu and then provide an estimated percentage of change for that contract that will occur when the contract is renegotiated and an explanation of the factors considered in the estimate. I am particularly interested in evaluations related to geologic constraints and projected production costs. Please provide the source of all information used and wherever possible, please provide copies of the information relied on. For any contracts that you don't think you'll be able to renegotiate, please provide an explanation of why and what plans PSCo has for obtaining replacement coal.

RESPONSE:

a) All information in this table is correct. An updated table is provided in the response to LWG1-5b.

b) See Attachment LWG1-5. Pricing information is Highly Sensitive Confidential information and will not be provided.

c) Doc 181171-10 Doc 183259 and Doc 181044 will be replaced with new contracts after a competitive bidding RFP process in mid-2008. The pricing under the existing contracts and replacement contracts is highly confidential. PSCo does not forecast coal prices, but instead relies upon industry experts and their professional opinions through paid subscriptions to proprietary reports protected by copyright. PSCo does not anticipate any problems replacing the coal with new contracts after current contracts expire.

Sponsor: Kathryn Valdez, Jeanette Schuck **Response Date:** February 12, 2008

Attachment CPUC1-5b

Doc. No.	Supplier	Mine	Plant(s)	Expiration Date	Quantity	% Plant(s) Req-2008	Note(s)
181171-18	Arch Coal Sales Company	Black Thunder	Arapahoe	12/31/2007	42,300 tons	N/A	Replaced by Doc No 183255
181171-20	Arch Coal Sales Company	Black Thunder	Arapahoe	12/31/2007	250K tons	N/A	Replaced by Doc No 183255
181171-10	Arch Coal Sales Company	Black Thunder	Arapahoe	12/31/2008	390K-410K tons/yr	58-61%*	
183255	Arch Coal Sales Company	Black Thunder	Arapahoe	12/31/2010	300K tons/yr	45%*	
183255	Arch Coal Sales Company	West Elk	Cherokee & Valmont	12/31/2009	230K tons/yr	8%*	
183220	Bowie Resources, LLC	Bowie	Cherokee & Valmont	12/31/2007	400K tons	N/A	Replaced by Doc No 183251
183251	Bowie Resources, LLC	Bowie	Cherokee & Valmont	12/31/2009	300K tons	11%*	
181044	Central Appalachia McClane Canyon	McClane Canyon	Cameo	12/31/2008	250K tons/yr	100%	
183252	COALSALES, LLC	Foidel Creek	Cherokee & Valmont	12/31/2012	2008 - 2.1M tons	74%*	
181562	COALSALES, LLC	Foidel Creek	Hayden	12/31/2011	Requirements	100%	
183217	Colowyo Coal Company	Colowyo	Craig	12/31/2017	100,857 tons/yr	33.52%	Partnership Agreement
37542	Foundation	Belle Ayr & Eagle Butte	Pawnee & Comanche	12/312009	Requirements	100%	
183253	Oxbow Mining LLC*	Elk Creek	Cherokee & Valmont	12/31/2009	240K tons/yr	8%*	
182603	Rio Tinto	Colowyo	Cherokee & Valmont	12/31/2007	250K tons	N/A	Replaced by Doc No 183252
183219	Trapper Mining	Trapper	Craig	12/31/2014	140,621 tons/yr	9.72%	Partnership Agreement
183259	Trapper Mining	Trapper	Craig	12/31/2008	545,000 tons	9.20%	Partnership Agreement
181881	Twentymile Coal Company	Foidel Creek	Cherokee & Valmont	12/31/2007	300K tons/yr	N/A	Replaced by Doc No 183252

Legend:

* Based on 2008-2012 PSCo Production Budget

Attachment 33
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**First Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**January 22, 2008**

DISCOVERY REQUEST LWG1-6:

Please provide the percentage of PSCo's coal and coal freight that is under long term contract for each of the years of the Resource Acquisition Period and for as many years of the planning period as are relevant. (i.e. once we reach the year where there is no coal or freight under long term contract, you can quit).

RESPONSE:

LWG1-6
Percentage under Contract

	2008	2009	2010	2011	2012	2013	2014	2015
Coal	101%	86%	29%	18%	6%	2%	2%	1%
Transportation	100%	43%	33%	31%	19%	19%	19%	19%

Sponsor: Kathryn Valdez

Response Date: February 12, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**First Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**January 22, 2008**

DISCOVERY REQUEST LWG1-9:

With respect to the market prices for electricity in Figure 1.7-2:

a) Please explain the "hump" between 2007 and 2013.

b) Please provide average on-peak and off-peak prices for market electricity for each month from January 1998-December 2007 and then projected forward to 2015.

c) Please explain in further detail how the implied heat rates and the estimated gas prices were used to project market prices for electricity.

d) Please provide an explanation and all data that were used to generate the assumption that electric rates would increase 2.33% per year after 2030.

RESPONSE:

a) The market price forecast was derived from a combination of sources, including market-based quotes for the early term, and studies from PIRA and CERA for the longer term. Each of the data sources project similarly-shaped patterns, with prices rising over the next several years, followed by a drop in the early part of the next decade.

b) For the historical price request, prices at the Palo Verde hub are shown in the table below. This is the closest hub to Public Service for which historical market prices are available for the time period requested. The third and fourth tables show the market prices used in development of the 2007 Colorado Resource Plan.

RESPONSE TO DISCOVERY REQUEST LWG1-9 continued:

Palo Verde On Peak (Approximate)

Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	22.48	24.51	29.49	205.72	23.52	40.78	47.04	49.00	60.69	54.02
2	20.15	21.27	31.00	215.30	23.54	54.44	43.02	48.22	53.97	59.17
3	21.62	21.16	30.95	208.18	34.27	54.67	42.20	52.21	46.62	50.66
4	25.76	26.70	37.15	212.77	29.94	43.06	46.65	54.46	50.04	58.82
5	21.20	28.88	70.86	253.94	27.34	48.49	53.22	50.60	51.06	65.47
6	20.69	33.80	176.22	86.16	34.65	53.58	51.86	54.86	61.54	69.62
7	43.24	47.02	184.74	67.49	40.40	61.84	61.07	72.44	87.01	84.81
8	50.97	43.44	232.88	52.50	31.81	52.05	52.81	78.69	64.94	68.51
9	43.36	33.29	140.98	29.88	32.61	44.51	41.60	85.71	44.54	54.68
10	27.07	41.21	93.12	27.68	33.81	46.16	47.31	90.43	48.71	60.58
11	28.05	31.83	128.87	24.90	34.43	37.70	51.89	64.81	54.55	51.93
12	27.52	30.86	264.84	28.10	39.89	45.19	55.58	94.42	55.33	59.27

Palo Verde Off Peak (Approximate)

Month	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	15.01	14.68	21.35	119.53	16.29	27.26	34.43	36.35	46.31	43.38
2	11.81	13.35	23.26	134.80	16.68	40.88	36.23	37.35	46.24	47.72
3	13.07	13.79	22.22	112.22	27.54	39.80	31.55	37.68	35.98	36.22
4	14.34	17.67	18.99	121.79	16.43	29.95	34.02	39.74	31.55	43.04
5	8.03	16.16	28.88	80.73	15.04	21.31	36.56	29.17	26.09	41.31
6	7.32	12.66	41.56	31.57	10.82	26.50	31.82	30.26	31.06	42.43
7	16.83	19.79	61.24	36.46	15.06	38.79	39.12	41.58	44.07	41.02
8	24.39	22.01	66.50	26.93	17.50	36.16	35.32	52.88	44.41	36.50
9	22.19	20.90	57.37	18.51	19.42	33.64	26.19	63.23	31.96	36.09
10	14.57	25.77	49.44	19.00	21.30	30.02	31.06	70.75	35.08	44.61
11	14.45	19.28	75.10	16.87	24.37	29.24	40.63	55.35	41.47	40.49
12	15.90	21.54	161.69	19.18	28.03	33.39	43.99	80.17	44.07	49.74

Resource Plan On Peak

Month	2008	2009	2010	2011	2012	2013	2014	2015
1	66.33	72.43	74.15	74.60	69.97	60.90	62.73	63.58
2	67.07	73.24	74.97	75.42	70.73	61.55	63.41	64.39
3	63.46	69.31	70.94	71.37	66.91	58.24	59.99	59.36
4	56.52	61.76	63.20	63.57	59.54	51.82	53.38	55.59
5	61.27	66.93	68.50	68.90	64.56	56.19	57.88	59.28
6	63.34	69.16	70.80	71.23	66.81	58.14	59.89	66.23
7	87.88	95.51	98.07	98.83	93.61	81.42	83.92	89.59
8	88.69	96.38	98.98	99.74	94.52	82.21	84.74	92.16
9	66.91	73.03	74.79	75.25	70.66	61.49	63.34	66.23
10	63.74	69.55	71.23	71.68	67.33	58.59	60.36	67.59
11	60.52	66.10	67.66	68.06	63.80	55.53	57.20	74.79
12	63.32	69.18	70.80	71.21	66.72	58.07	59.81	76.01

Resource Plan Off Peak

Month	2008	2009	2010	2011	2012	2013	2014	2015
1	50.82	55.96	57.16	56.35	56.44	49.57	50.67	50.62
2	51.97	57.23	58.45	57.62	57.72	50.70	51.83	51.14
3	46.37	50.99	52.10	51.38	51.42	45.14	46.15	47.35
4	41.56	45.66	46.66	46.03	46.03	40.40	41.31	43.96
5	40.49	44.61	45.56	44.90	44.99	39.52	40.40	41.63
6	42.42	46.80	47.78	47.07	47.21	41.48	42.40	45.77
7	50.44	55.62	56.79	55.96	56.10	49.30	50.38	54.89
8	50.61	55.73	56.92	56.11	56.20	49.37	50.46	56.86
9	43.74	48.14	49.17	48.48	48.55	42.63	43.58	47.88
10	41.21	45.28	46.27	45.65	45.65	40.06	40.97	50.04
11	44.39	48.59	49.70	49.08	48.96	42.93	43.92	58.86
12	48.17	52.84	54.02	53.31	53.26	46.73	47.79	60.51

c) For 2010 and beyond, the electricity-forward prices were derived from an implied heat rate model using fundamentally-derived market heat rates from proprietary analyses obtained from PIRA and CERA. The sources either provide explicit forecasts for heat rate or provide both a power and a gas forecast from which the heat rate can be calculated. The market heat rate is multiplied by the appropriate forecast of natural gas prices to obtain the final electricity price. Consistent with the methodologies used in the other analyses conducted as part of the 2007 Colorado Resource Plan development, Public Service used a compilation of prices from NYMEX, PIRA, CERA, and EIA for development of the base case natural gas price assumptions.

d) The 2007 Colorado Resource Plan base assumption was that nominal electricity rates in the long-run would increase in line with inflation. The inflation rate of 2.33% is based on the implied inflation rate calculated by comparing PIRA's and CERA's real and nominal natural gas price forecasts for the outer years. The rate is the simple average of the PIRA and CERA implied inflation rates from their respective forecasts.

Sponsor: Jon Landrum **Response Date:** February 1, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)))))	**First Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**January 22, 2008**

DISCOVERY REQUEST LWG1-10:

With respect to the CO2, sulfur dioxide and mercury emission costs discussed on page 1-57 of the Resource Plan:

a) Please provide a table showing the projected emission costs for each of these pollutants for each of the planning years.

b) Please provide a table showing the emission rate for each fossil fuel unit on the Xcel system and any units that Xcel purchases from as well as the energy market proxies (e.g. Four Corners, NW Colorado, SPP etc.) for CO2, sulfur dioxide and mercury.

c) Please provide the estimated number of MWh that each fossil fuel unit will produce each year during the planning period and the projected emission costs for CO2, sulfur dioxide and mercury for each unit for each year of the planning period.

d) Please provide a table showing the projected emission costs by pollutant (CO2, sulfur dioxide and mercury) for PSCo's system for each year of the planning period and the total emission cost for each year and for the full planning period

RESPONSE:

a. See Attachment LWG1-10.xls, sheet "Effluent_costs".

b. See Attachment LWG1-10.xls, sheets: "Thermal_unit_emission_rate_HG", "Thermal_unit_emission_rate_CO2", "Thermal_unit_emission_rate_SOX", "Purchase_&_market_CO2" for emission rate estimates used in the modeling of resource plans.

c. See Attachment LWG1-10.xls, sheets: "Transaction_GWh", "Thermal_GWh", "Econ_Energy_GWh" for GWh values. PSCo estimates that it has sufficient credits to not incur emissions costs for sulfur dioxide and mercury emissions. See Attachment LWG1-10.xls, sheets: "CO2_trans_costs", "CO2_thermal_costs", "CO2_econ_costs" for CO2 cost estimates.

d. PSCo estimates that it has sufficient credits to not incur emissions costs for sulfur dioxide and mercury emissions, however their credit value on a system basis along with CO2 cost estimates are provided in Attachment LWG1-10.xls, sheet: "Annual_estimated_emissions_cost"

Sponsor: Jeff Burke

Response Date: February 12, 2008

Unit	lbs./mmBTU
GILLETTE 1	119.0
WYGEN 1	205.0
CHEROKEE 1	209.0
CHEROKEE 2	233.0
CHEROKEE 3	235.0
CHEROKEE 4	218.0
COMANCHE 1	224.0
COMANCHE 2	253.0
PAWNEE 1	232.0
VALMONT 5	226.0
CRAIG 1	231.0
CRAIG 2	224.0
HAYDEN 1	245.0
HAYDEN 2	222.0
ZUNI 1	125.0
ZUNI 2	125.0
ALAMOSA CT 1	125.0
ALAMOSA CT 2	125.0
FT LUPTN 1	143.0
FT LUPTN 2	143.0
FRUITA 1	125.0
VALMONT 6 CT	176.0
FSV1	119.0
FSV2	119.0
FSV3	119.0
C.DIESEL 1	160.2
C.DIESEL 2	160.2
COMANCHE 3	205.0
BLDR75QF	119.0
Thermo Cogen	119.0
Monfort	119.0
PRPA_EXTENSION	205.0
Blue Spruce 1	119.0
Blue Spruce 2	119.0
TSGT_LIMON	119.0
VALMONT 7&8	119.0
ARAPAHOE 5&6	119.0
PLAINS END 1	119.0
TSGT BRIGHTON	119.0
FR_COAST	119.0
Rocky Mountain	119.0
MANCHIEF 1	119.0
MANCHIEF 2	119.0
FOUNTAIN VALLEY 1	119.0
FOUNTAIN VALLEY 2	119.0
FOUNTAIN VALLEY 3	119.0
FOUNTAIN VALLEY 4	119.0
FOUNTAIN VALLEY 5	119.0
FOUNTAIN VALLEY 6	119.0
Brush 1&3 Extension	119.0

Spindle 1	119.0
Spindle 2	119.0
Plains End 2	119.0
Brush 4D Extension	119.0
Brush 2	119.0
Pulverized Coal with Carbon Capture	102.5
Pulverized Coal with Carbon Capture	102.5
Nuclear	0.0
Nuclear	0.0
2 CT	119.0
LMS 2	119.0
CC	119.0
CT	119.0
Pulverized Coal with Carbon Capture	102.5
LMS 1	119.0
IGCC 100 MW	109.0
AVD_CC	119.0
IGCC	109.0
NUCLEAR	0.0
Pulverized Coal with Carbon Capture	102.5
IGCC Duct Firing	119.0
IGCC Duct Firing	119.0
ARAPAHOE CC	119.0
3 CT	119.0
Replacement CC 1	119.0
FSV_CT	119.0
FSV_CT	119.0
TSGT_LIMON	119.0
TSGT BRIGHTON	119.0
Brush_2 Extension	119.0
ARAPAHOE 4	216.0
CAMEO 2	227.0
CAMEO 1	254.0
ARAPAHOE 3	266.0

Attachment LWG1-10

Year	2007	2010	2011	2013	2017
Unit	lbs.x E-06 /mmBTU				
GILLETTE 1	0.000				
WYGEN 1	0.005				
CHEROKEE 1	0.790				
CHEROKEE 2	2.590				
CHEROKEE 3	0.360				
CHEROKEE 4	1.050				
COMANCHE 1	4.760	2.000			
COMANCHE 2	4.760	2.000			
PAWNEE 1	6.860		1.750		0.087
VALMONT 5	2.180			1.750	
CRAIG 1	0.860			0.600	
CRAIG 2	0.910			0.600	
HAYDEN 1	3.010			1.750	1.250
HAYDEN 2	1.070				
ZUNI 1	0.000				
ZUNI 2	0.000				
ALAMOSA CT 1	0.000				
ALAMOSA CT 2	0.000				
FT LUPTN 1	0.000				
FT LUPTN 2	0.000				
FRUITA 1	0.000				
VALMONT 6 CT	0.000				
FSV1	0.000				
FSV2	0.000				
FSV3	0.000				
C.DIESEL 1	0.000				
C.DIESEL 2	0.000				
COMANCHE 3	2.000				
BLDR75QF	0.000				
Thermo Cogen	0.000				
Monfort	0.000				
PRPA_EXTENSION	7.660				
Blue Spruce 1	0.000				
Blue Spruce 2	0.000				
TSGT_LIMON	0.000				
VALMONT 7&8	0.000				
ARAPAHOE 5&6	0.000				
PLAINS END 1	0.000				
TSGT BRIGHTON	0.000				
FR_COAST	0.000				
Rocky Mountain	0.000				
MANCHIEF 1	0.000				
MANCHIEF 2	0.000				
FOUNTAIN VALLEY 1	0.000				
FOUNTAIN VALLEY 2	0.000				
FOUNTAIN VALLEY 3	0.000				
FOUNTAIN VALLEY 4	0.000				
FOUNTAIN VALLEY 5	0.000				
FOUNTAIN VALLEY 6	0.000				
Brush 1&3 Extension	0.000				
Spindle 1	0.000				
Spindle 2	0.000				

Plains End 2	0.000
Brush 4D Extension	0.000
Brush 2	0.000
Pulverized Coal with Carbon Capture	1.000
Pulverized Coal with Carbon Capture	1.000
Nuclear	0.000
Nuclear	0.000
2 CT	0.000
LMS 2	0.000
CC	0.000
CT	0.000
Pulverized Coal with Carbon Capture	1.000
LMS 1	0.000
IGCC 100 MW	0.410
AVD_CC	0.000
IGCC	0.410
NUCLEAR	0.000
Pulverized Coal with Carbon Capture	1.000
IGCC Duct Firing	0.000
IGCC Duct Firing	0.000
ARAPAHOE CC	0.000
3 CT	0.000
Replacement CC 1	0.000
FSV_CT	0.000
FSV_CT	0.000
TSGT_LIMON	0.000
TSGT BRIGHTON	0.000
Brush_2 Extension	0.000
ARAPAHOE 4	6.000
CAMEO 2	0.100
CAMEO 1	0.100
ARAPAHOE 3	6.000

Attachment 36
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Second Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**February 29, 2008**

DISCOVERY REQUEST LWG2-1:

Referring to Table 1.6-2 "The Preferred Resource Plan:"

a) How were the levels of "Section 123 Resources" determined?
b) Were the 123 Resources allowed to be chosen by the model or chosen "by hand?"
c) If the Section 123 Resources were chosen "by hand," please list all factors used in determining which resources to choose and when.

d) Please forward all work papers and assumptions related to choosing more Concentrating Solar Power resources before 2015.

e) Please forward all work papers and assumptions related to choosing more than 200 MW of Concentrating Solar Power in 2015.

RESPONSE:

a.) The High Section 123 Plan was constructed by manually adding Section 123 Resources to the levels contained in the Low Section 123 Plan (i.e., which just meet the minimum requirements of HB07-1281 and HB07-1037). The additional levels of Section 123 Resources included in the High plan were also selected to achieve significant reductions in CO2 emissions. See discovery requests CPUC 12-3 and CPUC 6 for additional information.

b.) See response to LWG2-1a.

c.) Diversification of resource technologies, availability of technologies (e.g., commercially available or still in research and development stage), carbon impacts, system operation impacts, system load forecast, cost.

d.)

e.) The Company does not understand the question. The most CSP that was proposed by the Company for year 2015 is the 200 MW of the High Section 123 Plan. There are no work papers for higher amounts.

Sponsor: Jim Hill

Response Date: March 11, 2008

Attachment 37
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of **Public Service Company of Colorado** **For Approval of its 2007 Colorado** **Resource Plan**	)	**Second Set of Discovery Requests** **Of Ms. Glustrom** **Served On Public Service Company**
Docket No. 07A-447E	)	**February 29, 2008**

DISCOVERY REQUEST LWG2-3:

Referring to page 1-53 and the discussion of coal plant retirements, please provide total Annual Operating Costs for each coal plant on the PSCo system for the last 5 years and provide the annual operating costs for each of the following categories:

a) Labor
b) Fuel costs
c) Cooling water costs
d) Plant maintenance costs other than major upgrades
e) Plant upgrade costs, identifying the major upgrades completed
f) Ash disposal
g) Emission costs for SO2
h) Emission costs for NOx
i) Emission costs for mercury
j) Emission costs for other pollutants

RESPONSE:

See Attachment LWG2-3.

Sponsor: Loa Jansen

Response Date: March 11, 2008

Attachment LWG2-3

PSCo Coal Stations

ES Arapahoe Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 6,558,023	$ 7,108,818	$ 7,411,834	$ 8,453,561	$ 8,295,922
Fuel	$ 14,911,191	$ 13,030,310	$ 13,062,891	$ 18,055,886	$ 20,499,930
Water Cost (total water cost, object 723037)	$ 179,311	$ 463,590	$ 281,908	$ 447,273	$ 239,206
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 2,463,703	$ 3,814,472	$ 2,228,872	$ 2,528,019	$ 2,788,522
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -
Ash Disposal (estimated, began tracking by object in 2007)	$ 377,140	$ 433,191	$ 360,617	$ 575,408	$ 932,839
Emission costs for SO2 (essentially MERP costs)	$ 903,635	$ 537,420	$ 612,198	$ 786,639	$ 849,539
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -

ES Cameo Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 3,552,582	$ 3,858,017	$ 4,233,751	$ 4,422,539	$ 4,169,267
Fuel	$ 8,694,515	$ 8,105,952	$ 9,729,161	$ 9,714,611	$ 11,158,304
Water Cost (total water cost, object 723037)	$ -	$ -	$ 114,012	$ 118,324	$ 138,330
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 792,063	$ 800,938	$ 879,269	$ 2,190,645	$ 954,233
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -
Ash Disposal (estimated, began tracking by object in 2007)	$ 523,193	$ 554,734	$ 562,586	$ 541,644	$ 736,803
Emission costs for SO2	$ -	$ -	$ -	$ -	$ -
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -

ES Cherokee Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 16,328,267	$ 18,000,053	$ 18,561,570	$ 20,811,293	$ 19,391,716
Fuel	$ 59,726,850	$ 61,028,800	$ 66,672,114	$ 79,227,700	$ 84,536,547
Water Cost (total water cost, object 723037)	$ 606,498	$ 1,092,653	$ 1,512,754	$ 1,774,170	$ 1,773,963
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 8,688,655	$ 9,418,104	$ 7,662,936	$ 10,210,794	$ 8,439,595
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -
Ash Disposal (estimated, began tracking by object in 2007)	$ 4,408,923	$ 4,881,880	$ 4,872,890	$ 7,204,139	$ 6,980,664
Emission costs for SO2 (essentially MERP costs)	$ 3,517,171	$ 2,973,691	$ 3,672,452	$ 4,136,674	$ 4,750,519
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -

ES Comanche Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 9,874,308	$ 11,391,096	$ 12,029,409	$ 13,757,330	$ 14,884,716

Attachment LWG2-3

Fuel	$ 37,225,286	$ 34,611,803	$ 36,961,819	$ 56,758,421	$ 53,184,521
Water Cost (total water cost, object 723037)	$ 2,506,281	$ 2,324,175	$ 2,389,879	$ 2,698,642	$ 2,839,375
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 3,083,447	$ 8,867,051	$ 8,705,150	$ 4,283,168	$ 6,690,599
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -
Ash Disposal (estimated, began tracking by object in 2007)	$ -	$ -	$ -	$ -	$ -
Emission costs for SO2	$ -	$ -	$ -	$ -	$ -
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -
ES Pawnee Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 10,037,160	$ 11,660,368	$ 12,649,572	$ 12,962,069	$ 11,799,715
Fuel	$ 40,194,205	$ 27,383,595	$ 31,655,512	$ 45,849,514	$ 42,469,608
Water Cost (total water cost, object 723037)	$ 494,678	$ 615,061	$ 621,111	$ 773,020	$ 691,637
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 2,706,363	$ 4,623,127	$ 8,022,690	$ 5,090,478	$ 3,172,922
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -
Ash Disposal (estimated, began tracking by object in 2007)	$ -	$ -	$ -	$ -	$ 35,000
Emission costs for SO2	$ -	$ -	$ -	$ -	$ -
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -
ES PSCo share of Hayden Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 5,302,756	$ 5,566,387	$ 6,098,489	$ 6,560,311	$ 5,933,232
Fuel	$ 19,841,688	$ 20,997,490	$ 19,582,422	$ 31,898,100	$ 34,961,299
Water Cost (total water cost, object 723037)	$ -	$ 5,709	$ 20,148	$ 17,339	$ 28,365
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 3,065,035	$ 1,918,580	$ 1,541,746	$ 4,246,207	$ 2,287,821
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -
Ash Disposal (estimated, began tracking by object in 2007)	$ -	$ -	$ -	$ -	$ -
Emission costs for SO2 (lime, estimated 2003-4)	$ 750,000	$ 800,000	$ 876,792	$ 974,333	$ 1,398,647
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -
ES Valmont Plant	2003	2004	2005	2006	2007
Labor (Xcel Labor, O&M and Fuel Handling, Loaded)	$ 5,469,222	$ 6,500,542	$ 6,664,652	$ 7,203,640	$ 6,862,820
Fuel	$ 18,337,775	$ 17,165,266	$ 22,344,786	$ 23,078,234	$ 26,163,353
Water Cost (total water cost, object 723037)	$ -	$ 34,422	$ 148,317	$ 107,313	$ 57,023
Maintenance costs excl. upgrades (excl. Xcel labor)	$ 1,174,854	$ 1,795,550	$ 1,056,126	$ 1,478,613	$ 1,562,944
Plant upgrade costs (none, these items would be capital)	$ -	$ -	$ -	$ -	$ -

Attachment LWG2-3

Ash Disposal (estimated, began tracking by object in 2007)	$ 341,060	$ 441,467	$ 393,223	$ 318,433	$ 447,700
Emission costs for SO2 (essentially MERP costs)	$ 1,262,667	$ 1,212,814	$ 723,043	$ 875,193	$ 704,697
Emission costs for NOX (low NOX burners, not tracked seperately)	$ -	$ -	$ -	$ -	$ -
Emission costs for Mercury (none incurred to date)	$ -	$ -	$ -	$ -	$ -
Emission costs for other pollutants (none identified)	$ -	$ -	$ -	$ -	$ -

Attachment 38
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	))))	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	))	**March 7, 2008**

DISCOVERY REQUEST LWG3-1:

With respect to the analysis of the High Section 123 Resources, please provide all workpapers, assumptions and conclusions involving analyses of the High Section 123 option without the IGCC plant.

