Xcel Energy®

414 Nicollet Mall
Minneapolis, MN 55401

November 12, 2015

—Via Electronic Filing—

The Honorable LauraSue Schlatter,
The Honorable John Oxley
Office of Administrative Hearings
P.O. Box 64620
St. Paul, MN 55164-0620

RE: CO_2 ISSUES LIST
       INVESTIGATION INTO ENVIRONMENTAL AND SOCIOECONOMIC COSTS
       MPUC DOCKET NO. E999/CI-14-643
       OAH DOCKET NO. 80-2500-31888

Dear Judges Schlatter and Oxley:

I attach the CO_2 Issues List which the parties have been cooperatively working on together. The disclaimers on the cover sheet helped to smooth the process, but have also kept the door open on possible disputed areas. Even though there has been cooperation in putting this together, the parties are still reserving their rights to file comments on the issues list, which under the current case schedule would be due December 15, 2015.

I will mail two hard copies of the CO_2 Issues List.

Please contact me at james.r.denniston@xcelenergy.com or (612) 215-4656 if you have any questions regarding this filing.

Sincerely,

/s/

JAMES R. DENNISTON
ASSISTANT GENERAL COUNSEL

Enclosures
c: Service List

STATE OF MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS

FOR THE PUBLIC UTILITIES COMMISSION

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

CO$_2$ Issues List

Disclaimer and limitation on use of CO$_2$ Issues List:

This Issues List should not be viewed as an advocacy document. Instead it is designed to identify the important issues under discussion in this proceeding and connect them with references to where these issues were discussed in pre-filed testimony. If any issue is not mentioned in the document, parties can still argue that issue. Similarly, the brief descriptions here do not prevent parties from describing the issues differently or in greater detail in their briefs or post-hearing argument. The Issues List does not limit advocacy, nor should it be used to attempt to show an inconsistent position of a party. The proposed Findings of Fact and briefs of the parties should cite to the record, and do not need to be tied to the issues as described in this Issues List. To prepare this Issues List, each party assumed responsibility for the descriptions of the testimony of its witnesses; other parties do not, merely by joining in the submission of this document, agree to the descriptions of testimony of witnesses offered by other parties. To be clear, where the summary of the position of a witness in this Issues List references the testimony of another witness, the party whose witness testimony is being referenced is not responsible for how that testimony of its witness is being characterized.

Table of Contents

I.   Whether the Federal Social Cost of Carbon (SCC) is Reasonable and the Best Available Measure to Determine the Environmental Cost of CO_2? (Issue 1)

A. Support Adoption of FSCC

1.   Polasky

Record Citations:
Polasky Direct at 2, 7-26
Polasky Rebuttal passim
Polasky Surrebuttal passim, at 26
Polasky Rebuttal Schedule 1 (OMB Response to Comments) passim

Polasky (CEOs[1]): Dr. Polasky concluded that the Federal SCC as developed by the Interagency Working Group (IWG) is a reasonable and best available measure and recommended that the Commission adopt all four executive summary SCC values. According to Dr. Polasky, the IWG process to develop the SCC employed well accepted scientific methods and a transparent approach. The IWG also made reasonable and appropriate attempts to estimate the SCC given the inherent uncertainty, for example by using three different Integrated Assessment Models (IAMs), five different socioeconomic and emissions projections, three different discount rates, a range of parameter values for some parameters, and a probability distribution for the equilibrium climate sensitivity (ECS) parameter. Dr. Polasky stated that the IWG made a reasonable tradeoff when it decided not to use each IAM's internal assumptions but instead used different, harmonized assumptions to facilitate cross-model comparison. The IWG estimate of SCC summarizes the best available information and provides a well-developed and acceptable estimate of the expected value of future damages from CO_2 emissions. Dr. Polasky believed that the SCC is a conservative estimate that likely errs on the side of underestimating the damage from climate change because the IAMs do not give sufficient weight to potential catastrophic outcomes, the IWG used relatively high discount rates, the IAMs may not adequately account for impacts of climate change on economic growth, and the IAMs exclude several potentially important types of damages from climate change. According to Dr. Polasky, the IWG approach is based on a synthesis of the existing scientific understanding and as such it is a better approach than relying on the results of a single researcher based on their own particular set of assumptions.

Dr. Polasky supported all four summary SCC values: the 2.5, 3, and 5 percent discount rate average values as well as the 95th percentile value at 3 percent discount rate, for emission years 2010 through 2050. He recommended these values from Appendix A of the updated July 2015 Technical Support Document (TSD).

Dr. Polasky noted throughout his testimony that the Office of Management and Budget had issued a response to comments from the IWG which further explained the reasonableness of the IWG's assumptions and approach.

2.   Hanemann

Record Citations:

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[1] Clean Energy Organizations.

Hanemann Direct at 44, 66-69, 73-74
Hanemann Rebuttal at 16-17, 87-88
Hanemann Surrebuttal at 10-11, 30, 32-37

Dr. Hanemann (Agencies[2]): Dr. Hanemann stated that the IWG's methodology to develop the Federal SCC values is reasonable and the best available method to develop CO_2 values for Minnesota. According to Dr. Hanemann, the use of simplified representations of climate change and impacts in the IAMs is necessary and does not render them inappropriate for use in estimating the SCC. To the contrary, because of the constraints of computing capacity, it is essential to use reduced-form models in order to be able to combine emissions, climate change, and impacts in one unified assessment. Dr. Hanemann stated that it was appropriate for the IWG to use DICE, PAGE, and FUND models, standardize their inputs, and run them side-by-side for comparisons. Dr. Hanemann believed that the IAM damage functions used by the IWG are likely to understate the SCC. The federal SCC is updateable; while there remains uncertainty, as we know more about the likely trends for adaptation, mitigation and emissions, the SCC can be updated. He recommended as a reasonable and the best available point estimate $36 for emissions year 2015 and $42 for emissions year 2020 (both in 2007 dollars per metric ton), based on the updated July 2015 TSD and the 3 percent discount rate average SCC value. If Dr. Hanemann had to recommend a range of values, his recommendation was from $11 (5 percent discount rate average SCC value) to $56 (2.5 percent discount rate average SCC value) for emissions year 2015 and from $12 (5 percent discount rate average SCC value) to $62 (2.5 percent discount rate average SCC value) for emissions year 2020, based on the updated July 2015 Technical Support Document (TSD). If viewing the SCC "through the lens of risk management," Dr. Hanemann believed that the Commission could also consider the 95th percentile value at 3 percent discount rate ($105 for emission year 2015 and $123 for emission year 2020), although he does not appear to recommend this value.

3.   Abraham

Record Citations:
Abraham Rebuttal, at 28

Dr. Abraham addressed the validity of the IWG's use of a probability distribution of equilibrium climate sensitivities from the IPCC. He concluded that the climate science underlying the IWG's calculation of the social cost of carbon was sound and consistent with the consensus position of scientists and professionals with expertise in climate science.

4.   Rom

Record Citations: Rom Rebuttal at 8-19

Rom (DHE[3]): Although the SCC underestimates the costs of CO_2 emissions and accounts only for a bare minimum of damages to public health, Dr. Rom supported the use of the SCC as a reasonable and the best available estimate of the environmental and socioeconomic costs of CO_2 emissions. Dr. Rom stated that the SCC omits several key damages incurred by the public as a

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[2] Department of Commerce, Division of Energy Resources and the Minnesota Pollution Control Agency.
[3] Doctors for a Healthy Environment.

result of CO_2-induced climate change, particularly exacerbated health harms from ozone and $PM_{2.5}$ and increased air pollution from wildfires. Dr. Rom explained that increasing temperatures from climate change can affect pollutant levels by influencing the formation, transportation, dispersion, and deposition of pollutants such as ozone and $PM_{2.5}$. In addition, once these pollutants come into contact with human tissues, ambient temperatures can impact how significantly these pollutants affect the patient's health. According to Dr. Rom, none of the IAMs include damages from modification of ozone and $PM_{2.5}$ concentrations through warmer temperatures. Increased temperatures may also heighten the seriousness of health impacts from exposure to ozone and $PM_{2.5}$. Dr. Rom suggested that the SCC estimates should be considered lower bounds of the actual forecasted damages when they are used in a regulatory setting. He estimated that the SCC likely underestimates the health impacts of climate change by at least $930 billion in 2100.

5.   Kunkle

Record Citations: Kunkle Rebuttal at 2

Kunkle (CEBC[4]): Kunkle supported adoption of the Federal SCC as a reasonable and best measure available to account for externalized damage costs of carbon emissions. Proper valuation of the costs associated with the environmental pollution generated by the electricity industry will create a more level playing field, he argues, sending the right signals to the market to promote non-CO_2 emitting energy technologies and thus ramping up industries that can create jobs, strengthen the economy, and help support a cleaner and healthier environment.

6.   Rumery

Record Citations: Rumery Rebuttal at 2

Rumery (CEBC): Rumery supported adoption of the Federal SCC as a reasonable and best measure available to account for externalized damage costs of carbon emissions. Proper valuation of the costs associated with the environmental pollution generated by the electricity industry will create a more level playing field, he argues, sending the right signals to the market to promote non-CO_2 emitting energy technologies and thus ramping up industries that can create jobs, strengthen the economy, and help support a cleaner and healthier environment.

B. Oppose Adoption of FSCC

1.   Mendelsohn

Record Citations:
Mendelsohn Direct at 2, 7-17, Ex. 2 at 2, 9-10
Mendelsohn Rebuttal, Ex. 1 at 4-5
Mendelsohn Surrebuttal at 27-28, 33-34

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[4] Clean Energy Business Coalition.

Mendelsohn (Peabody[5]): According to Dr. Mendelsohn, it would be inadvisable to adopt the current Federal SCC as estimated by the IWG. Although DICE and FUND are frequently cited and have excellent reputations, the IWG did not use these models with the assumptions or for the purposes for which they were designed. The PAGE model should never have been included in the calculation of the SCC. Dr. Mendelsohn stated that the IWG did not in fact use the DICE, FUND, and PAGE models to estimate the SCC, because GDP estimates, population estimates, and emissions estimates were drawn from other models. The published native DICE and FUND values of the SCC are much lower than the IWG values. Dr. Mendelsohn stated that although well intentioned, the IWG made numerous theoretical and modeling errors and significantly overestimated the SCC. For example, the IWG did not take into account mitigation efforts currently in place or initiated in the future; used many of its own assumptions instead of the IAMs' assumptions (e.g., GDP, emissions, discount rates, and climate sensitivity); and assumed that future societies will not adapt to climate change and damages.

2. Tol

Record Citations:
Tol Rebuttal at 3-6, 8-9, 10-12

Tol (Peabody): Dr. Tol testified that the Federal SCC is not a reasonable measure and that the FUND model as used by the IWG was unrecognizable compared to the model he created. First, the IWG's estimates of the SCC using the FUND model went up substantially between 2010 and 2013. Dr. Tol was surprised by that. According to the way in which he ran the FUND model, the numbers went down during that time frame. In 2011, FUND estimated a social cost of carbon of $8.0 per ton. In 2014, it was $6.6 per ton, using the IWG's parameters and estimate of climate sensitivity. Second, the IWG process and the calculations themselves were not transparent, raising serious questions as to whether they are economically and scientifically valid. Third, the IWG did not use the Ramsey rule, under which the discount rate varies with economic growth. Dr. Tol believes that the Ramsey rule is the best approach. Under the IWG's approach, it puts a premium on the impacts in countries that grow faster than the USA. The effect can be substantial. For instance, using the FUND scenario as used by the IWG, impacts in China are weighted 46% to 87% higher than impacts in the USA. In other words, a $1.00 loss in the USA is counted as $1.00; but a $1.00 loss in China is counted as $1.46 to $1.87. The result of this approach is that the IWG effectively places more value on the circumstances in China than on those in the USA.

Dr. Tol testified that the climate sensitivity value plays an important role in determining what the impact of warming will be, because the initial impacts of climate change are positive, due to carbon dioxide fertilization, reduced winter heating, and fewer cold-related deaths.

3. Bezdek

Record Citations:
Bezdek Direct at 1-9, 26-27, 36
Bezdek Rebuttal, Ex. 1 at 19, 22-23, 29, 38-39, 46-49

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[5] Peabody Energy Corporation.

Bezdek (Peabody): According to Dr. Bezdek, the Federal SCC is not a reasonable and best available measure and the SCC estimates should not be used as environmental values in Minnesota. The SCC estimates are not credible and do not adequately consider the benefits of fossil fuels and CO_2 emissions. Dr. Bezdek stated that the IAMs are fatally flawed and unreliable, and therefore the IWG's estimates of the SCC are also fundamentally invalid and without scientific basis. Dr. Bezdek pointed out that numerous distinguished economists have concluded that the IAMs are "close to useless" as tools for policy analysis. The PAGE model, in particular, suffers from serious flaws and should not be used for policymaking.

4.   Spencer

Record Citations:
Spencer Direct at 3-6; Ex. 2, at 6
Spencer Rebuttal, Ex. 1, at 1
Spencer Surrebuttal at 16

Spencer (Peabody): Dr. Spencer addressed the validity of climate model projections of global and regional temperatures used in the determination of the SCC. He testified that all three independent classes of temperature observations – satellite, radiosondes (weather balloons), and land-based measurements -- show that the climate models used by governments for policy guidance show warming that is 2 to 3 times higher than the real climate system over the last 35 to 55 years, which is the period of greatest greenhouse gas emissions and atmospheric greenhouse gas concentrations. Recent research suggests that the climate models are too sensitive to these emissions, and that increasing greenhouse gases do not cause as much warming and associated climate change as is commonly believed. These results suggest that any SCC estimates based upon such models are biased high.

5.   Happer

Record Citations:
Happer Direct at 9, 12
Happer Rebuttal, Ex. 1, at 2-4
Happer Surrebuttal at 6, 9

Happer (Peabody): Dr. Happer noted that the IWG has ignored a great deal of science published after 2007 and refused to re-evaluate its chosen ECS value of 3.0 degrees, despite numerous papers showing a great deal of doubt about that number—including the IPCC AR5, which no longer offers 3 degrees as a "best guess." Dr. Happer believed IPCC climate models have consistently "run hot" (i.e., have overpredicted warming) and should not be used as the basis for policy decisions. Dr. Happer stated that if the benefits of more atmospheric CO_2 (such as carbon fertilization) were properly accounted for in the models, the benefits would far outweigh the losses and the SCC would be negative. Dr. Happer recommended negative CO_2 environmental values.

6.   Lindzen

Record Citations:
Lindzen Direct at 2-3, 8
Lindzen Rebuttal, Ex. 1, at 2-3
Lindzen Surrebuttal at 3, 15-29

Lindzen (Peabody): Dr. Lindzen testified that the current models attempting to determine a social cost of carbon are inherently biased high because they rely on IPCC's flawed and overestimated conclusions regarding the effect of increase in CO_2 concentrations on global climate. The IPCC models should not be used to estimate the SCC because they do not provide accurate or reliable information. Further, even the IPCC has lowered its numbers and its confidence. The IWG drew its ECS figures from AR4, drafted in 2007 (2°C to 4.5°C, with a "best estimate" of 3.0°C). The IWG declined to revisit the ECS question in any of the three revisions (May 2013, November 2013, and July 2015). AR4 stated that the ECS was "very unlikely" to be less than 1.5 °C, but AR5 gave 1.5 °C as the low end of the "likely" range with "high confidence." AR5 also declined to determine a "best estimate," while AR4 gave 3°C, which is the exact value assumed by the IWG. The stated reason for not citing a best estimate in the AR5 was the substantial discrepancy between observation-based estimates of ECS (lower), versus estimates from climate models (higher). Hence, AR5 reflects a tendency towards lower values of the ECS than the AR4. In addition, Dr. Lindzen noted that Figure 1 of Box 12.2 in the AR5 WG1 report shows that 11 out of 19 observational-based studies of ECS have values below 1.5°C in the range of their ECS probability distribution. Beyond the IPCC, 14 studies and 20 experiments validated a lower, tighter range for ECS between the 2010 TSD and the 2013 update to the TSD. Nevertheless, despite the fact that this science had been well known before its July 2015 revision, the IWG refused to revisit its ECS estimate.

7.   Smith

Record Citations:
Smith Direct at 14-37, Ex. 2 at 7-13, 40-49, Table 5, 64, 79, 83, 91, 99, 102-104
Smith Rebuttal at 4-6
Smith Surrebuttal at 8-9, 14-34

Smith (GRE/MP/OTP/MLIG[6]): According to Dr. Smith, the Federal SCC is not a reasonable and the best available measure of the environmental cost of CO_2, and it is not reasonable to rely upon the IWG's values for the SCC to determine Minnesota's CO_2 environmental values, because the sensitivity of the IAMs to unverified and non-scientific assumptions made by modelers, as well as by model users, throws into question the reasonableness of using any SCC value that the IAMs may produce. The SCC values lack reasonableness for national-level as well as state-level policy-making, and alternative approaches to the IAM-based SCC calculation of marginal damages may provide a more reliable set of values. Given the Public Utilities Commission's approach and instructions, however, Dr. Smith has focused her testimony on four assumptions that she concludes should be made differently *if* one desires to look to the IWG's SCC values. Correcting these assumptions will result in values that fit better with the IAMs'

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[6] Great River Energy, Minnesota Power, Otter Tail Power Company, and the Minnesota Large Industrial Group.

evidentiary foundations, have significantly less speculative content, and are more appropriate for use in a single state in the absence of reciprocity. Dr. Smith specifically criticized the IWG's framing assumptions with respect to (1) which ton to value; (2) modeling horizon; (3) discount rate; and (4) geographic scope of damages. Finally, she noted that the IWG's SCC values have not accounted for the possibility of leakage, which is a particular concern for reduction actions that take place within the electricity system of a single state that is interconnected to electricity systems in other states that are not participating in the same resource-planning restraints. With respect to which ton to value, Dr. Smith asserted that valuing the last ton inappropriately charges Minnesota with damages emitted by others elsewhere and in the future. Dr. Smith accordingly supports the use of a "first ton" and an average between the first and last ton rather than a "last ton." With respect to modeling horizon, Dr. Smith asserted that projecting damages out to the year 2300 requires extrapolation of the underlying damage functions well past their empirical bases to the point where the projections are so speculative as to be nearly worthless. With respect to discount rate, Dr. Smith stated that the use of a 2.5% rate is unsupported by empirical evidence, that Federal guidance identifies 3% as a lower bound for approximating the social rate of time preference, but actually requires use of a 7% rate when a regulation will affect private sector capital spending, because 7% approximates the opportunity cost of displaced private sector investment. Accordingly, Dr. Smith testified that the discount rate to be used have a lower bound of 3% and an upper bound of not less than 5%. Fourth, Dr. Smith stated that the use of global damages, rather than Minnesota damages or U.S. damages, is contrary to sound economic principles in the absence of reciprocal agreements with major emitting nations. Finally, leakage should be accounted for by applying a social cost of carbon value only to net emissions reductions estimates.

8. Gayer

Record Citations:
Gayer Direct at 8-10, Expert Report at 2-18
Gayer Surrebuttal at 2-9, 19-20

Gayer (MLIG[7]): According to Dr. Gayer, the global damages scope contained in the Federal SCC is not appropriate in the absence of explicit reciprocity by other states or other nations. The IWG's focus on global damages from incremental CO_2 emissions (or benefits from reducing CO_2 incrementally) is not consistent with sound benefit-cost practices, nor within the guidance provided by executive orders and the Office of Management and Budget (OMB), and would demand a dramatic shift in all state policies, including state poverty programs, if applied broadly. He stated that standard benefit-cost practice considers the benefits only for the jurisdiction that is bearing the costs of the policy (economic standing). While demonstrative feelings of altruism could justify considering benefits outside of Minnesota, any reasonable estimate of the magnitude of altruism would suggest only partial consideration of non-Minnesotans, with greater weight given in proportion to proximity. Since Minnesotans will accrue all costs, absent explicit reciprocity, it would be unreasonable for Minnesota to consider the environmental benefits to the entire global population. Adjusting damages estimates from a global to a national level would result in estimates that are 7% to 23% in magnitude of global damages. In the absence of even

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[7] Minnesota Large Industrial Group.

national reciprocity, adjusting damages estimates from a global to a state level would result in estimates that are approximately 0.4% of the global value.

Dr. Gayer did not opine upon, and did not endorse, any other IWG assumptions.

9. Martin

Record Citations:
Martin Direct at 4-10, 50-69
Martin Rebuttal at 2-8, 54-56
Martin Surrebuttal at 1-6, 32-34, 44-45

Martin (Xcel Energy[8]): Mr. Martin believed that the four Federal SCC executive summary values do not represent a reasonable and best available measure of the environmental cost of CO_2. He emphasized that there is inherent uncertainty in estimating long-term damages from climate change, and the IWG had to make policy judgments on certain issues when it developed the SCC values. While Mr. Martin did not endorse the SCC executive summary values, criticized many aspects of the IWG's methodology, and noted he would have preferred a regulatory cost approach, he nevertheless believed that (of the available damage cost approaches) the underlying SCC methodology and raw modeling outputs can be used as a reasonable and the best available starting point to develop a range of environmental values for CO_2. Mr. Martin opposed adopting any single point estimate or value, and instead proposed a range, which can be adjusted if the Commission decides to make different policy judgments than the IWG.

II. Issues Regarding the Federal Social Cost of Carbon (Federal SCC).

A. Is Federal SCC Based on a Damage Cost Approach? (Issue 2)

Record Citations:
Polasky Direct, at 24
Polasky Surrebuttal, at 18
Hanemann Rebuttal at 39-40
Hanemann Surrebuttal 43
Tol Rebuttal at 10-12
Mendelsohn Direct, Ex. 2, at 4-10
Mendelsohn Surrebuttal at 21-25
Smith Direct at 19-20, Ex. 2 at 5, 20-25
Smith Rebuttal at 4-5
Martin Direct at 65-67
Martin Surrebuttal at 32

Polasky (CEO): Dr. Polasky describes the IWG's SCC as the best available "damage-cost measure" of CO_2 emissions. He explains that the IWG applies the standard tools and methodologies of environmental and resources economics to climate change, an environmental problem that is greater in scope and temporal dimension than typical analyses.

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[8] Northern States Power Company, doing business as Xcel Energy.

Hanemann (Agencies): Dr. Hanemann stated that although the SCC estimates contain aggregated damage functions, these are fully consistent with the standard notion of a damage cost approach. He pointed out that it is not reasonable to expect the use of conventional dose-response functions on the spatial and temporal scales required for an IAM damage function, as argued by Dr. Smith.

Tol (Peabody): Dr. Tol argued that the Federal SCC was not a proper damages-cost measure because it necessarily incorporates complex and contingent human decisions on issues far afield from carbon emission, such as investment in infectious disease prevention or infrastructure.

Mendelsohn (Peabody): Dr. Mendelsohn argued that the Federal SCC was not a proper damages-cost measure because it failed to match marginal cost and marginal damage and measured the marginal damage at the wrong part of the curve. It assumed there would be little to no mitigation of the effects of climate change. He testified that the IWG's approach was not consistent with the conventional and universally accepted methodology for measuring externality values .Measuring the damages and cost correctly yields a much lower SCC. .

Smith (GRE/MP/OTP/MLIG): According to Dr. Smith, the SCC is not based on a damage cost approach, as the term has traditionally been used. She stated that the IAMs do not provide a damage cost estimate for two reasons. First, they use highly aggregated damage functions. Second, Dr. Smith maintained that a traditional damage cost approach for climate change would first estimate climate changes from emissions, then estimate physical impacts on various resources from climate changes (damages), and finally monetize these damages. However, the IAMs used by the IWG largely skip the detailed steps involved in estimating physical impacts, and monetize damages directly from climate changes. Dr. Smith also notes that aggregation largely eliminates the separation of physical damage estimates and the valuation of society's willingness to pay to avoid those damages that is a defining characteristic of the damage cost approach. She further notes that, when aggregated damage functions are employed by an IAM, it becomes very difficult to know what types of damages are included in a particular SCC estimate.

Martin (Xcel Energy): Mr. Martin stated that the Commission's definition of a damage cost approach, according to the original externalities proceeding, is simply an approach that attempts to place an economic value on the net damage to the environment caused by an energy resource, in contrast to other approaches (e.g., willingness to pay, cost of control, mitigation, risk of regulation.) Nothing in this definition requires disaggregated damage functions or an explicit step estimating physical impacts on resources.

B. Use of Federal SCC in Regulatory Proceedings (Issue 3)

Record Citations:
Hanemann Direct at 61-63
Hanemann Rebuttal at 16-17
Hanemann Surrebuttal at 32-33
Polasky Rebuttal at 33-34
Polasky Surrebuttal at 24
Smith Direct at 14-16, Ex. 2 at 32
Smith Rebuttal at 10-11

Smith Surrebuttal at 4-6
Gayer Direct, Expert Report at 6
Martin Direct at 6-7, 12-14
Martin Rebuttal at 19-22
Martin Surrebuttal at 7-9, 19-22

Hanemann (Agencies): Dr. Hanemann stated that state-level resource planning is a form of cost-effectiveness analysis, which is a particular type of cost-benefit analysis where the object is to identify the least cost means of achieving a given goal, and thus to maximize the net benefit. He noted that the IWG's estimate of the SCC was developed for use in cost-benefit analysis, and there is no reason that would preclude using the Federal SCC as the CO_2 externality value in Minnesota resource planning or other similar decisions. Dr. Hanemann noted examples where utilities in other states incorporate the SCC estimates, or at least an "internal price of carbon," in their resource planning documents.

Polasky (CEO): Dr. Polasky noted that the SCC is an estimate of external damages associated with emissions of a ton of CO_2. Such estimates are applicable to a wide range of applications including cost-benefit analysis as well as resource planning. According to Dr. Polasky, it is irrelevant whether there are differences between cost-benefit analysis and resource planning, and in fact, the fundamental logic applied in cost-benefit analyses and integrated resource planning is quite similar: they both inform decision-makers about the relative merits of different alternative choices.

Smith (GRE/MP/OTP/MLIG): Dr. Smith stated that the IWG's purpose for estimating the SCC is to allow federal agencies to incorporate the social benefits of reducing CO_2 emissions in cost-benefit analyses of regulatory actions that have small or marginal impacts on cumulative global emissions. She further noted that the IWG has never suggested that it intends the SCC to be used in other applications, such as state utility integrated resource planning. Dr. Smith stated that framing assumptions should be chosen to fit the context of how the results will be used, and that the different context of the Minnesota PUC proceedings entails evaluation of different framing assumptions than selected for the federal regulatory context.

