Joint Intervenors - Exhibit 2

BEFORE THE STATE OF MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS
FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION

In the Matter of the Application by Otter Tail Power	)	
Company and Others for Certification of	)	
Transmission Facilities in Western Minnesota	)	**OAH No. 12-2500-17037-2**
And	)	**MPUC Dkt. No. CN-05-619**
In the Matter of the Application to the Minnesota	)	**and**
Public Utilities Commission for a Route Permit for the	)	**OAH No. 12-2500-17038-2**
Big Stone Transmission Project in Western Minnesota	)	**MPUC Dkt. No. TR-05-1275**
	)	

Direct Testimony of
Ezra D. Hausman, Ph.D.
Synapse Energy Economics, Inc.

On Behalf of
Fresh Energy
Izaak Walton League of America – Midwest Office
Wind on the Wires
Union of Concerned Scientists
Minnesota Center for Environmental Advocacy

November 17, 2006

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I. PROFESSIONAL QUALIFICATIONS AND SUMMARY

Q. Please state your name for the record.

A. My name is Ezra D. Hausman.

Q. Where are you employed?

A. I am a Senior Associate with Synapse Energy Economics of Cambridge, Massachusetts.

Q. Please describe your formal education.

A. I hold a Ph.D. in Atmospheric Science from Harvard University, a master's degree in applied physics from Harvard University, a master's degree in water resource engineering from Tufts University, and a Bachelor of Arts degree from Wesleyan University.

Q. Please describe "atmospheric science."

A. Briefly, atmospheric science is the study of the chemistry, circulation and heat transfer processes of the atmosphere. It encompasses the study of how the atmosphere interacts with the ocean and land surface through chemical interactions, moisture exchange, and energy transfers, as well as the impact of the biosphere (life) on the chemistry of the atmosphere. These processes are central to what we think of as the "climate" of the Earth and, together with oceanic processes, they control the distribution of surface temperature and patterns of precipitation on the planet.

One way to understand the field of atmospheric science is as follows: A certain amount of energy reaches the surface of the Earth, as sunlight, every day. At equilibrium, the same amount of energy must be vented back to space, on average, every day. Atmospheric science is the science of all of those chemical, physical, hydrological, biological, and dynamical processes which work together to move that energy to the top of the atmosphere and to ultimately release it back into space.

Q. Please describe your experience in the field of atmospheric science.

A. For my doctoral research at Harvard University, I built a dynamic computer model of the ocean-atmosphere system to explore how a number of observed changes in atmospheric chemistry, ocean circulation and ocean surface temperature at the end of the last glaciation ("ice age") can be used to explain certain aspects of the warming of the planet at that time. I demonstrated, among other things, that the increase in atmospheric Carbon Dioxide (CO_2) at that time was both a result of and a strong positive feedback for the concurrent warming of the planet.

After graduation, I worked with researchers at Columbia University to develop private sector applications of climate forecast science. This led to an initiative called the Global Risk Prediction Network, Inc. for which I served as Vice President in 1997-1998. Specific projects included serving as Principal Investigator for a statistical assessment of grain yield predictability in several crop regions around the world based on global climate indicators, and for a statistical assessment of road salt demand predictability in the United States based on global climate indicators. I also prepared a preliminary design of a climate and climate forecast information website tailored to the interests of the business community.

Q. Please describe your work since 1998.

A. Since 1998 I have been primarily focused on electricity market issues, turning my numerical modeling and analytical skills to issues of electricity market structure, electric industry restructuring, asset valuation and price forecasting, and environmental regulations in the electric industry. In July 2005 I joined Synapse Energy Economics of Cambridge, Massachusetts, to continue this work but with a greater focus on the environmental, long-term planning and consumer protection aspects of the industry. This has given me an opportunity to apply my combined expertise, in atmospheric science and in the electric industry, to some of the most important issues facing the energy industry and, indeed, facing our society as a whole.

Q. Have you attached a copy of your current resume to this testimony?

A. Yes, as Exhibit JI-2-A.

Q. Please provide a summary your testimony.

A. I have been asked to testify on the environmental impact of the proposed transmission enhancements in Minnesota which would be necessary to allow the proposed Big Stone II unit to be built. I will focus on the most significant environmental impact of this combined project, which would be its contribution to atmospheric CO_2, the "greenhouse effect" and global climate change.

Human induced climate change is a grave and increasing threat to the environment and to human societies around the globe. The effects of this process are already observable and documented in the scientific literature, and are consistent with those predicted by computer models of the global climate. These same models predict much more severe effects to come, including sea level rise leading to inundation of coastal areas, dramatic changes in precipitation patterns across the globe, accelerated loss of habitat and species extinctions, and migration of pest species and disease vectors with associated human health impacts. Indeed, we are on a path that, if unchanged, is likely to bring about a climate well outside the range of anything ever experienced by our species, with the potential for severe and irreversible changes that will forever alter our environment, our economies and our way of life.

While some level of climate change is already a fact, computer models tell us that we can avoid or mitigate many dangerous impacts by limiting the further buildup of CO_2 in the atmosphere. Perhaps the most important and cost-effective way to achieve this is by limiting the burning of fossil fuels in the decades ahead, for example by making infrastructure investments which lead to electricity production by less carbon-intensive means. The proposed Big Stone II Project stands in stark contrast to this goal. Even if it is somewhat more efficient than other, older coal plants in the region, reliance on this facility would perpetuate a shortsighted and dangerous energy strategy for decades to come.

If this commission permits the proposed upgrades to the transmission network, it will allow Big Stone II to inject enormous amounts of CO_2 into the atmosphere for 50 years or more, and to exacerbate the dangerous buildup of greenhouse gases in the atmosphere. In this sense, the proposed transmission project would directly contribute to a problem that is likely to cause dramatic environmental and economic harm to societies around the globe, including to the communities in Minnesota. In my testimony I will discuss the nature of this severe environmental threat, and I will describe how Big Stone II and other coal plants present a material, adverse impact on the environment by contributing to it.

II. THE SCIENCE OF GLOBAL CLIMATE CHANGE

Q. Would you explain the "greenhouse effect"?

A. The planet's climate is a function of how much energy it receives from the sun, how much of that energy it retains, and how that energy is distributed throughout the planet (by wind and ocean currents, evaporation, condensation, and other mechanisms). Solar radiation arrives on earth, mainly in the form of visible light. That radiation is absorbed by the surface of the planet, which in turn radiates heat energy into the lower atmosphere. Some of that heat is trapped in the lower atmosphere by naturally-occurring gases, somewhat analogous to how heat is trapped in a greenhouse by the glass. This gives rise to the natural "greenhouse effect" and the heat-trapping gases are commonly called "greenhouse gases." The primary greenhouse gas is water vapor; other important greenhouse gases include CO_2, a byproduct of combustion, and methane.