RESPONSE:

The Company did not evaluate a High Section 123 Plan that did not include the IGCC plant.

Sponsor: Jim Hill

Response Date: March 21, 2008

Attachment 39
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of)
Public Service Company of Colorado)
For Approval of its 2007 Colorado)
Resource Plan)
)
Docket No. 07A-447E)

Third Set of Discovery Requests
Of Ms. Glustrom
Served On Public Service Company

March 7, 2008

DISCOVERY REQUEST LWG3-3:

For each coal plant on the PSCo system, please provide the following:

a) The amount of fly ash produced each year
b) The chemical analysis of the fly ash
c) The present disposition of the fly ash
d) The capacity of any fly ash disposal site and when it is expected to be full
e) The plans for disposal of the fly ash in 2010, 2015, 2020, 2025 and 2030, 2035 and 2040.

f) The present cost for fly ash disposal for that plant
g) Projected future costs for fly ash disposal for 2010, 2015, 2020, 2025, 2030, 2035 and 2040.

RESPONSE:

a) See Attachment LWG3-3 showing actual production amounts during 2006 and 2007 and projections for 2008, 2009 and 2010.

b) Data that is current and uses consistent analytic techniques is not available for each of the various fly ashes.

c) Attachment LWG3-3 provided in response to Request a) above indicates the proportion of ash production utilized in 2006 and 2007 and the portion forecasted to be utilized in 2008, 2009, and 2010. The remainder is disposed. Following are explanatory notes on each Station and its ash disposal requirements:

> Arapahoe Station: Commercial facilities are utilized for the relatively small proportion of Arapahoe Station ash production requiring disposal. Commercial disposal is expected to continue for the approximately 5-year duration that coal will be used to fuel the Station.

RESPONSE TO DISCOVERY REQUEST LWG3-3 continued:

Cameo Station: On site disposal is expected to continue for the approximately 2-year duration that coal will be used to fuel the Station.

Cherokee Station: Commercial facilities are utilized for Cherokee Station ash that requires disposal. It is expected that access to commercial disposal will continue for the foreseeable future and at costs reflecting inflationary increases.

Comanche Station: Comanche Station's reliance on full utilization for management of its ash is expected to change with installation of emissions control improvements on Units 1 & 2 and with Unit 3 being placed into service in 2009. On-site disposal capacity has been authorized and will be utilized for the foreseeable future.

Hayden Station: On-site disposal is expected to continue at Hayden for the foreseeable future.

Pawnee Station: Full utilization of Pawnee Station ash is expected to continue for several years or until emissions control modifications are made. When those modifications are made, it is expected that use of Pawnee Station's on-site disposal facility will resume.

Valmont Station: The majority of ash currently produced at the Valmont Station is disposed in its on-site facility. This disposal facility is expected to achieve its permitted capacity in approximately 2015. Options for management of the Valmont Station ash past that point are being evaluated. Such options include commercial disposal or acquisition of property to permit and develop dedicated disposal.

d) See above response.

e) See response to c) above.

f) See Attachment LWG3-3 listing actual costs incurred in 2006 and 2007 and forecasted costs for 2008, 2009, and 2010.

g) Costs for future ash disposal at those Stations that continue to rely on coal as a fuel are expected to follow an inflationary trend for the foreseeable future. Potential future ash disposal costs at the Pawnee Station are expected to be similar to those forecasted for the Comanche Station, adjusted for the relative amount of ash to be disposed. Ash disposal costs at the Valmont Station in the post-2015 era are subject to the current evaluation.

Sponsor: Quinn Kilty

Response Date: March 21, 2008

Xcel Energy Ash Production and Use

PSCo Region

		FLY ASH			BOTTOM ASH/SLAG		
		Tons Produced	Tons Utilized	% Utilized	Tons Produced	Tons Utilized	% Utilized
Year 2006 (Actual)							
PSCo SYSTEM PLANTS (all Pulv. Coal):							
Arapahoe	*PRB Coal; dry Na injection*	35,117	29,433	84%	19,384	0	0%
Cameo	*CO bituminous, high LOI*	86,552	0	0%	*(combined with fly ash)*		
Cherokee	*CO bituminous; 1&2 - dry Na inj.; 3&4 - dry FGD;*	401,602	9,843	2%	89,100	3,763	4%
Comanche	*PRB; Compliant Class C*	74,867	74,867	100%	224	224	100%
Hayden	*CO bituminous; dry FGD*	170,565	0	0%	42,641	0	0%
Pawnee	*PRB; Compliant Class C*	71,203	71,203	100%	12,874	12,874	100%
Valmont	*CO bituminous; dry FGD*	66,447	0	0%	0	0	0%
2006 Actual PSCo TOTAL		**906,353**	**185,346**	**20%**	**164,223**	**16,861**	**10%**
Year 2007 (Actual)							
PSCo SYSTEM PLANTS (all Pulv. Coal):							
Arapahoe	*PRB Coal; dry Na injection*	33,007	31,497	95%	6,947	3,385	49%
Cameo	*CO bituminous, high LOI*	115,497	0	0%	*(combined with fly ash)*		
Cherokee	*CO bituminous; 1&2 - dry Na inj.; 3&4 - dry FGD;*	381,848	8,593	2%	91,053	0	0%
Comanche	*PRB; Compliant Class C*	69,474	69,474	100%	13,631	13,631	100%
Hayden	*CO bituminous; dry FGD*	207,760	0	0%	41,554	0	0%
Pawnee	*PRB; Compliant Class C*	75,264	75,264	100%	6,795	6,128	90%
Valmont	*CO bituminous; dry FGD*	91,408	5,805	6%	0	0	0%
2007 Actual PSCo TOTAL		**974,258**	**190,633**	**20%**	**159,980**	**23,144**	**14%**
Year 2008 (Forecast)							
PSCo SYSTEM PLANTS (all Pulv. Coal):							
Arapahoe	*PRB Coal; dry Na injection*	45,449	36,359	80%	10,997	5,000	45%
Cameo	*CO bituminous, high LOI*	83,370	0	0%	*(combined with fly ash)*		
Cherokee	*CO bituminous; 1&2 - dry Na inj.; 3&4 - dry FGD;*	333,034	140,000	42%	70,655	40,000	57%
Comanche	*PRB; Compliant Class C*	67,116	67,116	100%	12,987	12,987	100%
Hayden	*CO bituminous; dry FGD*	200,000	0	0%	40,000	0	0%
Pawnee	*PRB; Compliant Class C*	75,264	75,264	100%	6,795	6,128	90%
Valmont	*CO bituminous; dry FGD*	79,832	6,800	9%	15,182	0	0%
2008 (Forecast) PSCo TOTAL		**884,065**	**325,539**	**37%**	**156,616**	**64,115**	**41%**
Year 2009 (Forecast)							
PSCo SYSTEM PLANTS (all Pulv. Coal):							
Arapahoe	*PRB Coal; dry Na injection*	35,079	31,571	90%	7,962	3,981	50%
Cameo	*CO bituminous, high LOI*	103,451	0	0%	*(combined with fly ash)*		
Cherokee	*CO bituminous; 1&2 - dry Na inj.; 3&4 - dry FGD;*	381,848	8,593	2%	91,053	0	0%
Comanche	*PRB; Compliant Class C*	159,729	0	0%	30,310	0	0%
Hayden	*CO bituminous; dry FGD*	207,760	0	0%	41,554	0	0%
Pawnee	*PRB; Compliant Class C*	90,470	90,470	100%	22,618	22,618	100%
Valmont	*CO bituminous; dry FGD*	68,611	3,431	5%	13,703	0	0%
2009 (Forecast) PSCo TOTAL		**1,046,948**	**134,065**	**13%**	**207,200**	**26,599**	**13%**
Year 2010 (Forecast)							
PSCo SYSTEM PLANTS (all Pulv. Coal):							
Arapahoe	*PRB Coal; dry Na injection*	35,079	31,571	90%	7,962	3,981	50%
Cameo	*CO bituminous, high LOI*	103,451	0	0%	*(combined with fly ash)*		
Cherokee	*CO bituminous; 1&2 - dry Na inj.; 3&4 - dry FGD;*	381,848	8,593	2%	91,053	0	0%
Comanche	*PRB; Compliant Class C*	268,903	0	0%	51,026	0	0%
Hayden	*CO bituminous; dry FGD*	207,760	0	0%	41,554	0	0%
Pawnee	*PRB; Compliant Class C*	90,470	90,470	100%	22,618	22,618	100%
Valmont	*CO bituminous; dry FGD*	68,611	3,431	5%	13,703	0	0%
2010 (Forecast) PSCo TOTAL		**1,156,122**	**134,065**	**12%**	**227,916**	**26,599**	**12%**

Attachment LWG3-3

Historical Ash Management Contribution of the Fuel Handling-NonLabor Costs for the PSCo Region

		ES Arapahoe Plant		ES Cameo Plant		ES Cherokee Plant		ES Comanche Plant		ES Pawnee Plant		ES Valmont Plant	
		FH-NL Total	FH-NL - Ash 46%	FH-NL Total	FH-NL - Ash 87%	FH-NL Total	FH-NL - Ash 89%	FH-NL Total	FH-NL - Ash 13%	FH-NL Total	FH-NL - Ash 13%	FH-NL Total	FH-NL - Ash 13%
%Ash NL													
Jan	2005 A	$ 122,890	$ 56,530	$ 62,601	$ 54,637	$ 334,668	$ 297,854	*Fully Utilized*		*Fully Utilized*		$ 135,857	$ 17,661
Feb	2005 A	$ 99,678	$ 45,852	$ 64,939	$ 56,497	$ 624,086	$ 555,437					$ 151,777	$ 19,731
Mar	2005 A	$ 78,955	$ 36,320	$ 60,805	$ 52,900	$ 409,769	$ 364,694					$ 146,530	$ 19,049
Apr	2005 A	$ 130,287	$ 59,932	$ 98,243	$ 85,471	$ 470,319	$ 418,584					$ 91,426	$ 11,885
May	2005 A	$ 91,382	$ 42,036	$ 69,147	$ 60,158	$ 679,546	$ 604,796					$ 144,299	$ 18,759
Jun	2005 A	$ 78,035	$ 35,896	$ 71,036	$ 61,802	$ 316,501	$ 281,686					$ 181,851	$ 23,641
Jul	2005 A	$ 108,085	$ 49,719	$ 73,380	$ 63,841	$ 621,458	$ 553,097					$ 130,296	$ 16,939
Aug	2005 A	$ 92,846	$ 42,709	$ 52,114	$ 45,339	$ 554,928	$ 493,886					$ 109,615	$ 14,250
Sep	2005 A	$ 96,342	$ 44,317	$ 89,311	$ 77,700	$ 315,333	$ 280,647					$ 110,339	$ 14,344
Oct	2005 A	$ 189,715	$ 87,269	$ 151,954	$ 132,200	$ 989,257	$ 880,439					$ 109,412	$ 14,224
Nov	2005 A	$ 104,726	$ 48,174	$ 75,366	$ 65,568	$ 452,969	$ 403,143					$ 136,013	$ 17,682
Dec	2005 A	$ 130,145	$ 59,867	$ (17,537)	$ (15,257)	$ 430,359	$ 383,019					$ 108,281	$ 14,077
FH-NL Ash Total			$ 608,621		$ 740,855		$ 5,517,282		$ -		$ -		$ 202,240
Jan	2006 A	$ 73,260	$ 33,699	$ 101,324	$ 88,152	$ 712,167	$ 633,829	*Fully Utilized*		*Fully Utilized*		$ 106,159	$ 13,801
Feb	2006 A	$ 85,618	$ 39,384	$ 38,911	$ 33,853	$ 497,322	$ 442,616					$ 45,524	$ 5,918
Mar	2006 A	$ 95,827	$ 44,081	$ 37,085	$ 32,264	$ 543,323	$ 483,557					$ 109,958	$ 14,295
Apr	2006 A	$ 161,612	$ 74,341	$ 68,925	$ 59,965	$ 676,174	$ 601,795					$ 128,513	$ 16,707
May	2006 A	$ 139,515	$ 64,177	$ 110,228	$ 95,898	$ 997,627	$ 887,888					$ 106,461	$ 13,840
Jun	2006 A	$ 192,397	$ 88,503	$ 74,346	$ 64,681	$ 637,797	$ 567,639					$ 108,287	$ 14,077
Jul	2006 A	$ 210,167	$ 96,677	$ 94,008	$ 81,787	$ 585,336	$ 520,949					$ 108,654	$ 14,125
Aug	2006 A	$ 280,239	$ 128,910	$ 72,734	$ 63,279	$ 1,219,641	$ 1,085,480					$ 107,178	$ 13,933
Sep	2006 A	$ 108,593	$ 49,953	$ 20,539	$ 17,869	$ 259,477	$ 230,935					$ 108,408	$ 14,093
Oct	2006 A	$ 195,736	$ 90,038	$ 68,539	$ 59,629	$ 1,156,864	$ 1,029,609					$ 107,473	$ 13,972
Nov	2006 A	$ 172,109	$ 79,170	$ 116,366	$ 101,238	$ 807,336	$ 718,529					$ 114,865	$ 14,932
Dec	2006 A	$ 154,537	$ 71,087	$ 24,432	$ 21,256	$ 774,134	$ 688,979					$ 107,541	$ 13,980
FH-NL Ash Total			$ 860,020		$ 719,870		$ 7,891,805		$ -		$ -		$ 163,673
Monthly FH-NL Ash Costs based on Invoiced Costs for 2007													
Jan	2007 A		$ 46,803		$57,939		$ 676,524	*Fully Utilized*		*Fully Utilized*			$62,028
Feb	2007 A		$ 42,471		$39,345		$ 612,502						$28,954
Mar	2007 A		$ 32,894		$48,452		$ 449,329						$38,580
Apr	2007 A		$ 41,314		$58,166		$ 612,573						$31,650
May	2007 A		$ 32,574		$47,731		$ 639,700						$13,873
Jun	2007 A		$ 25,824		$66,158		$ 570,697						$38,072
Jul	2007 A		$ 33,147		$45,938		$ 401,209						$33,061
Aug	2007 A		$ 36,799		$65,770		$ 494,801						$43,435
Sep	2007 A		$ 26,628		$20,507		$ 379,887						$31,489
Oct	2007 A		$ 25,390		$31,834		$ 222,390						$36,369
Nov	2007 A		$ 21,769		$18,199		$ 356,869						$37,382
Dec	2007 A		$ 32,594		$51,740		$ 407,123						$30,930
FH-NL Ash Total			$ 398,207		$ 549,779		$ 5,823,604		$ -		$ -		$ 425,823
Monthly FH-NL Ash Costs based on Forecast for 2008													
Jan	2008 F		$ 57,495		$43,241		$ 564,687	*Fully Utilized*		*Fully Utilized*			$40,247
Feb	2008 F		$ 56,919		$46,594		$ 564,119						$35,937
Mar	2008 F		$ 47,621		$48,639		$ 590,097						$37,694
Apr	2008 F		$ 50,608		$50,017		$ 584,263						$38,751
May	2008 F		$ 58,363		$46,643		$ 577,323						$38,200
Jun	2008 F		$ 56,826		$45,838		$ 566,452		$30,698				$38,761
Jul	2008 F		$ 59,979		$49,966		$ 620,039		$31,803				$40,735
Aug	2008 F		$ 60,535		$52,891		$ 626,992		$31,756				$41,353
Sep	2008 F		$ 58,053		$40,665		$ 556,729		$18,981				$38,325
Oct	2008 F		$ 59,992		$33,055		$ 514,820		$17,181				$39,459
Nov	2008 F		$ 48,570		$51,376		$ 614,212		$28,890				$37,770
Dec	2008 F		$ 59,901		$47,989		$ 611,157		$31,826				$37,366
FH-NL Ash Total			$ 674,862		$ 558,914		$ 6,992,890		$ 191,135		$ -		$ 464,598
Monthly FH-NL Ash Costs based on Forecast for 2009													
Jan	2009 F		$ 40,573		$48,601		$ 427,002		$124,968	*Fully Utilized*			$31,205
Feb	2009 F		$ 37,988		$44,686		$ 350,749		$72,485				$32,486
Mar	2009 F		$ 30,226		$49,263		$ 287,007		$87,964				$34,127
Apr	2009 F		$ 28,781		$47,732		$ 422,478		$114,391				$33,721
May	2009 F		$ 41,036		$49,088		$ 432,038		$88,053				$112,559
Jun	2009 F		$ 39,701		$47,009		$ 416,922		$77,514				$111,412
Jul	2009 F		$ 41,477		$49,482		$ 437,365		$124,867				$34,997
Aug	2009 F		$ 41,420		$49,486		$ 436,651		$80,365				$34,779
Sep	2009 F		$ 39,426		$47,150		$ 415,723		$85,577				$32,871
Oct	2009 F		$ 32,088		$45,811		$ 413,315		$203,150				$32,279
Nov	2009 F		$ 39,612		$47,693		$ 418,087		$170,856				$33,139
Dec	2009 F		$ 40,166		$48,242		$ 423,598		$170,190				$33,211
FH-NL Ash Total			$ 452,496		$ 574,243		$ 4,880,934		$ 1,400,382		$ -		$ 556,785
Monthly FH-NL Ash Costs based on Forecast for 2010													
Jan	2010 F		$ 42,598		$48,601		$ 434,248		$256,470	*Fully Utilized*			$32,759
Feb	2010 F		$ 39,885		$44,686		$ 357,063		$178,810				$34,105
Mar	2010 F		$ 31,735		$49,263		$ 292,542		$186,990				$35,828
Apr	2010 F		$ 30,218		$47,732		$ 429,663		$248,290				$35,402
May	2010 F		$ 43,084		$49,088		$ 439,338		$186,990				$116,166
Jun	2010 F		$ 41,683		$47,009		$ 424,038		$178,810				$116,963
Jul	2010 F		$ 43,547		$49,482		$ 444,739		$256,470				$36,741
Aug	2010 F		$ 43,487		$49,486		$ 444,010		$178,810				$36,512
Sep	2010 F		$ 41,394		$47,150		$ 422,820		$186,990				$34,509
Oct	2010 F		$ 33,690		$45,811		$ 420,391		$244,308				$33,887
Nov	2010 F		$ 41,589		$47,693		$ 425,212		$179,506				$34,791
Dec	2010 F		$ 42,173		$48,242		$ 430,800		$178,810				$34,866
FH-NL Ash Total			$ 475,084		$ 574,243		$ 4,964,862		$ 2,461,258		$ -		$ 584,530

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	**March 7, 2008**

DISCOVERY REQUEST LWG3-4:

For each coal plant on the PSCo system, please provide the following:

a) The number of acre-feet of water consumed per year.

b) The breakdown of what that water is used for.

c) The source of the water.

d) The cost of the water per year.

e) The company's projections of the cost of the water for each year of the planning period.

f) All analyses of the effects of climate change on this source of water for the planning period.

RESPONSE:

a. 2007 data is presented below

Coal fired Station	Water Consumed	Water Source
Arapahoe	1,422 AF	South Platte River
Cameo	95 AF	Colorado River / Government Highline Canal
Cherokee	7,858 AF	South Platte River, Clear Creek
Comanche	6,921 AF	Arkansas River
Hayden	5,007 AF	Yampa River
Pawnee	5,011 AF	South Platte River alluvium
Valmont	2,459 AF	Boulder and South Boulder Creeks

RESPONSE TO DISCOVERY REQUEST LWG3-4 continued:

b. Water is tracked based on total consumption by plant. There is no further breakdown

c. See above.

d. Provided as a response to LWG2-3, please reference LWG2-3 for data.

e. There is no water cost projection out to 2046.

f. There is no analysis of the effects of climate change out to 2046.

Sponsor: Loa Jansen **Response Date:** March 21, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)))))	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 7, 2008**

DISCOVERY REQUEST LWG3-5:

For each coal plant on PSCo's system, please provide the following:

a) Emissions of SO2 for each year from 2003-2007 and estimated emissions for 2010, 2015, 2020, 2025, 2030, 2035 and 2040 and actual or estimated costs for SO2 emissions for each of these years.

b) Emissions of NOx for each year from 2003-2007 and estimated emissions for 2010, 2015, 2020, 2025, 2030, 2035 and 2040.

c) Emissions of particulates for each year from 2003-2007 and estimated emissions for 2010, 2015, 2020, 2025, 2030, 2035 and 2040.

d) Emissions of volatile organic compounds for each year from 2003-2007 and estimated emissions for 2010, 2015, 2020, 2025, 2030, 2035 and 2040.

e) Emissions of carbon monoxide for each year from 2003-2007 and estimated emissions for 2010, 2015, 2020, 2025, 2030, 2035 and 2040.

e) Emissions of mercury for each year from 2003-2007 and estimated emissions for 2010, 2015, 2020, 2025, 2030, 2035 and 2040.

f) Plans for controlling mercury emissions in 2010, 2015, 2020, 2025, 2030, 2035 and 2040, a description of the technology intended to be used for mercury control, whether the Company believes this control will qualify as Maximum Available Control Technology ("MACT") and the estimated cost of controlling mercury in each of these years.

g) Pollution control equipment on each coal unit and approximate level of control achieved for each pollutant controlled by that equipment.

RESPONSE:

a) Actual SO2 emissions for **2003 – 2007** are contained in Attachment LWG3-5.A1. Actual costs for SO2 control reagents at each plant with existing SO2 controls are noted below.

RESPONSE TO DISCOVERY REQUEST LWG3-5 continued:

PSCo S02 Annual Reagent Costs ($/year)

Plant	2003	2004	2005	2006	2007
Arapahoe	708,976	383,030	523,082	768,875	674,478
Cherokee	3,400,369	1,761,878	2,825,260	3,491,971	3,532,892
Valmont	693,829	522,351	613,216	680,685	845,723
Hayden	1,054,895	1,315,588	1,534,912	1,819,243	2,076,201

b), c), d), e), f) See Attachment LWG3-5.A1 for **2003 - 2007** to question a) above regarding emissions of NOx, particulate, volatile organic compounds, carbon monoxide, and mercury.

f) The plans for controlling mercury on the PSCo units includes sorbent injection on all the Comanche units starting in late 2009 and on Pawnee Unit 1 starting in late 2011. Current Colorado mercury control regulations require some of our remaining units to begin controlling mercury in 2014. Specific compliance plans regarding the 2014 mercury control requirements have not been developed. The company does not know whether any of the proposed mercury controls will meet future Maximum Achievable Control Technology (MACT) requirements until EPA promulgates those rules. Future costs for mercury emission controls have not been developed at this time.

g) See Attachment LWG3-5.A1 for a list of the pollution control equipment on each unit and the approximate level of control.

a-f) **For future,** estimated emissions in parts a through f see Attachment LWG3-5.A2_future.xls for emissions levels for PSCo owned coal plants. The Strategist model does not provide SO2 emission cost output on a plant level, however aggregate SO2 emission costs in dollars for the PSCo owned coal plants were provided in response LWG1-10.xls (see worksheet "Annual_Estimated_Emission_Costs").