Gayer (MLIG): Dr. Gayer noted that the IWG was formed to arrive at an estimate of the SCC, which is an estimated externality value for a unit of carbon to use in regulatory-impact analyses of federal environmental regulations. There is no mention of intending the SCC's use in other applications such as state utility integrated resource planning.

Martin (Xcel Energy): Mr. Martin stated that the SCC was developed for a specific and limited purpose. It was designed as a component of cost-benefit analysis of proposed Federal regulations, as part of the regulatory impact analysis required by the OMB under Executive Order 12866. The intended purpose of the SCC is to help identify, among the vast array of possible regulations to reduce GHG emissions, those regulations that have positive net benefits. The SCC was not designed to develop the content of the regulation or influence the choice of options to comply. According to Mr. Martin, there is an important difference in using the SCC for its intended purpose and using the SCC for integrated resource planning and other Commission decisions, in which the SCC could potentially determine how to achieve CO_2 reductions by driving resource choices. This difference was one of the reasons why Mr. Martin

opposed adopting any single, or even all four, falsely precise SCC point estimates. Mr. Martin used the Clean Power Plan (CPP), where the EPA used the Federal SCC for regulatory impact analysis, as an example of how this purpose differs from integrated resource planning: in the CPP context, the SCC played no role in influencing the design of the regulation or selection of resource choices to comply, and precision was not important since the regulation's net benefits exceeded costs in EPA's view whether the SCC was $12 or $120 per ton. Mr. Martin also pointed out that the IWG in its July 2015 Response to Public Comments notes that it has not recommended the use of the SCC estimates outside its intended purpose of federal regulatory impact analysis, for example in state-level decision-making or as a "price on carbon."

C. IWG's Development of Federal SCC

1. Climate Change Models and Earth Temperature Data (Issue 4)

Record Citations:
Gurney Rebuttal at 9-13
Gurney Surrebuttal at 15-16
Abraham Rebuttal at 2-11, 20-27
Abraham Surrebuttal at 4-5, 8, 15, 21-22
Dessler Rebuttal at 3-23
Dessler Surrebuttal at 1-2, 3-4, 9-10
Polasky Direct at 3
Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 14
Bezdek Direct at 30-34
Bezdek Rebuttal, Ex. 1 at 4-11
Bezdek Surrebuttal at 2-12, 16-19
Happer Direct at 2, 8-9, Ex. 2 at 5-6
Happer Rebuttal, Ex. 1 at 5
Happer Surrebuttal at 5-10
Lindzen Direct at 3-4, 10, Ex. 2 lines 19-540
Lindzen Rebuttal, Ex. 1 at 3-5
Spencer Direct at 5-6, Ex. 2 at 1-4
Spencer Surrebuttal at 4-15, 19-29
Martin Rebuttal at 34-35

Gurney (Agencies): Dr. Gurney pointed out that the reduced temperature trend in the more recent time period (from 1998 to approximately 2014) is discussed and analyzed extensively in the peer-reviewed literature and within the IPCC Fifth Assessment Report. He noted that temperature records over the past 162-years show an increasing temperature trend, and the past 15-20 years referred to by Peabody witnesses show only a slowing of the general trend in a short time period. According to Dr. Gurney, a claim of no warming in this short time period is not a relevant assessment of the observational evidence of climate change, and should not be used to make statements regarding the long-term climate trend. He also noted that the scientific community has made extensive efforts to correct for urbanization and other effects in surface measurement records. He explained that the synthesis supplied by the IPCC is the best review of the temperature records. Dr. Gurney submitted with his Surrebuttal Chapter 2 of the IPCC 5th Assessment Report, which reviews temperature records, siting issues, urbanization effects, and

cites a long list of peer-reviewed papers regarding the methodological details and analysis. Dr. Gurney recommended that the ALJs reject Dr. Happer's testimony on "measurement error."

Abraham (CEO): According to Dr. Abraham, there are multiple lines of evidence showing that the climate is changing and that humans are the main reason for the change. Climate change is manifested by rising temperatures, loss of ice, rising seas, ocean acidification, and more extreme weather events. Dr. Abraham pointed out that Drs. Spencer, Lindzen, Happer, and Bezdek claim that global warming stopped approximately 20 years ago, based on temperature data of a small part of the atmosphere (Tropical Mid Troposphere). However, the Earth climate system consists of 93 percent of ocean, and less than 1 percent of atmosphere. Dr. Abraham noted that it is important to look at the largest thermal reservoirs: global ocean heat content data show a clear warming trend that has intensified since the 1990s; sea levels are rising because warmer water expands; ice regions are decreasing in mass; and surface temperatures of land and oceans are increasing.

According to Dr. Abraham, there is well-documented history of errors and inaccuracies regarding Dr. Spencer's satellite measurements, and it is clear that over-reliance on satellite measurements of a tiny fraction of the Earth's climate system is inappropriate to use as a benchmark of climate change. He noted that there is little evidence that surface temperature measurements are biased because of land-use or urban heat island effects; this issue has been researched in great detail and the strong conclusion is that their effects are negligible. Dr. Abraham pointed out that Dr. Lindzen's claim that the Earth's climate has a naturally occurring thermostat for limiting temperature increases was quickly and thoroughly rebutted by the scientific community. He argued that mutual support from many independent studies provides compelling evidence that there is very strong consensus among scientists that humans are causing climate change. Contrarian views, such as those of Drs. Spencer, Lindzen, Happer, and Bezdek have been found to be of low technical quality and have been corrected in the normal process of scientific exploration.

Dessler (CEO): According to Dr. Dessler, looking at all of the relevant data strongly supports the fundamental conclusion that the Earth is warming, humans are extremely likely responsible for the recent warming, and future warming carries with it the risk of significant harm. He noted that the global average temperature of the Earth is very stable, with year-to-year temperature variations of just a few tenths of a degree. Seemingly small changes in global average temperatures are associated with significant shifts in the Earth's climate. Dr. Dessler pointed out that Drs. Spencer, Lindzen, Happer, and Bezdek claim that the climate change has stopped or paused, based on satellite records. He noted, however, that satellite temperature records are not reliable for many reasons, and should not be used to validate climate models. According to Dr. Dessler, the most reliable data set to assess the Earth's temperature change is surface thermometer record, which shows that the climate has been continuously warming since the late 1970s, including the past two decades, although at slower pace. In addition, the ocean heat content has increased rapidly since 1998 and the extreme temperatures over land are becoming more extreme.

Polasky (CEO): According to Dr. Polasky, the overwhelming majority of scientific and peer-reviewed articles on climate change agree that emissions of CO_2 and other GHGs have a warming effect on the planet and that the evidence is sufficiently strong to justify policy action.

The IWG also addressed comments similar to those raised here about the scientific evidence establishing warming and the accuracy of the temperature response function used in the models.

Spencer (Peabody): According to Dr. Spencer, climate models are running substantially "hotter" than all available observational data, whether measured by satellites, weather balloons, or surface thermometers. Satellites provide the most detailed, reliable, and robust record of global temperature variations available since they were first launched in 1978. They provide nearly complete global coverage and are able to measure deep-layer atmospheric temperatures. He noted that surface thermometers tend to have long-term spurious warming effects over land from urbanization effects, and countries other than the U.S. and Europe, as well as oceans, have only fair to poor coverage. Dr. Spencer stated that contrary to almost all expectations, there has been no statistically significant warming in either satellite data or the weather balloon data for the last 18 years, even though models predicted the greatest warming between 1997 and 2014 (the greatest concentration of CO_2 in the atmosphere). Even the surface thermometer data run far below what climate models predict. Satellite data are particularly telling, because models predict that the deep-troposphere should warm even faster than the surface, but the satellite data show no significant warming where it would be most expected.

Happer (Peabody): According to Dr. Happer, there is no indication that the Earth's climate is changing in any manner that is not naturally-occurring and consistent with ordinary climate change patterns. Global warming basically stopped in 1998, and both ground-based observations and satellite measurements show virtually no warming in the lower atmosphere since 1998. Dr. Happer noted that ground-based warming measures are known to have serious systematic errors associated with loss of observing stations and urban heat island effects, both of which bias the results to more warming than actually exists. Also, recent ocean temperature data do not show warming. Dr. Happer stated that none of the IPCC climate models account for the warming hiatus; they predict about three times more warming than observed temperatures for both the atmosphere and oceans, and they should not be used as the basis for economic models or policy decisions. Dr. Happer argued that the ability to "backcast" does not make a model accurate—it must be able to predict accurately, and the IPCC models have consistently failed to do so.

Lindzen (Peabody): According to Dr. Lindzen, there is nothing seemingly unusual or man-made about the recent warming period (approximately from 1957 to 2008), and it appears to have ended about 18 years ago. There has been no statistically significant atmospheric temperature increases for the past 18 years. He noted that the IPCC climate models do not comport with observational data, and all IPCC models failed to predict the cessation of discernible warming over the past 18 years. Dr. Lindzen stated that since 2005, observational data show deep-ocean (below 700 meters) cooling, and for the upper 700 meters the observational data show inconsistent results.

Bezdek (Peabody): According to Dr. Bezdek, the most recent peer-reviewed literature confirms that emissions of CO_2 and other GHGs do not have a warming effect on the planet and the evidence is not sufficiently strong to justify policy action. He argued that over the past 18 years – a period when CO_2 emissions and concentrations have been increasing – there has been a hiatus with no significant global temperature increase. Even the IPCC authors acknowledge that there has been a hiatus in warming that they cannot explain. According to Dr. Bezdek, surface-level measurements of temperature are inaccurate and unreliable due to urban heat island effect.

Satellite datasets are more reliable and, for example, show that the hottest year on record was 1998.

Martin (Xcel Energy): Mr. Martin stated that he does not have a position on the various climate science questions raised by Peabody's witnesses, such as evidence on global warming and climate change in general or earth temperature measurement data.

2.   Equilibrium Climate Sensitivity (ECS) (Issue 5)

Record Citations:
Gurney Rebuttal at 17-18
Gurney Surrebuttal at 6-7
Hanemann Direct at 46, 52-53, 67-68
Hanemann Rebuttal at 31-33
Abraham Rebuttal at 3-4, 6-7, 25, 28
Abraham Surrebuttal at 5-8, 10-14
Dessler Rebuttal at 4-5
Dessler Surrebuttal at 4-6, 8-9
Polasky Rebuttal at 44-46
Polasky Rebuttal, schedule 1 (OMB Response to Comments) at 11-12
Bezdek Rebuttal, Ex. 1 at 23-28, 31-33
Happer Direct at 7-8, Ex. 2 at 2-8
Happer Rebuttal, Ex. 1 at 3-4
Happer Surrebuttal at 2-6
Lindzen Direct at 5, 8-9, Ex. 2 lines 19-540
Lindzen Rebuttal, Ex. 1 at 2-3
Lindzen Surrebuttal at 13-19
Spencer Direct at 7-8, Ex. 2 at 5-6
Spencer Rebuttal, Ex. 1
Spencer Surrebuttal at 15-19
Smith Rebuttal at 12-20
Martin Rebuttal at 34-35
Martin Surrebuttal at 6

Gurney (Agencies): According to Dr. Gurney, the doubling sensitivity value range reported in the IPCC Fifth Assessment Report (1.5°C to 4.5°C) is a range of values representative of a large body of peer-reviewed scientific literature and based on multiple lines of evidence. He noted that Dr. Happer's testimony makes a simple representation of the ECS, but the available evidence as represented by the IPCC Fifth Assessment Report does not support such a conclusion. Dr. Gurney explained that missing from Drs. Lindzen's and Spencer's testimony assessing model climate sensitivity, were a series of peer-reviewed papers that directly refute those cited by Drs. Lindzen and Spencer. Drs. Lindzen's and Spencer's testimony on the topic of climate sensitivity is not reliable because an objective, reliable assessment cannot be gleaned from testimony that narrowly cites one's own peer-reviewed work without citing or discussing peer-reviewed papers that directly refute that same work.

Hanemann (Agencies): Dr. Hanemann stated that the ECS characterizes how a doubling of the atmospheric concentration of CO_2 translates into an increase in global average annual temperature. ECS is the key to summarizing the response of the global climate system to increased radiative forcing from the accumulation of greenhouse gases (GHGs) in the atmosphere. He explained that, to standardize the three IAMs, the IWG made the value of ECS a random variable with the same probability distribution for all three IAMs to acknowledge the scientific uncertainty that exists regarding this key parameter. He stated that it was appropriate for the IWG to use the Roe and Baker probability distribution for ECS, because it is based on a theoretical understanding of the climate system's response to increased GHG concentrations and it is widely cited in the literature.

Abraham (CEO): According to Dr. Abraham, based on multiple lines of evidence (paleoclimate evidence, climate models, the instrumental record, and others), it is deemed likely that the ECS is between 1.5°C and 4.5°C with high confidence, and it is deemed extremely unlikely that the sensitivity is less than 1°C, also known with high confidence. He noted that it was reasonable for the IWG to rely on the probability distribution of ECS that was consistent with the ECS assumptions of the IPCC at that time (2°C to 4.5°C). The IWG stated in its July 2015 comments that it will continue to evaluate the latest science on ECS, including considering the IPCC Fifth Assessment Report values (1.5°C to 4.5°C) in its next update of the SCC. Dr. Abraham states that the ECS used by the IWG is sound and consistent with the consensus position of scientists and professionals with expertise in climate science.

Dessler (CEO): Dr. Dessler noted that although there is some evidence that the ECS is near the bottom of the current IPCC range (1.5°C), there is other evidence that it is near the top of the IPCC range (4.5°C). That is why the IPCC range is as wide as it is. Dr. Dessler argued that Drs. Spencer, Lindzen, and Happer are all incorrect and misleading when they claim that there is significant evidentiary support that the ECS is at the low end of the IPCC range or below it. They all refer to non-peer-reviewed and irrelevant sources, and misquote sources to claim support for their position. According to Dr. Dessler, there is simply no evidence to conclude that the IPCC's range is likely wrong.

Polasky (CEO): Dr. Polasky stated that the IWG applied a probability distribution for the ECS that corresponds with the most likely values recommended by the IPCC Fourth Assessment Report (2°C to 4.5°C). This distribution includes a relatively high probability of some of the lower values that Dr. Mendelsohn suggests, while also including a relatively low probability of significantly higher values for the ECS. Dr. Polasky noted that the IWG's use of a distribution of the ECS allows incorporating many possible future effects of CO_2 emissions on global warming, and this approach is a reasonable way to address uncertainty in climate sensitivity. Dr. Polasky noted that the IWG addressed this issue in its response to comments.

Lindzen (Peabody): According to Dr. Lindzen, an ECS value of more than 2°C is highly unlikely. The low value is not surprising because the direct "greenhouse" effect of doubling CO_2 is only 1°C. Scientists who argue for a higher climate sensitivity bear the burden of proving large positive feedback mechanisms, but no one has been able to demonstrate the existence of large positive feedbacks in the real world. Dr. Lindzen also testified about the Iris Effect, which is a negative feedback effect: increased sea surface temperatures in the tropics results in reduced cirrus cloud cover and thus more heat leaking into space. Recent research shows observational

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support for the Iris Effect, including research in papers delivered at a 2015 conference. While the Iris Effect has been controversial, much of the criticism has been overstated. In the end, it is a negative feedback with observational support, and scientists still haven't documented any strong positive feedbacks to support a high sensitivity value. The IWG relied on obsolete science on ECS when it chose to use the central value from the IPCC Fourth Assessment Report drafted in 2007. The IWG drew its ECS figures from AR4, drafted in 2007 (2°C to 4.5°C, with a "best estimate" of 3.0°C). The IWG declined to revisit the ECS question in any of the three revisions (May 2013, November 2013, and July 2015), even though the key scientific understandings had shifted. AR4 stated that the ECS was "very unlikely" to be less than 1.5 °C, but AR5 gave 1.5 °C as the low end of the "likely" range with "high confidence." AR5 also declined to determine a "best estimate," while AR4 gave 3°C, which is the exact value assumed by the IWG. The stated reason for not citing a best estimate in the AR5 was the substantial discrepancy between observation-based estimates of ECS (lower), versus estimates from climate models (higher). Hence, the scientific understandings in the AR5 reflect a tendency towards lower values of the ECS than the AR4. In addition, Dr. Lindzen noted that Figure 1 of Box 12.2 in the AR5 WG1 report shows that 11 out of 19 observational-based studies of ECS have values below 1.5°C in the range of their ECS probability distribution. Beyond the IPCC, 14 studies and 20 experiments validated a lower, tighter range for ECS between the 2010 TSD and the 2013 update to the TSD. Nevertheless, despite the fact that this shift in scientific understanding had been well known before its July 2015 revision, the IWG refused to revisit its ECS estimate. In his surrebuttal testimony Dr. Lindzen explained how the series of subsequent papers cited by Drs. Abraham and Gurney with respect to the Iris Effect did not support their argument. For example, Dr. Abraham selectively cited to only his own paper and ignored five published responses as well as a subsequent peer-reviewed article by Dr. Lindzen. Dr. Abraham cited to another paper that, once normalized to distinguish between cloud cover from cloud cover per unit cumulus, actually found a stronger Iris effect than originally expected. Dr. Abraham ignored 2015 research from the Max Planck Institute that continues to imply the existence of the Iris effect and suggests that a low-end climate sensitivity value of 1.5 °C is likely correct. Dr. Lindzen explained that the accusation that he was not relying on peer-reviewed literature was simply incorrect. In his direct testimony and his discovery responses, he cited to at least nine peer-reviewed papers (in addition to his own work) on the issue of climate sensitivity alone. In his surrebuttal testimony, Dr. Lindzen cited more than two dozen peer-reviewed papers showing that climate models run hotter than observations, 19 observational-based studies of ECS in Figure 1 of Box 12.2 in the AR5 WG1, and a further 14 studies and 20 experiments validating a lower range for ECS.

Happer (Peabody): According to Dr. Happer, the IWG has overestimated climate sensitivity values. Observations over the past two decades indicate that the ECS is somewhere between 0.5°C and 1.5°C, with a most likely value close to 1°C, and definitely less than the 3°C assumed by the IWG. Dr. Happer noted that the much larger ECS claimed by the IPCC comes from large positive feedbacks mechanisms, such as water vapor, which have not been proven.

Spencer (Peabody): Dr. Spencer testified that the IWG's high climate sensitivity value of 3.0°C is the most obvious reason for models warming too much. His own research finds a sensitivity value of about 1.3°C. This value is optimized to explain the history of deep ocean warming since the 1950s. An increasing number of peer-reviewed studies are suggesting much lower climate sensitivity than the IPCC and its climate models assume, possibly as low as 1°C or less

for doubling of atmospheric CO_2. Dr. Spencer testified that low climate sensitivity is the result of a growing recognition that positive feedbacks are more likely over-estimated rather than under-estimated. There has been a recent revival of interest in Dr. Lindzen's Iris Effect, and cloud feedbacks have always been a source of uncertainty.

Dr. Spencer's surrebuttal addressed the critiques of his methods that had been raised by Drs. Gurney and Dessler, pointing out that each was based on either adjustments that were themselves problematic or failed to show what Drs. Gurney and Dessler claimed they do. Dr. Spencer explained that satellite data are robust, that satellite datasets have been widely used in the climate research community for over twenty years, and that his work has been endorsed for its scientific merit by NASA and the American Meteorological Society. Further, all data are consistent: ultimately it does not matter whether one looks at land surface temperatures, sea surface temperatures, deep-ocean temperatures, radiosondes (weather balloons), or satellite measurements: climate models predict warming well in excess of what any of those datasets show. Dr. Spencer noted that there are reasons to prefer satellite data, because they provide nearly complete global coverage (except for small regions at the poles). They are able to measure deep layer atmospheric temperatures, without the spurious warming effects over land from urbanization effects that plague land-based thermometers. Further, only the U.S. and Europe are well sampled by thermometers, while most other countries have fair to poor coverage. He also noted that all methods of temperature measurements (whether satellites or other methods) are subject to adjustment, and that the adjustments to the satellite record tended to go in both directions, suggesting that those adjustments have been made impartially. He pointed out that the surface temperature data has usually been adjusted to show a warming trend, which is suspicious.

Bezdek (Peabody): Dr. Bezdek noted that the IWG has not updated the ECS employed in the IAMs, although many recent studies and experiments suggest lowering the climate sensitivity estimate. Even the IPCC Fifth Assessment Report states that the ECS is likely to range from 1.5°C to 4.5°C, not 2°C to 4.5°C that was used by the IWG. According to Dr. Bezdek, it was not appropriate for the IWG to use a calibrated version of the Roe and Baker distribution (published in 2007) as the common probability distribution of the climate sensitivity, because it is no longer scientifically defensible. He noted that using more up-to-date ECS distributions yields much lower probabilities of extreme global warming and produce significantly lower estimates for the SCC.

Smith (GRE/MP/OTP/MLIG): Dr. Smith did not take a position on the ECS values recommended by Drs. Spencer, Happer, and Lindzen. However, she noted that running the DICE 2010 model with the IMAGE socioeconomic scenario and a fixed ECS value of 1.5 °C at discount rates of 3% and 5% produced SCC estimates that are 60 percent to 65 percent lower than the IWG's estimates. Dr. Smith further compared her sensitivity analysis using DICE 2010, which yielded a range of $14 to $43 per ton, to that performed by Professor Mendelsohn which yielded a range of $4 -$6 per ton. She explained that, when adjustments are made for differences between her analysis and Dr. Mendelsohn's modeling for discount rate, emission year, different versions of DICE, and Dr. Mendelsohn's assumption regarding optimal temperature, they arrive at very similar values. Accordingly, Dr. Smith concluded that the lower SCC estimates in Professor Mendelsohn's analysis would be supported by the IWG's models if his alternative assumptions about ECS and optimal temperature levels were to be adopted.

Martin (Xcel Energy): Mr. Martin stated that he does not have a position on the various climate science questions raised by Peabody's witnesses, such as ECS.

3. Relationship between Emissions and Atmospheric CO_2 Concentration (Issue 6)

Record Citations:
Gurney Rebuttal at 7-9
Bezdek Rebuttal, Ex. 1 at 8
Lindzen Direct at 6
Lindzen Surrebuttal at 29-33

Gurney (Agencies): Dr. Gurney noted that it is well established through multiple lines of evidence that the long-term secular rise in CO_2 concentration in the Earth's atmosphere is driven by the combustion of fossil fuels. One example of evidence is the dilution of the well-known amount of $^{14}CO_2$, not contained in the fossil fuel derived CO_2, which can be tied to records regarding emissions from coal, oil, and natural gas consumption.

Lindzen (Peabody): Dr. Lindzen questioned the connection of fossil fuel emissions to atmospheric CO_2 concentrations and noted that numerous recent publications question both Dr. Gurney's evidence (including the source he cited for the $^{14}CO_2/CO_2$ ratio) and the IPCC's interpretation of the connection between fossil fuel emissions and atmospheric CO_2 content. Dr. Lindzen also noted in his surrebuttal that Dr. Gurney failed to cite any peer-reviewed publications to support his "multiple lines of evidence" except for one source (Tans, et al. 1979) that actually supports Dr. Lindzen's position. Dr. Lindzen pointed out that the only proof offered by Dr. Gurney actually substantiates the argument that the measurements do not change in the manner theorized and cannot support a clear measurement of the ratio that supposedly attributes CO_2 to fossil fuel combustion. According to Dr. Lindzen, it is well-known that the fraction of human induced CO_2 is small compared to the total CO_2 included in the atmosphere, and natural emission and sink rates are about 20 times greater than anthropogenic emissions.

Bezdek (Peabody): According to Dr. Bezdek, there is no evidence that CO_2 emissions are causing increased temperatures, and therefore there is also no evidence of CO_2's adverse impacts on humans and the environment.

4. Overestimating Warming (Issue 7)

Record Citations:
Gurney Rebuttal at 13-16
Gurney Surrebuttal at 16-17
Abraham Rebuttal at 12-18
Abraham Surrebuttal at 2-3
Dessler Rebuttal at 23-26
Dressler Surrebuttal at 2-3
Lindzen Direct at 2-4, 8, 10; Ex. 2 at 2-9, 11-14
Lindzen Rebuttal, Ex. 1 at 4-5
Lindzen Surrebuttal at 1-13

Spencer Direct at 3-4, Ex. 2 at 1
Spencer Rebuttal, Ex 1
Spencer Surrebuttal at 1-4
Happer Direct at 3-4, 6-8
Happer Rebuttal, Ex. 1 at 3-4
Happer Surrebuttal at 1, 5-6
Bezdek Direct at 2-5, 7-9
Bezdek Rebuttal, Ex. 1 at 2, 44-45
Bezdek Surrebuttal at 40-42, 58-63
Smith Rebuttal at 12-20
Martin Rebuttal at 34-35
Martin Surrebuttal at 6

Gurney (Agencies): Dr. Gurney pointed out that there is little discrepancy between the IPCC climate models and observed temperature trends when comparison is performed over appropriately long time periods. He noted that Peabody witnesses make claims based on a short time period from 1998 to approximately 2014, and this time period has been subject to active research within the climate science community. The fact that the IPCC models perform well over longer time periods must be prioritized over short-term discrepancies or short-term variability. Dr. Gurney explained that Dr. Lindzen provided no peer-reviewed support for his critique of a recent peer-reviewed paper that revises (very slightly) NOAA's temperature trend analysis.

Abraham (CEO): Dr. Abraham stated that the climate models are not over-predicting climate change, and the model predictions are in agreement with other methods to estimate climate changes, such as energy balance calculations and paleoclimate studies. He noted that in fact, there is evidence that the climate models have slightly underestimated warming in the upper 700 meters of the oceans and significantly underestimated ice loss. Dr. Abraham pointed out that when compared to observations, the climate models predict surface temperatures quite accurately. He noted that in support of their claims that the climate models overestimate climate change, Drs. Lindzen, Happer, and Bezdek all refer to the same figure, which focuses only on a portion of an upper layer of the troposphere (0.2 percent of the Earth climate system), was prepared for Congressional testimony rather than the peer-reviewed literature, and is misleading.

Dessler (CEO): According to Dr. Dessler, long-term comparisons between climate models and observations show that the overall agreement between models and observations is excellent. He noted that there is no support to claims that climate models have warmed two to three times faster than the observations over the last thirty-five to fifty-five years. He noted, however, that short-term variations in observed data may produce large differences if the time period analyzed is only a decade or two. According to Dr. Dessler, there is no evidence to claim that the climate models have been programmed to be too sensitive, as claimed by Drs. Spencer, Lindzen, and Happer.