Without the greenhouse effect, the earth would be far too cold to support liquid water, or probably any kind of life. Similarly with too strong of a greenhouse effect, the earth would be considerably warmer and might have no polar ice caps at all. These conditions have occurred in the geologic past, although not within the timeframe of the human species. With an even stronger greenhouse effect the earth could become extremely hot and uninhabitable, like the planet Venus. For all of recorded human history, the greenhouse effect has remained within a fairly narrow range, producing the relative climate stability that has allowed complex human civilizations to form and develop. During periods of geologic history that had different abundances of greenhouse gases such as CO_2, the earth had a very different climate.

Q. How have humans enhanced the natural greenhouse effect?

A. Human activities have increased the atmospheric concentration of several greenhouse gases, most notably of CO_2. This increase has come primarily from the burning of fossil fuels (coal, oil, and natural gas), and also from changes in land use such as deforestation, and to a smaller extent from the manufacture of cement. Of the fossil fuels, coal emits the most CO_2 per unit of energy obtained. Today the primary reason for burning coal in the United States is for the generation of electricity.

Because of the continuous and accelerating recovery and combustion of fossil fuels, the background level of CO_2 in the air has increased by roughly one third since preindustrial times. This means that the lower atmosphere does not lose heat to space as efficiently as it otherwise would, so the surface of the earth is generally warming. This is the phenomenon commonly referred to as “global warming.”

Global warming will affect different areas differently, changing the distribution of rainfall, warming many areas but cooling some others, changing the length of growing seasons, and so forth. Paradoxically, some areas are likely to become *cooler* as a response to global warming. To emphasize the range of the planet’s complex response to global warming, scientists have coined the term “global climate change.” I personally prefer to use the term "global climate change" in contexts such as this to emphasize that the impact of the increased atmospheric CO_2 burden will not just be measured in a few warm days, but in disruptions in the characteristics of climate that define our lives and our livelihoods.

III. SCIENTIFIC LITERATURE ON GLOBAL CLIMATE CHANGE

Q. In your opinion, what is the most comprehensive, reliable, authoritative, and scientifically credible account, relied upon by you and other experts in your field of climate science, regarding global warming, including the causes of global warming and the potential impacts on people and on the natural world?

A. There are a great number of studies published in distinguished, peer-reviewed scientific journals that are relied upon by scientists in developing a full understanding of the many aspects of climate science and climate change. However, perhaps unique to this area of science, there is a single source that has been carefully assembled by the leading researchers in the field to provide a comprehensive, reliable, authoritative, and scientifically credible compendium of this body of research. This source is the Third Assessment Report ("TAR") of the Intergovernmental Panel on Climate Change ("IPCC"), released in 2001. (The Fourth Assessment Report is expected to be released in early 2007.)

Q. What is the IPCC?

A. The IPCC was formed in 1988 by the World Meteorological Organization and the U.N. Environment Programme in response to rising concerns about global climate change. It provides an organizational structure for the work of hundreds of the world's leading researchers in climate science and related sciences. The IPCC does not do scientific research as an organization; rather, it assesses the scientific literature in an extremely methodical and transparent way, publishing consensus reports that reflect the work of scientists from around the world.

Q. Does the IPCC have any official role in advising policymakers?

A. Yes. In 1988 the United Nations General Assembly formally requested that the IPCC provide a comprehensive review and recommendations with respect to "the state of knowledge of the science of climate and climatic change."[1] In 1992, after receiving the IPCC's first assessment of the science, nearly every nation in the world, including the U.S., entered into the United Nations Framework Convention on Climate Change. The signers of the Framework Convention have asked the IPCC to provide full assessments of the state of climate science every 4 to 5 years, and to prepare various technical papers related to specific aspects of climate science, technology, and the social and economic impacts of climate change. The IPCC's assessments are therefore written with policy making in mind; they do not advocate for particular policies, but they do strive to provide comprehensive, policy-relevant information.

Q. Do the periodic assessments by the IPPC address the science of climate change?

A. Yes. The Report of Working Group I of the IPCC, entitled "Climate Change 2001: The Scientific Basis," is the part of the TAR that addresses the science of climate change. (Hereinafter "Working Group I Report".)

Q. How and by whom was the Working Group I Report prepared and reviewed?

A. The Working Group I report describes in its preface how it was prepared, stating: "This report was compiled between July 1998 and January 2001, by 122 Lead Authors. In addition, 515 Contributing Authors submitted draft text and information to the Lead Authors. The draft report was

[1] IPCC 2004 document, "Sixteen Years of Scientific Assessment in Support of the Climate Convention."

circulated for review by experts, with 420 reviewers submitting valuable suggestions for improvement. This was followed by review by governments and experts, through which several hundred more reviewers participated. All the comments received were carefully analyzed and assimilated into a revised document for consideration at the session of Working Group I held in Shanghai, 17 to 20 January 2001. There the Summary for Policymakers was approved in detail and the underlying report accepted."

The lead and contributing authors of this report were, like the IPCC itself, drawn from the ranks of the world's leading researchers. It is my opinion that the IPCC Working Group I report represents a thorough, fully informed, and authoritative assessment of scientific knowledge related to climate change as of the time that it was written.

Q. Is there a summary of the report?

A. Yes. The Summary for Policymakers was adopted as part of the Working Group I Report. A copy of the Working Group I Summary for Policymakers is attached as Exhibit JI-2-B to my testimony.

Q. Does the IPCC Third Assessment Report include an analysis of the potential impacts of global warming?

A. Yes. The IPCC Third Assessment Report (TAR) includes the report of Working Group II of the IPCC, entitled "Climate Change 2001: Impacts, Adaptation, and Vulnerability," hereinafter referred to as "Working Group II Report".

Q. Is there a summary of the Working Group II Report?

A. Yes. A copy of the Working Group II Summary for Policymakers is attached as Exhibit JI-2-C to my testimony.

Q. How was the Working Group II Report prepared and reviewed?

A. The preface of the Working Group II Report describes how it was prepared, stating: "The WGII report was compiled by 183 Lead Authors between July 1998 and February 2001. In addition, 243 Contributing Authors submitted draft text and information to the Lead Author teams. Drafts of the report were circulated twice for review, first to experts and a second time to both experts and governments. Comments received from 440 reviewers were carefully analyzed and assimilated to revise the document with guidance provided by 33 Review Editors. The revised report was presented for consideration at a session of the Working Group II panel held in Geneva from 13 to 16 February 2001, in which delegates from 100 countries participated. There, the Summary for Policymakers was approved in detail and the full report accepted."

As with Working Group I, the authors of the Working Group II report were among the leading researchers in their fields, and their findings are based on a comprehensive and detailed consideration of the science.

Q. Can you identify any other documents for a non-technical, policymaking audience which you consider to be authoritative on the subject of global warming?

A. Yes. A good example is a statement issued in 2005 by the U.S. National Academy of Sciences along with national science academies of Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, and the United Kingdom entitled "Joint Science Academies' Statement: Global Response to Climate Change," which I will refer to as the "Joint Science Academies Statement". The Joint Science Academies Statement is attached to my testimony as Exhibit JI-2-D. This is not a detailed review of the science, like the IPCC reports, but it is a strong statement of the consensus view of leading scientists around the world.