Sponsor: Gary Magno and Jim Hill **Response Date:** March 21, 2008

Attachment LWG3-5, A1
2003 - 2007 years

PSCo Annual Emissions 2003 - 2007

DATA YEAR 2003

	SO2 Tons	NOx Tons	PM Tons	VOC Tons	CO Tons	Hg lbs
Arapahoe 3	1188.8	1913.9	54.7	5.9	50.1	1.2
Arapahoe 4	1922.6	1202.7	99.7	12.7	109.0	2.3
Cameo 1	1173	694.6	5.8	3.6	31.2	0.3
Cameo 2	2014.6	712.8	82.7	6.1	50.9	0.6
Cherokee 1	2459.2	1628.3	42.1	12.4	109.4	1.8
Cherokee 2	1962.9	2923	37.7	11.7	104.2	1.6
Cherokee 3	529.3	2065.2	74.8	15.4	134.0	2.0
Cherokee 4	976.9	3837.2	72.3	27.5	224.7	3.6
Comanche 1	7168.5	4812.5	84.8	40.6	338.2	7.5
Comanche 2	9062.7	4299.4	69.4	47.1	393.1	8.7
Hayden 1	1001.6	3341.2	80.6	18.9	158.0	2.4
Hayden 2	1442.4	3909.8	121.8	31.9	265.6	4.0
Pawnee 1	16703	5369	137.3	73.2	611.1	15.5
Valmont 5	631.1	2476.5	50.0	16.6	154.5	2.4

DATA YEAR 2004

	SO2 Tons	NOx Tons	PM Tons	VOC Tons	CO Tons	Hg lbs*
Arapahoe 3	676.1	1,078	34.4	3.7	31.1	6.2
Arapahoe 4	2,024.3	1,262	117.7	14.5	120.9	24.3
Cameo 1	1,091.0	668.9	5.7	3.4	28.5	2.9
Cameo 2	1,877.4	676	76.6	5.6	46.9	4.7
Cherokee 1	2,162.5	1,344	37.3	10.5	90.4	17.4
Cherokee 2	1,940.9	2,361	31.1	9.0	77.0	15.0
Cherokee 3	664.2	1,838	72.8	14.2	119.5	24.2
Cherokee 4	1,678.6	4,267	92.5	34.3	283.7	57.8
Comanche 1	5,368.2	3,420	66.7	32.0	266.1	54.0
Comanche 2	8,581.6	4,241	68.4	46.5	388.9	78.6
Hayden 1	1,224.9	4,057	96.6	23.1	193.2	29.6
Hayden 2	1,391.1	3,653	112.8	30.1	251.1	38.5
Pawnee 1	12,549.6	4,515	123.2	65.7	549.1	128.0
Valmont 5	826.0	2,431	47.2	17.7	147.4	25.0

* Starting in 2004, PSCo began using a new methodology for calculating mercury emissions

DATA YEAR 2005

	SO2 Tons	NOx Tons	PM Tons	VOC Tons	CO Tons	Hg lbs
Arapahoe 3	940.1	1,446.9	46.2	5.0	42.0	11.3
Arapahoe 4	1,471.5	889.7	92.0	11.3	94.6	25.5
Cameo 1	1,018.3	593.4	5.0	3.0	25.5	3.0
Cameo 2	2,108.1	731.6	84.2	6.8	92.0	6.2
Cherokee 1	2,165.3	1,439.8	40.2	11.2	94.1	19.0
Cherokee 2	2,441.9	3,383.5	41.2	11.9	99.6	20.1
Cherokee 3	704.0	1,820.5	67.1	13.5	114.0	22.6
Cherokee 4	1,749.8	4,158.2	90.4	33.7	279.7	57.2
Comanche 1	6,613.0	4,058.7	65.9	41.3	343.8	69.6
Comanche 2	6,829.6	3,913.6	54.8	37.3	312.0	62.7
Hayden 1	1,297.5	4,094.7	99.2	23.5	196.0	53.8
Hayden 2	1,593.5	3,981.2	119.1	31.5	262.7	74.3
Pawnee 1	11,248.1	3,668.1	103.5	55.4	463.5	107.7
Valmont 5	878.6	2,514.1	61.1	22.9	190.3	25.0

DATA YEAR 2006

	SO2 Tons	NOx Tons	PM Tons	VOC Tons	CO Tons	Hg lbs
Arapahoe 3	879.9	1,705.9	55.7	6.0	50.3	19.0
Arapahoe 4	1,614.4	1,158.4	113.7	14.0	117.1	44.6
Cameo 1	687.0	394.3	3.4	2	16.8	2.0
Cameo 2	1,899.2	658.9	72.0	5.2	44.0	5.2
Cherokee 1	2,188.1	1,416.7	39.7	11.2	94.8	30.6
Cherokee 2	1,840.3	2,820.5	39.5	11.5	97.0	31.5
Cherokee 3	778.5	1,670.2	70.8	14.8	129.2	38.9
Cherokee 4	2,309.1	4,096.7	85.7	32.0	265.8	88.3
Comanche 1	6,299.9	3,927.1	88.4	42.6	355.0	71.7
Comanche 2	7,553.8	4,487.2	67.5	46.2	385.9	77.7
Hayden 1	1,056.6	3,535.4	86.5	19.4	162.5	47.0
Hayden 2	1,599.8	4,156.3	127.1	31.8	265.5	77.5
Pawnee 1	13,072.5	4,602.7	132.1	70.5	590.4	140.0
Valmont 5	748.0	2,303.9	42.4	16.0	132.8	30.0

DATA YEAR 2007

	SO2 Tons	NOx Tons	PM Tons	VOC Tons	CO Tons	Hg lbs
Arapahoe 3	1,025.7	1,729.2	56.5	7.2	67.8	22
Arapahoe 4	1,936.7	1,250.3	110.0	15.4	141.9	50
Cameo 1	1,011.7	637.0	5.2	3.3	29.2	3
Cameo 2	1,638.6	590.9	67.0	5.0	42.7	5
Cherokee 1	1,941.4	1,283.0	34.0	9.7	83.6	24
Cherokee 2	1,924.4	2,716.7	31.5	10.5	97.9	23
Cherokee 3	786.5	1,795.4	61.6	16.5	168.1	32
Cherokee 4	2,674.7	4,499.9	86.8	33.8	274.9	83
Comanche 1	6,413.0	4,138.2	92.6	44.8	372.3	75
Comanche 2	6,191.9	3,332.5	55.9	38.6	322.5	65
Hayden 1	1,248.4	4,061.5	101.1	22.6	188.9	54
Hayden 2	1,470.0	3,692.0	118.9	29.6	246.9	72
Pawnee 1	14,126.5	4,415.2	132.6	71.2	596.5	136
Valmont 5	787.9	2,360.7	44.2	17.1	139.2	44

Attachment LWG3-5. A1
2003 - 2007 years

PSCo Emission Control Information

	Particulate	Control Efficiency (%)	SO2	Control Efficiency (%)	NOx	Control Efficiency (%)
Arapahoe 3	Baghouse	99.9	DSI	32		
Arapahoe 4	Baghouse	99.9	DSI	38	LNB/OFA	35 - 45
Cameo 1	Baghouse	99.9				
Cameo 2	Baghouse	99.9			LNB/OFA	35 - 45
Cherokee 1	Baghouse	99.9	DSI	42	LNB/OFA	35 - 45
Cherokee 2	Baghouse	99.9	DSI	46		
Cherokee 3	Baghouse	99.9	LSD	86	LNB/OFA	35 - 45
Cherokee 4	Baghouse	99.9	LSD	82	LNB/OFA	35 - 45
Comanche 1	Baghouse	99.9				
Comanche 2	Baghouse	99.9			LNB/OFA	35 - 45
Hayden 1	Baghouse	99.9	LSD	82	LNB/OFA	35 - 45
Hayden 2	Baghouse	99.9	LSD	84	LNB/OFA	35 - 45
Pawnee 1	Baghouse	99.9			LNB/OFA	35 - 45
Valmont 5	Baghouse	99.9	LSD	86	LNB/OFA	35 - 45

DSI = Dry Sodium Injection

LSD = Lime Spray Dryer

LNB/OFA = Low NOx Burners with Overfire Air

SO2 emission control efficiency based on actual average values for each unit

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Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)))))	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 7, 2008**

DISCOVERY REQUEST LWG3-7:

For each coal plant on PSCo's system, please provide the following:

a) The amount of coal burned at the plant each year from 2003-2007 and the estimated amount of coal burned each year for the acquisition and planning periods.

b) The actual or estimated cost of the coal for that plant for each of the years 2003-2007 and each year of the acquisition and planning periods.

c) All analyses done on a mine-specific basis of future supplies of coal available for this plant.

d) All analyses done on projected annual coal costs specifically for this plant.

RESPONSE:

a) b) See Attachment LWG3-7ab.xls; See Attachment LWG3-7ab_future.xls

c) PSCo has not performed any such analyses.

d) The company's existing projected annual coal costs by plant are highly sensitive confidential information and will not be provided.

Sponsor: Kathryn Valdez and Jim Hill

Response Date: March 21, 2008

LWG3-7(a, b)

Plant	Year	Fuel	Data Source	Tons (000's)	cents/MMBtu
Arapahoe	2007	Coal	FERC	636.68	137.3
	2006	Coal	FERC	690.207	124.14
	2005	Coal	FERC	549.547	101.77
	2004	Coal	FERC	680.411	93.88
	2003	Coal	FERC	562.572	107.38
Cameo	2007	Coal	FERC	243.74	162.98
	2006	Coal	FERC	277.733	155.74
	2005	Coal	FERC	274.455	131.24
	2004	Coal	FERC	296.061	106.84
	2003	Coal	FERC	297.151	102.43
Cherokee	2007	Coal	FERC	2,179.14	141.76
	2006	Coal	FERC	2,453.00	146.14
	2005	Coal	FERC	2,360.53	106.63
	2004	Coal	FERC	2,204.65	101.38
	2003	Coal	FERC	2,059.60	102.82
Comanche	2007	Coal	FERC	2,976.25	105.15
	2006	Coal	FERC	3,075.47	96.93
	2005	Coal	FERC	2,437.53	76.64
	2004	Coal	FERC	2,727.89	70.82
	2003	Coal	FERC	2,973.55	68.74
Hayden	2007	Coal	FERC	1,764.74	156.71
	2006	Coal	FERC	1,603.99	156.86
	2005	Coal	FERC	1,831.93	101.87
	2004	Coal	FERC	1,793.14	100.85
	2003	Coal	FERC	1,697.50	102.23
Pawnee	2007	Coal	FERC	2,539.25	101.53
	2006	Coal	FERC	2,436.61	100.98
	2005	Coal	FERC	1,850.51	97.69
	2004	Coal	FERC	2,036.25	95.98
	2003	Coal	FERC	2,366.06	93.87
Valmont	2007	Coal	FERC	535.95	178.42
	2006	Coal	FERC	566.133	190.54
	2005	Coal	FERC	633.116	149.81
	2004	Coal	FERC	588.627	120.27
	2003	Coal	FERC	561.691	120.62

Unit Fuel Cost	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
($000)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Arapahoe 3&4	17,542	19,513	16,570	16,726	15,610	-	-	-	-	-	-	-	-	-	-	-	-	-
Cameo 1&2	9,143	9,280	7,468	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cherokee 1-4	97,339	96,751	86,646	91,358	86,996	89,389	92,513	91,537	92,682	96,341	94,586	96,929	101,032	100,339	95,599	96,882	99,835	105,124
Comanche 1-3	54,203	65,418	117,198	122,745	116,132	121,044	121,613	125,704	126,815	127,386	131,137	133,614	135,490	136,940	130,262	127,944	135,387	140,158
Craig 1&2	9,035	8,967	8,966	9,229	8,791	7,985	8,531	8,533	8,615	8,869	8,772	8,854	9,200	8,751	8,329	8,830	9,061	9,297
Hayden 1&2	29,992	30,261	30,087	31,729	25,139	24,944	26,174	24,609	25,647	27,095	25,464	26,837	28,204	27,022	26,161	26,679	26,188	11,209
Pawnee	41,428	43,044	41,911	36,014	42,730	43,375	38,136	43,785	44,252	39,954	46,351	47,010	42,037	48,952	47,118	40,937	48,783	50,369
Valmont	29,638	31,465	26,564	30,070	29,147	27,206	30,385	30,668	28,467	31,746	31,945	29,827	33,283	33,911	29,389	31,594	-	-
Total	288,321	304,698	335,409	337,868	324,546	313,944	317,352	324,837	326,478	331,392	338,256	343,071	349,245	355,916	336,859	332,866	319,255	316,156

YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR	YEAR
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
110,865	101,712	103,603	54,300	57,275	59,662	55,311	57,636	59,336	63,738	68,881	65,023	41,472	27,623	28,504	26,687	-	-	-	-	-
142,657	135,765	132,195	142,764	147,776	152,903	144,862	105,391	114,468	73,955	69,222	71,949	70,991	68,045	77,173	76,269	68,136	77,563	80,182	76,804	87,374
9,805	9,033	8,767	9,748	9,434	9,664	9,778	9,509	9,796	10,841	11,056	10,226	10,224	4,777	-	-	-	-	-	-	-
12,673	11,533	10,203	12,404	12,683	12,173	12,477	12,539	11,896	14,504	-	-	-	-	-	-	-	-	-	-	-
45,035	49,407	48,304	45,462	53,071	54,731	46,690	53,965	55,284	51,841	61,432	59,092	52,102	61,579	63,558	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
321,036	307,450	303,072	264,678	280,239	289,134	269,119	239,239	250,760	214,879	210,591	206,290	174,789	162,024	169,235	102,956	68,136	77,563	80,182	76,804	87,374

Attachment 43
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 7, 2008**

<u>DISCOVERY REQUEST LWG3-32:</u>

Please provide all analyses done of costs of air pollution on public health including costs of particulate emissions, carbon monoxide emissions, mercury and other hazardous pollutant emissions.

RESPONSE:

PSCo has not done any analyses of costs of air pollution on public health including costs of particulate emissions, carbon monoxide emissions, mercury and other hazardous pollutant emissions.

Sponsor: Frank Prager

Response Date: March 21, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 7, 2008**

DISCOVERY REQUEST LWG3-33:

Please provide all analyses done of the economic costs of non-attainment status for ozone for the Denver Metro region.

RESPONSE:

PSCo has not done any analyses of the economic costs of non-attainment status for ozone for the Denver Metro region.

Sponsor: Frank Prager

Response Date: March 21, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 7, 2008**

DISCOVERY REQUEST LWG3-34:

Please provide all analyses of the economic impacts (e.g. reduced income from fishing and tourism) resulting from acidification of high mountain watersheds due to acid deposition.

RESPONSE:

Except for studies that may have been performed by or on behalf of governmental entities or other parties and are already in the public record, PSCo has no analyses of the economic impacts resulting from the acidification of high mountain watersheds due to acid deposition.

Sponsor: Frank Prager **Response Date:** March 21, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Third Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 7, 2008**

DISCOVERY REQUEST LWG3-35:

Please provide all analyses done of the economic development impacts of concentrating solar power plants and CSP supply chain projects for Colorado's economy and state budget.

RESPONSE:

PSCo has not done any analyses of the economic development impacts of concentrating solar power plants and CSP supply chain projects for Colorado's economy and state budget.

Sponsor: Frank Prager

Response Date: March 21, 2008

Attachment 45
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Fourth Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 21, 2008**

DISCOVERY REQUEST LWG4-1:

For each coal plant on Xcel's system, please provide the following:

a) The mode of transportation for the coal used by the plant.

b) The ownership of the tracks for each "leg" of any rail journey.

c) For each leg of any rail journey, the present capacity of the tracks in trains/day.

d) For each leg of any rail journey, the present utilization of the tracks in trains/day.

e) For each leg of any rail journey any concerns Xcel has about service on that leg.

f) For each leg of any rail journey any required upgrades for that leg during the planning period for the Resource Plan and the associated costs of those upgrades and a timeline for completing these upgrades.

g) For the rail connections serving the Pueblo power plants:

i) What analyses have been done of increased track usage that would be required to service the new Unit 3?

ii) Are there track upgrades that will be required?

iii) How much would any needed upgrades cost?

iv) Please provide copies of all letters that have been written to the communities that will experience increased track usage associated with Unit 3.

v) Please provide all e-mails or summaries of phone conversations between Xcel and communities that will experience increased track usage associated with Unit 3.

h) All information regarding the expected life span of the coal mine supplying that coal plant.

i) All information regarding any planned expansions of the coal mine supplying that coal plant.

j) Any estimates of increased production costs associated with any planned coal mine expansions for the mine(s) serving that coal plant.

OBJECTION:

This request is overly burdensome. It requests information that is not germane to this proceeding. Public Service is not proposing in this docket to build any new coal plants. This request is not reasonably calculated to lead to the discovery of admissible evidence.

Sponsor: Paula Connelly

Response Date: April 10, 2008

Attachment 46
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Fourth Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 21, 2008**

DISCOVERY REQUEST LWG4-3:

For each coal plant on the Xcel system, please provide the cost of all projected capital expenditures needed between 2009 and 2015.

RESPONSE:

Per the Xcel Energy Capital Asset 2.2 Uniform Policy - Plant related expense forecasting will be performed minimally once a year for a five-year period. Please see Attachment LWG4-3, *PSCO_5-year_CapX.pdf.*

Sponsor: Loa Jansen

Response Date: April 10, 2008

Attachment LWG4-3

CBS capital = PSCo 2009 thru 2013 as of 040908

Version 22 2008 Actuals/Forecast

				2009	2010	2011	2012	2013	Sum:
				2009	2010	2011	2012	2013	Sum:
ES Arapahoe Plant	ES Arapahoe Plant	10508710	ARR0-C-09 Coal Mill Overhaul #	0	0	0	0	0	0
		10635784	ARR-4-C 09 Cooling Tower Switc	269,000	0	0	0	0	269,000
		10635789	ARR-4-C 10 Feedwater Heater Re	0	390,000	302,000	0	0	692,000
		10635805	ARR-3-C 10 Coal Mill Overhaul	0	152,000	0	0	0	152,000
		10635845	ARR-3-C 09 Coal Mill Overhaul	137,000	0	0	0	0	137,000
		10635908	ARR-4-C 12 Feedwater Heater Re	0	0	0	0	0	0
		10635914	ARR-4-C 08 FFDC Bag Replace	139,502	0	0	0	0	139,502
		10647478	ARR-4-C 09 Turbine Nozzle Bloc	610,000	0	0	0	0	610,000
		10786462	ARR-3-C 11 Auto Voltge Cont Ex	0	0	213,000	0	0	213,000
		10786928	ARR-0-C Capital Tools 2008	0	0	0	0	0	0
		10786932	ARR-0-C 09 Capital Tools 2009	51,000	0	0	0	0	51,000
		10786935	ARR-0-C Capital Tools 2010	0	51,000	0	0	0	51,000
		10786945	ARR-0-C Capital Tools 2011	0	0	54,000	0	0	54,000
		10808754	ARR -0-C 11 Coal Crusher	0	0	125,000	0	0	125,000
		10934525	ARR-4-C 11 Feedwater Heater Re	0	0	390,000	302,000	0	692,000
		10934533	ARR-0-C 08 Replace Obsolete CS	0	0	0	0	0	0
		10934564	ARR-4-C 09 Coal Mill Overhaul	232,000	0	0	0	0	232,000
		10934566	ARR-4-C 10 Coal Mill Overhaul	0	253,000	0	0	0	253,000
		10934568	ARR-4-C 11 Coal Mill Overhaul	0	0	259,000	0	0	259,000
		10934573	ARR-3-C 11 Coal Mill Overhaul	0	0	167,000	0	0	167,000
		10934604	ARR-0-C 11 CEMs Emission Monit	0	0	50,000	0	0	50,000
		10934619	ARR-0-C Capital Tools 2012	0	0	0	51,000	0	51,000
		10948055	ARR-O-C 10 Mercury Control-CEM	0	50,000	0	0	0	50,000
		11072464	ARR-0-C 11 Retire U3 & U4	0	0	639,817	38,389,017	15,995,424	55,024,258
		11072491	ARR-0-C 09 Acid Tank Rmve & Re	279,000	0	0	0	0	279,000
		11081944	ARR-0-C 10 New Gen U5 U6 U7	0	9,040,000	194,360,000	226,000,000	22,600,000	452,000,000
	ES Arapahoe Plant			1,717,502	9,936,000	196,559,817	264,742,017	38,595,424	511,550,760
ES Arapahoe Plant				1,717,502	9,936,000	196,559,817	264,742,017	38,595,424	511,550,760

				2009	2010	2011	2012	2013	Sum:
ES Cameo Plant	ES Cameo Plant	10527717	CAM0C U1 & U2 PULVERIZER OH	922,000	0	0	0	0	922,000
		10928942	CAM2C -REPL AIR HEATER BASKET	9,000	1,000,000	0	0	0	1,009,000
		11053800	CAM2C - U2 FFDC Bags replaceme	0	0	0	0	0	0
		11064025	CAM0C - Decommissioning Cameo	321,623	16,081,158	14,473,042	1,286,493	0	32,162,316
	ES Cameo Plant			1,252,623	17,081,158	14,473,042	1,286,493	0	34,093,316
ES Cameo Plant				1,252,623	17,081,158	14,473,042	1,286,493	0	34,093,316

				2009	2010	2011	2012	2013	Sum:
ES Cherokee Plant	ES Cherokee Plant	10512839	CHR4C New FFDC Controls	290,000	0	0	0	0	290,000
		10525121	CHR0C U123 SWT	0	0	0	(0)	0	(0)
		10525453	CHR4C U4 Replace U4 CWT	0	0	0	0	0	0
		10525594	CHR1C U1 Replace CWT	0	0	0	10,000	3,570,000	3,580,000
		10525638	CHRC4 Install Retaining Rings	0	0	0	0	0	0
		10637867	CHR2C S2 Fan Replacement	0	150,000	0	0	0	150,000
		10639522	CHR0P Purchase New Dozer	0	0	942,000	0	0	942,000
		10639648	CHR1C CEM System Install	0	0	0	120,000	0	120,000
		10639650	CHR2C CEM Install	0	0	0	120,000	0	120,000
		10639652	CHR3C CEM Install	0	0	0	120,000	0	120,000
		10639653	CHR4C CEM Install	0	0	0	120,000	0	120,000
		10639654	CHR3C FFDC Bag Replacement	859,000	0	0	0	0	859,000
		10639655	CHR4C FFDC Bag Replacement	0	1,357,000	0	0	0	1,357,000
		10641941	CHR4C Install Auto Sprinkler S	0	0	0	0	0	0
		10641944	CHR1C Condensate Flow	0	0	0	0	101,000	101,000
		10642018	CHR0C Replace SBAC	396,000	0	0	0	0	396,000
		10643501	CHR3C Mecury Monitors	0	0	0	0	0	0
		10799286	CHR0C South Platte Diversion	2,000,000	2,581,000	0	0	0	4,581,000
		10799335	CHR3C Turbine Station Batterie	0	0	0	0	0	0
		10799351	CHR3C C-3 Burner	0	0	814,000	0	0	814,000
		10799399	CHR1C Install U1 Economizer Se	0	0	0	16,000	1,750,000	1,766,000
		10799502	CHR3C Install Condenser retube	0	0	0	0	0	0
		10799507	CHR3C Install Lime spra;y drye	0	0	959,000	0	0	959[illegible]
		10799509	CHR3C Install hydrogen dryer	0	0	0	0	0	[illegible]
		10799515	CHR3C Install U3 retaining rin	0	0	0	0	0	0
		10799578	CHR4C Install unit 4 atomizer	0	981,000	0	0	0	981,000
		10807559	CHRC2 BART Burners	0	0	0	0	0	0
		10807567	CHRC4 BART Burners	0	0	0	0	0	0
		10808937	CHR4C ID Fan Drive Controls	0	0	14,000	1,208,000	0	1,222,000
		10919727	CHR4C - Burner Tilt Drives Tip	780,000	0	0	0	0	780,000