Spencer (Peabody): Dr. Spencer testified that all three independent classes of temperature observations – satellite, radiosondes (weather balloons), and land-based measurements -- show that the climate models used by governments for policy guidance have warmed 2 to 3 times faster than actual temperature data over the last 35 to 55 years, which is the period of greatest

greenhouse gas emissions and atmospheric greenhouse gas concentrations. According to Dr. Spencer, the climate models are too sensitive to CO_2 emissions, and increasing GHGs do not cause as much warming and climate change as is commonly believed. Therefore, any SCC estimates based upon such models will be biased high. The models, on average, produce tropospheric warming rates about two to three times those observed over the same time period. Dr. Spencer stated that whatever measurements are used, the result is the same: the rate of global warming is not nearly as high as the models predict. He argued that this calls into question the scientific reliability and predictive value of the models, and invalidates their use as the basis for SCC estimates. For the past 18 years, the models have totally failed to predict or explain that the warming has slowed to near-zero (hiatus in warming).

Happer (Peabody): Dr. Happer testified that the models "run hotter" than the actual temperature data. According to Dr. Happer, nearly all of the IPCC climate models have predicted several hundred percent more warming over the past twenty years than has actually been observed. He noted that today, observational data provides a good reason to doubt the large warming predicted by the IPCC climate models and shows that there is something seriously wrong with the models. In Dr. Happer's judgment, the models run three times too warm because they have assumed an ECS that is three times higher than the real value. He testified that no valid scientific basis for IWG's sensitivity value of 3.0°C and that the correct sensitivity value is in the range of 0.5° to 1.5°C. If there were strong positive feedbacks to give a large sensitivity, we would not have experienced a lack of warming for the past 18 years, when CO_2 emissions were steadily increasing. Dr. Happer testified that the sensitivity value makes all the difference. A low sensitivity value means modest warming that will be net beneficial. Warming will occur more at night than during the day and more during winter than summer.

Lindzen (Peabody): Dr. Lindzen testified that peer-reviewed publications reveal manifold problems with climate modeling, often resulting in a warming bias; climate models have been shown to be inaccurate; the warming rate is much smaller than the models project—within the span of natural variation—and climate researchers have pointed out many reasons for this. The climate models have not been able to simulate recent (past 15 years) observed temperatures, nor have they been able to simulate the 20th century historical temperature record. He testified that climate sensitivity is extremely unlikely to exceed 2 °C and is probably even lower. The IWG's sensitivity value of 3.0°C is based on the obsolete ECS values found in the IPCC Fourth Assessment (2007). The Fifth Assessment (2013) allows for 1.5°C within the IPCC's assessed "likely" range of "high confidence." Dr. Lindzen also demonstrated, in both his rebuttal and surrebuttal testimony, the obvious weaknesses in a recent paper (Karl et al. (2015)), showing that even taking the paper on its own terms, over 97% of climate models still run hotter than the higher temperatures shown in the paper. The Karl et al. (2015) paper cherry-picks start and end dates, contains adjustments that do not necessarily reflect impartial science, and begins from a weak dataset (NOAA ERSST) instead of more robust ones such as HadSST3.. The Karl et al. paper also interpolated temperatures in a manner that induced substantially exaggerated temperatures. Dr. Lindzen also referenced other researchers who have criticized the Karl et al. paper.

Bezdek (Peabody): According to Dr. Bezdek, the IPCC climate models have been unable to accurately predict temperatures over the past two decades, and their predictions are becoming increasingly inaccurate every year. He noted that even the IPCC authors acknowledge that there

has been a hiatus in warming that began about 18 years ago, and the climate models do not replicate the recent lack of global warming. Dr. Bezdek pointed out that numerous studies have questioned the degree to which the IAM damage functions actually incorporate the benefits of CO_2 for plants and agriculture. CO_2 fertilization helps explain why the climate models have been incorrect: higher-than-expected plant absorption of CO_2 has not been fully integrated into climate models.

Smith (GRE/MP/OTP/MLIG): Dr. Smith did not take a positon on the ECS values recommended by Drs. Spencer, Happer, and Lindzen. However, she noted that running the DICE 2010 model with the IMAGE socioeconomic scenario and a fixed ECS value of 1.5 °C at discount rates of 3% and 5% produced SCC estimates that are 60 percent to 65 percent lower than the IWG's estimates. Dr. Smith further compared her sensitivity analysis using DICE 2010, which yielded a range of $14 to $43 per ton, to that performed by Professor Mendelsohn which yielded a range of $4 -$6 per ton. She explained that, when adjustments are made for differences between her analysis and Dr. Mendelsohn's modeling for discount rate, emission year, different versions of DICE, and Dr. Mendelsohn's assumption regarding optimal temperature, they arrive at very similar values. Accordingly, Dr. Smith concluded that the lower SCC estimates in Professor Mendelsohn's analysis would be supported by the IWG's models if his alternative assumptions about ECS and optimal temperature levels were to be adopted.

Martin (Xcel Energy): Mr. Martin stated that he does not have a position on the various climate science questions raised by Peabody's witnesses, such as whether the IPCC climate models overestimate global warming.

5. Extreme Weather Events (Issue 8)

Record Citations:
Abraham Rebuttal at 19, Schedule 1, pp 3-6
Abraham Surrebuttal at 23-24
Dessler Rebuttal at 26-27
Bezdek Direct at 32-34
Bezdek Surrebuttal at 12-16
Happer Direct at 9
Happer Surrebuttal at 15-18Lindzen Direct at 6-7, 10-11, Ex. 2 lines 542-567
Mendelsohn Direct, Ex. 2, at 3-4
Lindzen Surrebuttal at 33-45
Martin Rebuttal at 34-35

Abraham (CEO): According to Dr. Abraham, the peer-reviewed science, including very recent research, demonstrates the evidence of increasing frequency and intensity of extreme weather events. Peabody witnesses cite non-peer reviewed literature to support their claim of no increase in extreme weather events, and their views on this matter conflict with the scientific literature.

Dessler (CEO): According to Dr. Dessler, several Peabody witnesses claim that there is no evidence that extreme weather events are increasing in frequency or intensity due to climate change. He pointed out that these statements are false and unsupported by peer-reviewed

literature, which indicates that humans are playing an increasingly important role in extreme temperature and precipitation events.

Happer (Peabody): According to Dr. Happer, there is not the slightest evidence for any significant increase in extreme weather events.

Mendelsohn (Peabody): Professor Mendelsohn testified that there is scant evidence that climate change has altered the frequency or intensity of extreme events to date. Citing peer-reviewed literature, Professor Mendelsohn testified that extreme events have not changed in either their intensity or their frequency in the last 100 years (citing Landsea et al. 2006), and that weather events such as floods and droughts continue as in the past. The harm that these events cause has increased because there is more in harm's way (citing Pielke et al. 2008). He further testified that the popular press and public are confused about weather versus climate change, and stated that returning greenhouse gas concentrations to their 1900 level immediately would not change the weather because current weather is part of our current climate.

Lindzen (Peabody): Dr. Lindzen noted that the potential impacts of global warming on drought, flooding, storminess, heat waves, melting sea ice, rising sea level, and similar issues have been largely unproven. The evidence showing such an increase tends to be "cherry picked" from short time scales and do not take into account larger spans of time. He stated that not only are those events not increasing in severity of number, but the evidence tying them to anthropogenic global warming is not credible. For example, the IPCC's latest Fifth Assessment Report presented a significant departure from the previous assessment, and showed less confidence that global drought or tropical cyclone activity has increased. According to Dr. Lindzen, warming should actually reduce the incidence of extreme weather because it will reduce the temperature disparity between the poles and the Equator.

Martin (Xcel Energy): Mr. Martin stated that he does not have a position on the various climate science questions raised by Peabody's witnesses, such as extreme weather events.

6. Damage Functions (Issue 9)

Record Citations:
Hanemann Rebuttal at 34-63, 88
Hanemann Surrebuttal at 14-17, 43
Polasky Direct at 18-24Happer Direct at 3, 5, 9-12, Ex. 2 at 8-11
Happer Rebuttal, Ex. 1 at 2-4
Happer Surrebuttal at 10-24
Lindzen Direct at 2-3, 7, Ex. 2 at lines 569-614
Rom Rebuttal at 9-12, 15-19
Lindzen Rebuttal, Ex. 1 at 2
Mendelsohn Direct at 8-10, Ex. 2 at 11-15
Mendelsohn Rebuttal, Ex. 1 at 3
Mendelsohn Surrebuttal at 2-5, 26
Bezdek Direct at 2-3, 6, 7, 9-20, 26
Bezdek Rebuttal, Ex. 1 at 13-20
Bezdek Surrebuttal at 20-57

Smith Direct at 18-20, Ex. 2 at 5, 20-25
Smith Surrebuttal at 9-14
Martin Rebuttal at 34-35
Martin Surrebuttal at 6

Hanemann (Agencies): According to Dr. Hanemann, the damage functions of DICE, FUND, and PAGE fairly accurately reflected the economic literature on climate impacts as of 2001. The empirical literature has exploded since then, and the newer studies generally indicate more severe damages than the earlier literature. Dr. Hanemann argued that if anything, the IAM damage functions used by the IWG are likely to understate the SCC. For example, the IAMs do not account for precipitation or extreme temperature events, do not monetize all possible damage categories, and do not capture climate tipping points. However, he noted that the damage functions in DICE, FUND, and PAGE are the only damage functions currently available for use in model inter-comparison exercises, and it was and still is today reasonable for the IWG to use them. Dr. Hanemann disagreed with the criticism that the IAM damage functions lack adequate foundation in economic theory, because this is irrelevant for the validity of damage functions, or that the IAM damage functions are invalid because they are not dose-response functions. It is not reasonable to expect the use of conventional dose-response functions on the spatial and temporal scales required for an IAM damage function.

Polasky (CEO): According to Dr. Polasky, the value of the SCC depends greatly on the probabilities of large damage events, and the IAMs used by the IWG are conservative in their representation of the potentially catastrophic outcomes from a fundamental shift or "tipping point" in the climate. The IWG did not change the original damage functions of the IAMs, and chose to accept this cautious representation of catastrophic outcomes. Dr. Polasky pointed out that the policy recommendations from the IAMs call for less drastic reductions in CO2 emissions than do models from the broader field of climate science, and much of this difference is due to the treatment of potentially catastrophic outcomes. He also noted that the damage functions in the IAMs exclude important categories of potential damages, those that are most difficult to model and estimate in monetary terms (e.g., extreme weather effects, ocean acidification, species loss, large biodiversity losses, and increased political instability and migration).

Rom (DHE): According to Dr. Rom, none of the IAMs used in the SCC include any accounting of the health impacts from the interaction between warmer temperatures and exposure to ozone and $PM_{2.5}$. The IAMs also do not account for the health impacts of wildfires, droughts, floods, reduced drinking water quality, and harmful aquatic blooms, nor do they account for the health impacts of non-fatal illnesses, hospitalizations and days of work lost from climate change exacerbated exposure to ozone and $PM_{2.5}$. The epidemiological data is clear that ambient temperatures have synergistic effects with exposure to ozone and $PM_{2.5}$, resulting in enhanced morbidity and mortality from natural causes as well as cardiorespiratory causes. Higher temperatures increase concentrations of ozone and $PM_{2.5}$, and they also affect how the body responds to those pollutants. The health effects of the interaction between temperature and exposure to ozone and $PM_{2.5}$ has been quantified as causing 13,000 and 57,000 deaths in 2050 and 2100, respectively, representing economic damages $160 billion and $930 billion in 2050 and 2100. These numbers may be underestimates, as other studies have found higher impacts.

Mendelsohn (Peabody): According to Dr. Mendelsohn, the scientific data warrant modifying the damages function of the DICE model so that the damages begin at temperatures 1.5°C to 2°C warmer than global average temperature levels in 1900. Research results do not suggest that the pre-industrial 1900 global temperature was the "optimal" climate, given that today's temperature is already 0.8°C warmer than in 1900. He argued that the results suggest that a slightly warmer climate is more optimal, at least in some regions including Minnesota, and net global benefits are maximized at a temperature 1.5°C to 2°C warmer than 1900 levels. Also, the net benefits and damages vary across the world by latitude and each affected sector. In his methodology based on the DICE model, Dr. Mendelsohn modified the damage function so that the damages begin at temperatures 1.5°C to 2°C warmer than global average temperature levels in 1900. His modification of the damage function of DICE was made in order to calibrate it to all the evidence about climate damage that has been accrued, based on more than two decades of empirical study, his own expertise, and peer-reviewed research in the field.

Happer (Peabody): Dr. Happer testified that IAMs fail to account adequately for the CO_2 fertilization effect and that their damages function is accordingly overstated. Plants are currently starved for CO_2, and higher emissions will restore some of the higher levels of CO_2 that have existed throughout history. Plant growth rates and drought resistance would benefit significantly from additional CO2. We can tell that photosynthesis evolved during periods of much higher CO2 concentrations, because the great majority of photosynthetic organisms (e.g., plants, algae) contain a protein called rubisco, which functions best when CO2 concentrations are higher and O2 concentrations are lower than those today. Many common plants, like trees, wheat, soybeans, and cotton, are actually at a handicap today because by historical standards there currently is too little, not too much, CO2 in the atmosphere. Higher levels of CO_2 will allow plants to utilize rubisco pathways, sunlight, and water more efficiently, resulting in higher agricultural yields than IAMs account for.

Lindzen (Peabody): According to Dr. Lindzen, the current economic damages models are inherently biased high because they rely on the IPCC's flawed overestimated conclusions regarding the effect of increases of CO_2 concentrations on global climate.

Bezdek (Peabody): According to Dr. Bezdek, the damage functions used in most IAMs are completely made up, with no theoretical or empirical foundation. They are simply a guess about the relationship between changes in temperature and GDP. Numerous researchers have concluded that the underlying uncertainty in the SCC is so large as to render the use of the SCC "close to useless" for policy purposes. The IAM damage functions are also inaccurate because they under-measure the beneficial effects of CO_2 fertilization.

Smith (GRE/MP/OTP/MLIG): Dr. Smith pointed out that the IAMs' damage functions are based on a limited number of studies of the economic impact of warming of 3°C or less. The IAMs, however, are used to predict the damage to the economy of much greater changes in temperature. Lacking any foundational data for the greater range, the modelers have had to extrapolate the shape of a damages curve above 3°C without being able to validate the shape with empirical data. Despite the absence of an empirical foundation, the higher damage levels at higher projected temperatures in the modeled damages curve elevate the IWG's SCC estimates. Quoting Professor Pindyck, Dr. Smith stated that "[IAMs] can say nothing meaningful about the kinds of damages we should expect for temperature increases of 5°C or more. ….Thus we are

left in the dark; IAMs cannot tell us anything useful about catastrophic outcomes, and thus cannot provide meaningful estimates of the SCC." In addition, the SCC estimates are speculative because of the lack of specificity of the dose-response relationships that are implicit in the IAMs' extrapolations. Dr. Smith also noted that a horizon of 2300 and projecting almost 300 years into the future is inherently highly speculative to the point where it is nearly worthless, causing the IWG's SCC values to be driven more by the speculative portions of the IAMs' damages functions than by the portions that have at least some evidentiary basis. Based on her critique of temporal and temperature extrapolation in the use of the IAMs' damage functions and to balance the need to account for damages with the need for an evidentiary foundation, Dr. Smith shortened the modeling horizon in her methodology, but did not alter the damage functions themselves.

Martin (Xcel Energy): Mr. Martin acknowledged that the IAM damage functions lack empirical calibration for greater temperature changes, but overall does not take a position on the various climate science questions raised by other witnesses, such as the damage function of the IAMs, and did not alter the IAM damage functions in deriving his recommended range.

7.   Modeling Horizon (Issue 10)

Record Citations:
Hanemann Rebuttal at 17-26
Hanemann Surrebuttal at 38, 43-45
Polasky Rebuttal at 14-20
Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 29
Bezdek Surrebuttal at 58-60Smith Direct at 22-23, 35, Ex. 2 at 65-79
Smith Surrebuttal at 14-21
Gayer Surrebuttal at 12-13
Martin Rebuttal at 25, 43-45
Martin Surrebuttal at 6, 30

Hanemann (Agencies): Dr. Hanemann agreed that there is obviously uncertainty regarding climate impacts 300 years from now. However, he pointed out that this is not a valid reason to truncate the modeling period. In fact, the IWG's emission projections to year 2100 and beyond cannot be supported by facts or evidence – by the nature of projections far in the future, they are based on reasonable assumptions. Therefore, the IWG's projections of emission outcomes in the year 2100 cannot be considered much less speculative than the projections after the year 2100. Dr. Hanemann stated that there is simply no historical data to which the social and economic impacts could be calibrated, however, this is not a valid reason to ignore unprecedented climate risks. He disagreed with Dr. Smith and Mr. Martin, and believed that the IWG's decision to estimate climate damages up to the year 2300 was appropriate. Regarding Mr. Martin's characterization of efforts "to model climate damages and societal response out to the year 2300" as being "equivalent to scientists in the early 1700s attempting to model our society today," Dr. Hanemann stated that Mr. Martin's characterization of what is involved in future projections of climate impacts and mitigation costs is not a good one because global average atmospheric CO_2 concentration has risen in the last 200 years to 400 ppm as of May, 2015, a concentration last seen several million years ago, before *Homo sapiens* existed, and likely outcomes are unprecedented.

Polasky (CEO): Dr. Polasky stated that a proper estimation of marginal damages from a unit of CO_2 emission requires accounting for the impact of that unit as far into the future as it is likely to remain in the atmosphere and cause damages. He believed it would be inappropriate to arbitrarily exclude any future time period where damages are likely to occur, as Dr. Smith proposed by shortening the time horizon to the year 2100 or at most to the year 2140. Dr. Polasky argued that the IWG determined, based on the best up-to-date scientific understanding, that the year 2300 was the appropriate time horizon required to capture all pertinent impacts associated with CO_2 emitted in the near term. He pointed out that it is impossible to predict with great accuracy what will happen in the year 2300, but it is just as impossible to predict with great accuracy what will happen in the year 2100 or 2140. Dr. Polasky disagreed with Dr. Smith's position that the damage functions used in the IAMs are only calibrated for the first few degrees of warming, and would be too speculative to estimate damages after the year 2100 when warming is likely to exceed 3°C. He pointed out that shortening the modeling horizon to the year 2100 (or 2140) would in effect assume that the damages at higher temperatures are zero, an assumption for which there is no rational or evidentiary basis. The modeling horizon is also discussed in the IWG's response to comments.

Bezdek (Peabody): Dr. Bezdek testified that making economic and technological assumptions out to 2300 is an exercise in science fiction. He testified that it is virtually impossible to make accurate energy forecasts even one or two decades into the future, much less centuries into the future. He discussed energy projections made in the 70s and 80s out to the year 2000 and how dramatically wrong they were even only a couple of decades ahead. He pointed out that even Mr. Martin agreed about the uncertainty surrounding the issue, especially mitigation and catastrophic impacts.

Smith (GRE/MP/OTP/MLIG): According to Dr. Smith, the IWG's emission projections up to the year 2300 lack an evidentiary basis, and therefore the modeling horizon should be shortened to the year 2100, or at most to the year 2140. She noted it is highly speculative to predict resource values, GDP structure, societal preferences, and CO_2 emissions out to the year 2300. Such far-future economic projections are inherently speculative, to the point where they are nearly worthless. Dr. Smith pointed out that the IWG made its own judgments on how to extend the EMF-22 projections (developed only through the year 2100) up to the year 2300, and these choices are not supported by facts, available evidence, or peer-reviewed analyses. She argued pointed out that as a result of the very long modeling horizon, the IWG's SCC values are driven more by the speculative portions of the IAMs' damage functions (damages from temperatures exceeding 43°C) than the portions that have at least some evidentiary basis. Dr. Smith pointed out that shortening the modeling horizon to the year 2100 or at most to the year 2140 would reduce speculation and uncertainty also because it would mitigate the IAMs' lack of endogenous societal response to climate damages by reducing the timeframe for unrealistic non-action. Responding to various critics, Dr. Smith testified that she does not claim that damages are zero after 2100 and 2140, but only that beyond that time the degree of speculation becomes too great to be appropriate for determining near-term financial investments in Minnesota's electricity power system. She concludes the degree of extrapolation based on convex damage curves in absence of any adaptive decision logic becomes too great to be appropriate for determining near-term financial investments in Minnesota's electricity power system, and that at this point the speculation in the IWG's emissions projections becomes particularly pronounced due to the fact that values after 2100 are extrapolated from the EMF 22 scenarios, because values after 2100 and

2140 suffer from lack of accounting for societal response, and because even the longest-lived technology rarely remains economical to operate more than about 80 years. Even extending that timeframe from 2100 to 2140 to account for presently foreseeable technological innovation, Dr. Smith testified that one needs a reasonable horizon beyond which there is a total lack of understanding about the impacts of temperature increases on society, rendering damages calculations purely speculative, which is an inappropriate basis upon which to make engage in resource planning.

Gayer (MLIG): Dr. Gayer testified that while uncertainty in and of itself does not justify inaction, the uncertainty of any prediction approaches infinity as time increases indefinitely. Citing Dr. Henry J. Aaron, Dr. Gayer pointed out that "[b]ecause error and uncertainty grow as the projection horizon is lengthened, in some cases lengthening the window is not useful and can degrade decision making."

Martin (Xcel Energy): Mr. Martin agreed that the further out in time, the more disconnected the IAM damage functions become from any empirical basis. In addition, the IAMs' incomplete modeling of adaptation, and absence of endogenous technological response by future societies to reduce CO_2 emissions, make the IAMs' predictions increasingly speculative over time. However, Mr. Martin pointed out that the climate changes are unlikely to suddenly drop to zero after the year 2100 or 2140. He did not propose changes to the IWG's modeling horizon and recognized that this is a policy judgment for the Commission to make. Mr. Martin noted that his recommended range could not be adjusted for a shorter modeling horizon by statistical treatment; this would require re-coding and re-running the IAMs.

8. Marginal Ton (Issue 11)

Record Citations:
Hanemann Rebuttal at 27-29
Mendelsohn Direct at 16-17, Ex. 2 at 9
Mendelsohn Rebuttal, Ex. 1 at 3
Mendelsohn Surrebuttal at 17-21Polasky Rebuttal at 9-14
Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 19-20
Smith Direct at 20-22, Ex. 2 at 50-64
Smith Surrebuttal at 22-25
Martin Rebuttal at 27-28, 45-47
Martin Surrebuttal at 30-31

Hanemann (Agencies): Dr. Hanemann disagreed with Dr. Smith's proposed "first ton approach," which assumes that when the SCC values are calculated for a certain year, for example the year 2020, then no emissions for CO_2 occur anywhere in the world after 2020. He stated that this assumption is clearly unrealistic and unreasonable – future climate damages depend on emissions that have already occurred and emissions that will occur in the future up to the year 2300. The SCC appropriately accounts for both past and future emissions.

Polasky (CEO): Dr. Polasky disagreed with Dr. Smith's approach which used what she describes as a "first ton" analysis to calculate her low-end value and to calculate an "average" which she offered as her high-end value. Dr. Polasky explained that Dr. Smith's approach is

contrary to basic marginal analysis, which is a fundamental principle agreed upon by economists. As explained by Dr. Polasky, Dr. Smith's actual argument is with the emission projections from which marginal damages are calculated and that her use of "first" "average" and "last" ton are unnecessary obfuscations. According to Dr. Polasky, the IWG used five different scenarios (EMF-22) to project future emissions, with a wide range of possible outcomes, and these represent the current, best understanding of future emissions. He stated that if Dr. Smith does not agree with the IWG emission projections, then she should use different projections; instead, she altered the IAMs assuming zero CO_2 emissions after the year 2020, calling this "the first ton" approach. Dr. Polasky asserts this is a completely unrealistic assumption without any rational or scientific basis. Based on this fact alone, it would not be appropriate for the Commission to rely on Dr. Smith's conclusions. The selection of emission scenarios is addressed in the IWG's response to comments.

Mendelsohn (Peabody): Dr. Mendelsohn testified that the IWG made a mistake in calculating the SCC using a simulation rather than optimization approach, which effectively assumes there is no mitigation now or in the future anywhere in the world, and therefore significantly overestimated the SCC by measuring marginal damages under the assumption of no mitigation. Dr. Mendelsohn explained that the proper way to measure the SCC is to equate marginal cost and marginal damage at the optimal mitigation level.

Smith (GRE/MP/OTP/MLIG): Dr. Smith noted that the IWG methodology calculates marginal damages from a ton of CO_2 as if it were the last ton to be added to a global 300-year projection of CO_2 emissions. She states it is inappropriate to assume that a particular ton of CO_2 emitted in the near future would be the last ton to be decided on as part of a 300-year "business as usual" baseline of otherwise unconstrained future emissions since many of the tons emitted that contribute to the SCC will not be emitted until much later than the Minnesota tons in question and by others than Minnesota, while the carbon emitted in Minnesota is no more or less harmful than carbon emitted elsewhere and is also no more or less harmful than any of the tons assumed to be emitted in the future. Dr. Smith note that, for example, the SCC value for 2020 depends on the concentration of greenhouse gasses projected to already exist by 2020, all emissions produced in 2020, and all emissions produced from 2020 into the far future. Dr. Smith noted that in the case of greenhouse gases, the marginal damage estimate varies with the baseline projection of greenhouse gas emissions and is higher if it is calculated against a baseline reflecting a world in which no greenhouse gas control policies are in place compared to a world that includes global greenhouse gas control policies. Dr. Smith thus concluded that a more appropriate marginal value should be calculated using a projection of CO_2 and other greenhouse gas emissions consistent with the global target that is considered appropriate to address climate change concerns, which the IWG did not do. To understand the sensitivity of the estimated SCC value to the question of which emissions levels should be the point at which the marginal damages should be computed, Dr. Smith considered that the marginal *benefit* is if the Minnesota tons in question are viewed as the first increment to all future anthropogenic tons, rather than the last increment to a business-as-usual baseline. To estimate the marginal value of the first ton, which is the lowest possible marginal value that the IWG's IAMs will produce, Dr. Smith modified the IAMs so that the baseline scenario represents no anthropogenic emissions occurring after 2020. She explained that this was merely an analytical device that allows one to infer the range of variation in the marginal damage estimate when using alternative future emissions projections. The first ton analysis creates a lower bound for the Minnesota CO_2 environmental cost value and

informs the Commission about how much of the IWG's marginal value estimate is due to emissions yet to be emitted, and not due to historical and present GHG emissions. It also allowed Dr. Smith to calculate the average marginal value by averaging first and last ton estimates. Dr. Smith testified that damages from emissions that Minnesota chooses to avoid or eliminate in an effort to show leadership in responding to climate change should be valued in a range between treating them as if they were the first incremental anthropogenic greenhouse gas ton to be emitted (going forward in time) and treating them as the marginal ton evaluated against a baseline reflecting a very large cumulative emissions reduction relative to the business-as-usual forecasts. To approximate these damages assuming use of IAMs, the upper bound should be set as the average of the marginal damage estimates for the first and last ton in the IWG projections.