Q. What is the US National Academy of Sciences?

A. The National Academy of Sciences (NAS) was formed by legislation signed in 1863, and as mandated in its Act of Incorporation it has since then served to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government. The National Academy of Sciences is comprised of approximately 2,000 members and 350 foreign associates, of whom more than 200 have won Nobel Prizes. Although chartered by the federal government, the NAS is a private, non-profit and independent scientific organization. It is currently headed by Dr. Ralph J. Cicerone, himself an atmospheric scientist with research interests in atmospheric chemistry and climate change. Election to the NAS is considered by many to be one of the highest honors an American scientist can receive.

Q. In addition to expressing its views in the Joint Science Academies Statement, has the NAS released any reports on climate change?

A. The NAS has issued a number of publications and reports on this subject, reflecting the importance with which the scientific community views this issue. In 2001, at the request of the Bush Administration, it released a study entitled "Climate Change Science: An Analysis of Some Key Questions," which endorsed the essential findings and predictions of the IPCC.

Q. In your opinion is the National Academy of Sciences qualified to assess and report on the scientific data related to the increased concentration of CO_2 and the effects of that increase on air, water, and natural resources?

A. Yes. The National Academy of Sciences is eminently qualified to address and produce authoritative reports on these issues.

Q. Would you say that there is a scientific consensus on the issue of global climate change?

A. There is an unequivocal scientific consensus on many aspects of the issue of global climate change. These aspects include:

- The fact that the CO_2 content of the atmosphere is increasing rapidly;
- The fact that this rate of increase, and the resulting abundance of CO_2 in the atmosphere, is unprecedented in at least the past 200,000 years, and probably much longer;
- The fact that the primary source of the increase is combustion of fossil fuels by human industrialized societies, i.e., that it is anthropogenic CO_2;
- The fact that the increased abundance of atmospheric CO_2 has a direct radiative forcing effect on climate by altering the heat transfer characteristics of the atmosphere;
- The fact that this change in the heat transfer properties of the atmosphere will have an impact on the climate of the planet;
- The fact that the climate of the earth is currently changing in ways that are consistent with model predictions based on the increased radiative forcing due to the anthropogenic increase in atmospheric CO_2, and that these changes include increased sea surface temperatures, increased sea level, loss of arctic permafrost, loss of mountain and polar glacier mass, and destruction of arctic habitat;
- The fact that these observed changes cannot be ascribed to any known natural phenomenon;
- The fact that the magnitude of climate impacts will increase with increasing atmospheric CO_2 content; and
- The fact that once the atmospheric abundance of CO_2 has been increased, it can only return to equilibrium levels through natural processes on a timescale of several centuries.

In addition, there is a strong scientific consensus that natural feedbacks in the climate system would, on balance, tend to reinforce warming rather than mitigate it—for example, a warmer world would have more water in the atmosphere, which would tend to make the greenhouse effect stronger. There is also a strong consensus that one effect of global climate change will be the migration of climate zones, such that human societies and natural ecosystems will find themselves poorly adapted to their local climate. This may be expected to result in disruption and dislocation of ecosystems, migration of pest species and disease vectors, and disruptions in agriculture. Finally, there is general agreement, if not yet consensus, that global climate change will lead to generally more extreme weather patterns across most of the globe, including more intense storms and rainfall events and more extreme dry spells.

Q. Do the documents identified in this testimony, including the IPCC Working Group reports and the Joint Science Academies Statement, support these conclusions regarding scientific consensus?

A. Yes. However, it is important to note that as the last Assessment Reports were released five years ago, and were even then retrospective in their analysis of the science; a great deal been learned and observed in the intervening years. These new observations and improved model studies have only strengthened the certainty with which the scientific community perceives the risks associated with climate change. I would expect that in the next Assessment Report, many more aspects of global climate change will be regarded as "unequivocal", and much more evidence of current, observable climate change impacts will be presented and reviewed.

IV. INCREASING ATMOSPHERIC CO_2 LEVELS

Q. Since the last IPCC report in 2001, what has been observed by climate scientists about global levels of CO_2?

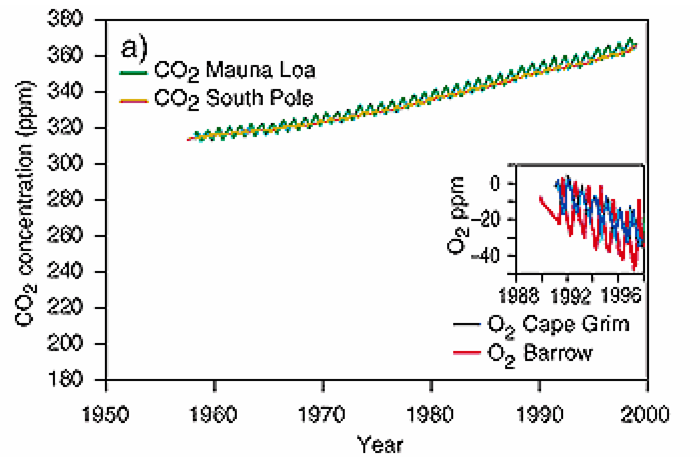
A. The level of CO_2 is still increasing. For example, the U.S. National Oceanic and Atmospheric Administration (NOAA) reported on May 1, 2006, that the average atmospheric carbon dioxide level increased from an average of 376.8 parts per million in 2004 to 378.9 parts per million last year.[2]

[2] *http://www.cmdl.noaa.gov/aggi*

Q. Could you put this modern increase in CO_2 levels into perspective?

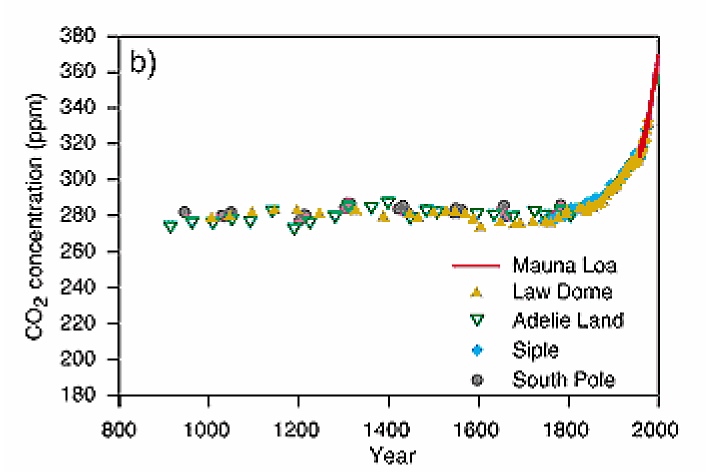
A. Yes. I will put this in context with reference to a few figures from the Working Group I Report. These figures present some of the key evidence demonstrating the nature of the modern rise in atmospheric CO_2. However, the evidence goes well beyond the few observations shown here.