		10919760	CHR2C - Low Nox Burners	0	1,371,000	11,220,000	0	0	12,591,000
		10931068	CHR2C U2 Replace CWT	0	0	0	0	0	0
		10931240	CHR0C #3 Ash Water Pump Replac	0	0	0	0	0	0
		10931382	CHR0C Install Coal Dumper	0	0	0	0	0	0
		10931392	CHR0C Install Galleon Crane	0	0	179,000	0	0	179,000
		10931404	CHR0C Install Two Coal Pulveri	0	0	0	0	0	0
		10931440	CHR1C Install Station Battery	0	145,000	0	0	0	145,000
		10931442	CHR2C Install Station Battery	0	145,000	2,000	0	0	147,000
		10931590	CHR4C Install Service Water T	0	0	0	0	0	0
		10931619	CHR2C FFDC Bag Replacement	0	0	0	0	0	0
		10931625	CHR1C FFDC Bag Replacement	0	0	550,000	0	0	550,000
		10931629	CHR4C Install new coal mills	0	0	0	0	0	0
		10931947	CHR0C United Fisher Ditch	0	0	0	0	0	0
		10931979	CHR3C Install new coal mills	0	78,000	9,581,000	0	0	9,659,000
		10933147	CHR4C Install Station Battery	0	0	3,000	92,000	0	95,000
		10983327	CHR0C Purchase Welding Machine	0	0	0	0	0	0
		11057330	CHR1C Install Battery Room Hea	37,000	0	0	0	0	37,000
		11057355	CHR0C Purchase 4 Welding Machi	19,000	0	0	0	0	19,000
		11057422	CHR1C - Unit 1 Coal Mill Overh	433,000	0	0	0	0	433,000
		11057450	CHR2C - Unit 2 Coal Mill Overh	433,000	0	0	0	0	433,000
		11057593	CHR0C Replace Vibration Monito	0	995,000	0	0	0	995,000
		11057595	CHR0C Balmac Vibration Analyze	0	8,000	0	0	0	8,000
		11057596	CHR0C Power Tool Analyzer	0	5,000	0	0	0	5,000
		11058086	CHR0C Portable Vibration Tool	0	36,000	0	0	0	36,000
		11058087	CHR3C - Unit 3 Coal Mill Overh	0	433,000	0	0	0	433,000
		11058089	CHR4C - Unit 4 Coal Mill Overh	0	265,000	0	0	0	265,000
		11059521	CHR4C - Install Turning Vanes	29,000	0	0	0	0	29,000
		11070554	CHR0C DCS Remote Access	0	117,000	0	0	0	117,000
		11072005	CHR1C - Sample Panel	0	96,000	0	0	0	96,000
		11072009	CHR3C - # 3 Ash Pump	0	168,000	0	0	0	168,000
		11072372	CHR0C - Rebuild Fisher Ditch	0	0	6,000	112,000	0	118,000
		11072380	CHR3C - Condenser Retube	0	0	1,785,000	0	0	1,785,000
		11072427	CHR3C - Hydrogen Dryer	0	0	196,000	0	0	196,000
		11072434	CHR0C - Ash Dewatering System	0	0	142,000	17,734,000	0	17,876,000
		11072457	CHR1C - Coal Mill Overhaul	0	0	484,000	0	0	484,000
		11072468	CHR2C - Coal Mill Overhaul	0	0	484,000	0	0	484,000
		11072477	CHR0C Instrument Air Dryer	0	0	51,000	0	0	51,000
		11072487	CHR0C - Trubine Crane Load Cel	0	0	65,000	0	0	65,000
		11072493	CHR0C - Pressure Module	0	0	9,000	0	0	9,000
		11072737	CHR0C Snorkel/Scissor Lift	0	0	19,000	0	0	19,000
		11072819	CHR4C - Generator Assement Eq	0	0	0	60,000	0	60,000
		11072825	CHR4C - Rebuild Coal Mill	0	0	0	560,000	0	560,000
		11072827	CHR4C - Nox Emissions Controls	0	0	0	5,000,000	0	5,000,000
		11072844	CHR1C - Gas Flow Monitor	0	0	0	106,000	0	106,000
		11072846	CHR2C - Gas Flow Monitor	0	0	0	106,000	0	106,000
		11072847	CHR3C - Gas Flow Monitor	0	0	0	108,000	0	108,000
		11072848	CHR4C - Gas Flow Monitor	0	0	0	104,000	0	104,000
		11074430	CHR1C - Install Opacity Monit	0	0	0	20,000	0	20,000
		11074432	CHR2C - Install Opacity Monit	0	0	0	20,000	0	20,000
		11074433	CHR3C - Install Opacity Monit	0	0	0	20,000	0	20,000
		11074436	CHR4C - Install Opacity Monit	0	0	0	20,000	0	20,000
		11074472	CHR1C - DAHS Data Aquire Syste	0	0	0	41,000	0	41,000
		11074480	CHR2C - DAHS Data Aquire Syste	0	0	0	41,000	0	41,000
		11074483	CHR3C - DAHS Data Aquire Syste	0	0	0	41,000	0	41,000
		11074488	CHR4C - DAHS Data Aquire Syste	0	0	0	41,000	0	41,000
		11074528	CHR3C - Coal Mill Overhaul	0	0	0	484,000	0	484,000
		11074538	CHR0C - Temp Calibrator Tool	0	0	0	6,000	0	6,000
		11078891	CHR4C - Hydrogen Leak Detector	0	0	0	0	153,000	153,000
		11078896	CHR4C - Turbine Fire Protectio	0	0	0	0	360,000	360,000
		11078905	CHR4C - Mercury Emission Contr	0	0	0	21,000	2,009,000	2,030,000
		11078910	CHR2C - Cooling Tower Rebuild	0	0	0	0	10,000	10,000
		11078944	CHR2C - Coal Mill Rebuild	0	0	0	0	612,000	612,000
		11078948	CHR3C - Coal Mill Rebuild	0	0	0	0	0	0
		11078951	CHR1C - Install ash blower	0	0	0	0	53,000	53,000
		11078955	CHR2C - Install ash blower	0	0	0	0	53,000	53,000
		11078968	CHR3C - Install ash blower	0	0	0	0	53,000	53,000
		11078971	CHR4C - Install ash blower	0	0	0	0	53,000	53,000
		11078990	CHR0C - Coal Dumper Replacemen	0	0	0	0	11,149,000	11,149,000
		11079027	CHR1C - Coal Mill Rebuild	0	0	0	0	612,000	612,000
		11079124	CHR3C - Install HP Heater	0	0	0	0	25,000	25,000
		11079145	CHR0C - Add Reservoir Storage	0	0	0	0	1,020,000	1,020,000
		11079157	CHR3C - Cooling Tower	0	0	0	0	25,000	25,000
		11079161	CHR0C - Install #3 Elevator Co	0	0	0	0	161,000	161,000
	ES Cherokee Plant			**5,276,000**	**8,931,000**	**27,505,000**	**26,451,000**	**21,769,000**	**89,932,000**
ES Cherokee Plant				**5,276,000**	**8,931,000**	**27,505,000**	**26,451,000**	**21,769,000**	**89,932,000**

				2009	2010	2011	2012	2013	Sum:
ES Chilled Water	ES Chilled Water	10543960	DCO0211 - Qwest 550 Chiller	0	0	0	0	0	0
		10645119	DCO0110 Republic Plza Interco	0	0	0	0	0	[illegible]
		10645122	DCO0110 World Trade Cntr Inter	0	0	0	0	0	[illegible]
		10645124	DCO0110 Colo State Bank Interc	0	0	0	0	0	0
		10804947	DCO0807 CCC CW Pumps	75,000	75,750	0	0	0	150,750
		10832554	DCO1206-Denver Judicial Ctr Co	497,000	530,250	0	0	0	1,027,250
	ES Chilled Water			572,000	606,000	0	0	0	1,178,000
ES Chilled Water				572,000	606,000	0	0	0	1,178,000

				2009	2010	2011	2012	2013	Sum:
ES Comanche Plant	ES Comanche Plant	10362252	COM0410 UO TRIPPER DECK AUTOMA	0	0	471,459	0	0	471,459
		10388360	COMANCHE UNIT #3	3,858,746	843,461	0	0	0	4,702,208
		10499049	COMANCHE UNIT 3 LAND PURCHASE	500,000	0	0	0	0	500,000
		10524416	COM1C COM #1 Emisson Contl (Un	1,049,769	(414,918)	0	0	0	634,851
		10524537	COMC COM2 Emission Contl (UNIT	517,018	(1,536,446)	0	0	0	(1,019,428)
		10526544	COM1C REPLACE U1 SH PENDANT PL	0	0	0	0	0	0
		10526552	COM1C REP U1-5 Feed Water Heat	0	146,025	2,237,631	0	0	2,383,656
		10609836	COM3C UNIT 3 STRUCTURES AND I	22,773,251	5,010,656	0	0	0	27,783,907
		10609961	COM3C UNIT 3 BOILER PLANT EQUI	25,214,337	6,038,424	0	0	0	31,252,761
		10609975	COM3C UNIT 3 TURBOGENERATOR FE	12,225,733	2,672,350	0	0	0	14,898,083
		10609994	COM3C UNIT 3 ACCESSORY ELECTR	5,348,757	1,169,153	0	0	0	6,517,910
		10609998	COM3C UNIT 3 MISC PLANT EQUIP	1,528,217	334,043	0	0	0	1,862,260
		10643719	COM1C 1-7 FEEDWATER HEATER RE	0	0	969,000	0	0	969,000
		10643743	COM1C U1 HYDROGEN COOLERS REP	0	0	303,431	0	0	303,431
		10643764	COM1C U1 AIR HEATER LOWER BAS	0	0	0	0	0	0
		10643802	COM1C U1 TURBINE VIBRATION MO	0	0	481,394	0	0	481,394
		10786884	COM1C SERVICE WATER SUPPLY PUM	0	0	0	0	0	0
		10786914	COM1C FAN VIBRATION MONITOR SY	0	319,073	0	0	0	319,073
		10788632	COM2C BOILER FEED PUMP MONITOR	0	0	0	519,950	0	519,950
		10788640	COM2C U2 4160V BREAKER REPLAC	0	0	0	402,384	0	402,384
		10788649	COM2C REP WEAR LINERS U2 COAL	0	578,086	0	0	0	578,086
		10788660	COM1C SOOTBLOWING AIR COMPRESS	0	0	1,530,000	0	0	1,530,000
		10933834	COM1C U1LP L-1 BLADE REPLACEME	0	0	0	0	0	0
		10934703	COM1C ID FAN VAR SPEED DRIVE C	0	0	0	0	0	[illegible]
		10934710	COM0C ACID PUMP BUILDING & SYS	0	0	0	0	0	[illegible]
		10934722	COM2C FFDC BAGS IN ALL 24 COM	0	0	0	0	0	0
		10934744	COM2C REP 2-7 FEEDWATER HEATER	126,050	1,861,772	0	0	0	1,987,822
		10934760	COM1C PULVERIZER FAN/HOUSING	663,508	0	0	0	0	663,508
		10934843	COM1C 2 SCRUBBER ATOMIZERS (OP	1,602,660	0	0	0	0	1,602,660
		10934851	COM02 ATOMIZER VEHICLE (OPS U	510,000	0	0	0	0	510,000
		10935389	COM2C U2 FRONT SUPERHEATER	1,042,562	10,380,504	0	0	0	11,423,066
		10935392	COM1C COMANCHEU1 4160 VOLT BRE	404,983	0	0	0	0	404,983
		10935395	COM2C U2SDA ELEVATOR SCRUB (U3	0	0	0	0	0	0
		10935397	COM1C TURBINE DIFFER EXPANION	0	0	0	0	0	0
		10940458	COM1C WATER WALL REPLACEMENT	47,000	218,025	6,806,532	0	0	7,071,557
		10940459	COM1C CEM REPLACEMENT	0	131,000	0	0	0	131,000
		10940461	COM2C CEM REPLACEMENT	0	131,000	0	0	0	131,000
		10940462	COM2C 2A-1 REVERSE AIR FAN ROT	0	51,000	0	0	0	51,000
		10940464	COM2C U2 SERVICE WATER TOWER	0	360,000	0	0	0	360,000
		10940465	COM1C REP U1 DIVISION PANNELS	37,000	382,548	6,204,414	0	0	6,623,962
		10940467	COM1C U3 SDA ELEVATOR (U3 RELA	0	102,000	0	0	0	102,000
		10940831	COM0C FIRE PROTECTION COAL SYS	0	0	406,000	0	0	406,000
		10940842	COM2C NEW SOOTBLOWING COMPRESS	0	0	1,813,123	0	0	1,813,123
		10940847	COM2C AIR HANDLING UNITS	0	0	1,147,500	0	0	1,147,500
		10940851	COM1C REP TURBINE LUBE OIL COO	0	0	260,000	0	0	260,000
		10940857	COM1C REP U1 BLOWDOWN PIPING	0	0	612,000	0	0	612,000
		10940858	COM1C 4160V ALLIS CHALMERS BRE	0	0	216,846	0	0	216,846
		10940860	COM1C REP AIR HANDLING UNITS	0	0	0	1,824,000	0	1,824,000
		10940861	COM1C U1 STACK GAS FLOW MONITO	0	0	0	128,588	0	128,588
		10940862	COM2C U2 STACK GAS FLOW MONITO	0	0	0	129,000	0	129,000
		10940863	COM2C U2 COOLING TOWER FAN SHR	0	459,000	0	0	0	459,000
		10940864	COM1C U1 COOLING TOWER FAN SHR	0	0	490,000	0	0	490,000
		10947706	COM2C TURBINE FIRE PROTECT SYS	790,164	0	0	0	0	790,164
		10948090	COM1C DAHS UPGRADE	0	0	91,467	0	0	91,467
		11072299	COM2C UNIT 2 BAGHOUSE COATING	3,000,004	0	0	0	0	3,000,004
		11072818	COM2C REPLACE U2 STATION BATTE	0	0	0	0	139,050	139,[illegible]
		11072820	COM1C RETUBE U1 CONDENSER	0	0	0	0	507,500	507,[illegible]
		11072830	COM1C REPLACE U1 OPACITY MONIT	0	0	0	0	73,888	73,888
		11072832	COM2C REPLACE U 2 OPACITY MONI	0	0	0	0	73,888	73,888
		11074533	COM3C UNIT 3 MAINTENANCE BUILD	2,496,356	0	0	0	0	2,496,356
		11074542	COM0C HOMELAND SECURITY CHEMIC	101,293	0	0	0	0	101,293
		11074554	COM2C MONITORING WELLS BOTTOM	0	0	0	0	50,000	50,000
	ES Comanche Plant			83,837,408	29,236,756	24,040,797	3,003,922	844,326	140,963,210

ES Comanche Plant				83,837,408	29,236,756	24,040,797	3,003,922	844,326	140,963,210

				2009	2010	2011	2012	2013	Sum:
rp PSCO	ES Corp PSCO	10636080	SER-0-C-CHM 10 Instrumenta CO	0	117,000	0	0	0	117,000
		10636104	SER-0-C-MMR 09 Portable Alloy	0	0	45,000	0	0	45,000
		10636106	SER-0-C-MMR 09 Thermography Ca	45,000	0	0	0	0	45,000
		10636110	SER-0-C-MMR 10 25 ft Videoprob	0	90,000	0	0	0	90,000
		10636113	SER-0-C-MMR 10 Digital Radiogr	0	95,000	0	0	0	95,000
		10636116	SER-0-C-MMR 10 Ultrasonic Flaw	0	0	84,000	0	0	84,000
		10636120	SER-0-C-MMR 10 Repl 3 Ultrason	0	20,000	0	0	0	20,000
		10636124	SER-0-C-MMR 09 Repl 2 Ultrason	84,000	0	0	0	0	84,000
		10789380	SER-0-C CHM 09 Ins. for Colora	153,000	0	0	0	0	153,000
		10789501	SER-O-CHM Instrumntation for C	0	0	269,000	0	0	269,000
		10799589	SER-0-C-MMR Tools - Misc.	0	0	0	28,000	0	28,000
		10933218	SER-0-C-MOB-2009 Misc. Tools	50,000	0	0	0	0	50,000
		10933221	SER-0-C-MOB-2010 Misc. Tools	0	50,000	0	0	0	50,000
		10933225	SER-0-C-MOB-2011 Misc. Tools	0	0	50,000	0	0	50,000
		10933227	SER-0-C-MOB-2012 Misc. Tools	0	0	0	50,000	0	50,000
		10935651	SER-0-C-MMR 09 Replace MicroPr	0	0	7,000	0	0	7,000
		10935672	SER-0-C-CHM 2008 Inst. for CO.	0	0	0	0	0	0
		10935681	SER-0-C-CHM 12 System Chem. mo	0	0	0	201,000	0	201,000
		10935688	SER-0-C-CHM 12 Inst. for CO La	0	0	0	142,000	0	142,000
		10935713	SER-0-C-PMO 09 Thermocouple Co	34,000	0	0	0	0	34,000
		10935721	SER-0-C-PMO 10 Per. Emissions	0	112,000	0	0	0	112,000
		10935724	SER-0-C-PMO 11 Perf or Emissio	0	0	112,000	0	0	112,000
		10935732	SER-0-C-PMO 12 Perf or Emissio	0	0	0	112,000	0	112,000
		10936059	SER-0-C-MMR 11 Tools-Misc.	0	0	56,000	0	0	56,000
		11083919	SER-0-C-PMO 13 Perf or Emissio	0	0	0	0	112,000	112,000
		11083922	SER-0-C-CHM 13 Inst. for CO La	0	0	0	0	119,000	119,000
		11083925	SER-0-C-MMR 13 Tools-Misc.	0	0	0	0	56,000	56,000
	ES Corp PSCO			366,000	484,000	623,000	533,000	287,000	2,293,000
ES Corp PSCO				366,000	484,000	623,000	533,000	287,000	2,293,000

				2009	2010	2011	2012	2013	Sum:
ES Denver Steam Pla	ES Denver Steam Plant	10514051	TED - Welton Main 1600 Block	0	0	0	0	0	0
		10514060	TED - Wewatta Main	869,000	1,667,000	0	0	0	2,536,000
		10514063	DSP0C - Deaerator Replacement	379,000	0	0	0	0	379,000
		10543878	TED - Welton Main 1400 Block	0	944,000	0	0	0	944,000
		10543897	DSP0C - Replace Water Softener	0	0	0	0	275,000	275,000
		10543917	TED - Trillium Mains & Custo	60,000	0	0	0	0	60,000
		10543941	DSP0C - 2009 Mains and New Cus	897,000	0	0	0	0	897,000
		10543958	TED - Glenarm St. Main Replac	551,000	0	0	0	0	551,000
		10544197	DSP0C - Oil Storage Tank	0	0	0	0	246,000	246,000
		10544222	TED - Welton Main 1500 Block	0	0	0	0	0	0
		10544248	TED - 19th St. Main Reroute	0	0	0	0	0	0
		10544270	TED - 18th St. Main Reroute	0	0	0	0	0	0
		10642043	DSP0C - 2010 Mains and New Cus	0	897,000	0	0	0	897,000
		10786717	DSP0C - 2011 Mains and New Cus	0	0	1,841,000	2,517,000	3,389,000	7,747,000
	ES Denver Steam Plant			2,756,000	3,508,000	1,841,000	2,517,000	3,910,000	14,532,000
ES Denver Steam Pla				2,756,000	3,508,000	1,841,000	2,517,000	3,910,000	14,532,000

				2009	2010	2011	2012	2013	Sum:
ES Fort St Vrain Plant	ES Fort St Vrain Plant	10539327	FSV0C - Evaporation Pond Liner	0	0	130,021	0	0	130,021
		10539430	FSV4C - Unit 4 SCR Catalyst Re	0	0	700,830	0	0	700,830
		10539455	FSV1C - Steam Turbine Condense	2,557,285	0	0	0	0	2,557,285
		10539472	FSV1C - CWT Fan Power System	0	1,594,221	0	0	0	1,594,221
		10539525	FSV0C - Performance Fuel Gas H	0	523,136	0	0	0	523,136
		10539710	FSV2C - HRSG Water Preheater R	0	0	0	60,725	754,791	815,516
		10636025	FSV0C - Diesel Storage Tank Re	75,704	0	0	0	0	75,704
		10636037	FSV0C - Cold Reheat Balancing	0	0	0	0	414,632	414,632
		10636058	FSV2C - Unit 2 CT Mark V (Cont	1,123,304	0	0	0	0	1,123,304
		10636066	FSV3C - U3 HRSG Econ Replaceme	0	0	0	0	845,967	845,967
		10636071	FSV3C - U3 CT Mark V Controls	0	1,099,222	0	0	0	1,099,222
		10637408	FSV1C - Switchgear Breaker Rep	286,276	0	0	0	0	286,276
		10714970	FSV3C - U3 CT 1st Stage Bucket	0	5,588,800	0	0	0	5,588,800
		10912263	FSV2C - Unit 2 Trb Compartment	0	0	0	0	0	0
		10924103	FSV2C - Unit 2 Comb Turb 1st S	0	0	0	5,193,363	0	5,193,363
		10924104	FSV2C - Combustion Trb Replace	0	0	0	1,500,000	0	1,500,000
		10924106	FSV4C - Unit 4 CT Mark V (Cont	0	0	0	917,000	139,000	1,056,000
		10924311	FSV0C - Platte River Pump Elec	0	0	0	0	235,216	235,216
		10926261	FSV0C - HRSG Nitrogen Layup Sy	0	0	0	0	0	0
		10935164	FSV2C - Fuel Gas Heat Exchange	0	0	0	523,136	0	523,136
		10935168	FSV1C - Steam Turbine Replacem	0	0	0	6,002,045	7,436,474	13,438,519
		10956006	FSV0C - Heat Recovery Steam Ge	0	0	0	452,280	336,000	788,280
		11014518	FSV Additional CT Purchase	0	0	0	0	0	0

		11068553	FSV0C - Security Sys Chem Faci	71,896	0	0	0	0	71,896
		11068565	FSV3C - U3 HRSG Drain System	564,687	0	0	0	0	564,687
		11068587	FSV3C - U3 HRSG Exhaust Damper	0	573,110	0	0	0	573,11[illegible]
		11078935	FSV4C - HRSG Water Preheater R	0	0	0	0	910,017	910,[illegible]
		11078938	FSV1C - U1 GSU Transformer Rep	0	0	0	0	4,565,304	4,565,3[illegible]
		11078950	FSV4C - U4 Purchase CT Compone	0	0	0	0	1,049,178	1,049,178
		11078954	FSV1C - Dump and Drag Valve Re	0	0	0	0	102,000	102,000
		11080817	FSV0C - Chemical Inj Sys Cable	0	0	0	0	0	0
		11082527	FSV Unit 5 Expansion	7,325,746	0	0	0	0	7,325,746
		11082533	FSV Unit 6 Expansion	7,325,746	0	0	0	0	7,325,746
	ES Fort St Vrain Plant			**19,330,644**	**9,378,489**	**830,851**	**14,648,549**	**16,788,579**	**60,977,112**
ES Fort St Vrain Plant				**19,330,644**	**9,378,489**	**830,851**	**14,648,549**	**16,788,579**	**60,977,112**

				2009	2010	2011	2012	2013	Sum:
ES Gen Mgr Colorado	ES Gen Mgr Colorado	10018844	CO Co Misc. Capital Projects	4,637,000	5,156,000	1,675,000	1,675,000	0	13,143,000
	ES Gen Mgr Colorado			**4,637,000**	**5,156,000**	**1,675,000**	**1,675,000**	**0**	**13,143,000**
ES Gen Mgr Colorado				**4,637,000**	**5,156,000**	**1,675,000**	**1,675,000**	**0**	**13,143,000**