Martin (Xcel Energy): Mr. Martin agreed that using the Federal SCC summary values would likely overstate damages solely attributable to Minnesota, because SCC values are calculated from a marginal ton of CO_2 as if it were the last ton added to the global GHG inventory, with no further reductions by others. He pointed out that the IWG's "last ton" methodology effectively assumes no further mitigation by others, and Minnesota emissions would be treated as if they are being added to a global GHG inventory as the last ton, when the atmospheric CO_2 concentrations are already high. Because the IAM damage functions are convex rather than linear, damages from a marginal ton will be much higher if treated as the last ton than as the first or average ton. This may be a factor causing the IWG methodology to overestimate damages, helping counterbalance other factors that cause the methodology to underestimate damages. However, Mr. Martin also stated that Dr. Smith's proposal to set global emissions to zero after year 2020 is entirely unrealistic. He noted that this issue remains a policy judgment for the Commission to decide and that his recommended range could not be adjusted for the first ton or average ton approach by statistical treatment; this would require re-coding and re-running the IAMs.

9.   Discount Rate (Issue 12)

Record Citations:
Hanemann Direct at 53-54,68-69, 73
Hanemann Rebuttal at 71-88
Hanemann Surrebuttal at 19-27, 31-32, 42, 46
Polasky Direct at 10-12, 20-21
Polasky Rebuttal at 20-24
Polasky Rebuttal Schedule 1 (OMB Response to Comments) 20-24
Polasky Surrebuttal at 8-13
Mendelsohn Direct at 11-12, Ex. 2 at 16-18
Mendelsohn Rebuttal, Ex. 1 at 5-8
Mendelsohn Surrebuttal at 28-32
Tol Rebuttal, Ex. 2 at 3-7
Bezdek Rebuttal, Ex. 1 at 28, 33-36, 45-46; Ex. 2 at 56, 58, 62, 63-64, 64-74 (passim)
Bezdek Surrebuttal at 59
Smith Direct at 23-26, Ex. 2 at 80-91
Smith Surrebuttal at 25-30
Martin Direct at 43-47, 59-60
Martin Rebuttal at 19, 41-43
Martin Surrebuttal at 6, 20-21, 30

Hanemann (Agencies): Dr. Hanemann explained how the IWG discounted the damages that went into the SCC. He said that the choice of discount rate fundamentally controls the weight being placed on outcomes that befall future generations, either giving them some consideration in today's assessment or essentially removing them from consideration. He explained that, for each model there were 50,000 sets of output, containing estimates of the annual damages over the period 2010 through 2100 due to warming induced by an emissions scenario. The IWG aggregated the damages over that span of time by assigning these damages a conventionally-expressed discounted present value: each year's damages were discounted back to 2010 and summed. A lower discount rate yields a larger discounted present value, while a higher discount rate yields a smaller discounted present value. Dr. Hanemann observed that the IWG's policy judgment was that discount rates of 2.5, 3, and 5 percent reflected "reasonable judgments under both descriptive and prescriptive approaches" to determining an appropriate rate of discount; the IWG selected 3 percent SCC value as the central estimate. Dr. Hanemann agreed with this choice and recommended retaining all three discount rates used by the IWG. It was appropriate for the IWG to use these three values, which are consistent with the values used in the existing peer-reviewed literature on the economics of climate change and GHG mitigation, ranging from 1.5 percent to 5.5 percent. Dr. Hanemann pointed out that there is a well-developed economic theory of the discount rate and a consumption rate of discount should be used for the SCC; a consumption rate of discount of 2.5 percent is compatible with calculations based on reasonable economic assumptions. However, Dr. Hanemann also noted that the 5 percent discount rate is likely to be too high to use in an intergenerational context and as an estimate of the social consumption rate of discount because the marginal utility factor which it reflects is likely to be overstated for several reasons. He pointed out that these same reasons, which also speak against using the standard formulation of the Ramsey rule, include: 1) we should place more weight on the well-being of future generations; 2) value of money declines as people get richer; 3) all impacts of climate change cannot be counted in terms of GDP; 4) a lower rate should be used to discount outcomes occurring in the distant future than in the near term; and 5) some risk aversion is appropriate given the uncertainties involved in estimating long-term climate impacts. Dr. Hanemann testified that Mr. Martin did not agree with Dr. Smith's recommendation to discard the 2.5 percent discount rate, and he agreed with Mr. Martin on that point.

Polasky (CEO): Dr. Polasky believed that the IWG appropriately chose the three discount rates of 2.5, 3, and 5 percent, which are reasonable and commonly used in estimates of the SCC. He pointed out that discount rates higher than 5 percent are rarely used, however, it is not uncommon to use rates below 2.5 percent. He noted that the IWG used relatively high discount rates although there is strong support among economists to use lower discount rates than the IWG used, for example, 1.4 percent based on the Stern Review. Dr. Polasky stated that if the Commission considers discount rates higher than 5 percent, then it should also include rates below 2.5 percent. However, he noted that a 7 percent discount rate is outside the range of discount rates used by researchers studying climate change; Dr. Tol's own survey of the climate change literature does not support using a 7 percent discount rate. Dr. Polasky argued that there is uncertainty regarding the underlying parameters for the Ramsey rule and no consensus how the specific values for the components of Ramsey equation should be selected. He noted that the IWG appropriately considered, but chose not to use, the Ramsey rule. He acknowledged that there are sound reasons to adopt a declining discount rate through time, however, the literature and research are just emerging, and it was reasonable for the IWG to not adopt a declining

discount rate at this time. The IWG explains its selection of discount rates and addresses these issues in its response to comments.

Mendelsohn (Peabody): Dr. Mendelsohn recommended using the DICE2013 model's variable discount rate, which starts at 5 percent and is calculated to be consistent with the growth in GDP per capita. He testified that this is a reasonably appropriate and conservative estimate of the discount rate, which takes into account the interaction of GDP growth rates and discount rates. Dr. Mendelsohn testified that the falling interest rate tied to slowing economic growth over time justifies a discount rate that falls over time, but it does not justify a lower fixed rate. Dr. Mendelsohn testified that the approach taken by the IWG (constant rate of discount) divorces the interest rate from the path of GDP, which is inconsistent with the DICE model and economic theory. He noted that the 2.5 percent discount rate chosen by the IWG may be appropriate for the 23rd century, but not for today. He believed that the IWG chose arbitrarily low discount rates, which also violates the Ramsey rule (the discount rate follows the rate of income growth/decline over time). He also testified that that the Office of Management and Budget (OMB) generally argues that public projects should use the market rate of interest (currently 5%). In cases where regulations force private companies to invest in projects with risky benefits, OMB recommends a 7% discount rate. Because climate change involves scientific uncertainties, a 7% discount rate may be fitting given the inherent risks associated with this uncertainty.

Tol (Peabody): Dr. Tol recommended a discount rate that is based on the Ramsey rule, which takes into account economic growth or decline over time and is based on the idea that receiving money today is preferred over receiving it in the future (a dollar gain today is worth more than a dollar gain in a year from now). He noted that the Ramsey rule implies that future impacts are more heavily discounted in more rapidly growing economies. The IWG, however, used a consumption rate of discount that is constant over time, regardless of the prospects for economic growth or geographic location of the climate change impacts. Dr. Tol testified that under the IWG's approach, impacts in China are weighted 46% to 87% higher than impacts in the USA. In other words, a $1.00 loss in the USA is counted as $1.00; but a $1.00 loss in China is counted as $1.46 to $1.87. The result of this approach is that the federal government effectively places more value on the circumstances in China than on those in the U.S.

Bezdek (Peabody): Dr. Bezdek noted that in the debate over the SCC and IAMs, nothing has attracted as much attention and criticism as the choice of discount rate to estimate present value of future impacts. He stated that ever since the IWG released the 2010 TSD, there has been intense criticism and debate over the failure to consider discount rates higher than 5 percent. Use of the three IWG discount rates (5 percent, 3 percent, and 2.5 percent) was not "neutral." Rather, the IWG violated OMB guidelines and used rates that are lower than the discount rates used in real-world decision making. Dr. Bezdek argued that the IWG should have used also a discount rate of 7 percent pursuant to OMB Circular A-4, which specifically stipulates that a 7 percent discount rate be used as well. Specifically, Circular A-4 states that "a real discount rate of 7 percent should be used as a base-case for regulatory analysis," and "you should provide estimates of net benefits using both 3 percent and 7 percent." Dr. Bezdek noted that in examining the use of the SCC in regulatory impact analysis, the State of North Carolina determined that "the sign of the SCC is apt to be negative at the 7 percent discount rate. A negative SCC indicates that the beneficial aspects of carbon dioxide emissions actually outweigh the costs." Robert Murphy testified before Congress that "[i]f the Working Group ran the

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computer models again, this time using a 7 percent discount rate and an earlier reference year such as 2015, presumably a larger fraction of simulations would register zero or negative values for the SCC, so that the mean result would itself be closer to zero -- or conceivably even negative, meaning that carbon dioxide emissions conferred extra benefits on humanity." Dr. Bezdek testified that peer-reviewed literature undermines the IWG's approach by criticizing the choice of discount rates and how they were handled in calculating the SCC. He noted Mr. Martin's criticism of the task of assigning a net present value as depending on the contentious choice of a discount rate.

Smith (GRE/MP/OTP/MLIG): Dr. Smith has noted that the discount rate is not only a very significant driver in the SCC-value calculations, but that many of the values recommended in the literature and in this proceeding are driven more than moral philosophy than informed by empirical analysis. Recommendations for the right discount rate can be categorized as either (1) descriptive of observed human behavior, consistent with market evidence that reveals human preferences, or (2) prescriptive or normative in nature, reflecting subjective moral judgments without evidentiary basis. Dr. Smith stated that the use of a 2.5% rate is unsupported by empirical evidence, does not meet the criteria that Minnesota used in the prior proceeding, and noted that an element of the IWG's decision to adopt this rate as one of three rates was to acknowledge a subjective view and ethical considerations among some policy analysts that people living today should not discount the consumption of future generations in the manner which they discount their own within-generation consumption choices. Dr. Smith testified that the use of 3% and 5% discount rates is reasonable and that Federal guidance identifies 3% as a lower bound for approximating the social rate of time preference, but requires use of a 7% rate when a regulation will affect private sector capital spending, because 7% approximates the opportunity cost of displaced private sector investment. Accordingly, Dr. Smith testified that the discount rate to be used should have a lower bound of 3% and an upper bound of not less than 5%, and calculated damages at discount rates of 3%, 5%, and 7%.

Martin (Xcel Energy): Mr. Martin recommended retaining all three discount rates (2.5, 3, and 5 percent) used by the IWG, and therefore argued that his position is neutral regarding discount rate choice. He disagreed with Dr. Smith's recommendation to discard the 2.5 percent discount rate. He noted that the selection of the discount rate is a policy judgment rather than an objective scientific choice, because there simply is no empirical evidence of the preferences of distant future generations supporting discarding the 2.5 percent discount rate. Mr. Martin noted that the Commission may choose to select different discount rates than the IWG, and explained how his recommended range of environmental values could be adjusted if the Commission decides to adopt values at only 3 and 5 percent discount rates.

10.   Geographic Scope (Issue 13)

Record Citations:
Hanemann Rebuttal 13-16
Hanemann Surrebuttal at 8-10
Polasky Rebuttal at 25-29
Polasky Surrebuttal at 20-21
Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 30-31
Bezdek Direct at 6-7, 22-24

Bezdek Surrebuttal at 52Mendelsohn Direct at 3-5, Ex. 2 at 4-5
Mendelsohn Rebuttal, Ex. 1 at 3-4, 9; Ex. 2 at 2-8
Smith Direct at 26-27, 36-37, Ex. 2 at 92-99
Smith Surrebuttal at 3-4, 6, 30-34
Gayer Direct at 6-10, Expert Report at 2-18
Gayer Surrebuttal 1-9
Martin Rebuttal at 27-28, 38-40
Martin Surrebuttal at 6, 29

Hanemann (Agencies): Dr. Hanemann stated that GHGs emitted at a particular location on the earth mix in the atmosphere with GHGs emitted from all other locations on earth, and contribute to climate change damages globally. A molecule of emitted GHG contributes to damages from climate change experienced everywhere around the globe, regardless of where it is emitted. The IWG acknowledged this fact and calculated global damages when it developed the Federal SCC. Dr. Hanemann argued that economic theory per se cannot prescribe the geographic scope of climate change impacts. He acknowledged that the geographic scope of damages is a policy decision for the Commission to make, however, he noted that the Department has recommended estimating global damages for CO_2 earlier in its comments in this Docket. According to Dr. Hanemann, Dr. Mendelsohn's statement of positive net effects of warming in Minnesota are speculative at best, and should not affect the determination of geographic scope of damages.

Polasky (CEO): Dr. Polasky argued that emissions of CO_2 in Minnesota will contribute to global environmental damages, and Minnesota law clearly intends for all environmental costs associated with electricity generation to be included in the damage values without placing any explicit geographic limits on those damages. With CO_2 emissions, we in Minnesota are causing direct harm (even though through a complicated biophysical process) to people across the planet. Dr. Polasky pointed out that environmental damages do not follow political boundaries. He stated that incorporating the SCC into Minnesota resource planning decisions is not an act of generosity that we are bestowing on the rest of the world, as argued by Dr. Gayer, but an act of taking responsibility for the results of our actions and showing leadership. Focusing solely on damages to Minnesota would significantly underestimate the value of the state's emission reductions. The IWG also explains why looking at global damages is important and responds to these same issues in its response to comments.

Mendelsohn (Peabody): Dr. Mendelsohn estimated that the American share of the SCC ("American Cost of Carbon") is currently about 5 percent of the global SCC, while the Minnesota share of damages ("Minnesota Cost of Carbon") is likely 0.1 percent of the global SCC (2 percent of the American Cost of Carbon) or may be negative. If the U.S. acted unilaterally to control emissions without action by the rest of the world, the U.S. would pay the full cost of these emission reductions, but 95 percent of the benefits would go to other countries. According to Dr. Mendelsohn, Minnesota is likely to be a beneficiary of climate warming now and over the next century, benefitting from increased productivity of its ecosystem and crops and decreased heating costs in winter. These benefits will far outweigh any likely damages from emissions in the state during the same period. Using the SCC values would mean that Minnesotans are paying mostly for damages outside the United States, while getting less than 1 percent of benefits, if lucky.

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Bezdek (Peabody): Dr. Bezdek argued that Minnesota's relatively northern location indicates that it would benefit more from mild warming because mortality from cold would be reduced. Minnesota agriculture is highly petrochemical intensive. Also, higher electrical rates would adversely affect Minnesota's lower-income residents. Regionally uneven benefits from carbon fertilization will accrue to Minnesota's benefit, not detriment.

Smith (GRE/MP/OTP/MLIG): According to Dr. Smith, only Minnesota damages should be included in the CO_2 environmental cost value. She notes that, while it might make sense for the Federal government to consider global damages when calculating the SCC because it has the authority to negotiate reciprocal international agreements to reduce global carbon emissions, Minnesota and other individual states lack authority to enter into international treaties. In the absence of reciprocal agreements, the vast majority of the benefits will not accrue to the community that will be bearing 100 percent of the cost, and the assurance that benefit-cost analysis will guide policy makers towards societal improvement is lost. Moreover, in the absence of concerted action, incorporating global damages would harm Minnesota and fail to help anyone else due to the extraordinarily small portion of Minnesota's CO_2 emissions as a percentage of global CO_2 emissions, while under a 3% discount rate approximately one-third of the estimated damages attributable to Minnesota under the IWG's calculations is actually attributable to the actions of others who will be contributing to future emissions, most of which will be non-U.S. in origin. Therefore, it is most appropriate to consider the benefits to Minnesotans from Minnesota's actions to reduce CO_2, given that the costs are paid by Minnesota electric customers. Dr. Smith further noted that by pricing its carbon emissions in ways that no other political jurisdictions are doing, Minnesota would place itself at a distinct and possibly substantial economic disadvantage. Lacking a modeling component inherent in the IAMs that will calculate Minnesota-only damages, Dr. Smith recommended calculating only U.S. damages and made this alternative framing assumption in her modeling. Although this change still significantly overstates Minnesota-specific damages, Dr. Smith argued it is more appropriate than using global damages. Dr. Smith also provided U.S. and non-U.S. components to her calculated values so that the Commission can determine whether and to what extent it wants to give weight to non-U.S. damages in the environmental cost values to reflect altruism of Minnesotans.

Gayer (MLIG): According to Dr. Gayer, the IWG's focus on global benefits is not consistent with sound benefit-cost practices, nor within the guidance provided by executive orders and the OMB. He argued that the regulatory guidelines and the stated aims of the pertinent environmental statutes suggest that Federal environmental policies should account for the benefits to residents in the U.S. and not the worldwide population. Dr. Gayer pointed out that determination of Minnesota environmental values is a unilateral policy without any reciprocity by other states or nations. Since Minnesotans will accrue all costs, absent explicit reciprocity, it would be outside of the typical practice of benefit-cost analysis for Minnesota to consider the environmental benefits to the entire global population. Dr. Gayer stated that there are countless examples of other policies (welfare, public education, tax, national defense) where the benefits and costs are considered for the jurisdiction enacting the program (e.g., "the society"), not the global population. He believed that demonstrative feelings of altruism could justify considering some benefits outside of Minnesota, but adopting a global measure of benefits would go far outside appropriate and proportional proximity considerations. According to Dr. Gayer, if Minnesota adopts a higher value for the SCC, at this time it will not lead others to reduce their

emission levels, which is why the global scope of the SCC is at this time inappropriate for Minnesota. Just because CO_2 is a global pollutant does not justify extending the benefits to the entire global population in a state-level benefit-cost assessment.

Martin (Xcel Energy): According to Mr. Martin, the decision whether to focus on global, U.S., or Minnesota damages is one of the IWG's subjective policy judgments rather than an objective scientific choice, and the Commission may choose to make a different policy judgment than the IWG. The Commission may have an interest in demonstrating environmental leadership and providing an example to encourage reciprocity by other jurisdictions. On the other hand, Mr. Martin noted that using the Federal SCC executive summary values would likely overstate damages solely attributable to Minnesota, because the SCC values are calculated based on global damages, even though any reductions in Minnesota's emissions are likely to have little effect on global damages. Yet Minnesota utility customers would bear greater direct costs. Mr. Martin urged the Commission to consider how to mitigate these impacts, and pointed out that his recommended range of environmental values could be adjusted to reflect other than global damages by applying an adjustment factor based on GDP.

11.   Standardization (Issue 14)

Record Citations:
Polasky Direct at 6-8
Polasky Rebuttal, schedule 1 (OMB Response to Comments), at 19
Polasky Surrebuttal at 21-22
Hanemann Direct at 34-42, 46-54
Hanemann Rebuttal at 43-44
Hanemann Surrebuttal at 10-13, 30, 33
Mendelsohn Direct at 16
Mendelsohn Rebuttal at 4-5

Polasky (CEO): Dr. Polasky describes the process by which the IWG selected the three most widely cited Integrated Assessment Models on which to base its SCC. He notes that the process the IWG used to develop the SCC was evaluate by the U.S. Government Accountability Office and attached that evaluation to his Direct Testimony. According to Dr. Polasky, the IWG wanted to respect the choices made by the model developers but also wanted to be able to compare the results across models. In order to allow this comparison, the IWG used a consistent set of inputs for three baseline assumptions, selecting a range of values as inputs for each of the three to account for uncertainty. Dr. Polasky acknowledged that there is a trade-off between internal consistency of each model and consistency across models. However, he noted that making the models comparable, the methods more transparent, and making it easy to update are all positive attributes. He concluded that the IWG made a reasonable decision considering these trade-offs. Dr. Polasky also noted that the IWG addressed this issue in its response to comments.

Hanemann (Agencies): Dr. Hanemann detailed how the DICE, FUND and PAGE models are similar or different from one another, and explained how the IWG was able to run the models side by side and average the results by first standardizing the model inputs and parameters. He explained that this is a standard practice in model inter-comparison exercises, and in his opinion, it would have been unreasonable if the IWG had not done this. Dr. Hanemann detailed how the

IWG standardized model inputs (the "drivers" of emissions") of future population, income, and emissions, as well as parameters for non-CO_2 radiative forcing and the climate sensitivity value. To standardize projections of income, population, emissions, and non-CO_2 radiative forcings, the IWG used results of the highly authoritative Energy Modeling Forum's (EMF) 22nd model inter-comparison study (Clarke et al., 2009). To standardize the value of the ECS, the IWG made ECS a random variable with the same probability distribution for all three models. (See Issue 5 above). Once annual damages were calculated, the IWG standardized the discount rate used to add up the annual damages and convert them to a present discounted value, using the three alternative discount rates. He further noted that, because PAGE and FUND are simulation models while DICE is an optimization model, IWG removed the optimization feature in DICE to put it on a common footing with the other two models, and remove differences between optimization and simulation would otherwise have confounded the comparison between DICE on one hand, and PAGE and FUND on the other. Also, in the optimization version of DICE, global emissions of CO_2 are assumed to be determined by a single decision maker who controls emissions made around the world, an assumption that simplifies the mathematical analysis, but is not a reasonable way to characterize how the world will proceed to deal with climate change. Dr. Hanemann explained that, contrary to Professor Mendelsohn's criticisms, when a model like DICE is run in a simulation mode, one can make different assumptions about income and population without changing the interest rate. Also contrary to Professor Mendelsohn's assertion that DICE accurately predicts GHG emissions based on GDP, Dr. Hanemann observed that there is no evidence that DICE has a good track record at projecting GHG emissions, or of predicting them more accurately than the EMF-22 exercise. Finally, the IWG did not standardize, but instead preserved how, given the emissions, each model individually (i) projected the change in atmospheric concentration of GHGs, and (ii) evaluated the economic cost of the damage caused by the warming generated by that change in atmospheric GHG concentration.

Mendelsohn (Peabody): Dr. Mendelsohn noted that the IWG substituted many of their own assumptions instead of using the assumptions in each model. He also noted that the IWG assumptions are not consistent with each other. For example, different GDP paths imply different future interest rates. However, the IWG failed to take into account the effect of different GDP paths on the interest rates used in its models. Therefore, the interest rates used by the IWG were not consistent with their assumptions about GDP. Dr. Mendelsohn also claims that one of the primary values of IAM models is that they carefully integrate economic assumptions across the economy. However, he states that the IWG exercise violates the assumptions of the IAM models by imposing its own standardized assumptions.

12.   Adaptation and Mitigation (Issue 15)

Record Citations:
Hanemann Rebuttal at 25-26, 70
Hanemann Surrebuttal at 6-7, 34-37, 40
Polasky Rebuttal at 13-14
Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 18-20
Polasky Surrebuttal at 20-21
Mendelsohn Direct at 16-17, Ex. 2 at 9
Mendelsohn Rebuttal, Ex. 1 at 3
Mendelsohn Surrebuttal at 17-21

Bezdek Direct at 6, Ex. 3 at pp. 107-114, 179-181
Smith Direct at 21-23, Ex. 2 at 72-73, 116-118
Smith Surrebuttal at 13-17
Martin Direct at 34
Martin Rebuttal at 9, 24-25, 47-51
Martin Surrebuttal at 38-39

Hanemann (Agencies): Dr. Hanemann pointed out that the IWG's emission scenarios all assume that GHG emissions are reduced eventually. Also, one of the five EMF-22 scenarios (the "550 ppm" stabilization scenario) assumes coordinated global action. He argued that it would be overly optimistic to assume that future societies will take action and not allow high levels of warming. First, there is a time lag of decades before the effects of today's emissions are translated into future warming, and future societies may be slow to act. Second, it is paradoxical for Dr. Smith to urge Minnesota to adopt lax regulations of GHG emissions on the specific basis that society will choose to avoid high levels of GHG emissions. Third, reduction of global CO_2 emissions are not determined by "society" as stated by Dr. Smith. They are determined by the 196 members of the UNFCCC, and individual countries have their own concerns, which makes collective action harder to achieve. However, Dr. Hanemann agreed with Mr. Martin that there is considerable technical innovation underway to reduce the CO_2 intensity of energy and significant governmental efforts to promote mitigation, but pointed out that in the US, there is also significant political opposition to these governmental efforts and outcomes are yet unclear. Dr. Hanemann strongly doubted that the uncertainty regarding adaptation and mitigation fully counterbalances the uncertainty regarding catastrophic damages. He explained that it is premature to claim that the SCC values may be too high because the IAMs do not adequately account for adaptation and mitigation. The fact remains that global emissions have risen significantly over the past 15 years and global emissions are currently on track to follow the highest of the four GHG concentration scenarios adopted by the IPCC for its Fifth Assessment Report. While lower emission and concentration scenarios may be achieved later in this century, Mr. Martin's confidence in that outcome is premature. In any event, the FCC is updatable: information received during the coming decades about the likely trend of emissions can be used to update future estimates of the federal SCC.

Polasky (CEO): According to Dr. Polasky, it is incorrect to state that the IAMs do not take into account any future mitigation, global climate policy, or technological change. He pointed out that the five Stanford Energy Modeling Forum (EMF-22) projections predict that in the future the economy will be much less CO_2 intensive; in other words, the EMF-22 projections already incorporate many emission-reduction technologies into the economy even though the total quantity of emission increases in four projections due to the growing global GDP. In addition the "550 ppm average" scenario predicts declining emissions, which can only occur if there is large-scale mitigation of CO_2 emissions in the rest of the world outside Minnesota. This is also explained in the IWG's response to comments.

Mendelsohn (Peabody): Dr. Mendelsohn testified that the IWG made a mistake in calculating the SCC using a simulation approach rather than an optimization approach which effectively assumes there is no mitigation now or in the future anywhere in the world, and therefore significantly overestimated the SCC. He pointed out that there is already mitigation today, and societies will learn more about climate change as the planet warms, and will likely react. If

societies learn that climate change is more harmful than we thought, they will take action and do more mitigation. Dr. Mendelsohn stated that there is extensive evidence that people have already adapted to the climate that they live in across the planet. He pointed out that climate change is a gradual, slow process, not a surprise, and it is very obvious that people will react. Adaptation will cause the actual damage from climate change to be a small fraction of potential damage.

Bezdek (Peabody): Dr. Bezdek testified that humans would flourish in a warmer climate, and he pointed to peer-reviewed and other literature showing that adaptation will increase the benefits even more and that adaptation to warming is an economically superior response compared to radical abatement.

Smith (GRE/MP/OTP/MLIG): Dr. Smith pointed out that it is unrealistic and contrary to current evidence to assume that future generations will not take any action to address climate damages from warmer temperatures, whether in the form of adaptation, technological innovation, or government action, but that such an assumption is the basis for the IWG's modeling choices. According to Dr. Smith, the IWG's 2300 model horizon assumes, unrealistically, that future generations will passively endure temperature changes as high as 10°C above pre-industrial levels, without taking any steps whatsoever to address the causes of such temperature changes. The fact that we are discussing the environmental impacts of GHG emissions now and that the Commission is taking steps to update its environmental values shows just how unrealistic that assumption is. Dr. Smith testified that the IAM extrapolations are entirely the subjective view of each IAM modeler, including the IWG, where it modified pre-programmed assumptions, based on reasoned beliefs, rather than evidence, and as a result of the very long modeling horizon, the IWG's SCC values are driven more by the speculative portions of the IAMs' damage functions than by the portions that have at least some evidentiary basis. Dr. Smith did not propose changes to the IAMs regarding adaptation and mitigation; however, her proposal to shorten the modeling horizon to year 2100 or year 2140 is in part based on assumptions regarding adaptation and mitigation. Dr. Smith also points out that the "last ton" approach of the IWG is inappropriate in part because it assumes no future action to mitigate emissions, and thereby increases the SCC estimate.

Martin (Xcel Energy): Mr. Martin stated that one factor that could cause the SCC to be overestimated is that the SCC methodology only partially captures societal adaptation and completely lacks endogenous modeling of technological innovations or future political action by governments in the face of severe climate change. It would be counterintuitive and contrary to current evidence to assume no future mitigation or adaptation by future societies despite severe climate damages. Mr. Martin pointed out that right now, there is tremendous technological innovation to reduce CO_2 intensity of energy, as well as governmental efforts at the state, federal, and global levels to mitigate CO_2 emissions. He argued that the IAMs' poor modeling of adaptation and endogenous technological change is a reason not to adopt the 95th percentile SCC value without the corresponding 5th percentile value. Mr. Martin noted that it would require changes to the IWG methodology and the IAMs' modeling to take into account future adaptation and mitigation in the Federal SCC values.

13.   Carbon Fertilization and Warming Benefits (Issue 16)

Record Citations:
Gurney Rebuttal at 2-7, 19-23
Gurney Surrebuttal 11-12, 17, 19
Hanemann Rebuttal at 2-12
Hanemann Surrebuttal at 8-10
Polasky Rebuttal at 52-56
Reich Surrebuttal at 2-14
Bezdek Direct at 2-3, 6, 9-34, 36-37; Ex. 2 at 10-48, 56-92
Bezdek Rebuttal, Ex. 1 at 12-22, 41, 64-74
Bezdek Surrebuttal at 20-57
Happer Direct at 3, 5, 9-12, Ex. 2 at 8-11
Happer Rebuttal, Ex. 1 at 2-4
Happer Surrebuttal at 10-24
Lindzen Direct at 7, Ex. 2 at lines 569-614
Mendelsohn Direct, Ex. 2 at 12
Mendelsohn Rebuttal, Ex. 1 at 3
Mendelsohn Surrebuttal at 2-5, 26
Martin Rebuttal at 34-35
Rom Direct at 3-8

Gurney (Agencies): Dr. Gurney noted that CO_2 fertilization effects are well understood and quantified at the individual leaf/plant scale in controlled or laboratory conditions. However, the magnitude of CO_2 fertilization in real-world conditions is extremely variable and dependent upon a wide array of factors, such as nutrient availability, water availability, species, soil type/conditions, light levels, etc. Dr. Gurney pointed out that Dr. Bezdek's testimony on CO_2 fertilization relies on a non-peer reviewed report, which represents results from laboratory or controlled conditions. The most comprehensive assessment of research to date by the IPCC found that the net effect of climate and CO_2 changes on crop productivity is negative at the global scale and the regional scale. Dr. Happer's claim that there is worldwide "greening" due to CO_2 fertilization is not supported by his chosen citation nor the IPCC review on the topic.

Hanemann (AGENCIES): Dr. Hanemann testified that Dr. Bezdek's analysis of agricultural benefits of CO_2 lacks credibility, and reporting negative impacts of climate change on crop yields has been far more common than reporting positive effects. Similarly, Dr. Mendelsohn's claims of positive net benefits from carbon fertilization effects are unfounded. Dr. Hanemann noted that for most but not all plants, photosynthesis increases when CO_2 rises. However, whether this translates into increased crop growth is less certain – fertilization effects vary by plant, temperature, ozone, soil, moisture, nutrient, and microclimate conditions. Increased weed growth may also interfere with plant growth. Dr. Hanemann pointed out that it is uncertain how well small-scale, controlled experimental results can be generalized at a large, field-level scale. He noted that at least DICE and FUND account for carbon fertilization in some manner. According to Dr. Hanemann, Dr. Mendelsohn's statement of positive net effects of warming in Minnesota are speculative at best, and Dr. Bezdek's analysis of CO_2 emissions on economic growth lacks scientific validity.

Polasky (CEO): Dr. Polasky stated that Dr. Bezdek's views on climate change are far outside the mainstream scientific understanding and ignore the bulk of available evidence. The overwhelming majority of economists and climate scientists conclude based on the evidence that the external costs of CO_2 emissions outweigh the external benefits, and it would be extremely inappropriate to adopt a value of zero for the SCC, as Dr. Bezdek recommends. Dr. Polasky noted that Dr. Bezdek's estimate of positive agricultural effects is not reliable and is based on unscientific approach in which the crop yield effects in laboratory experiments are used to project large-scale, on-field crop yield increases. Unlike laboratory conditions, crop yields in the field are affected by changes in water availability, temperature, other nutrients, and pests and pathogens, not only CO_2 fertilization effects. According to Dr. Bezdek, the IAMs already incorporate potential agricultural benefits from CO_2 emissions as well as the costs to agriculture, sea-level rise, and other categories. He noted that the IPCC Fifth Assessment Report concluded that studies from around the world show that climate change is negatively affecting wheat and corn yields for many regions, and that there has been little impact so far on soybean and rice yields.

Reich (CEO): According to Dr. Reich, climate change will likely have both positive and negative effects on Minnesota forests, with negative effects likely to outweigh positive effects in the near-term and with the aggregate impact becoming increasingly negative looking further into the future. He noted that it is important to recognize that climate change includes multiple, simultaneous changes: CO_2 concentrations and warming; soil water availability; magnitude of insects, diseases, invasive species, and fire. Dr. Reich pointed out that Dr. Mendelsohn cited as support to his assertions about Minnesota forests mostly sources that are global in nature, based largely on computer models rather than empirical evidence, and not the most recent or relevant publication on the topic. Dr. Reich stated that there is certainly no evidence to support the notion that Minnesota agriculture and crop production will generally benefit from rising CO_2 and associated climate change in the next seven decades. He noted that Dr. Bezdek supported his claims regarding increased crop production with largely irrelevant and non-peer-reviewed sources. Dr. Reich pointed out that for example corn, one of the main crops of Minnesota, has minimal increases in productivity from increased CO_2 concentrations due to its specific photosynthetic physiology (C4 photosynthesis).

Mendelsohn (Peabody): Dr. Mendelsohn stated that overall, carbon fertilization has increased crop yields by a far larger amount over declines across the entire world, suggesting a sizable net benefit. On the basis of more than two decades of empirical study, his own expertise, and peer-reviewed research in the field, Dr. Mendelsohn testified that the net change in ecosystems from global warming is likely to be beneficial over the next century. He noted that there is every reason to believe that Minnesota is currently and will continue to be a beneficiary of warming over the next century from the increased productivity of its ecosystems, from the increase in crop production, and from reductions in heating costs in winter. Ecological models suggest that Minnesota forests would become more productive and have more standing biomass as a result of near-term climate change. According to Dr. Mendelsohn, these benefits will far outweigh any likely damages in the state during this period.

Happer (Peabody): According to Dr. Happer, CO_2 is not a pollutant but a benefit to Earth, because it will only cause a small increase in temperature, and moderate warming will be a net

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benefit to the Earth. Additional atmospheric CO_2 will substantially increase plant growth rates and drought resistance, and satellite observations have shown a very pronounced "greening" of the Earth. Dr. Happer noted that most economic models fail to account for the major benefits to agriculture from increased CO_2, which increases the photosynthetic efficiency of most agricultural crops and forests and decreases many plants' water requirements. He stated that higher latitudes, including Minnesota, will also benefit from a longer growing season. According to Dr. Happer, CO_2 at atmospheric concentrations has no adverse effects on human health. Research has demonstrated the net benefits to human health from warmer temperatures: for example, warming will lead to less asthma and fewer respiratory illnesses.

Lindzen (Peabody): According to Dr. Lindzen, CO_2 is a plant fertilizer, not a pollutant, and the increasing levels over the past two centuries are significant contributors to increased agricultural productivity. He noted that mild warming will be beneficial to the public health by reducing cold-related mortality, and higher concentrations of CO_2 will not present a risk to health. Dr. Lindzen stated that warming at the levels that might realistically be anticipated (i.e., under 2°C for the foreseeable future) is estimated to be net beneficial.

Bezdek (Peabody): According to Dr. Bezdek, the environmental benefits of CO_2 emissions are enormous and have been widely documented and estimated. He argued that CO_2 is not a pollutant, is not harmful, and is actually good for the planet. Dr. Bezdek stated that CO_2 is not known to have any negative impacts on human health; cold is much greater health danger than heat, and humans would flourish in warmer climate. He noted that the effects of CO_2 on agriculture and agricultural productivity are positive and highly beneficial. Plants will flourish under higher CO_2 conditions, becoming healthier and more resistant to pests and disease. Plants also utilize hydration more efficiently in increased CO_2 conditions, which would offset the feared negative effects even if precipitation decreased. According to Dr. Bezdek, the effects of carbon fertilization have been validated in peer-reviewed literature and field observations. He pointed out that certainly Minnesota stands to benefit enormously from a warmer climate. He also noted that IAMs do not adequately take into account the CO_2 fertilization effects and thus substantially overestimate the SCC. Dr. Bezdek further testified that the effect of CO_2 fertilization on agricultural productivity can be quantified, and a doubling of the air's CO_2 content above the current level will increase the productivity of most herbaceous plants by about one third. The total economic value of the CO_2 benefit for 45 crops cumulatively totaled $3.29 trillion (1961-2012) and is forecast to total nearly $10 trillion (2012 – 2050). In addition, the social benefits of carbon are worth a comparable amount. Dr. Bezdek testified that the benefits of CO_2 emissions with respect to economic growth exceed by orders of magnitude the federal SCC figures -- the benefits estimates are so large as to relegate the federal SCC estimates to statistical noise. Dr. Bezdek finds that the benefits of CO_2 outweigh the costs by as much as 250:1.

Martin (Xcel Energy): Mr. Martin stated that he does not have a position on the various climate science questions raised by Peabody's witnesses, such as potential benefits of warming and CO_2.

Rom (DHE): According to Dr. Rom, a statement that humans will flourish in a climate warmed by CO2 emissions is deeply irresponsible and factually incorrect. He noted that the harmful public health impacts of warming climate are well established and well understood. Heat stress has been the leading weather-related cause of death in the United States since 1986, and although warmer temperatures would likely reduce deaths from extreme cold, projected increase in deaths

due to more frequent extremely hot days is much larger than the projected decrease in deaths due to fewer extremely cold days. Dr. Rom pointed out that Dr. Bezdek's assertions are based on selective, irrelevant, flawed, or non-peer-reviewed materials. By contrast, every major peer-reviewed study has concluded that a warming climate poses a human health risk, not a benefit.

14.   DICE Model (Issue 17)

Record citations:
Hanemann Direct at 23, 34-42, 46-52, 56-58, 65-68,
Hanemann Rebuttal at 4, 38-48, 54-55, 59, 63, 84
Hanemann Surrebuttal at 10-13,48
Mendelsohn Direct at 6-9, 13
Mendelsohn Direct Ex. 2 at 8-11, 14
Mendelsohn Surrebuttal at 34
Polasky Direct at 13-14, 18-20, 21-22,
Polasky Direct Schedule 2 at 6-7; 27;
Bezdek Direct at 4; 7-8; 26
Bezdek Direct, Exhibit 2 at 95-117
Bezdek Rebuttal at 61-62
Smith Direct Ex. 2 at 20-31, 33

Hanemann (Agencies): Dr. Hanemann discussed the similarities and differences among the three models. DICE is an optimization model, as opposed to a simulation model. The essence of the optimization is that investment, consumption and output across all periods considered should be chosen so as to maximize the discounted present value of wellbeing aggregated over the entire span of periods considered. The maximization across all periods determines the optimal values of the variables for each individual period. In the optimization version of DICE, global emissions of CO_2 are assumed to be determined by a single decision maker who controls emissions made around the world, an assumption that simplifies the mathematical analysis, but is not a reasonable way to characterize how the world will proceed to deal with climate change. The simplifications embedded in the optimization version of DICE generates a lower estimate of the social cost of carbon than is likely to occur in the real world. Contrary to Professor Mendelsohn's assertion that DICE accurately predicts GHG emissions based on GDP, Dr. Hanemann observed that there is no evidence that DICE has a good track record at projecting GHG emissions, or of predicting them more accurately than the EMF-22 exercise.

The version used by the IWG for its 2013 report was DICE 2010, which incorporated information from IPCC's Fourth Assessment Report. The standardization of income and emissions inputs and discount rates by the IWG across all three IAMs necessitated a change in the structure of DICE, by converting it to a simulation model. (See Issue 14 above). Dr. Hanemann explained that, contrary to Professor Mendelsohn's criticisms, when a model like DICE is run in a simulation mode, one can make different assumptions about income and population without changing the interest rate. Dr. Hanemann agreed with Professor Polasky, that the PAGE, FUND, and DICE models are the three most prominent economic climate change IAMs, and their use by the IWG was appropriate and preferred to selecting only one or two of the models.

Polasky (CEO): Professor Polasky testified that DICE is an IAM that uses a single function that relates temperature increases with reductions in GDP for the global economy. The function is calibrated to represent impacts for the categories of agriculture, sea-level rise, change in energy use, human health effects, non-market amenities, climate-sensitive human settlements and ecosystems, and catastrophic climate events. The fraction of economic output lost due to climate damages increases with the level of temperature alone (not with the rate of temperature change, as in FUND). As used by the IWG, DICE and other IAMs result in the federal SCC being a conservative value that likely underestimates damage caused by CO_2 emissions. Two recent articles have examined the DICE model and found that accounting for the possible impact of climate change on the growth rate of the economy increases the SCC.

Mendelsohn (Peabody): Professor Mendelsohn testified that DICE is an Integrated Assessment Model of the global economy that predicts future economic growth, energy demand, and greenhouse gas emissions. The model also captures how emissions alter greenhouse gas concentrations, temperature and global climate damage. The model is designed to calculate optimal mitigation strategies that balance the cost of emission reductions against the benefit of reduced damage. The model is designed to determine the optimal level of mitigation that equates marginal cost to marginal damage at every moment. The result is a set of prices that rises over time as the concentration of greenhouse gases rise over time. These prices are optimal; in other words, they are equal to the marginal damage of an emission at each moment of time. They consequently reflect the social cost of carbon at that moment.

The DICE model includes baseline assumptions about the important parameters that affect calculation of a social cost of carbon. The baseline parameter values reflect the opinions of the model's author, Professor William Nordhaus.

IWG made conceptual and computational errors running the DICE model for the federal SCC. The conceptual error was that they chose to evaluate the SCC assuming zero mitigation, ever. IWG also did not run the models correctly. IWG ignored the estimates within DICE for both the GDP and the discount rate. Accordingly, Professor Mendelsohn testified that the IWG did not use the true DICE model in generating the federal Social Cost of Carbon.

Professor Mendelsohn used the most recent version of DICE (DICE2013) to calculate the social cost of carbon in DICE, based on the price or current marginal damage of one ton of carbon dioxide in 2015. In calculating the social cost of carbon he adjusted the damage function in DICE. DICE assumes that the preindustrial temperature (the global temperature effectively in 1900) was the optimal temperature, and therefore any increase in temperature from 1900 is therefore harmful. However, empirical research suggests that the optimal temperature for the world may well be up to 2 degrees higher than the temperature in 1900. He therefore developed two alternative damage functions in DICE that adjust the temperature upon which net damages begin. One modified damage function assumes that net damage will not begin until temperature rises above 1.5℃ and the other modified damage function assumes net damage does not begin until temperature rises 2℃ above 1900 levels. Professor Mendelsohn also believes that the climate sensitivity values used by the IWG in running the DICE model are higher than what the IPCC recommends. The IWG used a mean climate sensitivity of 3.5℃ with a 95% confidence interval of 1.7℃ to 7.1℃. IPCC recommends a likely range of 1.5℃ to 4.5℃. Dr. Mendelsohn used a climate sensitivity of 3 degrees when running the DICE model to arrive at a value of $4 to

$6, but because there is convincing evidence that the ECS is lower than 3 degrees and because the IPCC 5th Assessment Report lowered the "likely" range to 1.5 and no longer recommends a "best estimate" of 3.0, he also provided ranges for an ECS at 1.5 or 2 degrees.

Bezdek (Peabody): Dr. Bezdek noted numerous criticisms of all three IAMs used by the IWG. With respect to DICE, he specifically noted that it has little or no disaggregation with regard to sectors and/or geographic regions in its damage estimations. The DICE model uses a single total damage function based on estimates of temperature related damages in several sectors including agriculture, forestry, coastal vulnerability, health, and outdoor recreation, among others. The simplicity and arbitrariness of the structure of the damage functions raises concerns regarding their accuracy. A second issue Dr. Bezdek notes is that the damage function in DICE is based on studies of impacts on the United States that are then scaled up or down for application to other regions, but global science as yet cannot predict with any accuracy at all what countries or regions may be impacted more or less than any others with any increase in average global temperatures. Overall, the degree of uncertainty within the process is immense and renders any IAM results highly questionable.

In addition, DICE under-accounts for CO_2 fertilization and the benefits of increasing atmospheric CO_2 concentrations.

Smith (GRE/MP/OTP/MLIG): Dr. Smith testified that of the models used by the IWG, the first version of DICE was introduced in 1992, containing much of the same structure and key elements that remain in DICE today (Nordhaus, 1992a, 1992b). The first version of the PAGE model was also introduced shortly after 1990 (Hope et al.¸1993), and FUND was introduced by 1995 (Tol, 1996). These IAMs have been used and repeatedly revised since, with results of analyses that have been done using them described in peer-reviewed articles. However, all of their SCC estimates are strongly determined by a relatively small set of judgments about input assumptions that cannot be subjected to empirical validation or other objective evaluation, particularly for projected temperature changes above 3°C and for damages in the far future.

Dr. Smith noted that a study of the IAM damage functions finds that they are simplified formulas that largely circumvent a key attribute of the damage function approach. In large part, the models do not use "dose-response" relationships between climate outcomes and physical measures of resource changes that can then be assigned monetary values, but instead calculate loss of societal value directly from temperature change levels. Such aggregation largely eliminates the essential separation of physical damage estimates and the valuation of society's willingness to pay to avoid those damages that is considered a defining characteristic of the damage function approach. To the extent that aggregated damage functions are employed by an IAM, it becomes very difficult to know exactly what types of damages are even included in a particular SCC estimate.

Dr. Smith testified that the IAMs may provide useful computational efficiency, but the IWG has used them in a way that is out of line with any realistic view of how actual climate change, if it turns out to be consistent with pessimistic views, will be addressed by society. The more pessimistic of the IWG's temperature projections are a result of the models' computations that could be expected given the IWG's fixed projections of GDP and emissions, and the high values the IWG assumed possible for the ECS. However, a good analyst observing such results would

quickly realize the error in the IWG's analytic framing. The IWG's analysis forces the emissions projections that drive those very high temperature outcomes to remain unchanged through the entire 300-year modeling horizon, no matter how high the scenario shows temperature to have risen. This is equivalent to assuming that a wealthy and growing society will sit by and accept (for up to 300 years) any amount or rate of temperature change that they may find occurring without any technological reaction.

For DICE 2010, which is used in IWG (2013), the damage function includes an aggregated damage function but also includes a term that accounts for the damage caused by seal level rise ("SLR") where the physical amount of SLR is a function of the change in temperature. Thus, the damage function in DICE 2010 did include one physical measure of damage, SLR, but all other monetary losses were still a function of temperature increase only. The SLR module that appeared in DICE 2010 has since been removed in the more recent version of DICE, DICE 2013R.

In May of 2013, the IWG released its technical update to its 2010 report based on newer versions of the three IAMs than were used in the 2010 analysis, but with no modification to the IWG socioeconomic scenarios or other IWG-determined assumptions. Thus, the 2013 analysis adopted the 2010 assumptions for model inputs such as the discount rate, geographic specification, time horizon, reference case socioeconomic and emission scenarios, or ECS. As a result of using more recent versions of SCC models available by the time the update process was initiated, the IWG's SCC estimates for the period 2020-2025 increased by about 60% to 75% (for the 3% and 5% discount rate cases, respectively). Dr. Smith testified that there is no easy way to determine the specific reasons for the increase in the SCC values, as multiple different elements of each IAM had been changed. Some of the changes were due to changes in the science assumptions of the models, and some due to changes in their damage functions.

15. FUND Model (Issue 18)

Record Citations:
Hanemann Surrebuttal at 29-30
Tol Rebuttal, Ex. 2 at 6-7
Mendelsohn Surrebuttal at 25-26
Rom Rebuttal at 9-10
Smith Direct Ex. 2 at 20-31, 33

Hanemann (Agencies): Dr. Hanemann stated that it is not a surprise that FUND, as run by the IWG, produced different results than FUND run in its native form. The IWG standardized the external model inputs for all three IAMs and used different drivers for emissions than those native to FUND. This standardization was reasonable and necessary in order to put the three models on a common footing and to make them more comparable.

Tol (Peabody): As the author of FUND, Dr. Tol's assessment was that the IWG may not have correctly operated FUND in generating its estimates. The inconsistency between the damage estimates generated when Dr. Tol operates the FUND model himself, and those produced by the IWG, raises in Dr. Tol's view questions as to whether the IWG's estimates lack economic and scientific reliability.

Mendelsohn (Peabody): Dr. Mendelsohn specifically criticized the IWG's decision to switch the FUND model from an optimization mode to a simulation mode. The IWG's simplification was intended to generate an artificially higher estimate of the SCC by downplaying the role of mitigation.

Rom (DHE): According to Dr. Rom, the FUND model limits mortality and morbidity from cardiovascular disease to urban areas, even though those impacts will be felt in rural areas as well. FUND also limits the total change in mortality to a maximum of 5% of baseline mortality per cause, but the actual mortality experienced may prove to be much larger than a 5% increase. FUND also excludes any accounting of the health impacts of wildfires, which can have devastating health effects.

Smith (GRE/MP/OTP/MLIG): Dr. Smith testified that of the models used by the IWG, the first version of DICE was introduced in 1992, containing much of the same structure and key elements that remain in DICE today (Nordhaus, 1992a, 1992b). The first version of the PAGE model was also introduced shortly after 1990 (Hope *et al.*¸1993), and FUND was introduced by 1995 (Tol, 1996). These IAMs have been used and repeatedly revised since, with results of analyses that have been done using them described in peer-reviewed articles. However, all of their SCC estimates are strongly determined by a relatively small set of judgments about input assumptions that cannot be subjected to empirical validation or other objective evaluation, particularly for projected temperature changes above 3°C and for damages in the far future.

Dr. Smith noted that a study of the IAM damage functions finds that they are simplified formulas that largely circumvent a key attribute of the damage function approach. In large part, the models do not use "dose-response" relationships between climate outcomes and physical measures of resource changes that can then be assigned monetary values, but instead calculate loss of societal value directly from temperature change levels. Such aggregation largely eliminates the essential separation of physical damage estimates and the valuation of society's willingness to pay to avoid those damages that is considered a defining characteristic of the damage function approach. To the extent that aggregated damage functions are employed by an IAM, it becomes very difficult to know exactly *what* types of damages are even included in a particular SCC estimate.

Dr. Smith testified that the IAMs may provide useful computational efficiency, but the IWG has used them in a way that is out of line with any realistic view of how actual climate change, if it turns out to be consistent with pessimistic views, will be addressed by society. The more pessimistic of the IWG's temperature projections are a result of the models' computations that could be expected *given* the IWG's fixed projections of GDP and emissions, and the high values the IWG assumed possible for the ECS. However, a good analyst observing such results would quickly realize the error in the IWG's analytic framing. The IWG's analysis forces the emissions projections that drive those very high temperature outcomes to remain unchanged through the entire 300-year modeling horizon, no matter how high the scenario shows temperature to have risen. This is equivalent to assuming that a wealthy and growing society will sit by and accept (for up to 300 years) any amount or rate of temperature change that they may find occurring without any technological reaction.

According to Dr. Smith, of the three IAMs used by the IWG only the FUND model assesses multiple values separately for many different types of physical resources. FUND version 3.8 has eight impact categories: agriculture, forestry, water resources, energy consumption (space heating/cooling), sea level rise (SLR), ecosystems, human health (diarrhea, vector-borne diseases, cardiovascular/respiratory mortality), and extreme weather (tropical storms, extra-tropical storms). Some of the individual damage functions in FUND involve sub-models predicting physical changes (*i.e.,* SLR and health impacts) that are then valued, but the separation of estimation of physical damage estimates and monetary valuation is missing for the other damage functions, even though the specific physical effects that they represent are individually identified. In spite of having a more bottom-up approach, FUND still faces the same issues with limited empirical evidence as a basis for choosing the damage function parameters. For example, the water resources impact category in FUND is calibrated to results from the mid-1990s which, in a 2002 paper, Tol refers to as being incomplete and "the model used… is therefore *ad hoc*."

In November of 2013, the IWG released a revision to its May 2013 report to correct results from its model runs using the FUND model (IWG, 2013). The corrected SCC values generally differ from the May version's numbers by about a dollar or less, and there were no modifications to the text of the May version other than to describe the nature of the error and revise the numerical results.

16.   PAGE Model (Issue 19)

Record Citations:
Hanemann Surrebuttal at 48
Polasky Rebuttal at 48
Bezdek Rebuttal, Ex. 1, at 38-40
Mendelsohn Direct at 7, Ex. 2 at 9
Smith Direct Ex. 2 at 20-31, 33

Hanemann (Agencies): Dr. Hanemann agreed with Dr. Polasky that the three IAMs used by the IWG are the most prominent economic climate change IAMs and that it was appropriate to use all three models, including PAGE, in the SCC methodology.

Polasky (CEO): Dr. Polasky stated that the PAGE model along with the FUND and DICE models are the three most prominent economic climate change IAMs. The inclusion of all three models in the SCC methodology was appropriate and preferable to selecting only one or two models. According to Dr. Polasky, the best approach to address the uncertainty regarding climate change is to incorporate several different methodologies and sets of assumptions. The IWG did this by running each of the IAMs and evaluating several key parameters with a wide range of values.

Bezdek (Peabody): Dr. Bezdek argued that the PAGE model, in particular, suffers from serious flaws and should not be used for policymaking. To begin with, PAGE was not designed for the use to which the IWG put it. Of the three IAMs used in deriving the SCC, PAGE stands apart: It is not a cost-benefit tool for optimizing policy, but, rather, is based on a categorically different "decision analysis" approach. PAGE was designed as an alternative to the rational-choice,

objective cost-benefit analysis that is the focus of DICE and FUND. Second, PAGE's damage equations were not designed to apply to the entire world. PAGE is fundamentally parametrized for the EU, and consequentially is less accurate for other regions. PAGE calculates damages in the European Union, then simply scales damages in other regions based on length of coastline in proportion to the European Union. Third, PAGE is skewed by its reliance on low-probability, high-impact events (sometimes referred to as "tails" in the literature, because of how they appear on probability graphs). PAGE includes, for example, scientifically bizarre scenarios such as CO_2 concentrations that become self-propagating rather than diminishing, which have been debunked by climate literature. Finally, PAGE is also the least transparent and publicly available of the three IAMs, generating little peer-reviewed material.

Mendelsohn (Peabody): Dr. Mendelsohn stated that the PAGE model was intended to be a tool to explore various assumptions on modeling parameters and one's imagination about what the impacts of climate change could be. As such, Dr. Mendelsohn had little confidence in the results generated by PAGE in contrast to DICE and FUND. He noted that PAGE captures the imagination of academics but is not well grounded in economic theory or empirical evidence.

Smith (GRE/MP/OTP/MLIG): Dr. Smith testified that of the models used by the IWG, the first version of DICE was introduced in 1992, containing much of the same structure and key elements that remain in DICE today (Nordhaus, 1992a, 1992b). The first version of the PAGE model was also introduced shortly after 1990 (Hope *et al.*¸1993), and FUND was introduced by 1995 (Tol, 1996). These IAMs have been used and repeatedly revised since, with results of analyses that have been done using them described in peer-reviewed articles. However, all of their SCC estimates are strongly determined by a relatively small set of judgments about input assumptions that cannot be subjected to empirical validation or other objective evaluation, particularly for projected temperature changes above 3°C and for damages in the far future.

Dr. Smith noted that a study of the IAM damage functions finds that they are simplified formulas that largely circumvent a key attribute of the damage function approach. In large part, the models do not use "dose-response" relationships between climate outcomes and physical measures of resource changes that can then be assigned monetary values, but instead calculate loss of societal value directly from temperature change levels. Such aggregation largely eliminates the essential separation of physical damage estimates and the valuation of society's willingness to pay to avoid those damages that is considered a defining characteristic of the damage function approach. To the extent that aggregated damage functions are employed by an IAM, it becomes very difficult to know exactly *what* types of damages are even included in a particular SCC estimate.

Dr. Smith testified that the IAMs may provide useful computational efficiency, but the IWG has used them in a way that is out of line with any realistic view of how actual climate change, if it turns out to be consistent with pessimistic views, will be addressed by society. The more pessimistic of the IWG's temperature projections are a result of the models' computations that could be expected *given* the IWG's fixed projections of GDP and emissions, and the high values the IWG assumed possible for the ECS. However, a good analyst observing such results would quickly realize the error in the IWG's analytic framing. The IWG's analysis forces the emissions projections that drive those very high temperature outcomes to remain unchanged through the entire 300-year modeling horizon, no matter how high the scenario shows temperature to have

risen. This is equivalent to assuming that a wealthy and growing society will sit by and accept (for up to 300 years) any amount or rate of temperature change that they may find occurring without any technological reaction.

For PAGE09, which is the version used in IWG (2013), the damage function is comprised of four types of impacts: sea level rise (SLR), economic impacts from temperature change, non-economic impacts from temperature change, and a discontinuity term. All impacts are specified as a percentage change in GDP. The economic and noneconomic impacts are polynomial functions of change in temperature (ΔT). The SLR impact is a polynomial function of an estimated physical change in sea level. Although there are other features in the PAGE damage calculation that add complexity, the only actual physical damage that is estimated before being monetized (in the manner of the usual notion of the damage cost approach) is SLR.

17. Use of the Mean (Average) of the SCC Values (Issue 20)

Record Citations:
Hanemann Direct at 73
Hanemann Rebuttal 66-71
Hanemann Surrebuttal at 13, 41, 47
Polasky Rebuttal at 34-39
Polasky Rebuttal, Schedule 1 (OMB Response to Comments) at 26
Bezdek Rebuttal, Ex. 1, at 38-40
Mendelsohn Rebuttal, Ex. 1 at 7, 9
Mendelsohn Surrebuttal at 27-28
Wecker Rebuttal, Ex. 2, at lines 119-340
Smith Rebuttal at 6-8
Gayer Surrebuttal at 13-18
Martin Direct at 3, 25-28
Martin Rebuttal at 16
Martin Surrebuttal at 9-11, 15-16

Hanemann (Agencies): Dr. Hanemann acknowledged that the IWG made a policy decision when it decided to average the results from the three IAMs equally. He stated that it was reasonable to average the results, and that he is not aware of any suggestions in the existing economic literature on this topic that would provide a basis for doing something different. According to Dr. Hanemann, in the climate change context, sound decision-making requires consideration of not only the typical or most likely outcomes, but also less likely outcomes that could have very large (or small, or even negative) damages (the tails of the distribution). Using the median would effectively chop off the tails of the distribution, and from a risk management point of view this would be inappropriate, because the goal of regulating GHG emissions is to avoid the risk of possibly very harmful climatic outcomes in the right tail of SCC probability distributions.

Polasky (CEO): For each discount rate the IWG took the average (mean) of the 150,000 outcomes as the basis of for the SCC, a method that according to Dr. Polasky is quite standard and reasonable. He pointed out that the mean incorporates information about both the magnitude of damages and the likelihood of these damages, making it more comprehensive than the median. The median ignores the magnitude of damages other than at the midpoint of the probability

distribution, whereas the mean incorporates both large and small values throughout the distribution. According to Dr. Polasky, with climate change the high damage values are the ones we should be especially concerned about, so ignoring information about potential high damages is particularly problematic. He argued that the mean is a much better measure than the median for summarizing information about the distribution of possible damages under climate change. Dr. Polasky noted that the IWG addressed this issue in its response to comments as well.

Mendelsohn (Peabody): Dr. Mendelsohn testified that there is no justification for averaging the results of the three models used by the IWG, which he argued was inappropriate for such different models. He specifically criticized the addition of the PAGE model to an average because of the skewing effect. For similar reasons, he also criticized Mr. Martin's averaging of discount rates in his analysis.

Bezdek (Peabody): Dr. Bezdek also criticized the IWG's inclusion of the PAGE model in its calculation of the SCC. Dr. Bezdek testified that the PAGE model suffers from serious flaws and should not be used for policymaking.

Wecker (Peabody): Dr. Wecker noted that the adoption of the IWG's averaging technique by Mr. Martin did not represent a well-founded, statistically sound method for aggregating the IWG outputs. It failed to consult or apply authoritative statistical literature on combining probabilistic forecasts and decision-making under uncertainty. It was an unprincipled analysis of the uncertainties involved because it merely treated them all as equally probable. This "principle of indifference" ignores substantial uncertainty regarding the relevance of the PAGE model outputs, a 7% discount rate, and other issues. For example, the climate sensitivity assumptions employed in the IWG models are likely overstated and, therefore, SCC estimates based on these models are likely biased high. An "averaging" approach is especially inappropriate to use for the discount rate. In addition, for 13 of the 15 distinct sets of IWG cost estimates calculated using the FUND IAM, the 5th percentile falls below zero. A value below zero implies that the corresponding SCC estimate is not "statistically significantly" greater than zero.

Smith (GRE/MP/OTP/MLIG): Dr. Smith pointed out that the IWG's method to base the SCC values on the mean is founded in standard statistical theory. Although Dr. Smith noted that statistical and decision theories indicate that using only the mean value may not always be appropriate, depending on the decision context and the nature of the underlying probability distribution, she pointed out that Mr. Martin has not identified any theoretical properties of a range around the median that makes it a more sound statistical choice for summarizing SCC uncertainty than a range of mean estimates. Like the IWG, Dr. Smith took the mean of 150,000 IAM estimates for each emission year and discount rate, in her case after re-running the IAMs with alternative framing assumptions. Dr. Smith testified that the lack of any sound statistical underpinning to Mr. Martin's suggested method is evidenced by the fact that the same data could be used to identify narrower and lower SCC ranges that have the same probability as the suggested range, and they could be used to identify wider and higher SCC ranges that have the same probability as Mr. Martin's range.

Gayer (MLIG): Dr. Gayer agrees with the use of mean risk in expected value calculations, but notes that other experts in this proceeding and the IWG have confused risk with uncertainty, which leads to excessive SCC values by the suggested use of the 95th percentile value as a risk

estimate, without including the 5th percentile. This analytical mistake is known as the Ellsberg Paradox.

Martin (Xcel Energy): According to Mr. Martin, simply averaging the 450,000 SCC values for any give emissions year is inappropriate, because the average is a poor indicator of central tendency for a non-normal, heavily skewed probability distribution such as the SCC. The average is greatly influenced by values that are much higher or much lower than most of the values. Mr. Martin stated that in the case of the SCC, the mean is significantly higher than the median, because of the long right tail of very high damage estimates that have a low probability of occurring. However, he recommended against either the median or mean values, because both would be single point estimates.

18.   Use of the 95th Percentile SCC Value at 3 percent Discount Rate (Issue 21)

Record Citations:
Hanemann Rebuttal at 87-88
Hanemann Surrebuttal at 34-35, 40
Polasky Direct at 18-20
Polasky Rebuttal at 35
Polasky Rebuttal, Schedule 1 (OMB Response to Comments) at 26-27
Polasky Surrebuttal at 24-25
Mendelsohn Direct at 11-12
Mendelsohn Rebuttal, Ex. 1, at 5-8
Mendelsohn Surrebuttal at 29
Tol Rebuttal, Ex. 2, at 3-4
Wecker Rebuttal, Ex. 2, at lines 336-340
Bezdek Direct, Ex. 2, at 78-79
Gayer Surrebuttal at 15-18
Martin Direct at 29-30
Martin Rebuttal at 16-17
Martin Surrebuttal at 16-17, 40

Hanemann (Agencies): Dr. Hanemann noted that if the SCC is viewed through the lens of risk management, the IWG's 95th percentile value would be a relevant consideration ($105 for emission year 2015 and $123 for emission year 2020, based on the July 2015 TSD). He stated that in other regulatory contexts involving low risk but potentially catastrophic outcomes it is common to focus attention on events that can occur with as little as 5% probability

Polasky (CEO): According to Dr. Polasky, the high end of the range of SCC values is not well represented by using only the mean SCC value at the three discount rates (2.5, 3, and 5 percent). The IWG appropriately chose the 95th percentile value because the SCC is likely to underestimate the true damages of CO_2 emissions. Dr. Polasky stated that the three IAMs used by the IWG are quite conservative in their representation of the potentially catastrophic outcomes from a fundamental shift in the climate. By not altering the damage functions in the IAMs, the IWG chose to accept this cautious representation of catastrophic outcomes. Dr. Polasky pointed out that the SCC distribution has a long right tail on the high side, but there is

not an equivalent long left tail on the low side. For this reason, the 95th percentile value contains useful information about potentially higher than expected damages and it should be used as a CO_2 value. The IWG also addressed the use of the 95th percentile figure in its response to comments.

Mendelsohn (Peabody): Dr. Mendelsohn testified that if policy makers arbitrarily choose different discount rates for different projects, they are implicitly adjusting the rate of return in just those projects. For example, if the government chooses to use 3% as the discount rate for mitigation and 5% for all other private and public projects, they are implicitly choosing to get a 3% rate of return on mitigation. The mitigation program would consequently be a relatively poor investment of public funds compared to other choices. Society would be better off investing current mitigation into a market fund that would pay for future mitigation. Using below-market interest rates effectively increases the overall cost of climate change by forcing every generation to spend too much on mitigation and specifically forcing the current generation to spend more on mitigation than future generations. This is not in the interest of all generations and very much not in the interest of those alive today. So there are deleterious consequences to selecting different discount rates for different projects, which is why OMB encourages all agencies to use the same discount rate.

Tol (Peabody): Dr. Tol disagreed with the IWG's use of discount rates and stated that the Ramsey rule was preferable. According to the Ramsey rule, the discount rate should vary with economic growth. The Ramsey rule makes sense because it relates the money discount rate to parameters underlying the "time value" of money – i.e., the reasons that receiving money today is preferred over receiving it in the future.

Wecker (Peabody): Dr. Wecker testified that taking the average of multiple discount rates is inappropriate because the true value is not unknown but is rather a policymaking decision that the ultimate decision maker must choose, guided by economic theory and other normative considerations.

Bezdek (Peabody): Dr. Bezdek testified that even using the extreme 3.0% 95th estimates, the benefits of CO_2 emissions exceed the costs by a ratio of between about 30-to-1 and 40-to-1.

Gayer (MLIG): According to Dr. Gayer, it would be a mistake to use the 95th percentile SCC value. Doing so over-weights uncertain risks relative to more certain risks, which would distort our policies and regulations in harmful ways. Dr. Gayer pointed out that the examples provided by Dr. Polasky (home insurance) and Dr. Hanemann (airplane) confuse uncertainty with risk and do not support selecting the 95th percentile SCC value as a risk estimate, without including the 5th percentile. Both examples put more weight on regulating uncertain, lower average, risk over regulating more certain, high average, risk. This analytical mistake is known as the Ellsberg Paradox.

Martin (Xcel Energy): Mr. Martin argued that there are four reasons why it would be inappropriate for the Commission to adopt the 95th percentile SCC value. First, it was statistically unsound for the IWG to present the 95th percentile value without the corresponding 5th percentile value. Second, while it is possible that the SCC underestimates catastrophic damages (justification for the 95th percentile), it is also possible that it underestimates adaptation

and mitigation (justification for the 5th percentile). Third, the 95th percentile represents an unreasonably low level of risk tolerance given that only 5 percent of the IAM model predictions exceed this value. Fourth, selecting the 95th percentile value along with the corresponding 5th percentile makes the SCC range so wide that it is not meaningful for resource planning purposes.

D. Uncertainty in the IAMs (Issue 22)

Record Citations:
Hanemann Direct at 42, note 32, 46, 52
Hanemann Rebuttal at 17-19, 24, 31-33, 58-62, 86-87
Hanemann Surrebuttal 24-26, 34-37, 45, 48
Polasky Direct at 8, 15-16
Mendelsohn Surrebuttal at 18
Tol Rebuttal, Ex. 2 at 8, 11-13
Wecker Rebuttal, Ex. 2 at lines 280-89, 316-323
Bezdek Direct at 8; Ex. 2 at 110-115
Smith Direct at 24
Smith Direct, Ex. 2 at 4-5, 7, 45, 65-91; Attachment 1 at 1, 5-6, 8-9, 23, 26, 30-37
Gayer Surrebuttal at 12-18
Martin Direct at 3-5, 15-16, 30-46
Martin Rebuttal at 8-9, 44

Hanemann (Agencies): Dr. Hanemann testified that the IWG addressed scientific uncertainty in certain parameters in the IAMs. He explained that the IWG's use of probability distributions for the numerical value of certain parameters in FUND and PAGE was intended to account for the scientific uncertainty regarding the value of those parameters. To acknowledge scientific uncertainty regarding equilibrium climate sensitivity (ECS), the IWG made the value of the ECS a random variable with the same probability distribution for all three models in each model run. The IWG, after consulting with lead authors of the relevant chapter in the IPCC 4th Assessment Report, selected the Roe and Baker (2007) probability distribution because it is widely used, is based on a theoretical understanding of the climate system's response to increased GHG concentrations and for other reasons detailed by Dr. Hanemann.

Dr. Hanemann noted that Mr. Martin correctly quoted Pindyck (2015) to the effect that uncertainty over climate sensitivity has increased, but Mr. Martin overlooked the economic implication --that the increase in uncertainty raises the SCC in Pindyck's economic model of climate change.

Dr. Hanemann observed that Dr. Smith's assessment of uncertainty did not acknowledge that tipping points could raise the IWG estimate of the SCC, and he explained that the existence of an uncertain threshold for a tipping point is shown to raise the current SCC value, and noted that the IWG reported that regulatory policy should include a degree of risk aversion. Dr. Hanemann explained that uncertainties about long-run growth, how fast the planet will warm, and how damaging the warming will be can be causes for risk aversion, and, if allowance is made for risk aversion, the effect is to lower the effective discount rate. Dr. Hanemann explained that, with respect to uncertainty and the IWG's discount rates, the IWG used three discount rates to span a plausible range of constant discount rates: 2.5, 3, and 5 percent per year. The IWG included the

low discount value, 2.5 percent, to incorporate the concern that interest rates are highly uncertain over time; 2.5 percent represents the average rate after adjusting for uncertainty using a mean-reverting and random walk approach as described in Newell and Pizer (2003), starting at a discount rate of 3 percent; and a rate below the riskless rate is justified if climate investments are negatively correlated with the overall market rate of return.

Regarding Mr. Martin's statements and illustration regarding a "wide range of uncertainty in the IWG's projections of future emissions" by year 2100, Dr. Hanemann demonstrated that the IWG's projection of emissions do not continue to grow in the two centuries following 2100, but rather level off and then decline. Next, regarding Mr. Martin's observations regarding uncertainty about adaptation and technological change, Dr. Hanemann stated that it is doubtful that uncertainty regarding adaptation and technological change counterbalances uncertainty regarding catastrophic damages from climate change. He explained that it is premature to claim that the SCC values may be too high because the IAMs do not adequately account for adaptation and mitigation. Global emissions are at the highest of the four GHG concentration scenarios in the IPCC 5th Assessment Report, which is similar to a baseline (unconstrained) trajectory. While lower emission and concentration scenarios may be achieved later in this century, Mr. Martin's confidence in that outcome is premature.

Dr. Hanemann agrees with Professor Polasky's critique of Dr. Smith, that, while uncertainty in assessing the social cost of carbon cannot be avoided, the uncertainty is not excessively speculative, and it is wrong to conclude that the proper response to large uncertainty is to ignore it. Dr. Hanemann also agreed with Professor Polasky's critique of Professor Mendelsohn regarding the IWG's use of all three prominent IAMs, that there is uncertainty regarding several aspects of climate change and the best method to approach estimating the SCC is incorporating several different methodologies and sets of assumptions.

Polasky (CEO): Professor Polasky testified that there is uncertainty in integrated assessment model inputs, and he testified that estimating the SCC is difficult in part because we are attempting to predict impacts far into the future for temperature changes that are potentially outside the range of recent historical experience. He further testified that although there is inherent uncertainty in predicting future damages, he stated that as better information becomes available, the SCC estimate should be adjusted.

Mendelsohn (Peabody): Professor Mendelsohn testified that uncertainty haunts the measurement of climate change, because the effect of greenhouse gases on temperature is uncertain, the impact of temperature change on the economy and nonmarket sectors is uncertain, and it is uncertain how effects will be distributed across the planet.

Tol (Peabody): Dr. Tol testified that the causal chain from carbon dioxide emission to social cost of carbon is long, complex and contingent on human decisions that are at least partly unrelated to climate policy. A change in radiative forcing leads to a change in climate, which sets in motion a number of feedback effects, each of which lead to further climate change and many of which vary with climate itself, making it difficult to estimate the climate effect of carbon dioxide emissions. That effect varies over time and is contingent on human choices within the domain of climate policy (e.g., emissions, land use) as well as outside that domain (e.g., investment in infectious disease, mitigation measures in coastal countries, etc.).

Wecker (Peabody): Dr. Wecker testified that the ranges of uncertainty inherent in the federal SCC calculations are likely wider than acknowledged by the IWG, or by Dr. Martin for Xcel. While the IWG attempted to address uncertainty by running the models based on probabilistic, Monte Carlo calculations for certain inputs such as climate sensitivity, there remains additional uncertainty that arises from ill-founded assumptions and arbitrary inputs used by the IWG when running IAMs. For example, the climate sensitivity assumptions employed in the IWG models are likely overstated and, therefore, SCC estimates are likely biased high. There is no rational basis to rule out the possibility of future revision or even overturning of the federal SCC or the model inputs upon which it is based. This possibility amounts to an additional source of genuine uncertainty concerning any inferences based on the IWG SCC. Furthermore, Dr. Wecker testified that the ranges of uncertainty reflected in Mr. Martin's reports fail to capture properly the full range of uncertainty in the IWG's SCC estimates.

Bezdek (Peabody): Dr. Bezdek testified that an IAM-based analysis suggests a level of knowledge and precision that is nonexistent, and allows the modeler to obtain almost any desired result because key inputs can be chosen arbitrarily. He testified that the National Academies of Science (NAS) found that the SCC assessment suffers from uncertainty, speculation, and lack of information about future emissions of greenhouse gases (GHGs), the effects of past and future emissions on the climate system, the impact of changes in climate on the physical and biological environment, and the translation of these environmental impacts into economic damages. He stated that the NAS concluded that any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional. Dr. Bezdek further testified that integrated assessment modeling contains significant uncertainty at each stage of the process are magnified and compounded by the uncertainties found in the next step, creating a "cascade of uncertainties". While IAM model builders are including techniques such as Monte Carlo analysis and stochastic simulation to address the uncertainties, the degree of uncertainty within the process is immense and renders any IAM results highly questionable.

Smith (GRE/OT/MP): Dr. Smith emphasized that in the face of uncertainties about key inputs into decisional models, conservative assumptions should be used, and speculation should be minimized. Dr. Smith for example noted uncertainties about the discount rate and testified that the IWG's use of 3% and 5% discount rates were reasonable, but that a 7% discount rate was required where regulations affect private sector capital spending, and that a 2.5% purely normative discount rate does not conform to criteria set by the Commission to base estimates of environmental cost values on evidentiary foundations and to use conservative assumptions in the face of significant uncertainty. The IWG's use of an analysis horizon of the year 2300 injects enormous uncertainty, which implicitly and unrealistically assumes that an advanced society will choose to endure temperature changes that rise higher than 10°C above pre-industrial levels without any technological response.

Dr. Smith testified that the damage functions in the IWG's IAMs are still founded on limited empirical evidence, the broad implications of which are very similar to damage relationships assumed in this proceeding in the 1990s, including by Mr. Ciborowski. What is new is the way the IWG has framed its analysis, causing the resulting SCC estimates to be much more heavily dependent on aspects of the IAM damage functions that are well beyond any evidentiary basis and much further into the realm of extrapolation and subjective judgment than the estimates

made by Mr. Ciborowski. Some of the assumptions reflect available scientific and economic evidence that is subject to varied interpretations, and hence are uncertain. Other assumptions are entirely judgmental. Some judgments are made by modelers when relevant scientific evidence does not exist but some numerical value is needed to complete the SCC calculation. Other judgmental inputs reflect normative concepts that are impossible to evaluate in an empirical manner. Some judgments are embedded in the computer code of the IAM and others are selected by the IAM user.

Dr. Smith's testimony included a report that she authored detailing the uncertainties inherent in the IAM inputs and damage functions. Referring to comments by MIT economics professor Robert Pindyck, Dr. Smith noted that the lack of clear theoretical or empirical bases for IAM damage functions means that the parameter values and functional forms for the damage functions used by the IWG are largely *ad hoc* and arbitrary. The modelers clearly recognize and readily concede the limitations in the empirical evidence that lies behind their models, including the damage function. Dr. Smith cites Richard Tol as admitting that this "does not result in a climate change impact model that is adequate. The accompanying static impact assessment is far from perfect, with many pieces missing and a lot of questionable assumptions." Prof. Nordhaus has similarly conceded that "the damage functions continue to be a major source of modeling uncertainty." Plausible parameters for the damage function lead to estimates of global damages that can differ by a factor of 20 or more within the range of parameters and range of temperature changes found in the IAM literature. Dr. Smith has written that "[m]odelers seem clearly to acknowledge the uncertainties in the damage functions in the IAMs. Tol reminds the reader that 'a lot of questionable assumptions' had to be made in developing the damage estimates. Nordhaus states that 'providing reliable estimates of the damages from climate change over the long run has proven extremely difficult.'"

Since the damage estimate is a central input to the SCC estimates, the large uncertainty in the damage function translates into uncertainty in the SCC estimates that could be correspondingly large. Dr. Smith has noted that the IWG has not analyzed the uncertainty of its SCC estimates as a result of damage function uncertainty. To counter the enormous uncertainties embodied in the IWG's SCC calculations, Dr. Smith recommends the adoption of alternative and realistic assumptions for estimating SCC values to be applied in Minnesota resource planning.

Martin (Xcel): Mr. Martin testified that the SCC is inherently uncertain and speculative. Deriving the SCC relies on making assumptions – from now until the year 2300 – about population and GDP growth, the emissions that result from that growth, the temperature change that results from emissions, the damages that result from temperature change, and the appropriate discount rates to apply to those damages. Each of these assumptions is uncertain, and uncertainty builds from one step to the next. The IWG's methodology for translating an incremental near-term CO_2 emission into an estimate of long-term climate damages involves a "causal chain," and each step in the causal chain is subject to significant uncertainty and each step depends on the prior step, so uncertainty builds across the causal chain. Even if CO_2 emissions were known with certainty, translating these into temperature change depends on assumptions about highly complex processes including equilibrium climate sensitivity, the global carbon cycle and radiative forcing. Even if temperature change were known with certainty, translating this into economic damages depends on assuming the shape and parameters of a damage function with very little empirical evidence on which to base these assumptions.

Assigning a net present value to damages depends on the highly contentious choice of discount rate. Mr. Martin further testified that the IAMs do not account for the possibility that future societies, in response to the impacts of climate change, are likely to develop new technologies with lower CO_2 intensity than was initially assumed, which makes the IWG's predictions increasingly speculative over time. He further stated that the IWG in 2015 acknowledges greater uncertainty in its projections of emissions beyond 2100.

Gayer (MLIG): Dr. Gayer testified that while uncertainty in and of itself does not justify inaction, the uncertainty of any prediction approaches infinity as time increases indefinitely. Citing Dr. Henry J. Aaron, Dr. Gayer pointed out that "[b]ecause error and uncertainty grow as the projection horizon is lengthened, in some cases lengthening the window is not useful and can degrade decision making." Dr. Gayer further testified that other experts in this proceeding and the IWG have confused risk and uncertainty, which leads to excessive SCC values by the suggested use of the 95th percentile value as a risk estimate, without including the 5th percentile. This analytical mistake is known as the Ellsberg Paradox.

E. Leakage (Issue 23)

Record Citations:
Hanemann Rebuttal at 29-31
Polasky Rebuttal at 29-30
Polasky Rebuttal, schedule 1 (OMB Response to Comments), at 32-33
Mendelsohn Direct at 5
Mendelsohn Rebuttal, Ex. 1 at 3-4
Mendelsohn Surrebuttal at 32-33
Smith Direct at 27-29, 34-35, Ex. 2 at 100-102
Gayer Surrebuttal at 9-11
Martin Rebuttal at 51-53
Martin Surrebuttal at 39-40

Hanemann (Agencies): Dr. Hanemann argued that there should be no adjustment for leakage when the SCC values are applied in Minnesota proceedings. He noted that even if some of the reduction in emissions in Minnesota would be offset by increased emissions in other jurisdictions, it does not mean that the Commission should apply the SCC values only to the emission reductions in Minnesota net of leakage. Dr. Hanemann stated that the Commission is not responsible for regulating the level of GHG emissions in other states or in the U.S., and does not regulate utilities in other states or other countries.

Polasky (CEO): Dr. Polasky explained that leakage does not affect the externality value for a ton of emissions, which is the objective of this proceeding. Rather, it is an issue that goes to how the Commission should implement policy in response to possible leakages. Dr. Polasky noted that the IWG addressed this issue as well.

Mendelsohn (Peabody): Dr. Mendelsohn argued that if Minnesota is the only state in its region to favor relatively high-cost CO_2 emission reduction options, increased costs for Minnesota businesses could become an incentive to move to other states, which would only relocate but not reduce emissions. He noted that high cost of carbon would also probably result in closing coal

plants in Minnesota and likely result in importing electricity from the neighboring states. As Minnesota reduces carbon emissions and eliminates low cost coal plants, utilities in neighboring states have a financial incentive to send their electricity to Minnesota. If Minnesota insists that imported electricity be low carbon, the utilities will send only their low carbon electricity to Minnesota. To replace this lost electricity, the utilities in neighboring states will then use new high carbon sources for their domestic state market. Although emissions in Minnesota would decrease dramatically, emissions in the neighboring states would increase accordingly, and the net reduction in the region would be less than the reduction in Minnesota. Dr. Mendelsohn stated that this leakage effect would mean that Minnesotans are paying a lot for a program that may have little regional or global benefit. He suggested that environmental values should be adjusted for leakage and applied only to emissions net of leakage.

Smith (GRE/MP/OTP/MLIG): Dr. Smith stated the IWG's SCC values have not accounted for the possibility of leakage, which is a particular concern for reduction actions that take place within the electricity system of a single state that is interconnected to electricity systems in other states that are not participating in the same resource planning constraints. Leakage is very likely to occur when one state adopts a policy, such as the use of a SCC in resource planning that has the effect of driving up that state's cost of energy production, while the cost of energy production in neighboring states remains unchanged because their energy production is exempt from the first state's policy. Studies indicate leakage occurs even on an international level, and it becomes an increasingly significant factor when actions are taken at a state or local level. According to Dr. Smith, the benefit of any reduction in CO2 emissions resulting from a particular policy depends on the net global reduction, not just the reduction in one specific jurisdiction. If CO2 emissions in Minnesota decrease as a result of applying CO2 values in the resource planning process, those reductions should be netted against any resulting CO2 emission increases in neighboring jurisdictions. Dr. Smith noted that leakage can occur through businesses relocating to avoid higher energy costs, or through the interconnected energy system dispatching fossil fuel units outside Minnesota. Leakage could be nearly 100 percent if reduced generation in Minnesota is replaced by fossil fuel generation in those states that are not imposing similar emissions reduction policies, or greater than 100 percent if reduced generation in Minnesota is replaced by generation in neighboring states from fossil power plants less efficient than those retired in Minnesota. Dr. Smith recommended that the range of environmental cost values adopted in this docket need not be adjusted for leakage in this docket, but should be adjusted based on potential leakage when used in particular resource planning dockets. Reflecting this view, she emphasized that the SCC dollar per ton estimates should be noted to be dollars per net ton of emission.

Gayer (MLIG): Dr. Gayer has testified that "there is some true (though difficult to estimate) SCC, and that this SCC value is not affected by leakage," but that "Minnesota must take seriously the problem of leakage, especially if it follows Dr. Polasky's advice to price CO2 much higher than neighboring states do (since Dr. Polasky admits it is doubtful the other states will follow Minnesota's lead)." If the SCC is applied inconsistently across states, then this would create a distortion that would lead to an increase in emissions outside of Minnesota, thus undermining the very purpose of Minnesota's regulation. Conceptually, Minnesota's adoption of a high SCC estimate could lead to more harm to the environment than would occur if Minnesota did not make any changes to its current regulation. Dr. Gayer thus noted that if Minnesota's adoption of a high SCC leads to no reduction in global emissions, then Minnesota should not

adopt such a SCC. After all, the goal is to reduce emissions, not to price emissions for the sake of pricing. It makes no sense for Minnesota to consider the costs of its action on others, but to ignore how Minnesota's actions could lead other states to harm Minnesotans (and the world). Ignoring leakage would be equivalent to regulating a firm that is polluting a river downstream even if one knows that this would lead the firm to relocate and pollute upstream, thus failing to achieve the regulation's objectives (reducing emissions) and potentially increasing exposure to more citizens. Dr. Gayer supported applying an adjustment to the *net* reduction in emissions, as proposed by Dr. Smith.

Martin (Xcel Energy): Mr. Martin agreed that unilateral application of CO2 environmental values in Minnesota, without a corresponding action by other states, is likely to result in shifting of emissions that will at least partially offset any emissions reductions in Minnesota. This could happen through business relocations or dispatch changes in the interconnected electricity system. Mr. Martin noted that the amount of leakage will vary depending on the type of issue and decision in question, and therefore the leakage adjustment should be made on a case-by-case basis in the individual docket and is outside the scope of this proceeding.

F. Scientific Process (Issue 24)

Record Citations:
Gurney Rebuttal at 7, 14, 24-28
Gurney Surrebuttal at 1-19
Polasky Rebuttal at 52-55
Abraham Rebuttal at 5-6, 27
Abraham Surrebuttal at 5-6, 8-10, 19-20
Dessler Surrebuttal at 1-10
Bezdek Surrebuttal at 66-83, 90-100
Happer Surrebuttal at 1, 3-4, 8-10, 15-18, 18-21
Lindzen Surrebuttal at 46-63
Tol Rebuttal at 9-10
Rom Rebuttal at 3-4, 6

Gurney (Agencies): Dr. Gurney explained the process of scholarly peer-review; it is considered mandatory in most academic journals which are the primary means of communicating research results and advancing the scientific body of knowledge. He described the IPCC and stated that the IPCC Assessment Report authors, including those who prepared the IPCC 5th Assessment Report, primarily review peer-reviewed material to arrive at a complete, balanced assessment of the most likely state of knowledge. Rather than "cherry-pick" a result by selecting a particular subset of papers, the Assessment Reports synthesize all research and identify levels of confidence in their findings, to arrive at an objective, unbiased assessment of what is known on climate change. Because the reviewing authors' synthesis of the peer-reviewed research is in turn subject to peer-review, the Assessment Reports have two layers of peer-review. The IPCC Assessment Reports are the most authoritative resource for providing a comprehensive synthesis of what is known on climate change.

Dr. Gurney demonstrated that certain Peabody witnesses show a persistent use of patterns of argumentation and reasoning that are misleading, biased, or otherwise flawed: selective citation,

misunderstanding of the cited literature or science, straw man argumentation, and attacking the messenger. For example, out of 54 citations in Dr. Bezdek's Direct, all but two sources were either federal agency reports, grey literature or popular literature. Dr. Bezdek has no published peer-reviewed work on CO_2 fertilization or the impact of climate change on food crops or agricultural productivity. Similarly, Dr. Happer's testimony relied in part on congressional testimony, which is not peer-reviewed scientific content. Dr. Happer has limited expertise in the subject of climate science or economics, as he has published no peer-reviewed papers in climate science or economics, and has performed no research related to climate modeling, the carbon cycle, or temperature measurements - all topics on which he provided testimony. Regarding Dr. Happer's claimed "measurement error," Dr. Gurney explained that the Happer Rebuttal cited nine papers to support his claim, of which three are from the peer-reviewed literature, and those three do not support Dr. Happer's testimony. Dr. Gurney explained that Drs. Bezdek, Happer, Lindzen, and Spencer rely on non-peer-reviewed literature, "cherry-pick" citations favorable to their positions, and make claims that are not supported by cited sources. Dr. Gurney suggested that the ALJ should not adopt the Bezdek Rebuttal Testimony as to any of the seven topics that relate to issues in physical or biological science.

Polasky (CEO): Dr. Polasky explains that Dr Bezdek's views are far outside the mainstream scientific understanding and ignore the bulk of available evidence.

Abraham (CEO): Dr. Abraham believed that the vast majority of experts are in agreement that humans are a major cause of climate change. He stated that the very small minority who claim otherwise, such as Drs. Spencer, Lindzen, Happer, and Bezdek, rely heavily upon selective, unscientific, non-peer-reviewed sources of information, many of which are from advocacy groups or political news organizations, or authored by themselves. They have neglected to inform the readers that many of these works have been criticized and found to be in error by the scientific community and corrected in the peer-reviewed literature. According to Dr. Abraham, the information that the Peabody witnesses rely upon is substandard for scientific discussion.

Dessler (CEO): According to Dr. Dessler, the conclusions offered in the testimonies of Drs. Spencer, Lindzen, and Happer in general are unreliable because they have not employed unbiased and rigorous scientific methods. They rely heavily on papers and other materials that do not appear in peer-reviewed literature and claim that the sources support their positions when in fact the sources are often irrelevant and simply do not say what is claimed. Dr. Dessler also stated that Drs. Spencer, Lindzen, and Happer exercise "cherry-picking" by choosing a small fraction of data favorable to their position and ignoring the vast majority of unfavorable data.

Happer (Peabody): Dr. Happer is the former chair of the physics department at Princeton University and chair of the University Research Board, Princeton's equivalent of Vice President for Research. He has published over 200 peer-reviewed scientific papers. He has done research in atmospheric physics and other areas. He is well known for his invention of the "sodium guide star" concept, used in all modern ground-based telescopes to compensate for deleterious effects of atmospheric turbulence on astronomical observations. He is very familiar with the climate models used by the IPCC and funded some of the early models when he was Director of Energy Research at the United States Department of Energy from 1990 to 1993, where he supervised a research budget of some $3.5 billion, including environmental and climate science. Dr. Happer pointed out that scientists should be guided by all of the data—including that which shows that

climate models have exaggerated warming by several hundred percent. Drs. Dessler and Abraham ignore credible peer-reviewed literature. Dr. Gurney is incorrect that the Peabody witnesses selectively cite or cherry-pick data. Focusing on extreme events such as drought and melting glaciers is actually an example of cherry-picking near-term problems that disappear when observed over a longer timeline. Dr. Gurney inaccurately accused Dr. Happer of mis-citing a graph. In fact, Dr. Happer accurately cited the graph. It was Dr. Gurney who altered the quotation of an article in order to reach a conclusion opposite to the article. Dr. Gurney also distorted the presentation of a chart in his testimony.

Lindzen (Peabody): As a response to claims about the quality of his research, Dr. Lindzen stated that a good portion of the criticism of his theories has been overclaimed. Politics and playground antics have begun to infect reasoned scientific discourse and distract from the importance of science and proceedings such as this. Peer-reviewed sources have a publication bias in favor of papers that promote the risks of global warming or support high values for the SCC. The so-called "consensus" may be a product of such a bias, and the "97%" figure has been debunked. Dr. Lindzen noted that even the IPCC does not limit itself to only peer-reviewed material and extensively uses grey literature in order to stay on the forefront of relevant science, cover local scientific perspectives, and capture recent developments. The IPCC also relies on information from advocacy groups. According to Dr. Lindzen, a major concern about the IPCC assessment reports is that they lack transparency and are potentially biased, through the selection of lead authors, review editors, and publications to consider.

Tol (Peabody): Dr. Tol noted that the argument that 97% of climate scientists have formed a "consensus" on anthropogenic climate change is based on discredited research that has been repeatedly disproven by better evidence and methods. He pointed out that studies are often praised out of political expedience rather than scientific validity, and that whistleblowers are vilified.

Rom (DHE): Dr. Rom notes that the statements of Dr. Bezdek and Professor Lindzen regarding the purported health benefits of global climate change are almost entirely based on industry funded reports that are not peer reviewed by the medical or public health community. Dr. Rom also notes that the extensive bibliography in Dr. Bezdek's testimony that is offered in support of the notion that humans would flourish in a warmer climate is an assemblage of marginalia that gives only the appearance of support for an otherwise unsupportable argument. By contrast, every peer-reviewed study that has addressed the issue comprehensively has concluded that a warming climate poses a human health risk, not a benefit.

Bezdek (Peabody): In response to Dr. Gurney's persistent use of a pattern of criticism of Peabody witnesses' research and sources, Dr. Bezdek pointed out in his surrebuttal that he and other Peabody witnesses have extensively cited peer-reviewed articles and publications that Dr. Gurney ignored in his count of peer-reviewed articles. For example, Dr. Gurney criticized the number of peer-reviewed sources in Dr. Bezdek's Direct Testimony, but Dr. Gurney ignored a 181-page appendix attached to that Direct Testimony, containing hundreds of peer-reviewed sources. Dr. Gurney also ignored Dr. Bezdek's extensive discovery responses containing hundreds of peer-reviewed citations. Dr. Bezdek also pointed out that Dr. Gurney himself cited only one peer-reviewed article in his criticisms of Dr. Bezdek. Dr. Bezdek stated that the labeling and marginalization of "dissenters" and "contrarians" inhibits real, evidence-based

science. Polarization and politicization of climate research has distorted and inhibited scientific and public policy discussions. According to Dr. Bezdek, it is not unusual for researchers and scientists to refer to materials that are not peer-reviewed, and witnesses for other parties, including Abraham, Hanemann, Polasky, Kunkle, Martin, and Rumery, also cite numerous non-peer-reviewed sources. In fact, the IWG process to develop the SCC was not peer-reviewed. In addition, Dr. Bezdek pointed out that the IPCC does not limit itself to peer-reviewed materials and its members have manipulated the peer-review process, including pressuring editors, breaching the confidentiality of the review process, and browbeating dissenting reviewers. Dr. Bezdek documented how an IPCC author expedited review for a supportive article and delayed review of a contrary article; IPCC authors acted as reviewers for articles they wished to rely on for their chapters; and IPCC authors used boycotts to pressure editors to resign over adverse papers.

III.   Alternatives: If the Federal SCC is not Reasonable and the Best Available Measure to determine the Environmental Cost of CO_2, what Measure is Better Supported by the Evidence?

A. Mendelsohn Proposal (Issue 25)

1.   Proposal

Record Citations:
Mendelsohn Direct at 3, 5-14, Ex. 2 at 1-2, 10-21
Mendelsohn Rebuttal, Ex. 1 at 4-5
Mendelsohn Surrebuttal 2-17, 21-34

Mendelsohn (Peabody): Dr. Mendelsohn used in his analysis the DICE model (2013 version), which is designed to calculate optimal mitigation strategies that balance the cost of emission reductions against the benefits of reduced damage. He adjusted some key parameters of DICE, including the shape of damage function and equilibrium climate sensitivity. He created two modified damage functions (no damage until temperature rises 1.5°C above 1900 levels and no damage until temperature rises 2°C above 1900 levels). According to Dr. Mendelsohn, this change was based on more than two decades of empirical study, his own expertise, and peer-reviewed research in the field. He explored several climate sensitivity values, including 1°C , 1.5°C , 2°C , 2.5°C , and 3°C. He used DICE's original emission and GDP forecasts and internal sliding discount rate that is calculated to be consistent with the growth in GDP per capita (starting at 5 percent and declining to 3.5 percent in the year 2100 and 2.7 percent in the year 2200). Dr. Mendelsohn used a climate sensitivity of 3 degrees when running the DICE model to arrive at a value of $4 to $6, but because there is convincing evidence that the ECS is lower than 3 degrees and because the IPCC 5th Assessment Report lowered the "likely" range to 1.5 and no longer recommends a "best estimate" of 3.0, he also provided ranges for an ECS at 1.5 or 2 degrees. Dr. Mendelsohn therefore provided ranges if the ECS is assumed to be 1.5°C ($0.30 to $0.80 per ton) or 2°C ($1.10 to $2.00 per ton). He testified that given the strong scientific evidence, a reasonable and the "best available measure" for the SCC is between $0.30 and $2.00/ton. Dr. Mendelsohn pointed out that his recommended values are consistent with values used by other states and countries, and sufficiently close to the values of neighboring states to limit leakage. Dr. Mendelsohn argued that the SCC, rather than using a "last ton" methodology

that assumes no future mitigation globally, should be measured based on the optimal path (optimal SCC), since this equates the marginal cost of mitigation to the SCC, which is the only measure that can lead to an efficient mitigation program.

2. Critiques of Mendelsohn's Proposal

Record Citations:
Hanemann Rebuttal at 40-46
Hanemann Surrebuttal at 10-11
Polasky Rebuttal at 46-52
Tol Rebuttal, Ex. 2 at 8-9
Smith Rebuttal at 16-20
Martin Rebuttal at 34-36

Hanemann (Agencies): According to Dr. Hanemann, Dr. Mendelsohn's methodology is lacking and therefore underestimates the SCC values. First, Dr. Mendelsohn used only the DICE 2013 model in his analysis. Second, he modified the damage functions of the original DICE model (no damage until temperatures rise 1.5°C or 2°C above global average temperatures in 1900) without giving convincing support or evidence for this change. Third, he used DICE in its native simplified optimization format and did not use the same standardized inputs on population, income, and emissions (EMF-22 scenarios) as the IWG. The required simplifications for optimization imply that abatement occurs more speedily than in the real world, that warming builds up less than is likely in the real world, and that damages are smaller than is likely in the real world. Fourth, he did not use probabilistic versions of the climate sensitivity and other model parameters. Dr. Hanemann pointed out that if Dr. Mendelsohn had kept his other modeling modifications intact, but changed his analysis to use DICE's default damage functions, the resulting SCC value for 2015 would have been $18.60. The changes that Dr. Mendelsohn made to DICE's default damage function alone lower the SCC by two-thirds or more.

Polasky (CEO): Dr. Polasky pointed out that Dr. Mendelsohn used in his methodology only the DICE model, which was originally created to find the optimal path of emissions reductions. The IWG did not run DICE with these assumptions, but used the same five socioeconomic and emissions scenarios (EMF-22) in all three IAMs. Dr. Polasky noted that Dr. Mendelsohn ran DICE to calculate the "optimal" SCC, and made additional changes to the damage function, ECS, and the discount rate. Dr. Polasky listed several reasons why this was inappropriate. First, it is unrealistic to assume an optimal level of emissions reductions, because there currently is no such global coordinated policy and getting such a policy does not appear likely any time soon. Second, Dr. Mendelsohn adjusted the DICE damage function so that damages begin when temperatures rise 1.5°C to 2°C above global average temperatures in 1900. This requires much greater temperature increases to generate large damages as compared to the standard DICE model. Third, rather than using a probability distribution for ECS, Dr. Mendelsohn used single values (1.5°C, 2°C, and 3°C), and his recommendation is based on these single values of ECS. The IWG used the whole distribution of ECS, and therefore took into account the uncertainty. Fourth, Dr. Mendelsohn used DICE's sliding discount rate that begins at 5 percent and declines to 3.5 percent in the year 2100 and 2.7 percent in the year 2200. However, the IWG's method to use three reasonable values is more appropriate and takes into account the uncertainty and disagreement regarding the discount rate. Dr. Polasky stated that while Dr. Mendelsohn's results

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represent one possible estimate for CO_2 at the low end of the distribution, the IWGs methodology and estimates are preferable to Dr. Mendelsohn's, because they take into account the wide variability among the different models and different assumptions that go into the models. The PAGE model along with FUND and DICE are the three most prominent economic climate change IAMs, and to use all three is appropriate and preferable to using only one of the models.

Tol (Peabody): In 2011, FUND estimated a social cost of carbon of $8.0 per ton. In 2014, it was $6.6 per ton. These estimates are based on the IWG's estimate of climate sensitivity, which was 3.0. Using the climate sensitivity values used by Professor Mendelsohn, FUND calculates the SCC as negative (-) $17.97 for a sensitivity value of 1°C, negative (-) $12.06 for a value of 1.5°C, and negative (-) $4.05 for a sensitivity value of 2.0°C.

Smith (GRE/MP/OTP/MLIG): According to Dr. Smith, the lower SCC estimates reported in Dr. Mendelsohn's analysis would be supported by the IWG's models, if his alternative assumptions about ECS and optimal temperature levels were to be adopted. If the IWG's ECS values were changed to 1.5 °C, this change alone would reduce the SCC estimate by roughly as much as applying Dr. Mendelsohn's assumption that the optimal temperature increase is in the range of 1.5°C to 2°C above 1900 levels. However, Dr. Smith did not have a position on the optimal temperature change threshold.

Martin (Xcel Energy): Mr. Martin did not have a position on the climate science questions that relate to Dr. Mendelsohn's methodology, such as the modified damage functions and ECS. However, Mr. Martin pointed out that the low and narrow SCC range proposed by Dr. Mendelsohn does not adequately capture the inherent uncertainty in predicting climate damages and imply an inappropriately high risk tolerance for the fact that the actual future damage values lie outside his proposed range.

B. Tol Proposal (Issue 26)

1. Proposal

Record Citations:
Tol Rebuttal, Ex. 2 at 4, 6-7.

Tol (Peabody): Dr. Tol, the primary author of the FUND model, testified that under the IWG's parameters FUND estimated a social cost of carbon of $8.0 per ton in 2011. In 2014, the FUND estimate was $6.6 per ton. Dr. Tol testified that the climate sensitivity value plays an important role in determining what the impact of warming will be, because the initial impacts of climate change are positive, due to carbon dioxide fertilization, reduced winter heating, and fewer cold-related deaths. Using the climate sensitivity values used by Professor Mendelsohn, FUND calculates the SCC as negative (-) $17.97 for a sensitivity value of 1°C, negative (-) $12.06 for a value of 1.5°C, and negative (-) $4.05 for a sensitivity value of 2.0°C.

2. Critiques of Tol's Proposal

Record Citations:
Polasky surrebuttal, at 14 – 18, 25

Hanemann Surrebuttal at 30-32

Polasky (CEO): Dr. Polasky responds to several of Dr. Tol's allegations regarding whether the IWG's SCC is a conservative value because it excludes possible damages. He concludes that Dr. Tol's criticisms do not change his opinion that the IWG SCC is a reasonable and best available measure of CO_2 externalities. According to Dr. Polasky, the IWG's approach of synthesizing the scientific understanding of many experts is preferable to an approach, as submitted by Dr. Tol, that relies on just one model and one researcher's assumptions.

Hanemann (Agencies): Dr. Hanemann defended the IWG's use of the FUND model, maintaining that standardizing the external model inputs in order to put all three IAMs on a common footing is the conventional practice in model inter-comparison exercises and it would have been unreasonable to do otherwise. Dr. Hanemann also defended the choice of discount rates used by the IWG and criticized Dr. Tol's formulation of the Ramsey rule that leads to higher discount rates. Dr. Hanemann criticized Dr. Tol's assumptions that what people expect out of life does not change over centuries, that society only cares about GDP, that outcomes are discounted at the same rate regardless of the time span involved and that there should be no allowance for risk aversion separate from intertemporal preferences. For these reasons, Dr. Hanemann maintained that Dr. Tol significantly underestimates the SCC.

C. Bezdek Proposal (Issue 27)

1. Proposal

Record Citations:
Bezdek Direct at 1-9, 26-28, 36
Bezdek Rebuttal, Ex. 2 at 19, 22-23, 29, 38-39, 46-49, 87-88
Bezdek Surrebuttal at 20-57, 66-71, 101-114

Bezdek (Peabody): Dr. Bezdek believed that the best available measure for estimating CO_2 damages should consider both the benefits and the costs of CO_2. In addition, meaningful government policies and regulatory decisions should not be arbitrarily changed every few years, as has happened to the SCC. Dr. Bezdek stated that the Minnesota CO_2 values established in 1997 should be kept as they are, or reduced to about $0.20 to $2.00 per ton or lower based on the following:

Dr. Bezdek provided cost-benefit data on the benefits of CO_2 fertilization on crop production, and the economic growth associated with carbon dioxide emissions. He noted that Dr. Gurney agrees that all available scientific evidence supports the general concept of a CO_2 fertilization effect. He testified that the effect of CO_2 fertilization on agricultural productivity can be quantified, and a doubling of the atmospheric CO_2 content above the current level will increase the productivity of most herbaceous plants by about one third. The total economic value of the CO_2 benefit for 45 crops cumulatively totaled $3.2 trillion, 1961-2012, and is forecast to total nearly $10 trillion, 2012 – 2050. He testified that the benefits of carbon dioxide emissions with respect to crop production worldwide are not explicitly included in the federal SCC figures and that if they were, the federal SCC estimates would be significantly smaller.

In addition, Dr. Bezdek testified that the benefits of CO_2 emissions with respect to economic growth exceed by orders of magnitude the federal SCC figures. He testified that fossil fuels, which in turn generate CO_2 emissions, are essential for world economic growth, and that significant CO_2 emission reductions will be associated with significant reductions in economic growth. This is due to the higher costs and decreased reliability of alternate forms of energy including wind and solar. He testified that, overall, the benefits of CO_2 emissions in terms of economic growth exceed the costs (as estimated by the IWG) by the following ratios:

- From 180:1 to 250:1 through year 2040, using a 5% discount rate
- Approximately 70:1 through year 2040, using a 3% discount rate
- Approximately 50:1 through year 2040, using a 2.5% discount rate

In response to Dr. Gurney's criticism of Peabody witnesses, Dr. Bezdek noted in his surrebuttal testimony that he has published one or more pieces of peer-reviewed scholarship in some 91 publications. Dr. Bezdek also pointed out in his surrebuttal that he and other Peabody witnesses have extensively cited peer-reviewed articles and publications, which Dr. Gurney simply ignored in his count of peer-reviewed articles. For example, Dr. Gurney did not mention a 181-page appendix to Dr. Bezdek's Direct Testimony containing hundreds of peer-reviewed sources, nor did Dr. Gurney mention Dr. Bezdek's extensive discovery responses citing to over 100 peer-reviewed sources. Dr. Bezdek also pointed out that Dr. Gurney himself cited only one peer-reviewed article in his criticisms of Dr. Bezdek. In regard to CO_2 fertilization, Dr. Bezdek listed hundreds of peer-reviewed articles supporting his position and explained that there are indeed thousands of studies demonstrating that carbon dioxide is beneficial to plant growth and that increased carbon dioxide emissions and increased global temperature will result in increased crop production. These have been published by some of the world's most distinguished scientists in books, working papers, conference proceedings, and the most prestigious international peer-reviewed scientific journals. Dr. Bezdek listed 73 peer-reviewed journals in which these studies have been published. Dr. Bezdek noted that Dr. Gurney ignored articles showing the inception of "greening" since the 1980s, an increase in the uptake of carbon as CO_2 increases (rather than the decline predicted by models), and that "greening" takes place despite other challenges to plant productivity — corroborated by over 450 citations provided in discovery responses and also ignored by Dr. Gurney. Dr. Bezdek also noted that the IPCC's findings were themselves supportive of the carbon fertilization thesis: Working Group I found that elevated CO_2 levels led to more photosynthesis and reduced transpiration, resulting in increased water-use efficiency. Working Group II also noted the impact of increased CO_2 on water use efficiency.

In response to Messrs. Rumery and Kunkle, Dr. Bezdek testified that while wind and solar energy sources have made many advances in recent years, they are not widespread enough to be able to support an electrical grid as a base load. Wind and solar are intermittent, unreliable, require back-up, are non-dispatchable, and are not available during emergencies. Thus, the addition of wind and solar energy resources in Minnesota will increase (not decrease) the need for fossil fuel generated electricity because consumers require reliable power that is available at all times, 24 x 7. Moreover, wind and solar are expensive energy sources and require government intervention in the form of mandates, subsidies, and tax credits in order to become viable energy sources.

2.   Critiques of Bezdek's Proposal

Record Citations:
Polasky Rebuttal, at 52-56
Abraham Rebuttal, at 21
Abraham Surrebuttal, at 21-22
Reich Surrebuttal, at 11-14
Hanemann Rebuttal at 8-11
Gurney Rebuttal at 2-7, 20, 24-28
Gurney Surrebuttal at 3-13,17-19

Polasky (CEO): Dr. Polasky asserts that Dr. Bezdek's views on climate change are far outside the mainstream scientific understanding and ignore the bulk of available evidence. Dr. Polasky states the Dr. Bezdek incorrectly assumes that the IAMs ignore possible benefits of CO2. He states that benefits are considered but because damages outweigh benefits, an overall cost is reflected in the damage functions.

Abraham (CEO): Dr. Abraham disagrees with Dr. Bezdek's claims regarding climate science. Dr. Abraham asserts that there is a clear consensus amongst climate scientists and that the more people know about climate science the more certain they are that humans are causing climate change.

Reich (CEO): Dr. Reich stated that Dr. Bezdek's allegations regarding CO_2 and increased crop production were inaccurate and unsupported by the sources he cited.

Hanemann (Agencies): According to Dr. Hanemann, Dr. Bezdek's methodology is lacking and therefore underestimates the SCC values. First, Dr. Bezdek erroneously ascribed positive value to CO_2 emissions based on the reasoning that humans benefit directly from CO2 emissions rather than from the use of energy. Second, Dr. Bezdek erroneously assumed that the benefit of CO2 emissions is constant, regardless of the energy source being used and where, or how, the emission was generated. Third, Dr. Bezdek's estimate did not control for any other factors that may affect global GDP, thus rendering his estimate meaningless with no scientific validity. In fact, Dr. Bezdek's estimate of benefits from CO2 emissions is actually picking up the effect on GDP on the cheap sources of energy that became available with the expanded use of fossil fuels.

Gurney (Agencies): Dr. Gurney testified that Dr. Bezdek's Direct testimony is factually incorrect and misleading regarding the CO_2 fertilization effect, which represents Dr. Bezdek's fundamental misunderstanding regarding the role of CO_2 fertilization within the wider topic of planetary greening. The issue is not whether there is a CO_2 fertilization effect, but rather, whether the impact is accurately included in present scientific knowledge of climate change impacts. In Dr. Gurney's judgment the CO_2 fertilization effect is included appropriately in reviews of climate change impacts on plants, and food crops in particular. Dr. Gurney explained that, like the testimony of other Peabody witnesses, Dr. Bezdek's testimony is flawed by persistent use of patterns of argumentation and reasoning that are misleading, biased, or otherwise flawed. Of the 54 citations in Dr. Bezdek's Direct all but two were federal agency reports, grey literature or popular literature rather than peer-reviewed research. Dr. Bezdek has

no published peer-reviewed work on CO_2 fertilization or the impact of climate change on food crops or agricultural productivity. Dr. Gurney unfavorably compared the reliability of Dr. Bezdek's work to that of the IPCC Assessment Reports, which, Dr. Gurney said, are the most authoritative resource for providing a comprehensive syntheses of what is known on climate change.

Rumery (CEBC): In response to Dr. Bezdek's assertion that fossil fuels are necessary for economic growth, Mr. Rumery testified that clean, renewable energy (including solar energy) is abundant and affordable, and that an increasing role of solar and renewable energy will not have a negative impact on economic development. Instead, solar and other renewable energy development stimulates job growth and economic investment while saving ratepayers money.

Kunkle (CEBC): In response to Dr. Bezdek's assertion that fossil fuels are necessary for economic growth, Mr. Kunkle testified that clean, renewable energy (including wind energy) is abundant and affordable, and that an increasing role of wind and renewable energy will not have a negative impact on economic development. Instead, development of wind and other renewable energy provides demonstrable savings in electricity costs and protections for ratepayers and a tremendous opportunity for economic growth, particularly in rural communities

D. Smith Proposal (Issue 28)

1. Proposal

Smith Direct at 14-37, Ex. 2 at 10-13, 40-103, Table 5
Smith Rebuttal at 4-5, 10-12
Smith Surrebuttal at 1-9, 14-35

Smith (GRE/MP/OTP/MLIG): Dr. Smith recommended that the Commission adopt a range of costs obtained by altering four key framing assumptions used by the IWG, namely time horizon, discount rates, which marginal value to use, and geographic scope, on the basis of specific criteria, and she recommended that the SCC dollar per ton estimates should be noted to be dollars per *net* ton of emission.

Dr. Smith recommended that the criteria for determination of environmental cost values for Minnesota should be as follows: the methodology should have a solid evidentiary basis, not be subject to excessive speculation, use conservative assumptions, and reflect the needs and impacts to residents of Minnesota. Dr. Smith stated that all but the last of these criteria is based on the ALJ Findings and Commission Order in the original 1993 Docket. She noted that these criteria were appropriate in that proceeding and no Party has offered any reasons why they should be discarded now. The last criterion is based on principles of benefit-cost analysis founded in economic welfare theory, which states that only the costs and benefits of the residents of the jurisdiction contemplating a regulation should be accounted for. Dr. Smith emphasized the importance of articulating specific criteria for determining the environmental values, because the wide range of possible methodologies, modeling assumptions, and values require that the Commission has a principled way to evaluate them.

With respect to time horizon, Dr. Smith proposed that the IAMs should be run through 2100, or at most 2140, rather than 2300. She asserted that a time horizon of 2100 was better supported by available empirical evidence and less speculative than a time horizon of 2300. With respect to the discount rate, Dr. Smith stated that the use of a 2.5% rate is unsupported by empirical evidence, that Federal guidance identifies 3% as a lower bound for approximating the social rate of time preference, but actually requires use of a 7% rate when a regulation will affect private sector capital spending, because 7% approximates the opportunity cost of displaced private sector investment. Accordingly, Dr. Smith testified that the discount rate to be used have a lower bound of 3% and an upper bound of not less than 5%.

With respect to which marginal ton to use, Dr. Smith noted that the IWG methodology calculates marginal damages from a ton of CO_2 as if it were the last ton to be added to a global 300-year projection of CO_2 emissions. She states it is inappropriate to assume that a particular ton of CO_2 emitted in the near future would be the last ton to be decided on as part of a 300-year "business as usual" baseline of otherwise unconstrained future emissions since many of the tons emitted that contribute to the SCC will not be emitted until much later than the Minnesota tons in question and by others than Minnesota, while the carbon emitted in Minnesota is no more or less harmful than carbon emitted elsewhere and is also no more or less harmful than any of the tons assumed to be emitted in the future. Dr. Smith note that, for example, the SCC value for 2020 depends on the concentration of greenhouse gasses projected to already exist by 2020, all emissions produced in 2020, and all emissions produced from 2020 into the far future. Dr. Smith noted that in the case of greenhouse gases, the marginal damage estimate varies with the baseline projection of greenhouse gas emissions and is higher if it is calculated against a baseline reflecting a world in which no greenhouse gas control policies are in place compared to a world that includes global greenhouse gas control policies. Dr. Smith thus concluded that a more appropriate marginal value should be calculated using a projection of CO_2 and other greenhouse gas emissions consistent with the global target that is considered appropriate to address climate change concerns, which the IWG did not do. To understand the sensitivity of the estimated SCC value to the question of which emissions levels should be the point at which the marginal damages should be computed, Dr. Smith considered that the marginal *benefit* is if the Minnesota tons in question are viewed as the first increment to all future anthropogenic tons, rather than the last increment to a business-as-usual baseline. To estimate the marginal value of the first ton, which is the lowest possible marginal value that the IWG's IAMs will produce, Dr. Smith modified the IAMs so that the baseline scenario represents no anthropogenic emissions occurring after 2020. She explained that this was merely an analytical device that allows one to infer the range of variation in the marginal damage estimate when using alternative future emissions projections, and is not in any way intended to suggest that the effect of prior emissions stop in the year 2100. Instead, the first ton analysis creates a lower bound for the Minnesota CO_2 environmental cost value and informs the Commission about how much of the IWG's marginal value estimate is due to emissions yet to be emitted, and not due to historical and present GHG emissions. It also allowed Dr. Smith to calculate the average marginal value by averaging first and last ton estimates. Dr. Smith testified that damages from emissions that Minnesota chooses to avoid or eliminate in an effort to show leadership in responding to climate change should be valued in a range between treating them as if they were the first incremental anthropogenic greenhouse gas ton to be emitted (going forward in time) and treating them as the marginal ton evaluated against a baseline reflecting a very large cumulative emissions reduction relative to the business-as-usual forecasts. To approximate these damages assuming use of IAMs, the upper

bound should be set as the average of the marginal damage estimates for the first and last ton in the IWG projections.

With respect to geographic scope, Dr. Smith testified that ideally only Minnesota damages should be included in the CO_2 environmental cost value. She notes that, while it might make sense for the Federal government to consider global damages when calculating the SCC because it has the authority to negotiate reciprocal international agreements to reduce global carbon emissions, Minnesota and other individual states lack authority to enter into international treaties. In the absence of reciprocal agreements, the vast majority of the benefits will not accrue to the community that will be bearing 100 percent of the cost, and the assurance that benefit-cost analysis will guide policy makers towards societal improvement is lost. Moreover, in the absence of concerted action, incorporating global damages would harm Minnesota and fail to help anyone else due to the extraordinarily small portion of Minnesota's CO_2 emissions as a percentage of global CO_2 emissions, while under a 3% discount rate approximately one-third of the estimated damages attributable to Minnesota under the IWG's calculations is actually attributable to the actions of others who will be contributing to future emissions, most of which will be non-U.S. in origin. Therefore, it is most appropriate to consider the benefits to Minnesotans from Minnesota's actions to reduce CO_2, given that the costs are paid by Minnesota electric customers. Dr. Smith further noted that by pricing its carbon emissions in ways that no other political jurisdictions are doing, Minnesota would place itself at a distinct and possibly substantial economic disadvantage. Lacking a modeling component inherent in the IAMs that will calculate Minnesota-only damages, Dr. Smith recommended calculating only U.S. damages and made this alternative framing assumption in her modeling. Although this change still significantly overstates Minnesota-specific damages, Dr. Smith argued it is more appropriate than using global damages. Dr. Smith also provided U.S. and non-U.S. components to her calculated values so that the Commission can determine whether and to what extent it wants to give weight to non-U.S. damages in the environmental cost values to reflect altruism of Minnesotans. Finally, Dr. Smith recommended that the Commission adopt these values on a net ton basis in order to account for leakage. After making these alternations to the SCC, Dr. Smith's proposed range for emissions in the year 2020 is $1.62 to $5.14 (in 2014 dollars per net metric ton). The low value is based on modeling damages from the first ton emitted, 5 percent discount rate, U.S. damages, and a modeling horizon to year 2100. The high value is based on the average of first ton and last ton emitted, 3 percent discount rate, U.S. damages, and a modeling horizon to year 2140.

Dr. Smith also provided SCC results for many alternative combinations of framing assumptions, in order to enable the Commission or ALJ to choose a range of values using whatever alternative assumptions they believe to be more appropriate than what she has recommended. Accordingly, she noted, they are not limited to only accepting or rejecting IWG SCC estimates.

2. Critiques of Smith's Proposal

Record Citations:
Hanemann Rebuttal at 24-26, 28-30, 63-64, 72, 77, 81-85
Hanemann Surrebuttal at 43-47
Polasky Rebuttal, at 6 – 31
Polasky Rebuttal, Schdule 1 (OMB Response to Comments) at 30-31

Martin Rebuttal at 25-29, 38-47
Martin Surrebuttal at 28-35

Polasky (CEO): Dr. Polasky states why the concerns raised by Dr. Smith are either not valid, or, if they touch on legitimate issues, why he considers the proposed alternatives to the IWG's SCC are inappropriate. With respect to Dr. Smith's use of a 2100 and 2140 time horizon, Dr. Polasky states that it is inappropriate and arbitrary to exclude any future time period where damages will likely occur. Because CO_2 can persist up to 200 years in the atmosphere, damages beyond 2100 and 2140 are likely. With respect to discount rate, Dr. Polasky disagreed with Dr. Smith's recommendation to reject the 2.5% discount rate because it is important to include a range, and because the 2.5% rate or lower rates are common in SCC analyses, as demonstrated by a study from Dr. Tol. With respect to marginal tons, Dr. Polasky asserted that Dr. Smith's marginal ton analysis was really based on her disagreement with the emission scenarios the IWG used. Dr. Polasky provided his rationale for why those emission scenarios are sound. He further explained that Dr. Smith's "first ton" analysis assumes zero worldwide CO_2 emissions after 2020, a projection Dr. Polasky noted as completely absurd. With regard to geographic scope, Dr. Polasky explained that restricting damages to the U.S. or Minnesota fails from an economic perspective because the theory of correcting externalities indicates that the emitting entity should incorporate the full damages caused by the pollution it emits and many of the damages from CO_2 emissions will result outside Minnesota or the U.S. Dr. Polasky noted that the IWG addressed the same issue in its response to comments. With regard to leakage, Dr. Polasky pointed out leakage, whether it exists or not, does not affect the externality value of a ton of CO_2.

Hanemann (Agencies): Dr. Hanemann criticized all four of Dr. Smith's alterations to the framing assumptions used by the IWG: time horizon, discout rates, which marginal value to use, and geographic scope. As a result, she underestimates SCC values. Curtailing the time horizon to end at 2100 assumes there are no damages after 2100. While damages after 2100 have uncertainty, they are nonetheless real and significant and need to be included in the estimation of the SCC. He criticizes Dr. Smith's decisions to reject the 2.5% discount rate and to include rates higher than 5%. High discount rates do not make sense in the context of intergenerational discounting, as was described in the discussion of discount rates above in section II.C.9. Dr. Hanemann objects to Dr. Smith's use of the first ton approach, which unrealistically assumes that when the SCC values are calculated for a certain year, for example, the year 2020, then no emissions for CO_2 occur anywhere in the world after 2020. A viable SCC must account for both past and future emissions. Finally, Dr. Hanemann rejects limiting consideration of damages to just Minnesota or just the U.S. Because emissions of CO_2 in Minnesota result in damages across the globe, global damages should be considered. Additionally, Dr. Hanemann criticizes Dr. Smith's argument that leakage should be taken into account in setting these values, her exclusion of catastrophic outcomes and her failure to account for risk aversion.

Martin (Xcel Energy): Mr. Martin disagreed with Dr. Smith's contention that her "alternate framing assumptions" are more objective, better supported in statute, or better supported in Commission precedent than the IWG policy judgments embedded in Xcel Energy's proposal. He noted that statute is silent on all of these framing assumptions, only requiring a practicable range. Precedent in the prior externalities docket is mixed, supporting Dr. Smith's alternate assumptions on discount rates and modeling horizon, but contrary to her alternate assumptions

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on U.S. damages and first-ton modeling. He disagreed that there is greater empirical basis for discarding than for using the 2.5 percent discount rate. He maintained that all four of the alternate assumptions are inherently subjective policy judgments, on which the Commission could legitimately decide to retain the IWG's policy judgments or instead to use its own. He indicated how Xcel Energy's proposed range could be adjusted without new modeling if the Commission agrees with Dr. Smith on modeling U.S. damages or dropping the 2.5 percent discount rate; but that if the Commission agrees with Dr. Smith on estimating average-ton damages or shortening the modeling horizon, these adjustments would require new modeling. In addition, Xcel Energy has addressed Dr. Smith's alternative framing assumptions in Issue 10 (Modeling Horizon), Issue 11 (Marginal Ton), Issue 12 (Discount Rate), and Issue 13 (Geographic Scope).

See Sections II.C.7-10, II.D, above.

E. Gayer Proposal (Issue 29)

1.   Proposal

Record Citations:
Gayer Direct at 6-10, Expert Report at 2-18
Gayer Surrebuttal at 19-20

Gayer (MLIG): According to Dr. Gayer, the global damages scope contained in the Federal SCC is not appropriate in the absence of explicit reciprocity by other states or other nations. The IWG's focus on global damages from incremental CO_2 emissions (or benefits from reducing CO_2 incrementally) is not consistent with sound benefit-cost practices, nor within the guidance provided by executive orders and the Office of Management and Budget (OMB), and would demand a dramatic shift in all state policies, including state poverty programs, if applied broadly. He stated that standard benefit-cost practice considers the benefits only for the jurisdiction that is bearing the costs of the policy (economic standing). While demonstrative feelings of altruism could justify considering benefits outside of Minnesota, any reasonable estimate of the magnitude of altruism would suggest only partial consideration of non-Minnesotans, with greater weight given in proportion to proximity. Since Minnesotans will accrue all costs, absent explicit reciprocity, it would be unreasonable for Minnesota to consider the environmental benefits to the entire global population.

The IWG estimated in the February 2010 TSD that U.S. damages range from 7 percent (based on the FUND model's regional damages) to 23 percent (based on the U.S. share of the global GDP) of global damages. Focusing only on the global aspect to the IWG's SCC, without endorsing any aspect of the IWG's SCC calculations, Dr. Gayer proposed using these percentages as conversion factors to derive U.S. damage values from the four Federal SCC executive summary values. Applying these adjustment factors to the IWG's November 2013 four SCC executive summary values for discount rates of 5%, 3%, 2.5%, and the 95th percentile of SCC estimates across the three IAM models at a 3% discount rate, Dr. Gayer arrived respectively at CO_2 environmental cost values of $0.77-$2.53, $2.24-$7.36, $3.57-$11.73, and $6.23-$20.47 (2010 damage value in 2007 dollars).

Dr. Gayer also proposed a Minnesota-damages-only value, which would be approximately 0.4 percent of the SCC based on Minnesota's GDP as a share of global GDP. Applied only to the 95th percentile SCC value yielded a high-end Minnesota damages estimate of $0.37 per metric ton of CO_2 (November 2013 TSD, 2010 damage values in 2007 dollars).

The same 0.4% factor can be applied to the global values found by Dr. Smith using her various adjustments to the IWG's SCC if those adjustments, or any of them, are accepted by the Commission.

2. Critiques of Gayer's Proposal

Record Citations:
Hanemann Rebuttal at 13-14, 44
Polasky Rebuttal, 26 – 28
Polasky Rebuttal, Schedule 1 (OMB Response to Comments), at 30-31
Martin Rebuttal at 29-32, 38-40

Polasky (CEO): Dr. Polasky stated that "economic standing" should extend to all parties damages by the emission of CO_2 and explained why anti-global poverty policy is not analogous. Dr. Polasky noted that the IWG addressed the issue of global vs. local damages in its Response to Comments.

Hanemann (Agencies): Dr. Hanemann rejected Dr. Gayer's choice to limit consideration of damages strictly to those in Minnesota. Because emissions of CO_2 in Minnesota have global impacts, global damages should be taken into consideration. Additionally, Dr. Hanemann argued in favor of the IWG's choices with respect to discount rates and other modeling choices.

Martin (Xcel Energy): Mr. Martin indicated that Dr. Gayer's proposal does use a damage cost approach, reflects absence of consensus on discount rate, and is replicable and updateable. He believes it does not reasonably address uncertainty, does not reflect a low degree of risk tolerance if the Commission retains a focus on global damages, does not use statistically sound methods (since it suffers from the same statistical flaws as the Federal SCC executive summary values on which it is based), does not minimize subjective judgments, and does not yield a practicable range (since Dr. Gayer proposes nine values for every emission year). Mr. Martin acknowledged that the choice of global, U.S. or Minnesota damages is inherently a subjective policy judgment for the Commission to make.

F. Martin Proposal (Issue 30)

1. Proposal

Record Citations:
Martin Direct at 50-69
Martin Rebuttal at 2-8, 54-56
Martin Surrebuttal at 9-16, 19-28, 33-35, 37, 42

Martin (Xcel Energy): According to Mr. Martin, the methodology to develop the environmental cost of CO_2 should be based on a balanced consideration of the following: use a damage cost approach; reasonably address the inherent uncertainty in estimating climate change damages over almost 300 years; reflect the absence of consensus on discount rate choice; use statistically sound methods; reflect an appropriate level of risk tolerance; minimize subjective judgments; yield a practicable range; and be transparent, replicable, and updatable. Mr. Martin believed that his proposal meets these criteria better than any other Party's proposal. He disagreed with Dr. Smith that her alternate framing assumptions are more consistent with Minnesota law, since the applicable statute is silent on all the framing assumptions. As for the criteria in the 1993 Docket, Mr. Martin stated that some of Dr. Smith's framing assumptions seem to be consistent with it (discount rate, modeling horizon) and some inconsistent with it (U.S./Minnesota damages, first ton approach). Mr. Martin also disagreed that Dr. Smith's alternate framing assumptions are less subjective or more evidence-based than those of the IWG that underlie his proposal. Mr. Martin also analyzed the proposals of all Parties under his proposed criteria in his Rebuttal Testimony.

In order to balance several competing considerations, Mr. Martin proposed a range based on the raw SCC modeling outputs and opposed selecting any single point estimate. His recommended range was based on an initial range from the 25th percentile at 5 percent discount rate to the 75th percentile at 2.5 percent discount rate (including approximately three fourths of all IAM predictions, which is a specified risk tolerance of 25 percent that this range excludes the actual value as predicted by the IAMs). Then, he equally weighted the values at 2.5, 3, and 5 percent discount rates at each end of the range, resulting in range bookends that correspond to the 36th and 74th percentiles of the combined discount rate distribution – a narrowing that he maintained is risk-averse from a climate damages perspective since it excludes more low than high damage estimates. According to Mr. Martin, this approach is neutral on the selection of the discount rate and appropriately balances uncertainty, risk tolerance, and practicability. He noted that this approach has an element of subjective policy judgment, as do all witnesses' proposals, but it is transparent and not arbitrary or unprincipled. Mr. Martin pointed out that it is incorrect to state that other percentiles could have been used to select a narrower or wider range with the same probability as the one selected by him (25th and 75th percentiles) – any other symmetrical percentiles (i.e., 10th and 90th, or 20th and 80th) would have a different probability. He also maintained that other percentiles proposed by Drs. Hanemann and Polasky (1st and 99th, 5th and 95th) would not be practicable because they would point in opposite directions in terms of resource planning, providing no useful guidance for Commission decisions. He noted that the equal weighting of the SCC values for each discount rate is agnostic and gives each rate equal emphasis. He also maintained that he has documented his rationale, methods, and data more explicitly and transparently than any other witness submitting testimony in this case. For example, for emission year 2020, Mr. Martin's proposed range is $12.13 to $41.40 (in 2014 dollars per short ton). Mr. Martin argued that his approach is transparent and appropriately balances many competing factors.

2.   Critiques of Martin's Proposal

Record Citations:
Hanemann Rebuttal at 66-71
Hanemann Surrebuttal at 38-40
Polasky Rebuttal at 32-42

Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 26
Bezdek Rebuttal, Ex. 1 at 44-52
Mendelsohn Rebuttal, Ex. 1 at 8-9
Wecker Rebuttal, Ex. 2
Smith Rebuttal at 2-12

Hanemann (Agencies): According to Dr. Hanemann, Mr. