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

In the Matter of the Further Investigation into
Environmental and Socioeconomic Costs
Under Minnesota Statute 216B.2422, Subdivision 3

OAH Docket No. 80-2500-31888

MPUC Docket No. E-999-CI-14-643

Exhibit _____

Rebuttal Testimony and Exhibits of

Professor Robert Mendelsohn

August 12, 2015

Q. Please state your name.

A. Robert Mendelsohn.

Q. Did you previously submit testimony in this proceeding?

A. Yes. I submitted pre-filed direct testimony on June 1, 2015.

Q. Have you reviewed other pre-filed testimony?

A. Yes. I reviewed written testimony by Michael Hanemann, Nicholas Martin, and Stephen Polasky.

Q. Have you prepared a rebuttal report that responds to this pre-filed testimony?

A. Yes, I have prepared a report, which is attached as Mendelsohn Rebuttal Exhibit 1.

Q. Have you responded to discovery requests in this proceeding?

A. Yes. I was asked to provide evidentiary support for certain statements. My responses, which are attached as Mendelsohn Rebuttal Exhibit 2, provide substantial support for my statements.

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Exhibit 1

to

Rebuttal Testimony of Professor Robert Mendelsohn

Professor Robert Mendelsohn

I have previously presented direct testimony in this proceeding and am presenting this rebuttal report in response to the testimony of Professor W. Michael Hanemann, on behalf of the Division of Energy Resources of the Minnesota Department of Commerce, in consultation with the Minnesota Pollution Control Agency, Professor Stephen Polasky, on behalf of Clean Energy Organizations, and Nicholas Martin, on behalf of Xcel Energy.

1. My Comments on The Testimony of Professor Hanemann and Professor Polasky.

It appears that Professor Michael Hanemann and Professor Stephen Polasky have been asked to give opinions outside their areas of expertise. Neither appears to be very familiar with Integrated Assessment Models ("IAMs") and the calculation of the social cost of carbon. Both of them rely on the estimate of the federal social cost of carbon developed by the U.S. government's Interagency Working Group ("IWG"), but they are especially unfamiliar with the many problems with the IWG estimates. In my opening direct testimony, I presented many criticisms of the IWG estimates, and these criticisms also apply to the attempt by Professors Hanemann and Polasky simply to follow the IWG.

Professors Hanemann and Polasky argue that the assumptions made by the IWG are reasonable and therefore endorse the IWG conclusions.[1] They do not offer a single criticism of the IWG methodology, although Professor Polasky argues that the numbers are too conservative. Professor Polasky argues that the damages are even higher than what the IAM's predict and the true value of time (the discount rate) should be even lower than 2.5%.[2] Except for Professor Polasky's criticisms, their primary comment on the SCC is that they agree with everything the IWG did. They present no additional evidence.

[1] Hanemann Testimony at 64-74; Polasky Testimony at 21-26.
[2] Polasky Testimony at 18-24

Professor Hanemann and Professor Polasky appear to be unaware that the IWG is measuring the SCC assuming that the rest of the world will never do any mitigation. They never mention this assumption. They are untroubled that a critical assumption in the IWG analysis is no reciprocal mitigation by any other state much less any other nation. They appear not to realize the IWG values assume that not only is Minnesota the first place to undergo mitigation, but it is the only place to ever do mitigation. They are not troubled that the cost of global mitigation is borne by Minnesota alone in this analysis. They are not troubled that the analysis assumes Minnesota is completely ineffective at being a leader for the world.

Professor Hanemann and Professor Polasky do not have any qualms about the global benefit perspective of the IWG SCC estimate. They are not in the least concerned that the cost of this program is borne entirely by the residents of Minnesota but the benefits fall almost entirely outside the United States. In fact, the residents of Minnesota would be lucky if they get 1% of the benefits of this costly program. There is every reason to believe that Minnesota will be a beneficiary of warming over the next century from the increased productivity of their ecosystems, from the increase in crop production, and from reductions in heating costs in winter. These will far outweigh any likely damage in the state during this period. Far future impacts may be harmful but it will take a long time before they outweigh the benefits over the next century. I am surprised that especially Professor Polasky (as a resident) does not warn his state that the high costs of this effort will yield very little (and possibly nothing) in benefits for the state.