The first graph shows the direct, instrumental measurements of CO_2 from Mauna Loa, in Hawaii, taken since the late 1950s. This graph shows both the seasonal variations in CO_2 associated with the growing season in the northern hemisphere, and the year-to-year increase in atmospheric CO_2 during this period:



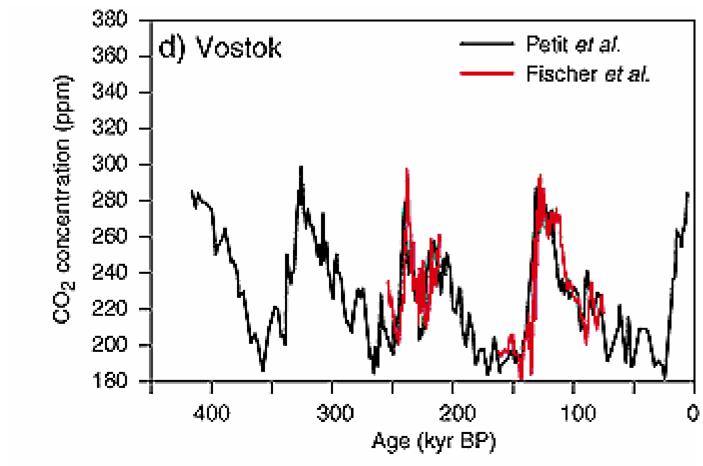
In this period alone, essentially my lifetime, atmospheric CO_2 has risen from under 320 ppm (parts per million, or number of molecules for every million molecules in the atmosphere) to almost 380 ppm, and the rate of increase is itself also increasing. (The inset shows the associated variation in atmospheric oxygen—CO_2 production always takes up oxygen from the atmosphere. While the decrease in atmospheric oxygen is not a concern, these data corroborate and support the CO_2 data.)

This next graph shows the history of atmospheric CO_2 for the last thousand years or so. This is measured in ancient air samples recovered from bubbles trapped in polar ice, in this case from various sites in Antarctica. The vertical scale is the same as in the previous graph, and in fact it also shows the Mauna Loa data for comparison:



These data demonstrate that CO_2 levels have been relatively steady in the atmosphere for over 1,000 years, a time of remarkably quiescent climate by geological standards, during which modern human civilization and culture have flourished around the world. The ice core data match up well with the beginning of the Mauna Loa data, and highlight the extraordinarily steep slope over which CO_2 has risen during the last 50-100 years. On the scale of most geological records, this line would be essentially vertical.

Finally, this last graph shows the variations in atmospheric CO_2 over the last four glacial cycles, also recovered from Antarctic ice cores, in this case a particularly deep core with a long time record known as Vostok. The vertical scale is the same as for the two previous graphs, while the horizontal scale is in thousand years before the present:



Remember that the Mauna Loa data begin just below 320 ppm, and increase rapidly from there. This is already significantly higher than the measured atmospheric abundance for any time in the last 400,000 years, although the variations during this period were considerable. (Some of these slopes appear quite steep too, but the time scale here is much, much longer.) The variations recorded at Vostok were accompanied by enormous changes in climate, including the advances and retreats of glaciers that at times covered much of the North American continent and Eurasia. As a rule over this period, low CO_2 intervals are associated with colder periods and relative glacial advance, while higher CO_2 is associated with the warmer interglacial periods.

We have excellent computer models to predict some of the effects of elevated CO_2 levels, and some of these are reflected in my testimony. Even without these model results, however, it would represent an extraordinary risk to push the climate system where it has never gone in over 400,000 years, and probably in tens of millions of years, when there is such a clear record of the relationship of CO_2 concentrations with climate. This is, in my opinion, a dangerous game to play with the only planet we have.

Q. How high are CO_2 levels projected to go in the century ahead?

A. There is an enormous range of uncertainty surrounding this question, having to do with such variables as population growth, economic activity, and technological change. In addition, there is a wide range of possible policy scenarios, ranging from business-as-usual (including continued and increasing reliance on coal-fired electricity generation) to very aggressive efforts to limit the disruptions and costs associated with climate change. The Working Group I Report presents a wide range of emissions scenarios, showing that atmospheric CO_2 could be anywhere from 500 ppm to 1000 ppm by the end of the current century, associated with a number of future emissions scenarios. *JI-2-B at 14.* This should be compared to a preindustrial level of about 280 ppm, and a level of about 380 ppm today. To achieve stabilization anywhere near the bottom of this range would require drastic cuts in emissions—ultimately reaching perhaps 70% or 80% below today's levels. The upper end of the range entails emissions at perhaps five times the rate seen today by the end of the century. However, this is consistent with current rates of growth in emissions, and assumes that projects such as Big Stone II will play a large role in meeting future energy needs.

Finally, I note that no one knows whether there is some "threshold" level at which catastrophic, irreversible climate change will occur. It is clear that the higher the concentration, the more likely it is that such a threshold will be crossed. But even without crossing such a threshold, computer models predict that the higher the CO_2 level in the atmosphere, the greater the environmental, economic and social dislocations that will result.

Q. How long will these increased CO_2 levels persist in the atmosphere?

A. The IPCC Working Group I Summary for Policymakers states that "several centuries after CO_2 emissions occur, about a quarter of the increase in CO_2 concentration caused by these emissions is still present in the atmosphere." *JI-2-B at 17.* Thus, CO_2 that we put in the atmosphere today will affect the climate of the planet for many centuries to come.

V. CLIMATE CHANGE TO DATE

Q. Please describe, in general, changes in global temperatures in the last century, and the likely causes of those changes.

A. The IPCC Working Group I Summary for Policymakers states that "[t]he global average surface temperature has increased over the 20^{th} century by about 0.6 °C." *JI-2-B at 2.* This is the conclusion drawn both from the more recent instrumental record, and from a number of so-called paleothermometers—the collected evidence from a large number of temperature proxies that all point the same direction.

We know that there is a causal relationship between atmospheric CO_2 levels and rising average surface temperatures. This relationship was originally postulated by the great mathematician and scientist Joseph Fourier as early as 1824, and was first quantified by Svante Arrhenius in 1896. As the quality of both measurement technology and numerical analysis have improved, these ideas have been strengthened and refined, and shown to be observable and measurable.

Q. How do we know that this warming is not part of a natural trend?

A. The IPCC Working Group I Summary for Policymakers concludes that "[t]here is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities….There is a longer and more closely scrutinized temperature record and new model estimates of variability. The warming over the past 100 years is very unlikely to be due to internal variability alone, as estimated by current models." *JI-2-B at 10*. [footnote omitted]

It goes on to state that "[i]n the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." *JI-2-B at 10.*

Finally, as I noted above, the direct impact of anthropogenic CO_2 on global temperature was first predicted *and quantified* more than 100 years ago. Today we have an excellent observational record and more sophisticated analytical tools that have shown these predictions to have been correct.

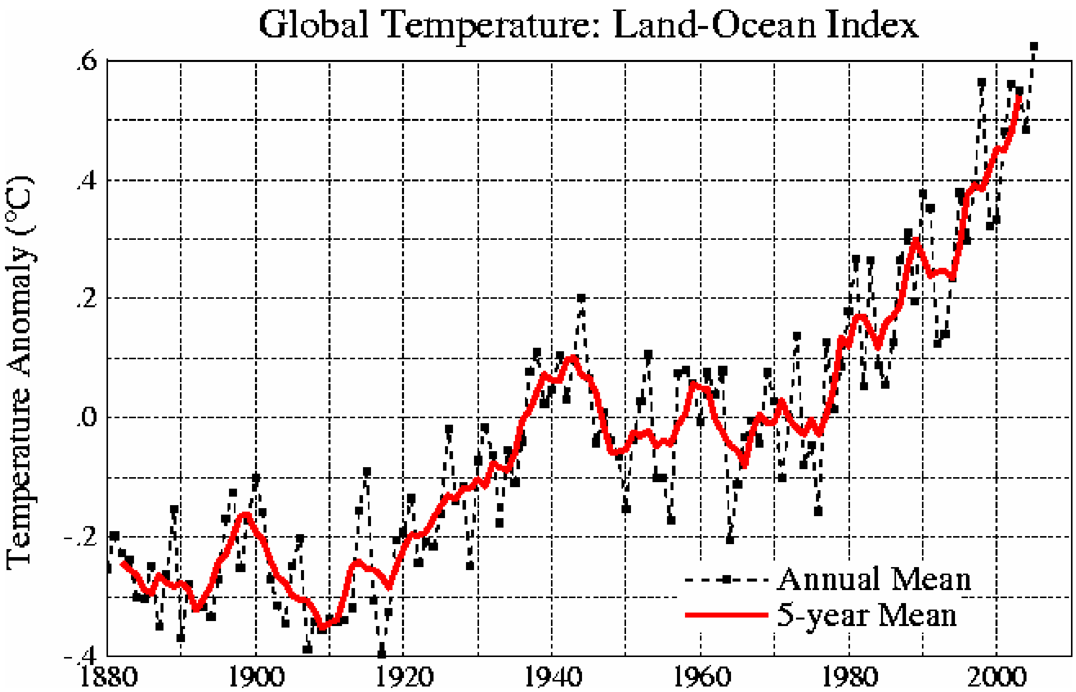
Q. Since the IPCC report was issued in 2001, what has been observed by climate scientists about global temperatures?

A. The highest annual average global surface temperature ever measured occurred during the 2005 calendar year, based upon an ongoing NASA analysis.[3] The NASA scientific team noted that 2005 was slightly warmer than 1998, the warmest previous year known. However, in 1998, there was an "El Niño" event,[4] which was not the case in 2005. This event has a strong effect on the equatorial Pacific surface ocean and would have affected the temperature record in that year.

Below I have reproduced one of the graphs from this study, showing the mean surface temperature "anomaly" from 1880 through the present. By anomaly, the authors mean the difference between the annual average surface temperature for a given year and the long-term average surface temperature, which they define as the overall average for the period 1951 through 1980. If a year is exactly average in terms of temperature, the anomaly would be zero. The graph also shows the "smoothed" 5-year mean temperature anomaly over this period:

[3] The GISS Surface Temperature Analysis is produced by Dr. James Hansen, director of NASA's Goddard Institute for Space Studies (GISS) at Columbia University in New York, along with Dr. Reto Ruedy and Dr. Ken Lo, also with the Goddard Institute, and Dr. Makiko Sato of the Columbia University Center for Climate Systems Research. The frequently-updated dataset is available online at *http://data.giss.nasa.gov/gistemp/ (last visited 11/15/06).*

[4] El Niño is an occasional disruption of the ocean-atmosphere system in the tropical Pacific, in which the trade winds weaken and warm water from the western boundary floods much of the surface equatorial Pacific. Thus this large warm anomaly would tend to elevate average global surface temperatures, independent of any other effects.



There are a number of ways to look at this. Four of the five warmest years on record have occurred since 2000. The ten hottest years on record have all occurred since 1990. Nineteen of the twenty warmest years on record have occurred since 1980, and so on. The evidence is consistent, statistically significant, and convincing. In addition, it is consistent with what is and has been predicted by computer models of the climate in response to today's elevated concentrations of atmospheric CO_2.

VI. EXPECTED FUTURE IMPACTS OF CLIMATE CHANGE

Q. What additional warming is predicted for the century ahead on a global level?

A. In 2001, the IPCC predicted that the average surface temperature of the earth will increase by 1.5 to 5.8 °C by 2100. The range reflects uncertainty about future emission levels and about precisely how the earth and atmospheric dynamics will respond to those emissions. In my opinion, as I will discuss below, this range is conservative.

Q. Can you provide any perspective on the significance of the projected changes in global temperatures in this century?

A. Temperature changes of 1.5 to 5.8 °C may sound small, but for perspective, the average surface temperature differential between the last ice age and the present was itself only about 5°C. During the last ice age, earth was a profoundly different place, with much of North America covered by an ice sheet a mile or more thick. At the upper range of the IPCC's 2001 warming prediction, earth would experience a warming equivalent to the one that melted that ice sheet. The recovery from the last major glacial period took on the order of 10,000 years. The warming we are discussing here will occur within a single century.

Q. What kinds of impacts are associated with warming projections in this range?

A. The IPCC Working Groups I and II Reports predict a large number of very serious negative impacts associated with this warming, including:

- rising sea levels, exposing coastal areas to increased risk of inundation and storm damage;
- Damage to or loss of natural ecosystems, such as prairie wetlands and alpine;
- Migration of habitats, leading to species extinctions and expansion of disease vectors and pests;
- heat waves leading to higher human morbidity and mortality from heat stress;
- more intense precipitation events resulting in increased floods, mudslides, and soil erosion; and
- increased summer drying in most continental interiors resulting in more droughts; reduced crop yields, reduced water availability and quality.

In addition, recent research[5] has established a surprisingly clear statistical link between tropical sea surface temperatures and the strength of tropical

[5] For example, see K. Emanuel, "Increasing destructiveness of tropical cyclones over the past 30 years", *Nature* 436(4):686-688, August, 2005; also P. J. Webster *et al.,* "Changes in Tropical

hurricanes. (I say this clarity is surprising because there is a great deal of natural variability in hurricanes, so such a well-defined relationship was not anticipated by, for example, the IPCC reports.) Thus, a temperature increase of the predicted magnitude may be expected to show up as a further increase in the number of very strong hurricanes, along with the associated damage to property and loss of life.

The higher the atmospheric abundance of CO_2 rises, the more severe we can expect these impacts to be; to some extent they are expected even at the lower warming projections. Indeed, there is evidence that the 0.6 °C warming we have experienced to date has already initiated many of these impacts.

Q. Are the impacts of future warming likely to unfold gradually?

A. The scientific evidence shows that this is unlikely. While computer models are generally unable to predict specific abrupt climate changes, we know from the geologic record that when the planet is changing from one type of climate to another, such as from an ice age to an interglacial, it often changes dramatically in an abrupt, lurching fashion. The well-dated ice core records, show several abrupt and sudden climate swings, during the warming period following the last ice age, of a magnitude that would be extremely disruptive were they to occur today.[6] Unfortunately, it is extremely difficult to predict at what level of atmospheric CO_2 such abrupt climate events would be likely to occur, or what their nature would be.

Q. Can you comment on the uncertainty associated with global climate change predictions?

A. Yes. There has been a great deal of confusion related to the "uncertainty" associated with predictions of impacts related to global climate change. The

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Cyclone Number, Duration, and Intensity in a Warming Environment", *Science* Vol. 309 No. 5742, September 2005.

[6] See, for example, National Research Council, "Abrupt Climate Change: Inevitable Surprises," National Academies Press, 2002, online at *http://www.nap.edu/books/0309074347/html/* (last visited 11/15/06).

climate system is extremely complicated, even chaotic in its response to perturbations; this is well established based upon ice core records and other geologic evidence. Computer models of the climate are unable to capture this characteristic of the climate well, as they tend to dampen out extreme effects. Thus while there is indeed a great deal of uncertainty in the impact of global warming, this should not be taken as "uncertainty" that the problem exists or that it poses a serious threat—the uncertainty lies in the risk that the climate system may in fact react much more severely than the models predict. In my judgment, climate scientists have been extremely conservative in not over-predicting the impacts of global climate change, largely publishing and publicizing impacts that they feel are virtually certain to occur. In this sense, action taken to reduce carbon emissions today, while fully justified to avoid the well-understood and near-certain impacts of climate change, is also essential as insurance against the possibility of much more severe impacts that are more poorly understood.

VII. IMPACTS OF CLIMATE CHANGE ON MINNESOTA

Q. Turning now to the regional impacts of climate change, can you identify any credible sources that forecast the impacts of increased atmospheric CO_2 on the geographic region around Minnesota?

A. First let me note that it is much more difficult to predict climate change impacts for specific areas with high confidence than it is for the planet as a whole, because of the significant complexities associated with changes in atmospheric circulation and cycling of moisture. Further, even the most highly resolved climate models still treat the Earth in large chunks compared to human scales—the most recent GISS model,[7] for example, has a grid size of 4^o longitude by 3^o latitude. At this scale the state of Minnesota would fit into a bit more than two grid squares.

[7] A climate model produced by NASA's Goddard Institute for Space Studies (GISS) at Columbia University in New York.

Nonetheless, certain forecasts can be made for mid-continental areas such as Minnesota, which appear to be a robust feature of climate models. Furthermore, a team of leading university and government scientists in the Great Lakes region conducted an extensive study in 2003 of the likely impacts of climate change in the Great Lakes area, including Minnesota, which provides valuable guidance. The report, entitled "Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems" ("Great Lakes Study"), was co-sponsored by the Ecological Society of America and the Union of Concerned Scientists. I consider this report to present scientifically sound, credible projections of the likely impacts of climate change in this region.

Q. What approach did the Great Lakes Study use in forecasting local impacts of increased atmospheric CO_2?

A. The Great Lakes Study based its analysis upon global climate simulations using two of the world's leading climate models. In addition, they analyzed historical climate and weather data to establish relationships between climate trends, which can be predicted by the models, and local temperature and weather characteristics.

Q. What did the Great Lakes Study team conclude about the likely impacts of climate change on the region?

A. I will quote from the subreport which deals specifically with impacts on Minnesota:

> **Climate Projections**
> In general, Minnesota's climate will grow considerably warmer and probably drier during this century, especially in summer.
>
> • *Temperature:* By the end of the 21st century, temperatures are projected to rise 6–10 °F in winter and 7–16 °F in summer. This dramatic warming is roughly the same as the warming since the last ice age. Overall, extreme heat will be more common and the growing season could be 3–6 weeks longer.
>
> • *Precipitation:* While annual average precipitation may not change much, the state may grow drier overall because rainfall cannot

> compensate for the drying effects of a warmer climate, especially in the summer. Seasonal precipitation in the state is likely to change, increasing in winter by 15–40% and decreasing in summer by up to 15%. Minnesota, then, may well see drier soils and perhaps more droughts.
>
> • *Extreme events:* The frequency of heavy rainstorms, both 24-hour and multiday, will continue to increase, and could be 50–100% higher than today.
>
> • *Ice cover:* Declines in ice cover on the Great Lakes and inland lakes have been recorded during the past 100–150 years and are expected to continue.
>
> **How the Climate Will Feel**
> These changes will dramatically affect how the climate feels to us. By the end of the century, the Minnesota summer climate will generally resemble that of current-day Kansas, and winters may be like those in current-day Wisconsin.

The report goes on to project specific impacts on the region, including impacts on water resources, agriculture, human health, wetlands and shorebirds, recreation and tourism, and forests and terrestrial wildlife. *All* of these impacts will be disruptive to the environment and communities in the state.

As a result of these changes, Minnesotans are likely to experience increased heating for more of the year, which will lead to increased evaporation and transpiration and ultimately to decreased soil moisture. This is likely to harm both agriculture and natural vegetation. There will be an increase in heat stress and associated human health impacts as the number of extremely hot days increases, and an increase in the incidence of heat-related morbidity and mortality. Although total rainfall may not change appreciably or may even increase, the region can expect an increased probability of severe drying and drought in the summer months coupled with more extreme rainfall events, with resulting ecological and economic damage.

Plant and animal species that reside in Minnesota will be displaced, and others will encroach as the habitat conditions change within the state and in the surrounding regions. Some, perhaps many, species of plants and animals will not be able to adapt to change or will be out-competed for resources. Agricultural pests and diseases are likely to spread as a result of the disruption of ecosystems. As a result of increased storm intensity, flooding and pollution of streams from soil erosion can be expected to increase.

In addition, a large percentage of prairie wetlands will be damaged or dry up, particularly the ephemeral seasonal wetlands that are so important to waterfowl production, likely resulting in a loss of waterfowl population. The impact on Prairie Pothole Region, wetlands and waterfowl will be discussed more fully below.

Q. Is it likely that most of the climate change impacts in Minnesota will be detrimental?

A. Yes. It is an unfortunate fact that most of the climate changes described in the Great Lakes Study are likely to be detrimental to the environment and communities of Minnesota. In fact, *any* rapid change in hydrology, temperature, seasonality, and habitat is likely to be economically and socially disruptive. The ecosystem and agriculture of the state and region exist in a balance, which is adapted to a certain set of climatic conditions, including a long-term range of variability. Once this system is changed that balance is disturbed, invariably resulting in damage to the natural system as it exists and is valued today.

Q. Is your testimony on these climate change trends supported by specific findings and conclusions in the IPCC report, Working Group I?

A. Yes. While the Working Group I Report does not specifically address climate change impacts in Minnesota, it does address regional impacts and reaches conclusions which are consistent with those that I have presented.

Q. What are the key findings and conclusions from that Report to which you refer?

A. The IPCC Working Group I Summary for Policymakers presents a table of forecasts along with estimates of their likelihood of occurrence (*JI-2-B at 15, Table 1)*, which includes the following conclusions that support the statements I have made (footnotes omitted in quotations):

1. "Increase of heat index over land areas" is projected to be "very likely, over most areas" during the 21st century.

2. "More intense precipitation events" are projected to be "very likely, over many areas" during the 21st century.

3. "Increased summer continental drying and associated risk of drought" is projected to be "likely, over most mid-latitude continental interiors" in the 21st century.

Q. Are you familiar with and have you reviewed a recent publication by W. Carter Johnson and coauthors, entitled "Vulnerability of Northern Prairie Wetlands to Climate Change", appearing in the October, 2005 issue of the journal Bioscience?[8]

A. Yes.

Q. Can you summarize the approach taken by the researchers as reported in this article?

A. The researchers base their analysis on global circulation models predictions of future climate, with increased atmospheric CO_2, in the Prairie Pothole Region (PPR). The PPR includes almost half of Minnesota, in addition to northern Iowa and Nebraska, most of the eastern Dakotas and parts of the Canadian provinces of Alberta, Saskatchewan and Manitoba.

[8] Johnson, W.C., B.V. Millett, T. Gilmanov, R.A. Voldseth, G.R. Guntenspergen and D.E. Naugle, "Vulnerability of Northern Prairie Wetlands to Climate Change", *Bioscience 55(10),* pp.863-872, October, 2005.

The authors then apply these climate conditions to a calibrated model of the PPR wetlands to determine how the wetlands will respond and what the implications will be for migrating waterfowl, in what they refer to as the "heart of the PPR's 'duck factory' during the 20th century." [p. 869]

Q. What do the authors conclude regarding expected future changes in climate in this region?

A. Johnson and coauthors summarize the climate model results as follows:

> Increased drought conditions in the PPR are forecast to occur under nearly all global circulation model scenarios. Regional climate assessments suggest that the central and northern Great Plains of the United States may experience a 3.6 °C to 6.1 °C increase in mean air temperature over the next 100 years. Longer growing seasons, milder winters in the north, hotter summers in the south, and extreme drought are projected to be a more common occurrence over the PPR. Trends in mean annual precipitation are more difficult to predict, and range from no change to an increase of 10% to 20% concentrated in the fall, winter, and spring, accompanied by decreased summer precipitation and a higher frequency of extreme spring and fall precipitation events. [pp. 864-865. References removed.]

Q. Can you comment on the conclusions reached in that article regarding the impact of these changes on the ecology of the Prairie Pothole Region?

A. The authors find that global climate change is likely to have a significant negative effect on this region, and ultimately on the population of waterfowl that use this region as a breeding ground:

> The observed sensitivity of the model to climate variability suggests that wetlands in the drier portions of the PPR, such as the US and Canadian High Plains, would be especially vulnerable to climate warming, even if precipitation were to continue at historic levels. Only a substantial increase in precipitation would counterbalance the effects of a warmer climate. Additionally, the most productive wetlands, currently centrally located in the PPR, may become marginally productive in a warmer, drier future climate. Historically a mainstay for waterfowl, the region including the Dakotas and southeastern Saskatchewan would become a more episodic and less

> reliable region for waterfowl production, much as areas farther west have been during the past century. [p. 871]

Interestingly, the authors find this to be the case even though some regions will become wetter and others will become dryer:

> A logical question is whether the favorable water and cover conditions in the eastern PPR that we simulated can compensate for habitat losses in the western and central PPR. Historically, the eastern PPR and northern parklands served as a safe haven for waterfowl during periodic droughts. Today, however, options are limited, because more than 90% of eastern PPR wetlands have been drained for agricultural production. Although wetland restoration programs have been under way since the mid-1980s, less than 1% of basins drained in Minnesota and Iowa have been restored. Restoration efforts in the east have developed slowly, largely because of the high cost of farmland easements. [pp.871-872, references removed]

Q. Does this finding support your assertion, stated earlier, that *"any* rapid change in hydrology, temperature, seasonality, and habitat is likely to be economically and socially disruptive"?

A. Yes.

Q. Have you quantified the likely economic impacts of global warming, either in Minnesota or globally?

A. While I am quite confident that the economic impacts of all of the damages I have mentioned will be quite large, I have made no independent estimate of how costly this is likely to be. However, I am familiar with at least one very recent and comprehensive study which has attempted to make such an estimate on a global basis. This study, entitled the *Stern Review on the Economics of Climate Change* ("Stern Review"), was commissioned by the U.K. Chancellor of the Exchequer and released in October of this year.[9]

[9] Nicholas Stern, "Stern Review on the Economics of Climate Change," Report to the Prime Minister and Chancellor of the Exchequer, Oct. 2006, available on-line at *http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm* (last visited 11/15/06).

Q. What did the Stern Review conclude on the global costs of climate change?

A. The Stern Review conclusions are summed up as follows:

> Using the results from formal economic models, the Review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more. (*Summary of Conclusions, p. vi)*

VIII. BIG STONE II CO_2 EMISSIONS

Q. Are fossil-fired electric generation plants in the United States, such as the proposed Big Stone Project, a significant contributor to the production and build-up of these gases?

A. Yes**.** The United States contributes more than any other nation, by far, to global greenhouse gas emissions on both a total and a per capita basis, contributing 24 percent of the world CO_2 emissions from fossil fuel consumption.

Coal-fired power plants in the United States already emit almost one-third of U.S. emissions, or 8% of all the world's anthropogenic CO_2 into the atmosphere, a staggering contribution to the global buildup of greenhouse gases. Further, recent analysis has shown that in 2004, power plant CO_2 emissions were 27 percent higher than they were in 1990.[10] Coal fired power plants in the United States are unquestionably a major and growing source of greenhouse gases, and thus represent a significant cause of global climate change.

[10] EIA, "Emissions of Greenhouse Gases in the United Sates, 2004;" Energy Information Administration; December 2005, xiii

Q. Other than their relative contribution to increasing atmospheric CO_2 each year, are there any other characteristics of coal-fired power plants like the proposed Big Stone II Project that raise particular concerns regarding climate change?

A. Yes. Large, base load coal plants in the United States are built to produce electricity for decades, as long as 70 years in the case of some of the older plants still operating today. The evidence I have presented and discussed in my testimony shows that climate change is a serious threat to the environment and to human societies, including those of Minnesota, and that that threat is becoming increasingly obvious and severe. Today, the United States is almost alone among industrialized nations in failing to impose any cost on our electric sector or our industries for producing the greenhouse gases that cause this problem. As a result, utilities around the nation are making plans to invest in infrastructure that will emit CO_2 by the millions of tons into the indefinite future. The Big Stone II proposal is a good example of this shortsighted and distorted investment strategy.

Q. What would the lifetime emissions of CO_2 from the Big Stone II Project be?

A. If built and operated as proposed, Big Stone II would add over 4.7 million tons of CO_2 to the atmosphere every year of its operational life, inexorably and significantly contributing to the buildup of greenhouse gases in the atmosphere. That amounts to emissions of about 235 million tons of CO_2 injected into the atmosphere over the first fifty years of operation.

Q. Could you compare the projected CO_2 emissions from the Big Stone II Project to Minnesota emissions today?

A. The Big Stone II Project's annual emissions would represent a significant increase in carbon emissions relative to Minnesota's existing levels.

According to the EPA,[11] Minnesota's electric sector CO_2 emissions in 2003 (the last year for which these figures are available) were 35.7 million tons of CO2. The Big Stone II Unit's emissions of 4.7 million tons of CO_2 per year would therefore represent an addition of 13% to Minnesota's electric sector emissions. Alternatively, at 4.7 million tons per year the emissions from the Big Stone Unit II would be equivalent to the CO_2 emissions from about 700,000 additional cars—an additional 28% of current emissions today from all of the cars registered in the state.[12] Either way, this represents a large step in the wrong direction if the goal is to protect both global climate and the environment in Minnesota and the surrounding regions by stabilizing atmospheric CO_2 at any acceptable level.

Q. What is the significance of the Midwestern United States to the Global Warming phenomenon?

A. The Midwest is America's heartland and responsible for 20% of the CO_2 emissions in the United States, and 5% of the world's total emissions. The Midwest alone is responsible for more global warming gas pollutants than any country in the world other than the U.S. itself, China, the former Soviet Union, India and Japan.

IX. SCIENTIFIC CONCLUSIONS RELATED TO LEGAL STANDARDS

Q. What is your opinion as to whether the Big Stone II Project will, or is likely to, materially adversely affect the environment?

A. My opinion is that the emissions of over 4.7 million tons of CO_2 per year from this proposed facility would cause material, adverse and irreversible damage to the environment. I am especially concerned that, considering its expected lifetime of 50 years or more and the slow recovery time for

[11] U.S. EPA, "CO2 Emissions from Fossil Fuel Combustion," dataset available online at *http://www.epa.gov/climatechange/emissions/downloads/CO2FFC_2003.pdf* (last visited 11/15/06).

[12] Estimate based on average vehicle emissions of 13,500 lbs/year of CO2 (U.S. EPA, "EPA's Personal Greenhouse Gas Calculator) and 2.5 million cars registered in Minnesota (Federal Highway Administration, State Motor Vehicle Registrations – 2004).

atmospheric CO_2, these emissions will contribute to elevated levels of CO_2 in the atmosphere, to increased radiative forcing of climate and to accelerated global climate change for several centuries to come. I consider this to be a material, adverse impact on the environment, both globally and in Minnesota and the surrounding region.

Q. Will the Big Stone II Project protect or enhance environmental quality?

A. No. Although there may be some benefits to the pollution controls proposed for Big Stone I as a part of this project, the overall impact of the Big Stone II Project is a threat to environmental quality because it will contribute significantly to the build-up of CO_2 in the atmosphere, increasing the danger of adverse impacts associated with global warming that I have discussed above. The scientific evidence clearly shows that averting these impacts and associated costs will require reductions, not increases, in greenhouse gas emissions as quickly as possible, and over a sustained period of time. Building the Big Stone II Project is a significant step in the wrong direction that will make it harder to achieve the necessary CO_2 reductions to protect and enhance the environment.

Q. How do the effects of Big Stone II on the natural environment compare to the effects of energy alternatives like demand-side management, wind, natural gas, and hydro power?

A. Any of these alternatives are preferable to Big Stone II from the standpoint of CO_2 emissions and impact on global climate. Demand-side management and wind are effective means of meeting energy needs with little to no environmental impact, while modern natural gas power generation produces much more energy per unit of carbon emissions than does even the most efficient coal burning technology. Hydro power is also an emissions-free energy source, but as it often produces substantial local environmental impacts, it is impossible to state generically how the effects would compare with other alternatives. However, it is my opinion that in general, any of these options is preferable to coal-fired generation from an environmental standpoint because they contribute so much less than Big Stone II would to the most serious environmental threat we face this century.

Q. In your professional opinion, does the Big Stone II Project provide benefits to society in a manner compatible with protecting the natural environment, including human health?

A. No. For all of the reasons I have outlined above, I conclude that the Big Stone II Project would produce and deliver energy at a high cost on society in terms of its contributions to global climate change, with its associated adverse impacts on the natural environment, human health and society at large.

In fact, this Project will result in long-term impairment of the environment by increasing the carbon dioxide levels in the atmosphere. I state this based both on the volume of carbon dioxide emissions that it will cause over its lifetime, over 225 million tons, and on the fact that this will elevate the carbon dioxide load of the atmosphere for several centuries. This Project, by itself and cumulatively with other electrical generation plants, will exacerbate the effects of global warming and global climate change. The ultimate level of carbon dioxide in the atmosphere will determine how much global warming, and hence how much environmental damage, ultimately occurs.

The adverse environmental impacts of global climate change, including regional impacts on the patterns of temperature and precipitation to which our ecosystems, our society and our agriculture are adapted, will be made more severe than they would be without this Project and without the cumulative effect of this and other coal-fired electric generation plants. As noted earlier in this testimony, such changes are likely to include increasingly severe summer droughts, more intense storms and extreme rainfall events, increased soil erosion and silting, and the loss of much of the prairie pothole wetland resource and its associated waterfowl populations.

In contrast, developing non-fossil approaches to meeting energy needs will materially reduce the ultimate severity of climate impacts and the ultimate costs of remediation. Thus the contribution of the Big Stone II Project to the impacts and costs I have discussed are avoidable and unnecessary, given the available alternatives to coal-fired generation.

Q. In summary, what would you say is the significance of the Big Stone II Project to the problem of Global Climate Change, assuming that it would contribute over 4.7 million tons of CO_2 emissions each year for approximately the next 50 years, or longer?

A. The significance of the proposed Project is this: This Project, alone and in combination with other coal-fired energy conversion facilities, will contribute materially and significantly to the environmental, social and economic destruction associated with global climate change. We cannot pretend to be protecting the environment of either Minnesota or the world at large from this overwhelming threat while we continue to build long-lived infrastructure that has exactly the opposite effect. In this respect, I conclude that the Big Stone II Project will have a significant, long-term, and costly adverse impact on the environment both in Minnesota and throughout the region, the continent and the planet as a whole.

Q. Does this conclude your testimony?

A. Yes.