				2009	2010	2011	2012	2013	Sum:
ES Hydro Colorado	ES Ames Plant	10223788	AMH Ferc Relicensing	69,238	15,027	15,027	0	0	99,292
		10531584	AMH0C-Howards Fork Diversion D	0	0	0	0	117,000	117,000
		10637483	AMH0C-Powerhouse Bridge Crane	0	0	0	0	50,000	50,000
		10910818	AMH Station Batteries Rplcmt	0	20,000	0	0	0	20,000
		10924830	AMH-Replace B.N.Vibrate Monito	0	98,000	0	0	0	98,000
		10924838	AMH-Auxillary Transformer Rplc	70,000	0	0	0	0	70,000
		10925108	AMH-Rplc Howards Lk Surge Tank	0	200,000	0	0	0	200,000
		10925572	AMH-Ferc Lic Compliance PM E	0	0	100,000	100,000	0	200,000
		10929986	AMH- Trout Lk Valve House Valv	0	0	0	730,000	0	730,000
		10929987	AMH-Generator Disconnets and T	0	0	0	45,000	0	45,000
		11078127	AMH - Lake Fork Bypass Valve R	0	0	0	0	168,000	168,000
	ES Ames Plant			**139,238**	**333,027**	**115,027**	**875,000**	**335,000**	**1,797,292**
	ES Cabin Creek Plant	10361996	CCH Penstock Liner & Concrete	2,164,000	0	0	0	0	2,164,000
		10531425	CCH0C-Common Spherical Valve D	0	0	0	0	0	0
		10531431	CCH0C-Governor DC Pump System	0	0	0	0	0	0
		10531437	CCH0C-Draft Tubes & Seals B Rp	0	0	0	0	0	0
		10531445	CCH0C-Rplc.Quonset Bldg Crane	0	0	0	0	375,000	375,[illegible]
		10531451	CCH0C-FERC License Application	460,660	2,700,000	1,600,000	830,000	800,000	6,390,[illegible]
		10910821	CCH Station Battery Rplcmt	0	0	0	0	0	0
		10924400	CCH-Guanella Pass ROCK Wall Re	0	0	0	0	0	0
		10924867	CCH-Powerhouse HVAC system rpl	0	0	0	0	200,000	200,000
		10924880	CCH-Rplc A Liq Rheos Heat Exch	0	0	0	0	54,000	54,000
		10929989	CCH- Replace Station Air Compr	0	0	0	100,000	0	100,000
		10935201	CCH-Guanella Pass Rd-Elect Rel	0	0	0	0	0	0
		11060308	CCH - Capacity Upgrade 2015	0	0	0	0	0	0
		11078208	CCH -Rplc.Decompression #3 Air	0	0	0	0	175,000	175,000
	ES Cabin Creek Plant			**2,624,660**	**2,700,000**	**1,600,000**	**930,000**	**1,604,000**	**9,458,660**
	ES Georgetown Plant	10531469	GTH1C-Generator Rewind Unit 1	0	0	245,000	0	0	245,000
		10531528	GTH1C-Governor Control Unit 1	0	0	150,000	0	0	150,000
		10531532	GTH2C-Generator Rewind Unit 2	0	0	0	250,000	0	250,000
		10531537	GTH2C-Governor Control Unit 2	0	0	0	150,000	0	150,000
		10543014	GTH0C -Forebay Mud Valve Repla	0	0	0	0	464,000	464,000
		10637599	GTH0C-Replace Manual Building	0	0	0	78,000	0	78,000
		10910842	GTN -Station Battery Rplcmt	0	20,000	0	0	0	20,000
		10929994	GTN-Resurface Clr Lk Dam surfa	0	0	0	375,000	400,000	775,000
		11079975	GTN -Rplc.Mid.section of Pnstk	0	0	0	0	830,000	830,000
	ES Georgetown Plant			**0**	**20,000**	**395,000**	**853,000**	**1,694,000**	**2,962,000**
	ES Salida Plant	10514677	SAH0C-Remote Control PLC Replc	38,000	0	0	0	0	38,000
		10787457	SAH U1 Replace Penstock	32,000	32,000	32,000	32,000	32,000	160,000
		10908772	SA2 DAM Concrete Structural Rp	0	86,000	0	0	0	86,000
		10910932	SAH U1 Station Batteries Rplcm	0	0	0	0	20,000	20,000
		10910933	SAH U2 Station Batteries Rplcm	0	0	0	0	20,000	20,000
		10911047	SAH U1 Garfield Flowline Rplcm	0	0	0	210,000	0	210,000
		10924909	SAH U2 Penstock Replacement	32,000	32,000	32,000	32,000	32,000	160,000
		11079979	SAH U1-Gen.Protective Relay Rp	0	0	0	0	80,000	80,000
	ES Salida Plant			**102,000**	**150,000**	**64,000**	**274,000**	**184,000**	**774,000**
	ES Shoshone Plant	10531539	SSH0C-Emergency Spillway Repla	0	0	0	853,000	400,000	1,253,000
		10637516	SSH0C-Tainter Gates Replacemen	0	0	0	400,000	0	400,000
		10992398	SSH-Rebuild SSH Building CWIP	0	0	0	0	0	[illegible]
		11004406	SSH-SSH A&B Penstocks&Upstream	0	0	0	0	0	[illegible]
		11017955	SSH -Tools, Shop & Garage Equi	0	0	0	0	0	0
		11017966	SSH -Power & Office Equip.& F	0	0	0	0	0	0
	ES Shoshone Plant			**0**	**0**	**0**	**1,253,000**	**400,000**	**1,653,000**
	ES Tacoma Plant	10224143	TAH Ferc Relicensing	129,475	25,182	25,182	0	0	179,839
		10637529	TAH0C-Narrow Gauge RR Track Ca	0	50,000	0	0	0	50,000
		10924937	TAH- Rplc Animas River Retain	0	0	0	114,000	0	114,000

		10924938	TAH 1-Rplc Protective Relays	0	0	0	32,000	114,500	146,500
		10926343	TAH U2 Replace Protective Rela	0	0	0	32,000	114,500	146,500
		10929484	TAH-Cascade Diversion Dam Rplc	0	0	500,000	0	0	500,000
		10929487	TAH-FERC Lic Compliance PME	0	0	500,000	200,000	0	700,000
		10929489	TAH-Cascade Trash Rake Grizzly	0	0	150,000	0	0	150,000
		10930059	TAH-Rplc Cascade Flowline Griz	0	0	0	1,200,000	0	1,200,000
		11080497	TAH -Canyon Creek Diversion Rp	0	0	0	74,000	0	74,000
		11080502	TAH -Cascade FLOWLINE Liner Rp	0	0	0	800,000	800,000	1,600,000
		11080505	TAH -Cascade FLUME Rplcmt	0	0	0	3,300,000	0	3,300,000
		11080635	TAH -Housepower Transformers.R	0	0	0	45,000	0	45,000
		11080646	TAH -Plant Switchyard,Subst.Eq	0	0	0	200,000	0	200,000
		11080664	TAH -U1 Generator.Line Breaker	0	0	0	50,000	0	50,000
		11080673	TAH -U2 Generator.Line Breaker	0	0	0	50,000	0	50,000
		11080681	TAH -U3 Generator.Line Breaker	0	0	0	50,000	0	50,000
		11080719	TAH -U1.GSU Transformer Rplcmt	0	0	0	166,600	0	166,600
		11080726	TAH -U2 GSU Transformer Rplcmt	0	0	0	166,600	0	166,600
		11080730	TAH -U3 GSU Transformer Rplcmt	0	0	0	166,800	0	166,800
		11080731	TAH -Stagecoach Spillway Rplcm	0	0	0	640,000	0	640,000
	ES Tacoma Plant			**129,475**	**75,182**	**1,175,182**	**7,287,000**	**1,029,000**	**9,695,839**
ES Hydro Colorado				**2,995,373**	**3,278,209**	**3,349,209**	**11,472,000**	**5,246,000**	**26,340,791**

				2009	2010	2011	2012	2013	Sum:
ES Pawnee Plant	ES Pawnee Plant	10267973	PAW2C - Pawnee Unit #2	0	0	0	0	323,760,000	323,760,000
		10539415	PAW0C - Water Treatment Buildi	0	141,930	0	0	0	141,930
		10539757	PAW1C - Replace Boiler Feed Pu	90,591	0	0	0	0	90,591
		10539765	PAW1C - Replace Generator Volt	147,903	0	0	0	0	147,903
		10539775	PAW1C - Replace Main Turbine C	395,749	0	0	0	0	395,749
		10539800	PAW1C - Replace No.5 HP Feedwa	0	0	0	468,500	358,400	826,900
		10539838	PAW1C - Replace #7 HP Feedwate	0	0	0	469,000	358,400	827,400
		10539844	PAW1C - U1 Cooling Tower Deck/	793,337	0	0	0	0	793,337
		10539851	PAW1C - Replace Treated Water	0	0	0	0	509,075	509,075
		10539878	PAW1C - Stack Lighting Replace	0	0	0	0	96,925	96,925
		10542702	PAW1C - Maintenance Shop Addit	0	0	0	2,138,000	0	2,138,000
		10542908	PAW1C - U1 Coal Mill Gearbox	575,646	0	0	0	0	575,646
		10542914	PAW1C - Mercury Emissions Con	0	20,905	1,279,276	0	0	1,300,181
		10542918	PAW1C - U1 Condensate Polishin	0	0	399,840	1,840,160	0	2,240,000
		10542925	PAW1C - Pawnee Boiler Acoustic	0	7,175	261,350	0	0	268,525
		10542929	PAW1C - Pawnee Boiler Sectiona	0	0	0	213,800	0	213,800
		10542943	PAW0C - Pawnee Maintenance Loc	0	0	0	0	64,140	64,140
		10542956	PAW0C - Automate Coal Belt Wa	0	438,439	0	0	0	438,439
		10542962	PAW0C - Pawnee Coal Dozer Repl	0	0	0	0	1,145,464	1,145,464
		10623192	PAW0C - Reline 36" Storm Sewer	62,980	399,806	0	0	0	462,786
		10623195	PAW1C - Rep Furnace SH Div Wal	0	345,044	505,498	3,681,958	0	4,532,500
		10635377	PAW1C - Turbine Fire Protectio	0	0	0	0	492,647	492,647
		10635408	PAW0C - 2008 Capital Tools	0	0	0	0	0	0
		10635417	PAW0C - 2009 Capital Tools	50,000	0	0	0	0	50,000
		10635422	PAW0C - 2010 Capital Tools	0	25,000	0	0	0	25,000
		10635424	PAW0C - Hydrogen Gas Generator	0	0	0	0	116,378	116,378
		10635427	PAW1C - CEM Replacement	0	0	5,100	224,100	0	229,200
		10635435	PAW1C - U1 Coal Mill Gearbox	0	616,991	0	0	0	616,991
		10635675	PAW0C - #16 Belt Conv Cover Re	0	270,000	0	0	0	270,000
		10635715	PAW1C - Turbine 7th Stage Repl	0	0	0	392,000	102,000	494,000
		10635723	PAW1C - Primary Superheater Re	1,917,426	0	0	0	0	1,917,426
		10635732	PAW1C - Primary Air Fan Replac	0	0	0	1,474,090	224,000	1,698,090
		10637306	PAW1C - Coal Mill Gearbox	0	0	0	0	0	0
		10762128	PAW1C - PAH to CM PA Hdr Exp J	674,685	0	0	0	0	674,685
		10762133	PAW1C - Secondary AH to Blr Ex	728,434	0	0	0	0	728,434
		10783627	PAW1C - BART SO2 Controls	30,002	40,522,514	0	61,502,745	0	102,055,261
		10783634	PAW1C - BART NO2 Controls	0	0	4,544,226	2,856,602	0	7,400,828
		10783661	PAW0C - 2011 Capital Tools	0	0	51,000	0	0	51,000
		10783663	PAW1C - Coal Mill Gearbox	0	0	654,065	0	0	654,065
		10908413	PAW1C - HRA Division Wall Repl	1,113,000	0	0	0	0	1,113,000
		10913715	PAW1C - Primary Air Fan Rotor	0	35,630	756,126	0	0	791,756
		10924154	PAW0C - Rotary Dumper Componen	0	0	0	103,000	2,240,000	2,343,000
		10924158	PAW0C - 2012 Capital Tools	0	0	0	25,000	0	25,000
		10924160	PAW0C - Grove Crane Replacemen	0	0	0	500,320	0	500,320
		10924161	PAW0C - Lighting Coal Pile	0	0	0	300,088	0	300,088
		10924165	PAW0C - Replace Wet Pipe Fire	0	0	0	353,688	0	353,688
		10924166	PAW0C - Pawnee 834 Coal Dozer	0	0	0	1,145,464	0	1,145,464
		10924169	PAW0C - Conveyor Cover Replace	0	0	0	533,193	0	533,193
		10924172	PAW1C - Coal Mill Gearbox	0	0	0	669,279	0	669,279
		10935211	PAW0C - Yard Lighting Wiring R	0	0	0	1,096,100	0	1,096,100
		11068598	PAW1C - U1 Primary Air Fan Mot	190,491	0	0	0	0	190,491
		11068606	PAW1C - U1 CWT Fan Vibr Monito	0	98,618	0	0	0	98,618
		11068612	PAW0C - Planning/Stores Office	0	97,342	0	0	0	97,342

		11078125	PAW1C - U1 ID Fan Variable Spe	0	0	0	0	503,172	503,172
		11078402	PAW1C - Continuous Emissions P	0	0	0	0	329,069	329,069
		11078415	PAW1C - Coal Mill Gearbox	0	0	0	0	693,533	693,53[illegible]
		11078422	PAW1C - U1 Electro-Hydraulic U	0	0	0	0	24,818	24,[illegible]
		11078449	PAW1C - U1 Economizer/Pyrite A	0	0	0	0	72,929	72,92[illegible]
		11078454	PAW0C - Fly Ash Disposal Pit	0	0	0	0	2,999,799	2,999,799
		11078470	PAW1C - Unit 1 #6 HP Feedwater	0	0	0	0	51,500	51,500
		11078756	PAW0C - 2013 Capital Tools	0	0	0	0	25,000	25,000
		11078758	PAW1C - U1 Digital Control Sys	0	0	0	0	2,054,940	2,054,940
	ES Pawnee Plant			**6,770,244**	**43,019,394**	**8,456,481**	**79,987,087**	**336,222,189**	**474,455,395**
ES Pawnee Plant				**6,770,244**	**43,019,394**	**8,456,481**	**79,987,087**	**336,222,189**	**474,455,395**
				2009	2010	2011	2012	2013	Sum:
ES Peaking Colorado	ES Fruita Plant	10930186	FRU CT-Contols Replacement	0	0	0	311,000	0	311,000
		11079969	FRU -Rplc Obsolete Synch.on CT	0	0	0	86,000	0	86,000
	ES Fruita Plant			**0**	**0**	**0**	**397,000**	**0**	**397,000**
	ES Wind Ponnequin	10542818	PWF0C - Transformer Replacemen	82,387	0	0	0	0	82,387
		10542835	PWF0C-Blade Replacement	0	538,000	0	0	0	538,000
		10637541	PWF0C - Replace Blades	0	0	0	0	0	0
		10637549	PWF0C - Replace Gearboxes	0	0	0	0	0	0
		10637560	PWF0C - Wind Turbine Controls	420,466	279,748	0	0	0	700,214
		10683086	PWF0C - Ponnequin Vestas Gener	0	0	207,145	0	0	207,145
		10783507	PWF0C - PWF Meteorological Tow	0	0	179,645	0	0	179,645
		10923849	PWF0C - Security Equipment	0	0	164,200	0	0	164,200
		10923877	PWF0C - Communication System	0	0	0	213,586	0	213,586
		10923880	PWF0C - Replace Gearboxes	0	0	0	280,705	0	280,705
		11072673	PWF0C - Power and Control Cabl	0	0	0	0	421,120	421,120
		11072679	PWF0C - Generator/Gearbox Moni	0	0	0	0	331,520	331,520
	ES Wind Ponnequin			**502,853**	**817,748**	**550,990**	**494,291**	**752,640**	**3,118,522**
ES Peaking Colorado				**502,853**	**817,748**	**550,990**	**891,291**	**752,640**	**3,515,522**
				2009	2010	2011	2012	2013	Sum:
ES PSCo Craig	ES PSCo Craig	10643047	CRG0C - Yampa Capital 06	5,000,000	5,000,000	0	0	0	10,000,000
		10798867	CRG0C - Yampa Capital 2012	0	0	1,500,000	1,500,000	0	3,000,000
	ES PSCo Craig			**5,000,000**	**5,000,000**	**1,500,000**	**1,500,000**	**0**	**13,000,000**
ES PSCo Craig				**5,000,000**	**5,000,000**	**1,500,000**	**1,500,000**	**0**	**13,000,[illegible]**
				2009	2010	2011	2012	2013	Sum:
ES PSCo Hayden Pla	ES PSCo Hayden Plant	10513324	HASCC - Rail Coal Delivery Sys	5,956,000	8,999,000	11,308,000	0	0	26,263,000
		10513334	HAS1C - Feedwater Heater Level	0	0	0	0	0	0
		10513335	HAS2C - Feedwater Heater Level	0	0	68,000	0	0	68,000
		10523209	HAS1C - Replace Baghouse Bags	232,000	0	0	0	0	232,000
		10523211	HAS2C - Turbine HPIP Upgrade	0	0	0	0	0	0
		10523212	HAS2C - Reheater Replacement	0	0	0	0	0	0
		10523218	HAS2C - Station Battery Replac	0	0	41,000	0	0	41,000
		10523221	HASCC - New D9 Bulldozer	0	0	0	0	0	0
		10523224	HAS1C - Retube Condenser	0	0	25,000	655,000	0	680,000
		10523228	HAS1C - Replace Station Batter	64,000	0	0	0	0	64,000
		10523229	HAS1C - Turbine Overhaul Compo	0	0	0	238,000	0	238,000
		10523230	HAS1C - Bottom Ash System Comp	0	0	0	0	0	0
		10523231	HAS1C - Turbine Bearing Temp M	76,000	0	0	0	0	76,000
		10636179	HAS1C - Air Inleakage Monitor	0	0	0	0	0	0
		10636184	HASCC - Control Room HVAC Syst	0	0	0	501,000	0	501,000
		10636193	HASCC - LP Ash Water Pump	0	0	0	0	0	0
		10636200	HAS2C - Cooling Tower Transfor	0	0	84,000	0	0	84,000
		10636212	HAS2C - Generator Retaining Ri	0	0	187,000	0	0	187,000
		10636215	HAS2C - LG/2H Transformer	0	0	0	0	0	0
		10636219	HASCC - New Scraper	0	0	0	425,000	0	425,000
		10636222	HASCC - New Road Grader	0	0	446,000	0	0	446,000
		10636224	HASCC - New Tools/Vehicles	0	0	0	0	27,000	27,000
		10636233	HASCC - Tripper Deck Automatio	0	0	0	0	0	0
		10636830	HAS2C - Air Inleakage Monitor	0	0	0	0	0	0
		10791757	HAS2C - Replace Baghouse Bags	116,000	116,000	0	0	0	232,000
		10791768	HASCC - Process Pond	21,000	0	0	0	0	21,000
		10791779	HAS2C - Replace turbine blades	0	0	0	0	0	0
		10798242	HAS2C - BART NOx Controls	0	0	0	0	187,000	187,000
		10798245	HAS1C -Fire System Turbine Lub	0	0	0	0	173,000	173,000
		10798246	HAS2C -Fire System Turbine lub	0	0	0	0	86,000	86[illegible]
		10798247	HAS2C -New Bottom ash system	0	0	63,000	0	0	63,[illegible]
		10798248	HASCC -New Elevator Controls A	0	109,000	0	0	0	109,000
		10798249	HASCC -New ash haul road	0	0	0	0	0	0
		10798250	HAS1C -Replace Economizer	0	0	23,000	1,135,000	0	1,158,000
		10798251	HAS1C -Replace CEMS	0	0	38,000	278,000	0	316,000
		10798252	HAS1C -Replace COM	0	0	23,000	116,000	0	139,000
		10798253	HAS1C -New Cooling Tower Compo	0	0	172,000	149,000	149,000	470,000

		10798254	HAS2C -New Cooling Tower Compo	0	0	85,000	74,000	74,000	233,000
		10798255	HAS1C -Generator Rewind	0	0	23,000	904,000	0	927,000
		10798256	HAS2C -New Elevator Controls	0	0	84,000	0	0	84,000
		10798257	HAS1C -New BART NOx Controls	0	0	377,000	3,171,000	0	3,548,000
		10931967	HASCC - Small Tools	0	0	0	0	0	0
		10931968	HASCC - Small Tools	0	0	30,000	0	0	30,000
		10931969	HASCC - Small Tools	0	0	0	0	0	0
		10931971	HASCC - Small Tools	0	0	0	27,000	0	27,000
		10931994	HAS1C - Current Transformer	227,000	0	0	0	0	227,000
		10931999	HAS1C -New Coal Feeder System	0	655,000	0	0	0	655,000
		10932007	HAS1C -New Condensor Vacuum pu	0	0	270,000	0	0	270,000
		10932010	HASCC - New D9 Caterpillar Doz	0	0	0	380,000	0	380,000
		10932012	HASCC - New Rubber Tire Dozer	0	0	0	714,000	0	714,000
		11043458	HASCC-DCS Test Compiler	0	0	0	0	0	0
		11052291	HAS2C-Expansion Joints	0	0	0	0	0	0
		11052292	HAS1C-Schweitzer Relays	60,000	0	0	0	0	60,000
		11052293	HAS2C-Schweitzer Relays	0	0	30,000	0	0	30,000
		11052294	HAS2C-Circ Water Valve	0	0	0	0	0	0
		11052295	HASCC-Vibration Monitor	0	0	0	0	0	0
		11052296	HAS2C-Station Batteries	0	0	0	0	0	0
		11052298	HASCC-Surface Grinder	0	23,000	0	0	0	23,000
		11078107	HAS1C - Turbine to DCS Interfa	227,000	0	0	0	0	227,000
		11078122	HASCC - High Lift	23,000	0	0	0	0	23,000
		11078133	HASCC-Fuel Pipe Replacement	0	122,000	0	0	0	122,000
		11078141	HAS2C-Replace 2G/2H Transforme	0	68,000	0	0	0	68,000
		11078153	HAS2C-Replace Furnace Reheater	0	0	0	0	193,000	193,000
		11078155	HAS2C-Replace CEMS	0	0	0	0	19,000	19,000
		11078157	HAS2C-Replace COM	0	0	0	0	11,000	11,000
		11078158	HASCC-Replace Station paging s	0	0	0	0	433,000	433,000
		11078161	HAS2C-Mercury Emission Control	0	0	0	0	963,000	963,000
		11078163	HAS1C-DCS/SOE	0	0	0	0	10,000	10,000
		11078389	HAS2C-Turbine HP/IP/LP Upgrade	0	0	0	0	2,099,000	2,099,000
		11078394	HASCC - Roof Replace Coal Hand	0	0	0	0	119,000	119,000
	ES PSCo Hayden Plant			7,002,000	10,092,000	13,377,000	8,767,000	4,543,000	43,781,000
ES PSCo Hayden Pla				7,002,000	10,092,000	13,377,000	8,767,000	4,543,000	43,781,000

				2009	2010	2011	2012	2013	Sum:
ES Valmont Plant	ES Valmont Plant	10362021	VAL04006 Ash disposal Cell Con	378,000	229,000	391,000	307,000	316,000	1,621,000
		10513271	VAL5C -REPLACE 4160V Breakers	0	0	398,000	464,000	0	862,000
		10513283	VAL5C - REPLACE AUX BOILER	0	0	0	0	410,000	410,000
		10522028	VAL0C Replace Dam Rip Rap	257,000	0	0	0	0	257,000
		10522042	VAL0C Valmont 480V Breaker Rep	16,000	506,000	0	0	0	522,000
		10522044	VAL0C Leggett Inlet Diversion	699,000	0	0	0	0	699,000
		10522048	VAL0C Old Side Stack Demoliti	0	0	0	0	578,000	578,000
		10522051	VAL0C Replace Turbine Deck Ro	295,000	0	0	0	0	295,000
		10522055	VAL0C ID Fan Drive Replacemen	0	0	222,000	315,000	0	537,000
		10634809	VAL5C Repl Boiler Igniters&Bur	0	0	268,000	1,225,000	0	1,493,000
		10634812	VAL5C Turb RHT Valves & Main S	0	482,000	0	0	0	482,000
		10643444	VAL0C Leggett Outlet Cooling	0	0	0	0	3,190,000	3,190,000
		10643446	VAL5CAbate Boiler Lower Dead A	0	933,000	0	0	0	933,000
		10799150	VAL5C - Economizer Replacement	1,708,000	1,424,000	0	0	0	3,132,000
		10799202	VAL5C - 316B Inlet Modificatio	401,000	0	0	0	0	401,000
		10799290	VAL5C -Replace Boiler Controls	0	0	276,000	986,000	0	1,262,000
		10799338	VAL5C- Replace 1/2 baghouse ba	0	0	751,000	0	0	751,000
		10799342	VAL5C-Replace Baghse Hopper Va	0	0	80,000	0	0	80,000
		10799348	VAL0C - Replace Old Side Roof	0	0	326,000	0	0	326,000
		10799358	VAL5C Turbine Lube Oil Fire Sp	0	189,000	0	0	0	189,000
		10799569	VAL5C Replace WHSE HVAC System	0	0	250,000	0	0	250,000
		10918781	VAL5C - BART NOx Controls	0	0	1,020,000	2,856,000	0	3,876,000
		10926403	VAL5C- Replace 1/2 baghouse b	0	0	0	751,000	0	751,000
		10926441	VAL5C - Replace Deluge Valves	0	0	0	250,000	0	250,000
		10929024	VAL5C - REPL CONTROLS WDPF	0	0	0	0	0	0
		10930969	VAL5C-Generator Core Cond Moni	0	90,000	0	0	0	90,000
		10932514	VAL5C -Scrubber Inlet SO2 Anal	0	139,000	0	0	0	139,000
		11053786	VAL5C -VAL New Reverse Power	0	0	0	0	0	0
		11054175	VAL5C - Leggett Outlet Temp Mo	0	167,000	0	0	0	167,000
		11054325	VAL5C - RPL Main Transformer	0	0	0	0	206,000	206,000
		11054603	VAL5C -Repl Horizontal Superhe	0	0	0	0	360,000	360,000
		11054610	VAL5C - Repl Turbine EHC Syste	0	0	0	0	195,000	195,000
		11065811	VAL0C - Railroad Track Replace	0	0	0	0	214,000	214,000
		11065820	VAL5C -Rpl Boiler Feedpump Mot	0	0	0	0	177,000	177,000
		11069431	VAL5C - Generator H2 Cooler Re	0	605,000	0	0	0	605,000
		11069435	VAL5C - Generator H2 Seal Repl	0	1,001,000	0	0	0	1,001,000
		11069436	VAL5C-Duct Expansion Joint Rep	0	187,000	0	0	0	187,000
		11069483	VAL5C Repl Turbine Bldg Swamp	0	0	165,000	0	0	165,000

		11069489	VAL5C Coal Yard Office & Lckr	0	0	0	143,000	0	143,000
	ES Valmont Plant			**3,754,000**	**5,952,000**	**4,147,000**	**7,297,000**	**5,646,000**	**26,796,000**
ES Valmont Plant				**3,754,000**	**5,952,000**	**4,147,000**	**7,297,000**	**5,646,000**	**26,796,000**

				2009	2010	2011	2012	2013	Sum:
ES Zuni Plant	ES Zuni Plant	10513960	ZUN1C - Unit 1 Turbine Vibrati	0	0	0	0	0	**0**
		10513967	ZUN2C - Unit 2 Turbine Vib Sys	88,000	0	0	0	0	**88,000**
		10513989	ZUN0C - All Asbestos Abatemen	238,000	0	0	0	0	**238,000**
		10641923	ZUN 2008 Install Cathod Protec	145,000	0	0	0	0	**145,000**
		10643618	ZUNC-Install security system	0	0	140,000	0	0	**140,000**
		10915844	ZUN2-Rep Station Backup Batter	0	0	45,000	0	0	**45,000**
		10931401	ZUN0511-Replace Zuni Safety Va	0	0	0	0	0	**0**
		10931407	ZUN0311 Rep Zuni 1B Boiler Tub	0	0	0	0	0	**0**
		10931414	ZUN0509 Rep Station Air Comp	62,000	0	0	0	0	**62,000**
		10931416	Zun0509 Capital Tools	0	0	0	0	0	**0**
		11060299	2009 Zuni Plant Retirement	0	0	0	0	0	**0**
		11064788	2009 Zuni Plant Retirement	363,868	3,638,685	1,091,605	24,379,186	5,458,027	**34,931,371**
	ES Zuni Plant			**896,868**	**3,638,685**	**1,276,605**	**24,379,186**	**5,458,027**	**35,649,371**
ES Zuni Plant				**896,868**	**3,638,685**	**1,276,605**	**24,379,186**	**5,458,027**	**35,649,371**
			Sum:	**146,666,515**	**156,115,439**	**300,205,792**	**449,150,545**	**440,062,185**	**###########**

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)))))	**Fifth Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 28, 2008**

DISCOVERY REQUEST LWG5-8:

Please provide all analyses done of incorporating more renewable and efficiency resources above the High 123 scenario including their potential benefits to act as a hedge against increase costs of natural gas and coal.

RESPONSE:

The Company has not evaluated resource plans containing renewable and DSM resources in excess of those contained in the 2007 CRP.

Sponsor: Jim Hill

Response Date: April 18, 2008

Attachment 48
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Fifth Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 28, 2008**

DISCOVERY REQUEST LWG5-11:

Please provide all analyses of constraints in future coal supply as a result of increasing overburden and other geologic and surface constraints in the Powder River Basin.

RESPONSE:

No such analysis conducted by PSCo exists.

Sponsor: Kathryn Valdez

Response Date: April 18, 2008

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Fifth Set of Discovery Requests Of Ms. Glustrom Served On Public Service Company**
Docket No. 07A-447E	)	**March 28, 2008**

DISCOVERY REQUEST LWG5-12:

Please provide all analyses of future limitations on the supply of coal from Colorado mines due to geologic or surface constraints.

RESPONSE:

No such analysis conducted by PSCo exists.

Sponsor: Kathryn Valdez

Response Date: April 18, 2008

ttachment 50
ocket 07A-447E
lustrom Answer Testimony

Re: In The Matter of the Application of
Public Service Company of Colorado
For Approval of its 2007 Colorado
Resource Plan

Docket No. 07A-447E

Fifth Set of Discovery Requests
Of WRA
Served On Public Service Company

March 26, 2008

DISCOVERY REQUEST WRA5-1:

For every fossil fuel plant currently owned by PSCo or serving the current PSCo load requirement:

a. Please describe the cooling type(s) utilized and whether any modifications of same are proposed by 2020.
b. Please describe the water requirements (both diversions and consumption) in terms of daily, monthly, and annual volumes (in gallons or acre-feet).
c. Please explain the seniority of the associated water rights.
d. Please name the surface and/or groundwater source(s) for these rights.
e. Have water deliveries have ever been suspended or terminated during commercial operation of the relevant power plant? If so, please explain.
f. Has PSCo undertaken or does it otherwise utilize any forecasts of expected water delivery under one or more contingencies including, but not limited to, extreme drought conditions?

RESPONSE:

a. Wet cooling towers: Arapahoe, Cherokee, Comanche, Hayden, Pawnee;
Once through cooling: Cameo (utilizing Government Highline Canal), Valmont (utilizing the Valmont reservoir complex)

No changes, except parallel cooling system for Comanche 3, which comes on line in 2009.

RESPONSE TO DISCOVERY REQUEST WRA5-1 continued:

b. Annual Volumes Consumption – see answer to LWG3-4; daily and monthly divide annual numbers by 365 and 12, respectively.

Annual diversions:

Arapahoe	1,822 AF
Cameo	39,100 AF
Cherokee	9,716 AF
Comanche	9,228 AF
FSV	3,875 AF
Hayden	5,007 AF
Pawnee	6,622 AF
Valmont	water diversions from raw water reservoir are not tracked
Zuni	774 AF

Daily and monthly divide by 365 and 12 , respectively.

c. Plants are served by by both firm contract water from various water providers and a number of owned water supplies. The owned water supplies have a wide variety of seniorities, but the overall portfolio of water rights provide a reliable and firm water supply for all plants.
d. See answer to LWG3-4.
e. No. Plant generation has never been curtailed die to lack of raw water supply.
f. See answer to LP3-10.

Sponsor: Don Halffield **Response Date:** April 24, 2008

Attachment 51
Docket 07A-447E
Glustrom Answer Testimony

Re: In The Matter of the Application of Public Service Company of Colorado For Approval of its 2007 Colorado Resource Plan	)	**Sixth Set of Discovery Requests Of the CPUC Staff – Ron Davis Served On Public Service Company**
Docket No. 07A-447E	)	**December 20, 2007**

DISCOVERY REQUEST CPUC6-18:

Please explain the basis for the assumption in the base forecast that extremely hot summer weather will not continue in the future. (Page 1, Lines 15-16; Exhibit KTH-1, Vol. 1, Page 1-19)

RESPONSE:

According to the National Weather Service, four years out of the last 10 – 2000, 2001, 2003, and 2005 – are among the 10 warmest July's in Denver in the 135 years that weather data has been collected here. 2005 was the second warmest. The average temperature for the month of July was more than 3 degrees higher than normal in each of these years. Three years from the 1930's – 1934, 1936, and 1939 – were all hotter than any other years in Denver history with the exception of 2005. 1934 was the warmest ever. After the 1930's, temperatures in Denver reverted to more normal levels. We expect the same return to normal temperature levels to occur during the forecast period.

Sponsor: Jannell Marks

Response Date: January 3, 2008

Attachment 52
Docket 07A-447E
Glustrom Answer Testimony

final report

National Rail Freight Infrastructure Capacity and Investment Study

prepared for

Association of American Railroads

prepared by

Cambridge Systematics, Inc.
100 Cambridge Park Drive, Suite 400
Cambridge, Massachusetts 02140

date

September 2007

Table of Contents

Executive Summary

This study is an assessment of the long-term capacity expansion needs of the continental U.S. freight railroads. It provides a first approximation of the rail freight infrastructure improvements and investments needed to meet the U.S. Department of Transportation's (U.S. DOT) projected demand for rail freight transportation in 2035. The U.S. DOT estimates that the demand for rail freight transportation – measured in tonnage – will increase 88 percent by 2035.

The study was commissioned by the Association of American Railroads (AAR) at the request of the National Surface Transportation Policy and Revenue Study Commission. The Commission is charged by Congress to develop a plan of improvements to the nation's surface transportation systems that will meet the needs of the United States for the 21st century.

The study focuses on 52,340 miles of primary rail freight corridors, which carry the preponderance of rail freight traffic.[1] These corridors, which constitute about one-third of all continental U.S. rail freight miles, are expected to absorb the bulk of the forecast traffic and nearly all of the investment to expand capacity.

The study estimates the need for new tracks, signals, bridges, tunnels, terminals, and service facilities in the primary corridors. The study does not estimate the cost of acquiring additional land, locomotives, and freight cars, or the cost of replacing and updating existing track, facilities, locomotives, and freight cars. The study assumes no shift in modal tonnage shares among rail, truck, and water beyond those projected by the U.S. DOT.

The study does not forecast passenger rail demand or estimate future passenger rail capacity needs; however, capacity is provided for the long-distance Amtrak and local commuter passenger rail services that are currently operated over rail freight lines. Additional investment, beyond that projected in this report, will be needed if the freight railroads host increased levels of passenger rail service. The Commission has convened a passenger rail committee that is studying the need for improvements and investments to support passenger rail demand through 2035. The findings of that committee will be reported separately.

This study estimates that an investment of $148 billion (in 2007 dollars) for infrastructure expansion over the next 28 years is required to keep pace with economic growth and meet the U.S. DOT's forecast demand. Of this amount, the Class I freight railroads' share is projected to be $135 billion and the short line

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[1] Nearly all of these primary corridor miles are owned and operated by the seven Class I freight railroads: BNSF Railway, Canadian National (Grand Trunk Corporation), Canadian Pacific (Soo Line), CSX Transportation, Kansas City Southern, Norfolk Southern, and Union Pacific. There are more than 550 short line and regional freight railroads.

4.4 CURRENT VOLUMES COMPARED TO CURRENT CAPACITY

Current corridor volumes were compared to current corridor capacity to assess congestion levels. This was done by calculating a volume-to-capacity ratio expressed as a level of service (LOS) grade. The LOS grades are listed in Table 4.3.

Table 4.3 Volume-to-Capacity Ratios and Level of Service (LOS) Grades

	LOS Grade	Description		Volume/Capacity Ratio
▨	A	Below Capacity	Low to moderate train flows with capacity to accommodate maintenance and recover from incidents	0.0 to 0.2
▨	B			0.2 to 0.4
▨	C			0.4 to 0.7
░	D	Near Capacity	Heavy train flow with moderate capacity to accommodate maintenance and recover from incidents	0.7 to 0.8
▓	E	At Capacity	Very heavy train flow with very limited capacity to accommodate maintenance and recover from incidents	0.8 to 1.0
█	F	Above Capacity	Unstable flows; service breakdown conditions	> 1.00

Source: Cambridge Systematics, Inc.

Rail corridors operating at LOS A, B, or C are operating below capacity; they carry train flows with sufficient unused capacity to accommodate maintenance work and recover quickly from incidents such as weather delays, equipment failures, and minor accidents. Corridors operating at LOS D are operating near capacity; they carry heavy train flows with only moderate capacity to accommodate maintenance and recover from incidents. Corridors operating at LOS E are operating at capacity; they carry very heavy train flows and have very limited capacity to accommodate maintenance and recover from incidents without substantial service delays. Corridors operating at LOS F are operating above capacity; train flows are unstable, and congestion and service delays are persistent and substantial. The LOS grades and descriptions correspond generally to the LOS grades used in highway system capacity and investment requirements studies.

A rail corridor that is operating at a volume-to-capacity ratio of 0.7 (the boundary between LOS C and LOS D), is operating at 70 percent of its theoretical maximum capacity. This is considered to be the corridor's practical capacity because a portion of the theoretical maximum capacity is lost to maintenance, weather delays, equipment failures, and other factors. A corridor operating at LOS C will have stable train flows, ensuring that schedules can be met reliably and safely, and permitting timely recovery from service disruptions. At LOS D, a corridor will have stable operations under normal conditions, but service can quickly become unstable with unplanned and unanticipated disruptions. At volume-to-capacity ratios significantly greater than 0.8 (e.g., at LOS E or F), train flow rates and schedule reliability deteriorate and it takes longer and longer to recover from disruptions. To provide acceptable and competitive service to shippers and receivers, railroads typically aim to operate rail corridors at LOS C/D or better.

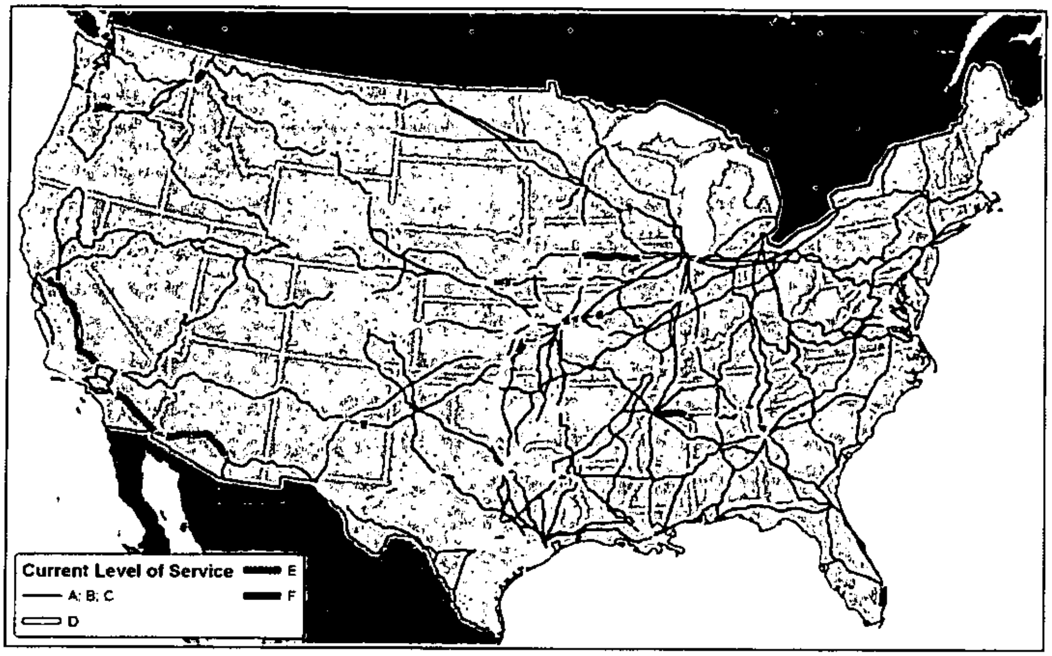
Figure 4.4 maps the volume-to-capacity ratios, expressed as LOS grades, for each primary rail corridor, based on current train volumes and current capacity.[16] For legibility, rail corridors operating at LOS A, B and C (below practical capacity) have been mapped in green. Corridors operating at LOS D (near practical capacity) have been mapped in yellow, and corridors operating at LOS E (at practical capacity) have been mapped in orange. Rail corridors operating at LOS F (above capacity) have been mapped in red.

Analysis of the current levels of service, summarized in Table 4.4, shows that 88 percent of today's primary corridor mileage is operating below practical capacity (LOS A/B/C), 12 percent is near or at practical capacity (LOS D/E), and less than 1 percent is operating above capacity (LOS F).

---

[16] Current volumes are based primarily on shipment volumes reported in the 2005 STB Carload Waybill Sample. These volumes do not reflect fully recent increases in coal shipments moving from Western coal fields (e.g., Powder River Basin) to Eastern utilities nor the recent increases in intermodal containers delivered by water to East Coast ports and transferred to rail for inland delivery. Current capacity is based on 2007 information.

Figure 4.4 Current Train Volumes Compared to Current Train Capacity



Source: Cambridge Systematics, Inc.

Note: Volumes are for the 85th percentile day.

Table 4.4 Primary Rail Corridor Mileage by Current Level of Service Grade

Current Volumes and Current Capacity

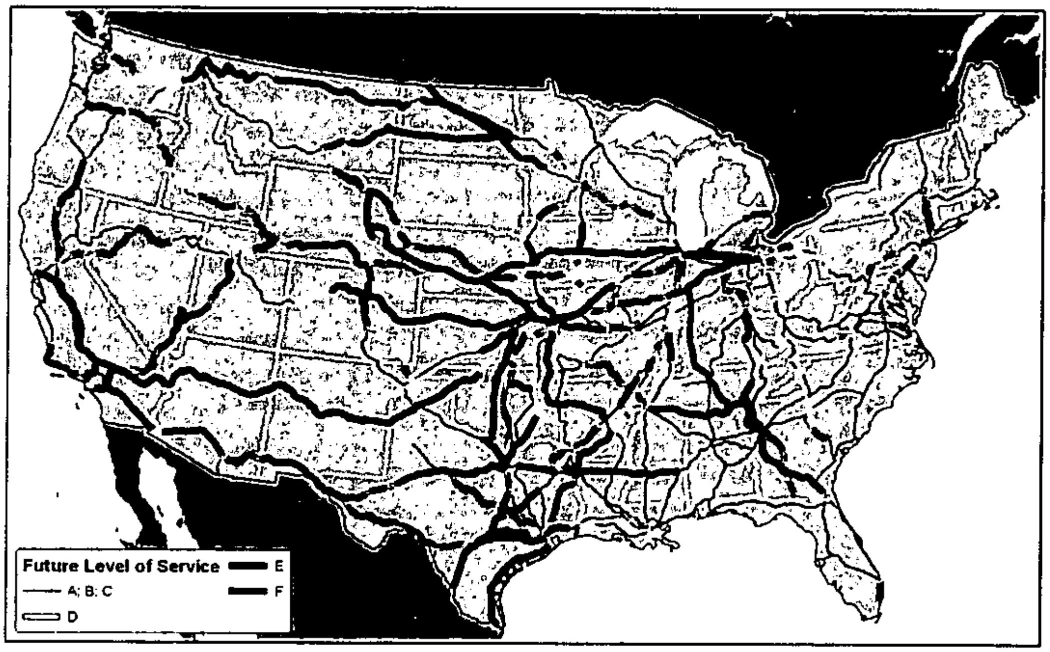
	LOS Grade	Total Mileage	Percentage
■	A	9,719	19%
	B	15,417	30%
	C	20,683	39%
□	D	4,952	9%
□	E	1,461	3%
■	F	108	<1%
	Totals	52,340	100%

Source: Cambridge Systematics, Inc.

5.2 FUTURE VOLUMES COMPARED TO CURRENT CAPACITY

Future volumes were compared to current capacity to estimate future volume-to-capacity ratios. This information was used to determine where demand will exceed capacity and where improvements will be required to avoid congestion. Figure 5.4 compares 2035 volumes in trains per day to current corridor capacity. The volume-to-capacity ratios are expressed as LOS grades for each primary rail corridor. Again, for legibility, rail corridors operating at LOS A, B, and C (below practical capacity) have been mapped in green. Corridors operating at LOS D (near practical capacity) have been mapped in yellow, and corridors operating at LOS E (at practical capacity) have been mapped in orange. Rail corridors operating at LOS F (above capacity) have been mapped in red.

Figure 5.4 Future Corridor Volumes Compared to Current Corridor Capacity
2035 without Improvements



Source: Cambridge Systematics, Inc.

Note: Volumes are for the 85th percentile day.

Analysis of the 2035 levels of service, summarized in Table 5.1, shows that—without improvements—45 percent of primary corridor mileage will be operating below capacity (LOS A/B/C), 25 percent will be operating near or at capacity (LOS D/E), and 30 percent will be operating above capacity (LOS F). The resulting level of congestion would affect nearly every region of the country and would likely shut down the national rail network.

Table 5.1 Primary Rail Corridor Mileage by Future Level of Service Grade
2035 without Improvements

	LOS Grade	Total Mileage	Percentage
▨	A	4,895	9%
	B	6,626	13%
	C	11,708	23%
	D	5,353	10%
■	E	7,980	15%
■	F	15,778	30%
	Totals	52,340	100%

Source: Cambridge Systematics, Inc.

ttachment 53
ocket 07A-447E
lustrom Answer Testimony

Re: The Investigation and)
Suspension of Tariff Sheets Filed by)
Public Service Company of Colorado)
With Advice Letter No. 1454 - Electric)
Docket No. 06S-234EG)

Second Set of Discovery Requests
Of the RUC Staff -
Served On Public Service Company

July 14, 2006

DISCOVERY REQUEST NO. RUC2-10(a):

With respect to Mr. Imbler's Direct Testimony, page 8, line 20 through page 9 line 13, please provide the following:

a. The name and size of each coal plant that was or is being affected by the problems with the rail delivery of coal;

RESPONSE:

Arapahoe, 156 MW
Cherokee, 715 MW
Comanche, 660 MW
Pawnee, 505 MW
Valmont, 186 MW

Sponsor: Pat Panzarino

Response Date: July 27, 2006

Re: The Investigation and Suspension of Tariff Sheets Filed by Public Service Company of Colorado With Advice Letter No. 1454 – Electric Docket No. 06S-234EG	)))))	**Second Set of Discovery Requests Of the RUC Staff - Served On Public Service Company July 14, 2006**

DISCOVERY REQUEST NO. RUC2-10(b):

With respect to Mr. Imbler's Direct Testimony, page 8, line 20 through page 9 line 13, please provide the following:

b. For each coal plant, the period of time that it was affected by the coal delivery problems, the amount of coal that was not delivered to the plant as expected, the percentage of that plant's annual usage, the number of megawatt hours (MWh) lost due to the coal delivery problems and the cost of the replacement fuel or power that was used to make up for the lost MWh;

RESPONSE:

See Attachment RUC2-10b. The MWh's that could not be generated by base load coal fired generation due to coal delivery problems were replaced with purchased power and the consumption of alternative fuels in order to conserve coal inventories. The number of MWh's replaced in 2005 was 728,806, and 204,804 in YTD 2006. The cost of replacement fuels and power was $37.3 million in 2005 and $11.6 million YTD 2006. Costs attributable to replacement coal and power were allocated to Comanche, Pawnee, Cherokee, Arapahoe and Valmont in 2005 and Comanche and Pawnee in 2006.

Sponsor: Pat Panzarino **Response Date:** July 27, 2006

ttachment 54
ocket 07A-447E
lustrom Answer Testimony

Subcontract Report
NREL/SR-550-39291
April 2006

Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California

May 2005 – April 2006

L. Stoddard, J. Abiecunas, and R. O'Connell
Black & Veatch
Overland Park, Kansas

NREL Technical Monitor: M. Mehos
Prepared under Subcontract No. AEK-5-55036-01

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This publication received minimal editorial review at NREL

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

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Executive Summary

This study provides a summary assessment of concentrating solar power (CSP) and its potential economic return, energy supply impact, and environmental benefits for the State of California. Emphasis was placed on in-state economic impact in terms of direct and indirect employment created by the manufacture, installation, and operation of CSP plants. The environmental impact of CSP relative to natural gas fueled counterparts was studied. The value of CSP as a hedge against natural gas price increases and volatility was also analyzed.

Black & Veatch chose a 100 MW parabolic trough plant with 6 hours of storage as the representative CSP plant to focus the results of the study. Cumulative deployment scenarios of 2,100 MW and 4,000 MW between 2008 and 2020 were assumed. Based on estimates provided by the National Renewable Energy Laboratory (NREL), future CSP technology improvements were incorporated into the study by assuming that 150 MW and 200 MW plants would be constructed starting in 2011 and 2015, respectively. The NREL estimates include reduced installed costs over time as a result of technology learning and increased construction efficiency. The levelized cost of electric production was calculated for each CSP plant.

There are indications that recently bid trough plants may have somewhat lower capital costs than those used in this report; however, these data are not publicly available. Overall, while lower capital costs can somewhat lower the economic impact in California, the decrease is not expected to significantly change the conclusions of this report.

Currently (and for the foreseeable future), natural gas fueled combustion turbine based power plants are the most frequent choice for new power plants in California. As suggested in Table ES-1, the utility electric supply needs served by simple cycle and combined cycle plants tend to be those that might be served by CSP with storage. Thus, these two gas technologies are identified as conventional technology benchmarks for comparison of CSP competitiveness and economic impacts.

Table ES-1
Power Plant Characteristics

	Typical Size	Typical Duty	Capacity Factor
Simple Cycle	85 MW	Peaking	10 percent
Combined Cycle	500 MW	Intermediate	40 percent
CSP with 6 Hours Storage	100 to 200 MW	Intermediate or Peaking	40 percent

A comparison of the levelized cost of energy (LCOE) revealed that the LCOE of $148 per MWh for the first CSP plants installed in 2009 is competitive with the simple cycle combustion turbine at an LCOE of $168 per MWh, assuming that the temporary 30 percent Investment Tax Credit is extended. The LCOE for the CSP plant is higher than the $104 per MWh LCOE of the combined cycle combustion turbine plant.[1]

The economic impacts of CSP construction and operation were estimated with standard economic tools. Black & Veatch used the Regional Input-Output Modeling System (RIMS II) developed and maintained by the US Bureau of Economic Analysis. This analysis revealed that each 100 MW of CSP results in 94 permanent operations and maintenance jobs compared to 56 and 13 for combined cycle and simple cycle combustion turbine plants, respectively. In terms of economic return, for each 100 MW of installed capacity, the CSP plant was estimated to create about $628 million in impact to gross state output compared to an impact of about $64 million for the combined cycle plant and $47 million for the simple cycle plant. The higher CSP state economic impacts are due, in part, to the greater capital and operating costs of CSP plants. However, irrespective of plant cost, it should be noted that a greater percentage of each CSP investment dollar is returned to California in economic benefits. For each dollar spent on the installation of CSP plants, there is a total impact (direct plus indirect impacts) of about $1.40 to gross state output for each dollar invested compared to roughly $0.90 to $1.00 for each dollar invested in natural gas fueled generation.

For plants installed in the latter stages of the deployment scenarios, CSP cost reductions become evident and the solar technology becomes a potentially competitive choice for both peaking and intermediate duty cycles. As shown in Table ES-2, CSP plants installed in 2015 are projected to exhibit a delivered LCOE of $115/MWh,[2] compared with $168/MWh for the simple cycle combustion turbine and $104/MWh for combined cycle plants. At a natural gas price of about $8 per MMBtu, the LCOE of CSP and the combined cycle plants at 40 percent capacity factor are equal.[3] Note that this analysis does not assume improvements to combustion turbine power generation technology, which were outside the scope of this study. However, assuming that improvements to combustion turbine power generation efficiency and cost are likely to be modest, the LCOE of CSP in 2015 is likely to be competitive with combustion turbine power generation technologies.

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[1] These prices use the California Market Price Referent (MPR) gas price forecast, which is equivalent to $6.40/MMBtu escalated at 2.5 percent annually. All dollars are $2005.

[2] With the permanent 10 percent ITC. With the 30 percent ITC, the cost drops to $103/MWh.

[3] The MPR gas forecast for 2015 is $8/MMBtu. Futures prices on NYMEX were well above $10/MMBtu for the last four months of 2005, and are down to roughly $7.50/MMBtu as of April 1, 2006.

Table ES-2
Delivered Levelized Energy Cost and Economic Impacts for CSP and Gas Technologies in 2015 ($2005)

	Delivered Energy Cost	Permanent Jobs, per 100 MW	GSP, $million per 100 MW
Simple Cycle*	$187/MWh	13	$47
Combined Cycle*	$119/MWh	56	$64
CSP with 6 Hours Storage**	$115/MWh	94	$628

*The 2015 MPR natural gas price of $8.00 per MMBtu escalating at 2.5 percent annually was used.
**CSP assumes permanent 10 percent ITC.

CSP is a fixed cost generation resource - that is the cost of generating each MWh of electricity is primarily dependent on the capital cost of the facility, rather than on fuel costs as is the case with natural gas fueled generation. Therefore, installation of more fixed-cost generation on the California electric system could reduce the effect on electricity prices resulting from natural gas price increases and volatility. This is relevant to current generation investment decisions because of recent natural gas price volatility and price increases as shown on Figure ES-1.

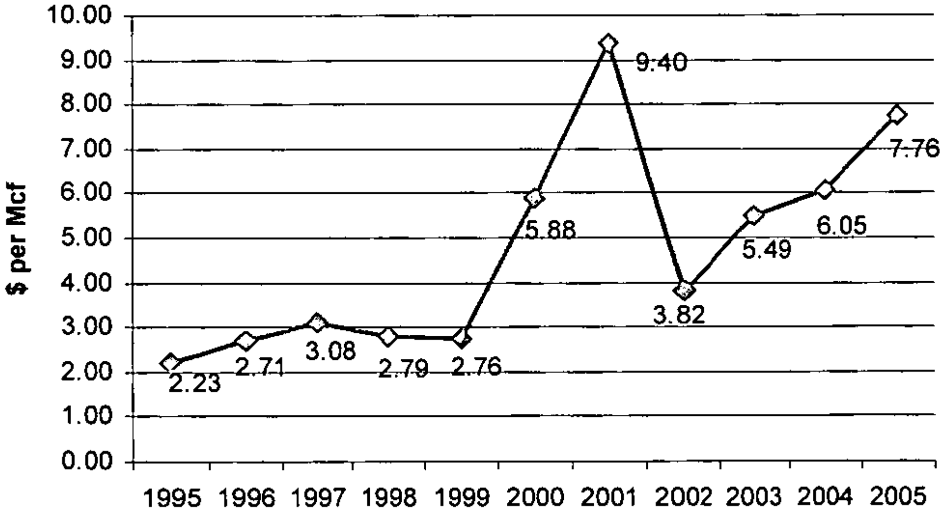

Figure ES-1
California Electric Power Sector, Annual Average Natural Gas Prices, $ per Mcf
(Source: Energy Information Administration)[4]

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[4] Data for 2005 is for January through November only. Data found at www.eia.doe.gov.

Recent studies have suggested that the installation of CSP, wind or other non-gas plants in lieu of new natural gas fueled generators can relieve a portion of the demand pressure behind gas price volatility. Lawrence Livermore Laboratory and others suggest that the natural gas price could decline by one to four percent for each change of 1 percent in demand. The 4,000 MW high deployment scenario could result in a savings of $60 million per year for natural gas in California for a 1 percent price reduction for a 1 percent usage reduction. At the higher price impact range, the California savings could be four times greater.

Power generation with CSP technology does not result in any significant air emissions compared with a business as usual approach. Therefore, if the installation of CSP avoids the installation of new natural gas fueled power stations or avoids the operation of existing power stations, there would be a net reduction in air emissions in California. Using the natural gas combined cycle plant – the cleanest, most efficient fossil technology – as a proxy, data for criteria air emissions reductions were developed. For the 4,000 MW deployment scenario, at least 300 tons per year of NO_x and 7.6 million tons per year of CO_2 would be avoided. If the fossil displacement is simple cycle gas turbines or coal fired plants, these values would be larger.

Black & Veatch has made the following conclusions about the deployment of CSP from this analysis:

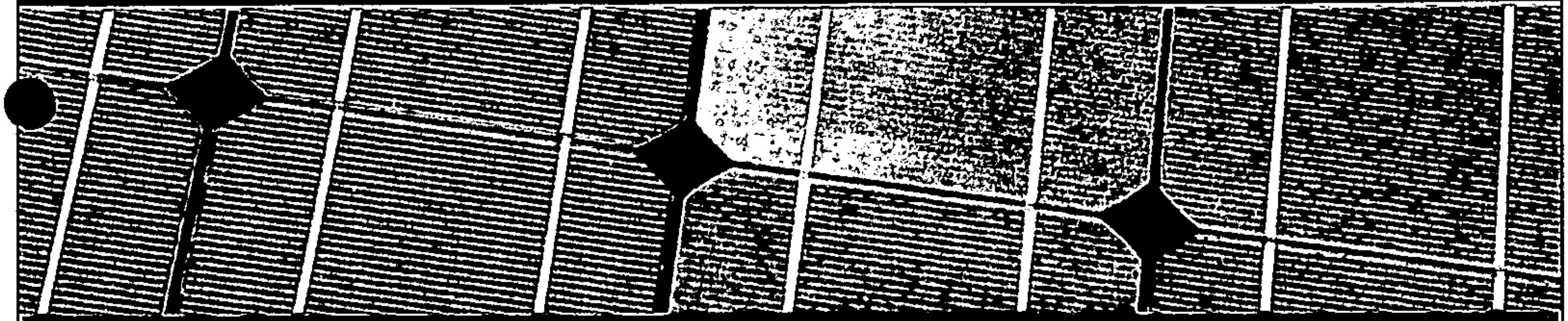
- California has high quality solar resources sufficient to support far more CSP than either the 2,100 MW or 4,000 MW scenarios analyzed.
- Depending on the CSP plant interconnection point and the load profile of the local electricity provider, CSP with 6 hours of storage could perform peaking and/or intermediate generation roles for a utility.
- Investment in CSP power plants delivers greater return to California in both economic activity and employment than corresponding investment in natural gas equipment:
  - Each dollar spent on CSP contributes approximately $1.40 to California's Gross State Product; each dollar spent on natural gas plants contributes about $0.90 - $1.00 to Gross State Product.
  - The 4,000 MW deployment scenario was estimated to create about 3,000 permanent jobs from the ongoing operation of the plants.
- Operations period expenditures on operations and maintenance for CSP create more permanent jobs than alternative natural gas fueled generation. For each 100 MW of generating capacity, CSP was estimated to generate 94 permanent jobs compared to 56 jobs and 13 jobs for combined cycle and simple cycle plants, respectively.

- Energy delivered from early CSP plants (startup in 2007) costs more than that delivered from natural gas combined cycle plants[5] ($157 per MWh vs. $104 per MWh, based on a 30 percent ITC for CSP). With technology advancements, improvements to CSP construction efficiency, and with higher gas prices consistent with 2015 MPR projections, CSP becomes competitive with combined cycle power generation ($115 per MWh vs. $119 per MWh, even with the permanent 10 percent ITC). Most of the economic and employment advantages are still retained.
- CSP plants are a fixed-cost generation resource and offer a physical hedge against the fluctuating cost of electricity produced with natural gas.
- Each CSP plant provides emissions reductions compared to its natural gas counterpart; the 4,000 MW scenario in this study offsets at least 300 tons per year of NO_x emissions, 180 tons of CO emissions per year, and 7,600,000 tons per year of CO_2.

The economic and employment benefits, together with delivered energy price stability and environmental advantages, suggest that the CSP solar alternative would be a beneficial addition to California's energy supply. While early CSP plants are more costly than their traditional gas counterparts, subsequent plants are estimated to become nearly cost competitive on a levelized cost of energy basis.

---

[5] Based on MPR gas prices for 2007, $6.40/MMBtu, and assuming a 100 MW CSP plant with 6 hours storage and a 500 MW combined cycle plant. Both CSP and combined cycle plants operate at 40 percent capacity factor. All dollars are $2005.



SOLAR ENERGY TECHNOLOGIES PROGRAM

Attachment 55
Docket 07A-447E
Glustrom Answer Testimony

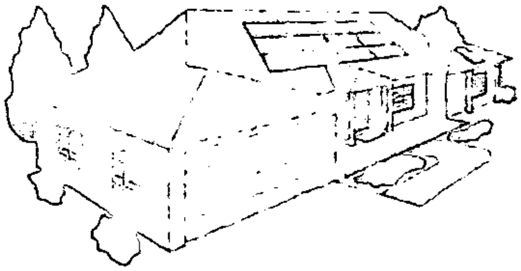
CONCENTRATING SOLAR POWER

FY2009
Proposed Solar Initiative

Budget Summit Meeting
National Press Club

March 15, 2007

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable



Introduction

Recent developments in the western United States serve to illustrate the growing concern over greenhouse gas emissions, and consequently, a market climate that is open to further deployment of concentrating solar power (CSP) in that region of the country.

In September 2006, California enacted the California Global Warming Solutions Act of 2006, which requires the state to reduce its greenhouse gas emissions by 25 percent by 2020.[i] In March 2007, California and four other western states (Arizona, New Mexico, Oregon, Washington) announced the Western Regional Climate Action Initiative in which they agreed to work together to cut their states' greenhouse gas emissions. With the large solar resources available in the Southwest, CSP-generated electricity could play an important role in helping these states meet their emissions reduction goals. In the longer term CSP-generated electricity could help all the states reduce their greenhouse emissions.

Solar energy is the southwest's most abundant renewable resource. In fact, California, Arizona, and New Mexico have enough combined solar energy to provide all the power needed by the entire country. CSP technology is the least expensive solar technology for providing large quantities of electrical power, and with sufficient storage, it can deliver baseload power. At a time when large quantities of carbon-free power will be needed; CSP power plants, constructed primarily of concrete, glass, and steel, can be quickly constructed and brought on line. The yearly CO2 emissions from a 1,000 MW coal plant are approximately 2,300,000 tons. The yearly CO2 emissions from a 1,000 MW CSP plant would be nearly zero (there may be some need for grid power during the operation of the plant). With access to adequate transmission, CSP could provide inexpensive carbon-free electricity to the entire country.

Initiative Objective

Develop concentrating solar technology that provides baseload power at a price competitive with carbon constrained coal.

Goals

- Intermediate power at \$0.05 - \$0.07/kWh by 2015 (moved up from 2020) and
- Baseload power at \$0.05/kWh[ii] by 2020 (including systems with 60% - 75% capacity factor)

During the last three years, members of the Solar Program met with the energy and economic advisors to governors, energy regulators, state legislators, utilities, and other stakeholders in California, Nevada, Arizona, and New Mexico. These meetings were to provide them the economic, environmental, and energy benefits of CSP. Each state expressed an interest in CSP, although their interest was tempered by the high cost of the technology. They were, however, encouraged by the Program's projections of significant cost reduction and also showed interest in finding ways to support and incentivize the deployment of CSP in their states. Nevada subsequently implemented tax incentives that have led to the construction of a 64MW CSP plant outside of Las Vegas.

Utility representatives expressed particular interest in CSP because its ability to store energy enables solar power to be dispatched to the grid through their entire period of peak demand, or whenever else it is needed. CSP was also attractive in their eyes because of its size (50-250MW), use of conventional steam turbine power blocks, and the ability to hybridize CSP plants with natural gas.

Market Status:

Worldwide, CSP is currently being developed for utility-scale, central power generation markets in the U.S., Spain, North Africa, and Israel. Spain is the most active in CSP development as a result of a 2004 Royal Decree that offers a "feed-in tariff" for solar thermal electricity of 0.18 €/kWh for 25 years, and the first 200MW of CSP deployed in the country will receive an additional 0.03 €/kWh. Four tower and three trough plants, totaling 180MW are currently under construction/development, and three of the plants are slated to have between six and sixteen hours of thermal storage. With interest continuing to rise, and the national electric utilities planning on developing as many as one dozen 50MW trough plants, discussions are already underway to extend the extra 0.03 €/kWh premium to the first 500MW deployed in the country.[iii]

In the U.S., nine CSP power plants totaling 354 MW have been operating reliably in California for over 16 years, and CSP seems poised to grow significantly in the state. Each of the three major California utilities (Southern California Edison, San Diego Gas and Electric, and Pacific Gas and Electric) have signed power purchase agreements for a CSP project or are in the final stages of doing so. In August 2005, Southern California Edison (SCE) signed a power purchase agreement for 500 MW of CSP dish-engine systems on a 4,500 acre site near Victorville, CA, with an option to expand the project to 850 MW. In September 2005, San Diego Gas & Electric (SDG&E) signed a power purchase agreement for a 300 MW dish-engine project in California's Imperial Valley, with an option of expanding the project to 900 MW.[iv] In August 2006, the Pacific Gas and Electric Company initiated plans with Luz II, LLC, to purchase at least 500 MW of solar energy beginning in the spring of 2010.[v]

The state of Nevada has put in place tax credits enabling the aforementioned construction of a 64 MW CSP project near Las Vegas (expected to be operational in April 2007). Nevada Power will purchase the power from the plant. A 1 MW CSP system, completed in 2006, is operating in Arizona for Arizona Public Service. In addition, several other utilities, under the leadership of Arizona Public Service, are investigating the potential of forming a consortium that would buy power from a 250 MW CSP plant built in Arizona.

The southwestern states also have strong renewable portfolio standards (RPS) which require that a specific portion of a state's electricity consumption be met by renewable energy by a certain year. RPS' are chief among the state policies to promote renewable energy, and some even specify that a certain amount of power must come from solar energy. Table 1 below lists the requirements of the RPS's in the six Southwestern States.[vi]

State	Requirement
Arizona	15% by 2025
California	20% by 2010
Colorado	10% by 2015
Nevada	20% by 2015, 5% Solar
New Mexico	20% by 2015
Texas	5,880MW (~4.2%) by 2015

Table 1. RPS Requirements in Southwestern States

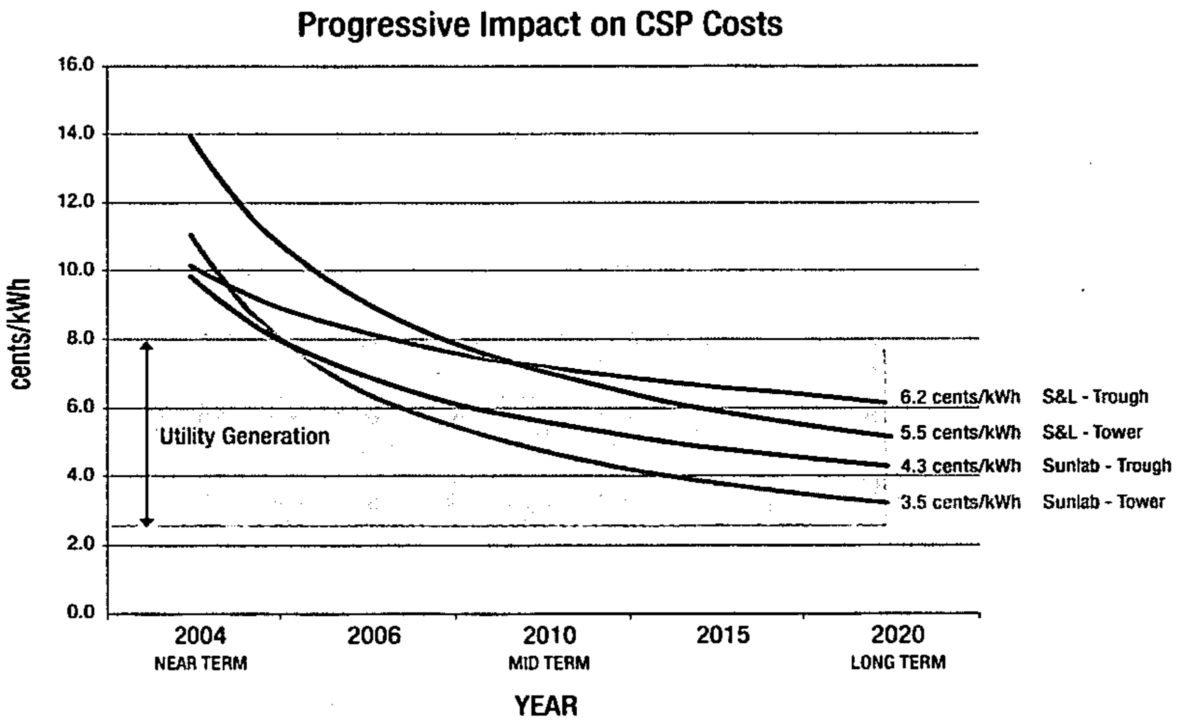


Figure 1. Sargent & Lundy CSP Cost Reductions Projections

CSP Costs:

As with all new energy technologies, cost is an issue. The Solar Program addressed the cost issue by commissioning a detailed technical analysis of CSP by an independent engineering firm and then having the analysis reviewed by the National Research Council. Sargent and Lundy (S&L) was selected to conduct this analysis on the basis, among other factors, of its independence from the CSP industry and its recognized performance in conducting due diligence studies for the fossil power industry. S&L estimated that the cost of CSP technology can be significantly reduced from today's 12-14 cents/kWh. As shown in (Figure 1), S&L shows troughs at 6.2 cents/kWh and power towers at 5.5 cents/kWh. Sandia and NREL (Sunlab) predict costs could be even lower.

Since the S&L report was completed in 2003, the experience gained from trough plants being built in the U.S. and Spain is enabling industry to lower their cost through mass production and building larger plants. Figure 2 illustrates potential cost reductions for parabolic trough CSP systems.

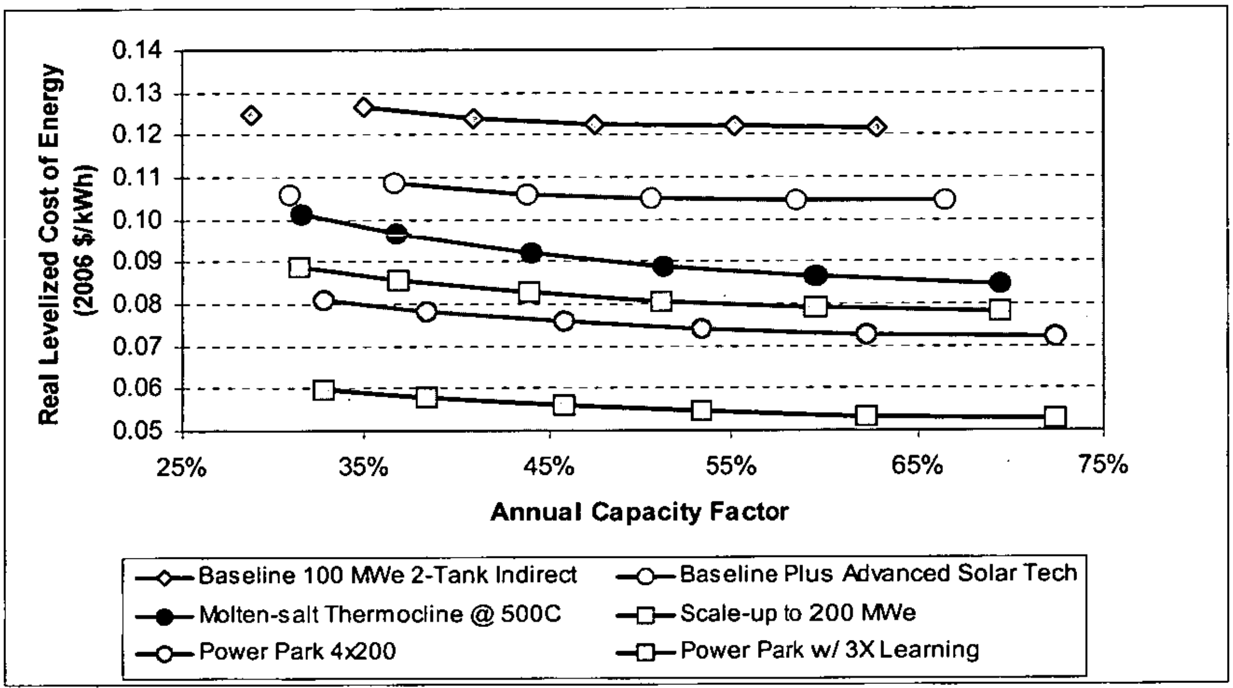


Figure 2. Potential Cost Reductions for Troughs source: NREL

New CSP concepts such as the compact linear Fresnel reflector (CLFR), a variation of a trough, are also being touted for their potentially low cost.

CSP as Baseload Generation:

After realizing market penetration for CSP within the intermediate and peak load markets in the near term, CSP could expand into baseload generation markets through the use of thermal storage technologies, thereby providing a renewable alternative to baseload coal power. CSP technologies convert solar energy into thermal energy which is then stored in large tanks. This is an efficient way of keeping the energy until it's needed, at which time the hot fluid, often a molten salt mixture, is pumped to a power block where it is converted to electrical power through a turbine.

The ability of CSP technologies to store energy presents an opportunity for DOE to establish an R&D effort that focuses on a solar technology that can produce baseload power at about 5 cents/kWh. Such systems would include 13-16 hrs of thermal storage and would compete with the cost of power from coal plants using sequestration. It is expected that an aggressive R&D program could achieve the cost goal by 2020.

It is also important to note that the baseload power market in 2020 is projected to be considerably different from its current manifestation, and consequently more attractive for CSP deployment. If coal is used for baseload generation in a future carbon-constrained market, sequestration or other carbon limiting technology would have to employed, raising the price of coal-generated electricity.

With the prices of fossil-fuel based energy fluctuating significantly over the past few years, it is difficult to estimate the cost for baseload power in a future carbon-constrained economy. However, two recent studies have attempted to answer this question. Black & Veatch (B&V), the global engineering and consulting firm, estimates the cost of electricity produced from coal (with sequestration) will be about 8 cents/kWh[vii]. A 2002 estimate by the IPCC, which can be seen in Figure 3, projects the cost of coal with sequestration between 5.5 -9 cents/kWh (2002 dollars).

US$2002	Pulverized Coal	Natural Gas CC	Integrated Coal Gasification CC
Cost of Electricity w/o CCS ($/kWh)	**0.043–0.052**	**0.031–0.050**	**0.041–0.061**
Carbon Capture & Sequestration			
- Increased fuel requirements	**24-40%**	**11-22%**	**14-25%**
- CO2 Avoided	**81-88%**	**83-88%**	**81-91%**
- Cost of Carbon Capture ($/kWh)	0.019–0.047	0.012–0.029	0.010–0.032
- Mitigation Cost ($/tCO2 avoided)	30–71	38–91	14–53
Cost of Electricity w/ CCS ($/kWh)	**0.063–0.099**	**0.043–0.077**	**0.055–0.091**
Potential value of EOR ($/kWh)	**0.014–0.018**	**0.006–0.007**	**0.013-0.015**

Natural Gas Price: 2.8-4.4 US$/GJ (LHV)
Coal Price: 1.0-1.5 US$/GJ

Figure 3. IPCC Special Report – Carbon Sequestration – 2002.

As shown in the S&L report (Figure 1), power towers are estimated to be able to generate low cost power. That technology has been missing from the Solar R&D portfolio for the last five years because of a lack of industry activity. Now, however, a power tower has been built in Spain (where three more are under development, one of which is slated to have sixteen-hour molten salt storage)[viii] and another is under development in South Africa. In addition, a new power tower concept has been introduced by industry, distributed power towers, that is touted for its potentially high efficiency and low cost. This would be an opportune time for DOE to take another look at power towers.

CSP Potential:

The arid region from southern California to west Texas has solar energy resources that are among the best in the world (Figure 4). A study done for the Western Governors' Association determined that the seven States in the Southwest (Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah) have the combination of solar resource and available suitable land to generate up to 6,800 GW (Table 2). To put this in perspective, the electric generating capacity of the entire country is about 1,000 GW.

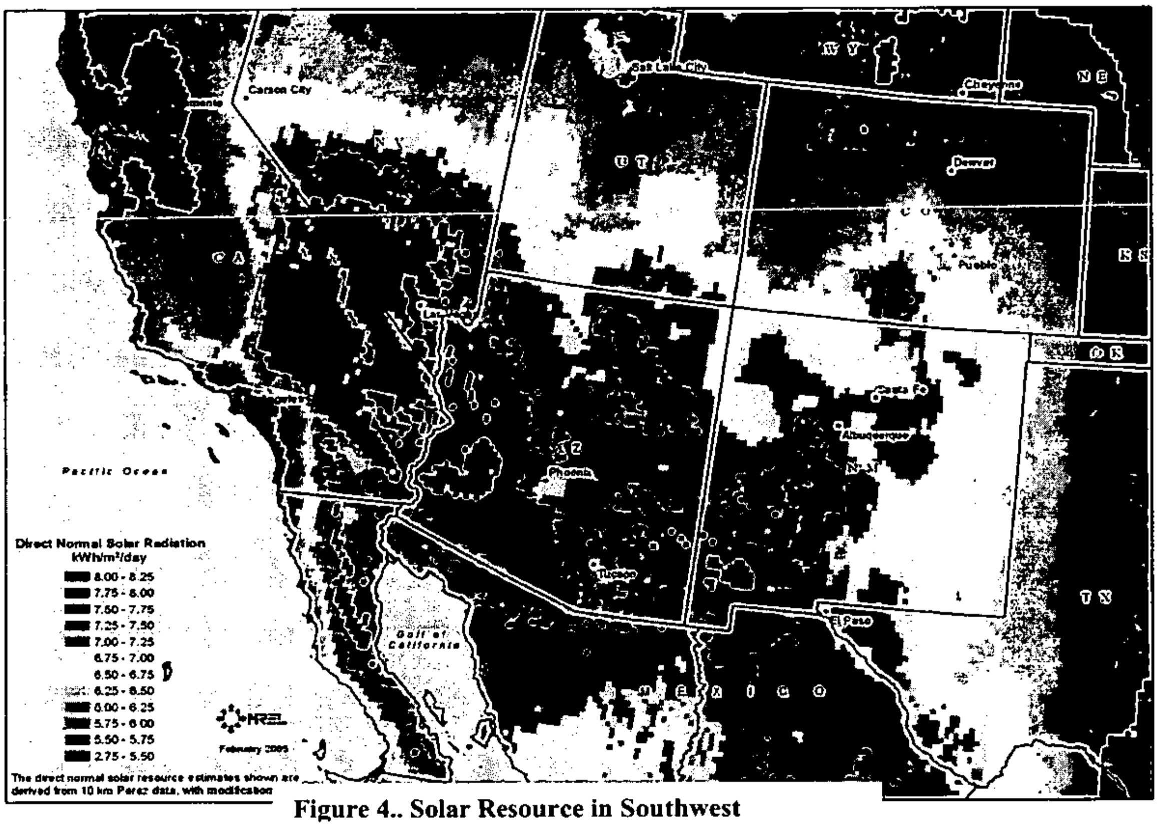


Figure 4.. Solar Resource in Southwest

State	Land Area (mi²)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	19,279	2,467,663	5,836,517
CA	6,853	877,204	2,074,763
CO	2,124	271,903	643,105
NV	5,589	715,438	1,692,154
NM	15,156	1,939,970	4,588,417
TX	1,162	148,729	351,774
UT	3,564	456,147	1,078,879
Total	53,727	6,877,055	16,265,611

Table 2. Potential Solar Capacity in Southwest

In the last two years utilities have demonstrated a serious interest in CSP. There are several reasons:

- The widespread availability of solar energy throughout the Southwest provides utilities with flexibility in locating CSP plants near existing or planned transmission lines.
- Placing CSP plants on the "right" side of congestion can reduce grid congestion and increase grid reliability.
- CSP electricity production aligns closely with periods of peak electricity demand, reducing the need for investment in new generating plants and transmission system upgrades.
- Thermal storage or the hybridization of CSP systems with natural gas avoids the problems of solar intermittency and allows the plant to dispatch power to the line when it is needed.
- Large centrally-located power plants are the types of systems that the utilities have operated for years and with which they are most comfortable.
- Once the CSP plant is built, its energy costs are fixed; this stands in contrast to fossil fueled plants that have experienced large fluctuations in fuel prices during the last several years.
- The economic studies performed by the states show that a relatively small up-front investment can result in downstream tax revenues for the state and local governments.

Environmental and Energy Benefits:

In addition to the California Global Warming Solutions Act of 2006, and the newly announced Western Regional Climate Action Initiative, as of October 2006, more than 300 mayors representing over 50 million Americans had agreed to take steps to reduce greenhouse gas emissions.[ix] Because of these actions, utilities around the U. S. are concerned about future greenhouse gas regulations and, in the southwest at least, are resigned to the fact that sooner or later they will be asked by their regulatory commissions to reduce carbon emissions.

Constraints on greenhouse emissions, the need to clean up the coal combustion process and/or sequester CO_2, will likely make fossil fuel-generated power more expensive, thereby improving the economics of CSP projects.

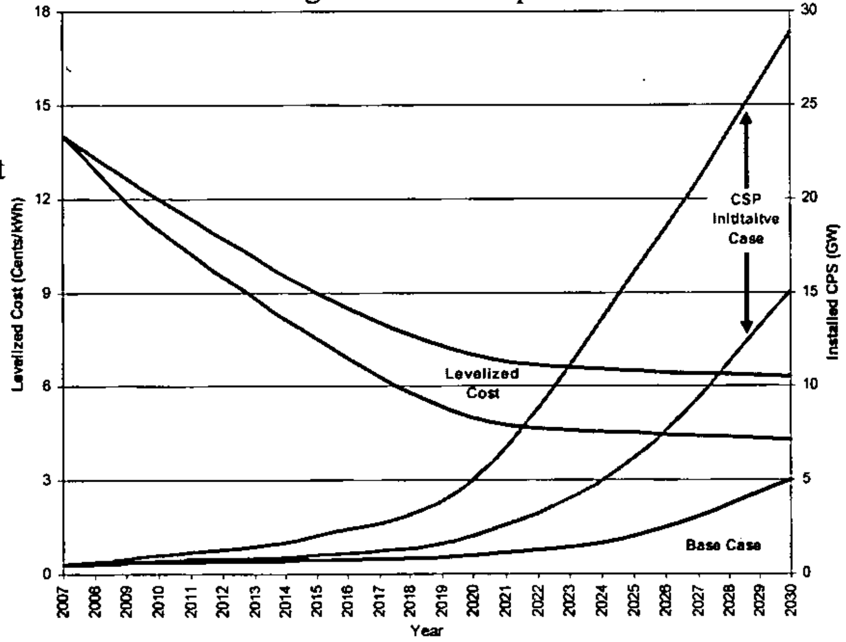


Figure 5: CSP Market Penetration Forecast. source NREL

CSP generated electricity provides all of the environmental benefits that many renewable energy technologies, reducing air pollution and the generation of green house gases. The magnitude of the environmental impact of CSP depends on the fuel source that it replaces for electricity generation. The table below, which is based on EIA data, compares the relative emissions from a 1000 MW coal-fired, gas-fired, and CSP power plant, each having the same capacity factor. An estimate of CSP's market penetration done by NREL (Figure 5) shows between 15,000 and 28,000 MW of installed capacity by 2030. This would result in a savings of 34-64 million tons of CO2 emitted to the atmosphere each year relative to coal plants of similar capacity.

Tons of Pollutant from 1000 MW Power Plant

	CO2	SOX	NOX
Coal	2,300,000	1,900	1,800
Natural Gas	1,293,750	1	362
CSP w/12hrs	0	0	0

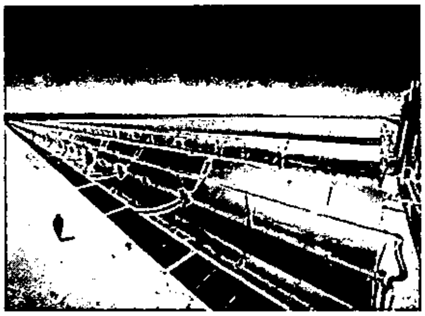
Table 3. Environmental Aspects of CSP Plant

The market penetration shown in Figure 5 was generated by EIA's National Energy Modeling System (NEMS). It assumed the cost of CSP as shown in Figure 5. EIA data was used for the cost of other fuel options for generating electricity (e.g. natural gas, nuclear). For this analysis, NEMS used the AEO 2007 reference case assumptions about the cost of carbon capture and sequestration. Under these assumptions, the incremental cost of carbon capture and sequestration for coal is 2.6 to 3.0 cents/kWh initially, and declines over time to 1.4 to 1.7 cents/kWh by 2030. Market penetration would be higher if the B&V or IPCC estimates for the cost of sequestered coal were used. The model assumes that the lowest cost fuel will supply the increased need for power. It does not account for a near-term market driven by state renewable portfolio standards. Due to transmission limitations, the model also constrains the CSP market to the west.

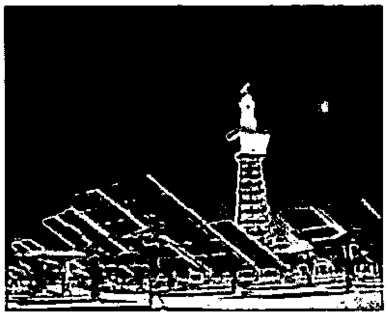
Long Term Potential

As shown in Table 2, the southwest has enough solar energy to provide far more power than it needs. Two major barriers exist from harnessing that potential. One is the cost of converting solar energy to electricity. This initiative would eliminate that barrier. The other is transmission. Transmission of power is a problem throughout the west and, indeed, throughout the country. In the near-term, transmission lines are being planned that will bring solar energy to the load centers in the southwest and up to the northwest. The U.S. is fortunate in that it has an abundance of solar energy in close proximity to major population centers (e.g. San Diego, Los Angeles, San Francisco, Phoenix, Las Vegas, Albuquerque, Denver). These cities could be receiving the benefits of solar energy within a decade or less. However, with the advent of a high voltage DC transmission grid, solar power from the southwest could provide power to the northeast (Boston, New York, and Washington DC) for about 1.5 cents/kWh more than it costs in the southwest[x]. It could provide power to Midwest (Chicago, St Louis, Minneapolis) and the south (Dallas, Houston, New Orleans) for a premium of less than a penny per kWh.

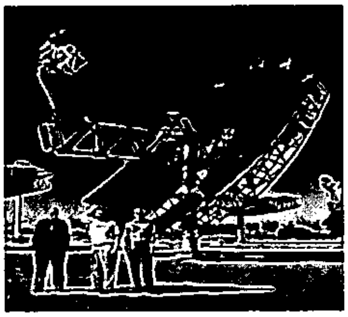
CSP Technology:
Concentrating Solar Power (CSP) technologies comprise three distinct types of systems: troughs, power towers, and dish Stirling solar power generators.



Toughs



Power Towers



Dish Engines

Troughs and Power Towers convert solar energy into thermal energy which is then stored in large tanks (Figure 6). This is an efficient way of keeping the energy until it's needed, at which time the hot fluid, often a molten salt mixture, is pumped to a power block where it is converted to electrical power through a turbine. These technologies are least expensive when built in modules of 100-250 MW. They use conventional steam turbine power blocks to generate electricity. Dish-engine systems are built in 10-25 kW modules and can be combined in fields of as many dish systems as desired. As noted above, two California utilities have initiated dish projects of several hundred megawatts. Dish-engine systems do not currently have thermal storage, but can produce power when the sun is not shining by running the engine on natural gas.

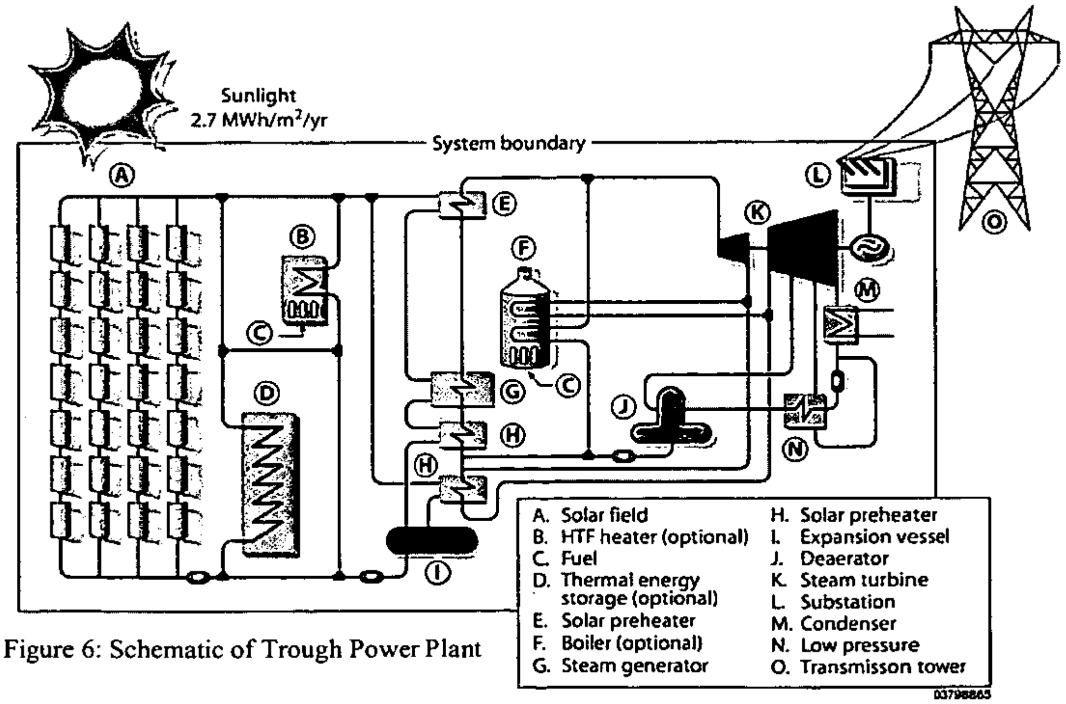
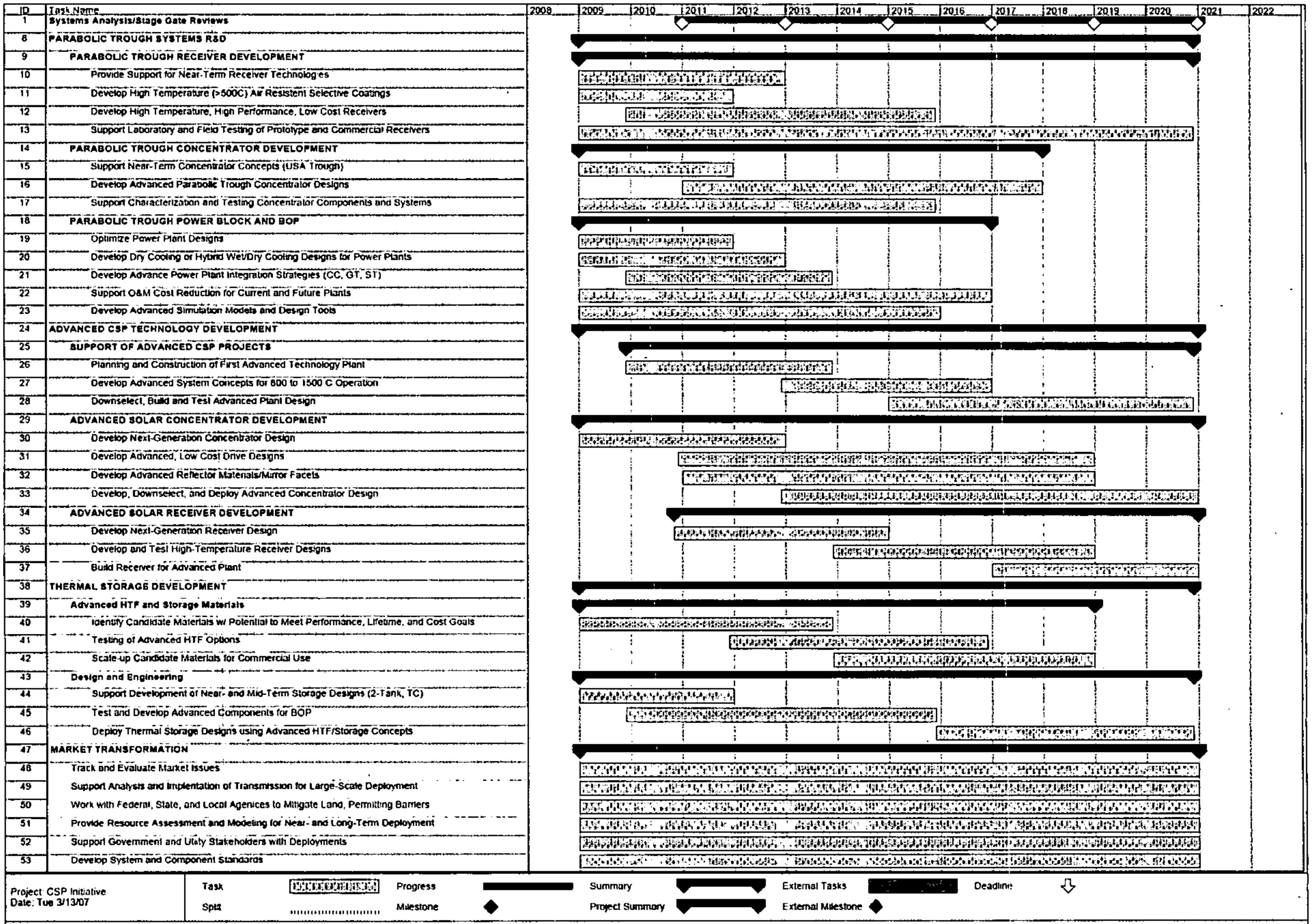


Figure 6: Schematic of Trough Power Plant

Activities



ID	Task Name
1	**Systems Analysis/Stage Gate Reviews**
8	**PARABOLIC TROUGH SYSTEMS R&D**
9	**PARABOLIC TROUGH RECEIVER DEVELOPMENT**
10	Provide Support for Near-Term Receiver Technologies
11	Develop High Temperature (>500C) Air Resistent Selective Coatings
12	Develop High Temperature, High Performance, Low Cost Receivers
13	Support Laboratory and Field Testing of Prototype and Commercial Receivers
14	**PARABOLIC TROUGH CONCENTRATOR DEVELOPMENT**
15	Support Near-Term Concentrator Concepts (USA Trough)
16	Develop Advanced Parabolic Trough Concentrator Designs
17	Support Characterization and Testing Concentrator Components and Systems
18	**PARABOLIC TROUGH POWER BLOCK AND BOP**
19	Optimize Power Plant Designs
20	Develop Dry Cooling or Hybrid Wet/Dry Cooling Designs for Power Plants
21	Develop Advance Power Plant Integration Strategies (CC, GT, ST)
22	Support O&M Cost Reduction for Current and Future Plants
23	Develop Advanced Simulation Models and Design Tools
24	**ADVANCED CSP TECHNOLOGY DEVELOPMENT**
25	**SUPPORT OF ADVANCED CSP PROJECTS**
26	Planning and Construction of First Advanced Technology Plant
27	Develop Advanced System Concepts for 800 to 1500 C Operation
28	Downselect, Build and Test Advanced Plant Design
29	**ADVANCED SOLAR CONCENTRATOR DEVELOPMENT**
30	Develop Next-Generation Concentrator Design
31	Develop Advanced, Low Cost Drive Designs
32	Develop Advanced Reflector Materials/Mirror Facets
33	Develop, Downselect, and Deploy Advanced Concentrator Design
34	**ADVANCED SOLAR RECEIVER DEVELOPMENT**
35	Develop Next-Generation Receiver Design
36	Develop and Test High-Temperature Receiver Designs
37	Build Receiver for Advanced Plant
38	**THERMAL STORAGE DEVELOPMENT**
39	**Advanced HTF and Storage Materials**
40	Identify Candidate Materials w/ Potential to Meet Performance, Lifetime, and Cost Goals
41	Testing of Advanced HTF Options
42	Scale-up Candidate Materials for Commercial Use
43	**Design and Engineering**
44	Support Development of Near- and Mid-Term Storage Designs (2-Tank, TC)
45	Test and Develop Advanced Components for BOP
46	Deploy Thermal Storage Designs using Advanced HTF/Storage Concepts
47	**MARKET TRANSFORMATION**
48	Track and Evaluate Market Issues
49	Support Analysis and Implentation of Transmission for Large-Scale Deployment
50	Work with Federal, State, and Local Agenices to Mitigate Land, Permitting Barriers
51	Provide Resource Assessment and Modeling for Near- and Long-Term Deployment
52	Support Government and Utity Stakeholders with Deployments
53	Develop System and Component Standards

Project: CSP Initiative
Date: Tue 3/13/07

Proposed Budget:

A detailed analysis was done by Sandia and NREL to estimate the cost of achieving the intermediate goal by 2015 and the baseload goal by 2020. It showed a CSP activity of $50M per year thru 2020 funded by DOE. The majority of this funding would be placed in contracts with industry. The remaining amount would be provided to Sandia and NREL for system analysis and component testing in support of industry. It is assumed that there would be an industry cost share of at least 50% on all engineering contracts.

Element	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total
Trough	20	17	16	13	11	11	7	6	6	6	6	6	125
Advanced Technology	10	12	14	16	18	20	24	25	29	29	30	27	254
Storage	10	12	12	13	13	11	7	6	6	6	6	6	108
Market Trans., Facilities	10	9	8	8	8	8	12	13	9	9	8	8	110
Total (millions)	50	50	50	50	50	50	50	50	50	50	50	47	597

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[i] "AB 32 Assembly Bill," California Legislature, Retrieved on September 31, 2006, from http://www.leginfo.ca.gov/pub/bill/asm/ab_0001-0050/ab_32_bill_20060831_enrolled.html

[ii] At an industry meeting in March 2007 there was a discussion on the cost of baseload power in the future. Utility representatives indicated that the cost of baseload power in 2020 would likely be higher than 5 cents/kWh. The Solar Program will establish the long term goal for CSP after convening a meeting of industry and utilities.

[iii] www.mileniosolar.com, www.solucar.es, www.solarpaces.org/News/Projects/Spain.htm

[iv] "SDG&E Signs Solar Power and Other Renewables Energy Pacts," San Diego Gas & Electric Press Release, September 7, 2005

[v] "PG&E Announces Significant New Green Power," PG&E Press Release, August 10, 2006

[vi] "State Clean Energy Maps and Graphs," Union of Concerned Scientists, Updated October 14, 2005, Retrieved on October 12, 2006 from http://www.ucsusa.org/clean_energy/clean_energy_policies/state-clean-energy-maps-and-graphs.html

[vii] Black & Veatch, analysis done for NREL, 2006.

[viii] "CSP Project Developments in Spain," SolarPaces.org, http://www.solarpaces.org/News/Projects/Spain.htm

[ix] "US Mayors Climate Protection Agreement," U.S. Conference of Mayors, September 8, 2006, Retrieved on October 12, 2006, from http://www.seattle.gov/mayor/climate/default.htm

[x] NREL analysis done for CSP industry meeting, March 7-9, 2007.