If Minnesota chooses a high price of carbon (above $40/ton), coal may no longer be viable in the state, and coal plants in Minnesota may then be forced to shut down. Utilities that rely on natural gas are hoping that they will fill the void, increasing the cost of power to Minnesota. However, it is likely that Minnesota will also import power from neighboring states. Minnesota may insist that this power be based on low carbon fuels. So neighboring

states may simply assign the power from their natural gas power plants to the Minnesota market and then increase the coal plants in their own state for their own use. This will give neighboring states an advantage over Minnesota because they will have cheaper electricity rates. It also undermines the Minnesota carbon program because although emissions in the state fall dramatically, emissions from the region may not change nearly as much. There will be leakage as emissions are simply reassigned (not reduced) from Minnesota to neighboring states sharing the same grid. The net effect of leakage makes the program globally ineffective. Minnesota will be achieving a lot less than it hopes with this program.

Professor Polasky and Hanemann both claim that the IWG SCC is respectable because it is based on three respectable models: DICE, FUND, and PAGE.[3] However, their testimony reveals that they are aware that the IWG did not use the DICE, FUND, or PAGE model to estimate the SCC. Professor Hanemann and Polasky acknowledge that the GDP estimates, the population estimates, and the emission estimates were all drawn from other models or from the IWG alone.[4] The IWG did not cite any results that actually come from the DICE, FUND, or PAGE models. All the results mentioned in the IWG are from a hybrid model that uses different assumptions from different places. The IWG does not even compare the estimates in their report with the published findings of these three models.

Although Professor Polasky and Professor Hanemann are careful in their own research on ecosystems and contingent valuation surveys, respectively, they appear to be unaware that one of the primary values of IAM models is that they carefully integrate economic assumptions across the economy. At least the DICE and FUND model are internally consistent. The IWG exercise violates the carefully constructed assumptions of these IAM models with IWG assumptions. The IWG made several mistakes forcing their

[3] Hanemann Testimony at 66; Polasky Testimony at 24-25.
[4] Hanemann Testimony at 46-48; Polasky Testimony at 8-9.

own GDP, population, emission, and interest rate assumptions into these IAM models. Professors Polasky and Hanemann do not address this issue at all.

First, the IWG assumes that income, population, and the interest rate are all independent. They act as if one can make whatever assumption about all three of these variables one wants. The IWG abandons the assumptions in DICE that generate different interest rates depending on the growth of income per capita (GDP and population). One cannot make different assumptions about income and population without changing the interest rate in DICE.

DICE is very carefully calibrated to predict emissions depending on GDP and an observed decay rate in emission per unit of GDP. These assumptions are overridden in the IWG analysis. Emissions and GDP are assumed to be independent. In fact, the IWG assumptions for population, GDP, and emissions from 2100 through 2300 have never been peer reviewed. The IWG results are based on long term assumptions that have not been evaluated. It is simply not correct to argue that the IWG results depend on three well reviewed models. Professor Hanemann and Polasky do not appear to be aware that the social cost of carbon estimates that would come from the DICE and FUND models are not consistent with the estimates of the IWG.

Professor Hanemann endorses the low discount rates of 2.5% and 3% used by the IWG to evaluate the future impacts of climate change.[5] Professor Polasky feels the IWG interest rates are too high and presses for an interest rate of 1-2%.[6] When one uses a low discount rate to evaluate the benefits of a project, one is effectively assuming that getting this rate of return is acceptable for this project. Of course, that also means society gets very little in return for making this investment compared to the myriad other public and private

[5] Hanemann Testimony at 68-69, 73.
[6] Polasky Testimony at 12, 20-21.

investments society can make at higher rates of return. The benefits of the project seem higher but actually the project is less worthwhile. The Professors' support for low interest rates appears to be more advocacy than expert advice.

Arguments have been made by economists why discount rates may fall in the far future. They are based on a slowing of the growth of income. For example, the DICE model assumes that interest rates will fall as per capita income falls. Although interest rates are 5% today in DICE, they fall to closer to 3.5% by 2100. Professor Hanemann and Professor Polasky appear not to be aware that DICE itself has a falling interest rate tied to a slowing of economic growth over time. This justifies a discount rate that falls over time but it does not justify a low fixed rate.

Professor Polasky argues that we should use a low interest rate because the damage function in the IAM's is not high enough to measure the true damage of a 6°C warming.[7] If the IAM's cannot measure the damage of large warming, why would one change the interest rate? Why not change the damage function? But Professor Polasky does not cite any evidence to show what the true damage of a 6°C warming would be, nor does he cite evidence to support his projected warming of 6°C.

Professor Polasky argues that the damage functions in the IAMs underestimate damage.[8] But he does not cite research supporting the claim (that warming is occurring at 6 degrees and what the damage level at 6 degrees might be) nor does he cite research that the aggregate estimates in the IAMs are too low. Moreover, why would he have confidence in the results of the IAMs if he believes that the IAM damages are too low?

[7] Polasky Testimony at 19, 20-24.
[8] Polasky Testimony at 18-20, 21-24.

Professor Hanemann has estimated a damage function for farmland in the United States.[9] It is a quadratic damage function based on temperature over the growing season in the United States. It is not consistent with the damage function in the IAM models based on the change in global temperature since preindustrial times.

Both Professor Hanemann and Professor Polasky believe it is appropriate that the IWG averaged the results across the DICE, FUND, and PAGE models.[10] That implicitly means they feel all three models are equally valid. They treat the single equation damage function of DICE, the uncalibrated probabilistic damage function of PAGE, and the carefully calibrated sector-specific regional damages of FUND as equally valid. No justification is given for this treatment.

Professor Hanemann and Professor Polasky suggest there is an ethical reason to adopt low interest rates.[11] If that were true, they should endorse a public policy that encourages an across the board reduction in the interest rate. This would make all investments more attractive. One would not only invest more in preventing climate change but one would also invest more in other public investments such as schools, hospitals, roads, aircraft carriers, and tanks. One would also invest more in cars, housing, malls, and factories. But the Professors are not really arguing for a low interest rate. They are simply arguing for more funds to be spent on climate change mitigation.

Economists are not exactly experts in ethics. However, Professors Hanemann and Polasky weigh in that a low discount rate is necessary for ethical reasons.[12] They argue we must not discount the benefits to future generations using the value of time that we use for ourselves (the interest rate).[13] We must give more resources to future generations and use

[9] Hanemann Testimony at 27-29.
[10] Hanemann Testimony at 46, 73; Polasky Testimony at 6, 14, 17, 24-25.
[11] Hanemann Testimony at 53, 68-69, 73; Polasky Testimony at 11-12, 20-21.
[12] Hanemann Testimony at 53, 68-69, 73; Polasky Testimony at 11-12, 20-21.
[13] Hanemann Testimony at 68-69, 73; Polasky Testimony at 12, 20-21.

less ourselves. The problem with this argument is that global warming projections all assume that future generations will be wealthier than we are. It is the future high-income generations that create the huge emissions that cause the SCC to rise in the IWG analyses. By lowering the discount rate, the professors are shifting the burden of paying for climate change away from these future wealthier generations and putting the cost instead on the present generation. It is not clear why the present relatively poor generation should have to bear more than their fair share of the cost of this intergenerational policy. It is not at all clear why a low discount rate is "ethical."

Professor Hanneman and Professor Polasky acknowledge that the IWG estimates of the SCC changed dramatically between 2010 and 2013.[14] However, neither seemed particularly concerned about the magnitude of the change. They simply accepted the fact that it was updated. However, it is of great concern for utilities making multi-million-dollar long-term investments, if the value of those investments can shift so quickly over such a short time. The justification for this large shift would have to be a major scientific advance. However, what we learn from the IWG is the justification for the change is that the authors of the DICE, FUND, and PAGE models made some minor adjustments in their models. An additional change in the SCC has already been announced by the OMB. Additional minor flaws in the calculations have been identified by Anne Smith in her direct testimony. A process which is this vulnerable to minor modifications is not reliable. There is simply too much money resting on the SCC estimate for such a casual process.

2. <u>My comments on the testimony of Nicholas Martin.</u>

Nicholas Martin has been working for the private sector for 15 years. Mr. Martin argues that the uncertainty inherent is estimating the SCC suggests that there is no single number one can use to value carbon.[15] He suggests that the court rely on a range of values based on arbitrary assumptions about eliminating the bottom and top 25% of the

[14] Hanemann Testimony at 56-59; Polasky Testimony at 14, 17, 26.
[15] Martin Testimony at 3-7, 30-50, 50.

distribution.[16] His assumption of what SCC values to eliminate unfortunately violates his own rule not to be subjective. His desire to have a range of values and not a single value makes the process of using the SCC completely arbitrary and capricious which violates another of his own principles about transparency. Mr. Martin never explains why the expected value of this distribution is not a reasonable tool for regulatory analysis as suggested by the risk literature.

Mr. Martin proposes to aggregate results based on three different discount rates.[17] He appears to be unaware that this is logically inconsistent since the discount rates are not uncertain, they are simply controversial. This introduces more uncertainty in the analysis than is really there. Mr. Martin assumes that all of the IWG runs are valid descriptions of what may happen in the future. As I have already discussed, that assumption is not reasonable.

3. Further Evidentiary Support for my testimony.

I am also attaching to my rebuttal report my responses to discovery requests I have received in this proceeding, which asked me to provide evidentiary support for the following statements:

- *"Ecological models suggest that Minnesota forests would become more productive and have more standing biomass as a result of near term climate change."*
- *"A slightly warmer, wetter, and CO2-enriched world may be a better place."*

My responses to the discovery requests demonstrate the substantial support for my statements.

[16] Martin Testimony at 57-58.
[17] Martin Testimony at 59-60.

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In the Matter of the Further Investigation in to Environmental and Socioeconomic Costs Under Minnesota Statute 216B.2422, Subdivision 3

OAH Docket No. 80-2500-31888
MPUC Docket No. E-999-CI-14-643
Exhibit 2
to
Rebuttal Testimony of
Professor Robert Mendelsohn
August 12, 2015

State of Minnesota
DEPARTMENT OF COMMERCE
DIVISION OF ENERGY RESOURCES

Robert Mendelsohn Rebuttal
Ex. 2
OAH 80-2500-31888
MPUC E-999/CI-14-643

Utility Information Request

Docket Number: E999/CI-14-643

Date of Request: June 22, 2015
Due Date: July 10, 2015, per agreement between the parties

Requested From: All Intervening Parties

Analyst Requesting Information: Zac Ruzycki

Type of Inquiry:

[ ] Financial	[ ] Rate of Return	[ ] Rate Design
[ ] Engineering	[ ] Forecasting	[ ] Conservation
[ ] Cost of Service	[ ] CIP	[X] Other:

If you feel your responses are trade secret or privileged, please indicate this on your response.

Request No.	
1	If applicable, please provide any and all work associated with the development of your proposed social cost of carbon (SCC) value, including live spreadsheets, workbooks, and any other documents pertaining to the development of the methodology in an open format available for examination and editing. **Response of Peabody Energy Corporation ("Peabody")** Peabody objects to this request as vague and overly broad. Peabody further objects to this request to the extent it seeks information or documents protected by the work-product doctrine. Peabody further objects to this request to the extent it seeks information that is public and equally available to the Department of Commerce. Subject to and without waiving the foregoing objections, Peabody will produce a memorandum by Professor Robert Mendelsohn describing the publicly available code and software he used, and the modeling outputs he obtained. These modeling outputs also will be produced. The produced documents are being provided both electronically and on a disc sent to the address indicated in the cover letter accompanying this information request.

Response by: Robert Mendelsohn
Title: _____
Department: Yale University
Telephone: _____

List sources of information:

Supporting Documentation Concerning DICE Runs

The analysis relies on DICE2013R. The computer code for DICE2013R was downloaded from:

http://www.econ.yale.edu/~nordhaus/homepage/Web-DICE-2013-April.htm

The program is labelled "vanilla" by Professor Nordhaus and contains both a BAU and an optimal scenario.

DICE2013Rv2_102213_vanilla_v24b.gms

The GAMS software was used to calculate the results with this program.

In order to match the IWG results to 2300, the DICE model was run to 2400 but the results were stored only up to 2300. The runs were made by Jonghyun Yoo under the direction of Robert Mendelsohn.

RESULTS

There are three files of results: BASIC DICE, ANNUAL IMPACTS, and CLIMATE SENSITIVITY RUNS.

The BASIC DICE runs stored the output of DICE for four scenarios:

DICE with all its baseline assumptions on "Optimal"

DICE with all its baseline assumptions on "BAU"

DICE with a damage function that begins at 1.5C above preindustrial

DICE with a damage function that begins at 2.0C above preindustrial

For each of the runs described above, the ANNUAL IMPACT FILE calculates the damage each year from the baseline and the damage with one gigaton added per year in 2015-2019 (from a background level of 29 Gt/yr). The difference in damage is then divided by the tonnage added to get a marginal value of a metric ton in the 2015 period.

The CLIMATE SENSITIVITY RUNS explain how the "Optimal" results would change if one assumed the climate sensitivity (the long run temperature change associated with doubling greenhouse gases) was different from 3.0C. A separate analysis is done with each damage function. The damage functions explored include the DICE original damage function, the damage function starting at 1.5C above preindustrial, and the damage function starting at 2C above preindustrial.

CLEAN ENERGY ORGANIZATIONS
INFORMATION REQUESTS

Date of Request: July 6, 2015

Requested By: Leigh Currie
Minnesota Center for Environmental Advocacy
26 East Exchange Street, Suite 206
St. Paul, MN 55101-1667
lcurrie@mncenter.org
651-287-4873 (direct)

Attorney for Izaak Walton League of America – Midwest Office, Fresh Energy, Sierra Club, and Minnesota Center for Environmental Advocacy (collectively "Clean Energy Organizations")

Requested From: Peabody Energy

Response Due: July 16, 2015

In the Matter of the Further Investigation into Environmental and Socioeconomic Costs Under MN Statute 216B.2422, Subdivision 3

PUC Docket No. E999/CI-14-643

INFORMATION REQUESTS NOS. 2-10 OF CLEAN ENERGY ORGANIZATIONS TO PEABODY ENERGY

To Roger Bezdek:

2. On pages 2, 9, and 16 of his Direct Testimony, Dr. Bezdek references "thousands" of studies demonstrating that carbon dioxide is beneficial to plant growth. Provide citations for the studies that purport to demonstrate that increased carbon dioxide emissions and increased global temperature will result in increased crop production.

RESPONSE:

Please see response contained in the attached Exhibit A.

3. On page 8 of his Direct Testimony, Dr. Bezdek states: "Researchers have thus concluded that IAMs are of little or no value for evaluating alternative climate change policies and estimating the SCC." List the names of the researchers who have reached these conclusions and provide citations to the publications in which those researchers have made those statements.

RESPONSE:

Please see response contained in the attached Exhibit A.

4. On page 26 of his Direct Testimony, Dr. Bezdek states "rigorous assessment of these IAMs by leading economists have concluded that the IAMs are 'close to useless.'" List the name "leading economists" who have reached these conclusions and provide citations to the publications in which those economists have made those statements.

RESPONSE:

Please see response contained in the attached Exhibit A.

To Robert Mendelsohn:

5. On page 4 of his Direct Testimony, Dr. Mendelsohn states: "Ecological models suggest that Minnesota forests would become more productive and have more standing biomass as a result of near term climate change." Provide citations for the ecological models referenced in this statement.

RESPONSE:

Dr. Mendelsohn's views on ecosystem productivity under climate change were formed as part of his research on forests with Professor Sohngen. This research indicates that global forests will increase the supply of timber as a result of climate change. The papers from that work include:

Sohngen, B. and R. Mendelsohn. 2003. "An Optimal Control Model of Forest Carbon Sequestration" *American Journal of Agricultural Economics* **85** 448-457.

Sohngen, B., R. Mendelsohn and R. Sedjo. 2002. "A Global Model of Climate Change Impacts on Timber Markets" *Journal of Agricultural and Resource Economics* **26:** 326-343.

Sohngen, B., R. Mendelsohn and R. Sedjo. 1999. "Forest Management, Conservation and Global Timber Markets" *American Journal of Agricultural Economics* **81:** 1-13.

Sohngen, B. and R. Mendelsohn. 1998. "Valuing The Market Impact of Large-Scale Ecological Change: The Effect of Climate Change on US Timber", *American Economic Review* **88:** 686-710.

Sohngen, B. and R. Mendelsohn. 1997. "A Dynamic Model of Carbon Storage in the United States During Climatic Change." Critical Reviews in Environmental Science and Technology. 27:s309-s321 (Special Edition).

Sohngen, B., R. Mendelsohn, and R. Neilson. 1998. "Predicting CO_2 Emissions From Forests During Climate Change: A Comparison of Natural and Human Response Models", *Ambio* **27:** 509-513.

Sohngen, B. and R. Mendelsohn. 2007. “The Effect of Technical Change in Forestry on Global Sequestration” in Schlesinger, M., Kheshgi, H., Smith, J. de la Chesnaye, F. Reilly, J., Wilson, T. and Kolstad, C. (eds.) *Human-Induced Climate Change: An Interdisciplinary Assessment* Cambridge University Press, Cambridge UK p227-237.

Sedjo, R., B. Sohngen, and R. Mendelsohn. 2001. “Estimating Carbon Supply Curves for Global Forests and Other Land Uses.” Discussion Paper 01-19. Washington: Resources For the Future.

Sohngen, B., R. Mendelsohn, R. Sedjo, K. Lyon. "Human Adaptation in Ameliorating the Impact of Climate Change on Global Timber Markets" in *Climate Change Mitigation and European Land-use Policies.* N. Adger, D. Pettenella, and M. Whitby (eds.) CAB International, NY 1998.

Mendelsohn, R. and B. Sohngen. 2015. “Historic Carbon Emissions from Land Use” Manuscript, Yale University, New Haven CT.

The economic analyses of forestry are in turn based on quantitative ecological models. These models of large scale ecosystems were at first comparative equilibrium studies trying to understand how these ecosystems would change in response to past climate changes as well as future ones.

Emanuel, W. R., H. H. Shugart, and M. P. Stevenson. "Climate Change and the Broad-Scale Distribution of Terrestrial Ecosystem Complexes." *Climatic Change* 7(1985):29-43.

Haxeltine, A. "Modelling the Vegetation of the Earth." Unpub. Ph.D. diss., Faculty of Science, Plant Ecology, Lund University, Lund, Sweden, 1996.

Haxeltine, A., and I. C. Prentice. "BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition Among Plant Functional Types." *Global Biogeochemical Cycles* 10,4(1996):693-709.

Joyce, L. A., J. R. Mills, L. S. Heath, A. D. McGuire, R. W. Haynes, and R. A. Birdsey. "Forest Sector Impacts from Changes in Forest Productivity Under Climate Change." *J. Biogeography* 22(1995): 703-13.

Melillo, J. M., A. D. McGuire, D. W. Kicklighter, B. Moore, III, C. J. Vorosmarty, and A. L. Schloss."Global Climate Change and Terrestrial Net Primary Production." *Nature* 363(1993):234-40.

Neilson, R. P., and D. Marks. "A Global Perspective of Regional Vegetation and Hydrologic Sensitivities from Climate Change." *J. Vegetation Sci.* 5(1994):715-30.

Olson, J. S., J. A. Watts, and L. J. Allison. "Carbon in Live Vegetation of Major World Ecosystems." Rep.No. ORNL-5862, Oak Ridge National Laboratory, Oak Ridge TN, 1983.

Shugart, H. H., M. Antonovsky, M. Ya, P. G. Jarvis, and A. P. Sandford. "C0$_2$, Climatic Change, and Forest Ecosystems." In *The Greenhouse Effect, Climatic Change, and Ecosystem*, eds. B. Bolin, B. R. Doos, J. Jager, and R. A. Warrick, pp. 475-521. Chichester, UK: John Wiley & Sons, Ltd., 1986.

Solomon, A. M. "Transient Response of Forest to C02-lnduced Climate Change: Simulation Modeling Experiments in Eastern North America." *Oecologia* 68(1986):567-79.

Solomon, A., N. H. Ravindranath, R. B. Steward, M. Weber, and S. Nilsson. "Wood Production Under Changing Climate and Land Use." In*Climate Change 1995:Impacts, Adaptation, and Vulnerability,* eds., R. T. Watson, M. C. Zinyowera, and R. H. Moss, pp. 487-510. London/New York: Cambridge University Press, 1996.

More recent ecosystem literature deals with dynamic vegetation models:

Cramer, W., A. Bondeau, FI Woodward, et al. 2001. Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models. *Global Change Biology*. 7: 357-373.

Gerber, S., J. Fortunat and I .C. Prentice. 2004. Sensitivity of a dynamic global vegetation model to climate and atmospheric CO2. *Global Change Biology* 10, 1223–1239.

Scholze, M., W. Knorr, NW. Arnell, and IC Prentice. 2006. A climate-change risk analysis for world ecosystems. *Proceedings of the National Academy of Sciences* 103(35): 13116–13120.

Sitch, S., C. Huntingford, N. Gedney, P. E. Levy, M. Lomas, S . L . Piao, R . Betts, P. Ciais, P. Cox, P. Friedlingstein, C. D. Jones, I. C. Prentice, and F. I . Woodward. 2008. Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using five Dynamic Global Vegetation Models (DGVMs), *Global Change Biology* 14, 2015–2039.

Smith, T. M., and H. H. Shugart. 1993. "The Transient Response of Terrestrial Carbon Storage to a Perturbed Climate." *Nature* 361: 523-26.

6. *On page 8 of his Direct Testimony, Dr. Mendelsohn states that "[a] slightly warmer, wetter, and CO_2-enriched world may be a better place." Provide the basis for this statement, including citations as appropriate.*

RESPONSE:

The materials cited in response to Question 5 address why ecosystems in Minnesota are likely to benefit from climate change which is part of the response to Question 6. In addition, it is expected that agriculture in Minnesota will benefit.

Professor Mendelsohn's report, at p. 5, states that "Research suggests that damage in America will be concentrated in the warmer states along its southern border (Mendelsohn, Nordhaus, and Shaw 1994; 1996; Mendelsohn and Neumann 1999, Mendelsohn 2003). Minnesota will likely benefit from current emissions . . . . "

The cited works are:

Mendelsohn, R., W. Nordhaus and D. Shaw. 1996. "Climate Impacts on Aggregate Farm Values: Accounting for Adaptation", *Agriculture and Forest Meteorology* **80:** 55-67.

Mendelsohn, R., W. Nordhaus and D. Shaw. 1994. "Measuring the Impact of Global Warming on Agriculture", *American Economic Review* **84:** 753-771.

Mendelsohn, R. and J. Neumann (eds.) 1999. *The Impact of Climate Change on the United States Economy* Cambridge University Press, Cambridge, UK

Mendelsohn, R. "Assessing The Market Damages From Climate Change" in J. Griffin (ed) *Global Climate Change: The Science, Economics, and Politics* Edward Elgar Publishing, UK, 2003, pp 92-113.

Additional works include:

Robert Mendelsohn, "The Impact of Climate Change on Agriculture in Asia," 13 J. Integrative Agric. S2095 (2013).

Mendelsohn, R and A. Dinar. 2009. *Climate Change and Agriculture: An Economic Analysis of Global Impacts, Adaptation, and Distributional Effects.* Edward Elgar Publishing, England.

Mendelsohn, R. 2001. *Global Warming and the American Economy: A Regional Analysis*. Edward Elgar Publishing, England.

Ariel Dinar and Robert Mendelsohn (eds), *Handbook of Climate Change and Agriculture* (Edward Elgar Publishing, England, 2011).

Robert Mendelsohn and Ariel Dinar, *Climate Change and Agriculture: An Economic Analysis of Global Impacts, Adaptation, and Distributional Effects* (Edward Elgar Publishing, England, 2009).

Dinar, A., R. Hassan, R. Mendelsohn, and J. Benhin, *Climate Change and Agriculture in Africa: Impact Assessment and Adaptation Strategies* (EarthScan, London, 2008).

Joel Smith and Robert Mendelsohn (eds.), *The Impact of Climate Change on Regional Systems: A Comprehensive Analysis of California* (Edward Elgar Publishing, Northampton, MA, 2006).

R. Mendelsohn. 2014. "The Impact of Climate Change on Agriculture in Asia" Journal of Integrative Agriculture 13: 660-665.

Kala, N. P. Kurukulasuriya, and R. Mendelsohn. 2012. "How Will Climate Change Shift Agro-Ecological Zones and Impact African Agriculture" Environment and Development Economics 17: 663-687.

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In addition, Professor Mendelsohn's report, at p. 12, states "carbon fertilization has increased crop yields by a far larger amount across the entire world (Kimball 1983) suggesting a sizable net benefit. The warmer temperatures are encouraging ecosystems to move poleward (IPCC 2013b) which is a change that may lead to damage in some places. For example, plants have flowered earlier, birds have arrived sooner after winter, and birds have over wintered in more northern locations in the northern hemisphere. However, the carbon fertilization of trees has also led to an overall increase in ecosystem productivity and standing biomass (Gerber et al. 2004) which is an overall net benefit for ecosystems."

The cited works are:

Gerber, S., J. Fortunat, and I .C. Prentice. 2004. "Sensitivity of a dynamic global vegetation model to climate and atmospheric CO2" Global Change Biology 10: 1223–1239.

Intergovernmental Panel on Climate Change (IPCC). 2013b. Impacts, Adaptation and Vulnerability, Cambridge University Press, Cambridge UK.

Kimball, B. A. 1983. "Carbon Dioxide and Agricultural Yields: An Assemblage and assessment of 430 prior observations" Agronomy Journal 75: 779-788.

Related work on carbon fertilization include:

Acock, B. and Allen, L.H. Jr. 1985. Crop responses to elevated carbon dioxide concentration. In: *Direct Effects of Increasing Carbon Dioxide on Vegetation.* DOE/ER-0238. B.R. Strain and J.D. Cure (eds.). US Dept. of Energy, Carbon Dioxide Res. Div., Washington DC. pp. 53-97.

Kimball, B.A., Mauney, J.R., Nakayama, F.S. and Idso, S.B. 1993. Effects of increasing atmospheric CO_2 on vegetation. *Vegetatio* **104/105:** 65-75.

To Richard Lindzen:

7. Provide the basis (including all computer codes) for the graphs contained in Exhibit 2 to Dr. Lindzen's direct testimony.

RESPONSE:

The graphs are the results of simple calculations made by Professor Lindzen in order to identify the amount of cancellation needed by high sensitivity models. The energy balance model used is fully described in Lindzen and Giannitsis (1998). The equation is essentially the one-dimensional heat equation, which is linear and whose numerical solution is standard elementary applied math. (Professor Lindzen used the program Mathcad 15.)

Lindzen, R.S. and C. Giannitsis (1998) On the climatic implications of volcanic cooling. *J. Geophys. Res.*, **103**, 5929-5941.

8. Provide the basis (including, as appropriate, citations to the peer-reviewed literature in which these statements have been published) for the following statements:

a. p. 2, line 22: "only mild warming at most, which will be beneficial to the planet and to society as a whole."

RESPONSE:

The benefits of mild warming and increased CO_2 levels are addressed in Professor Lindzen's report at lines 569-608, which contains references to:

Driessen, P. and R. Arnold, 2014, Miracle Molecule: Carbon Dioxide, Gas of Life, Available as Kindle book from Amazon.com, 40 pp.

Goklany, I., 2012, Humanity Unbound How Fossil Fuels Saved Humanity from Nature and Nature from Humanity, Cato Policy Analysis No. 715, 33 pp.

Guo, Y., Gasparrini, A., Armstrong, B., Li, S., Tawatsupa, B., Tobias, A., & Williams, G. (2014). Global Variation in the Effects of Ambient Temperature on Mortality: A Systematic Evaluation. Epidemiology, 25(6), 781-789

Idso, C. et al, 2000, Ultra-enhanced spring branch growth in CO2-enriched trees: can it alter the phase of the atmosphere's seasonal CO2 cycle? Environmental and Experimental Botany, Volume 43, Issue 2, April 2000, Pages 91-100

Further references include:

State of Minnesota
DEPARTMENT OF COMMERCE
DIVISION OF ENERGY RESOURCES

Nonpublic ☐
Public ☐

Utility Information Request

Docket Number: E999/CI-14-643

Date of Request: June 22, 2015
Due Date: July 2, 2015

Requested From: All Intervening Parties

Analyst Requesting Information: Zac Ruzycki

Type of Inquiry:

[ ] Financial	[ ] Rate of Return	[ ] Rate Design
[ ] Engineering	[ ] Forecasting	[ ] Conservation
[ ] Cost of Service	[ ] CIP	[X] Other:

If you feel your responses are trade secret or privileged, please indicate this on your response.

Request No.	
1	If applicable, please provide any and all work associated with the development of your proposed social cost of carbon (SCC) value, including live spreadsheets, workbooks, and any other documents pertaining to the development of the methodology in an open format available for examination and editing. **PEABODY ENERGY CORPORATION ("PEABODY")** **SUPPLEMENTAL RESPONSE** **DATED JULY 17, 2015** Peabody restates its objections to this request. Peabody objects to this request as vague and overly broad. Peabody further objects to this request to the extent it seeks information or documents protected by the work product doctrine. Peabody further objects to this request to the extent it seeks information that is public and equally available to the Department of Commerce. Subject to and without waiving the foregoing objections: Peabody is providing information from Professor Mendelsohn regarding the modified damage function described in his report.

Response by: Robert Mendelsohn
Title:
Department: Yale University
Telephone:

List sources of information:

Original damage function in the DICE is,

$$\Omega(t) = 0.00267 \times [T_{AT}(t)]^2$$

where omega is annual climate damage as a percent of GDP and T_{at} is temperature change from 1900.

The two modified damage functions alter the relationship with T_{at}. Damage does not start at 1900 T but rather at 1900 T +1.5C or +2C.

For example, the damage with the +2C rule is the following:

If $T_{AT}(t) \geq 2$,
$\Omega(t) = 0.00267 \times [T_{AT}(t) - 2]^2$

If $T_{AT}(t) < 2$,
$\Omega(t) = 0$

Response by: Robert Mendelsohn

Title:

Department: Yale University

Telephone:

List sources of information: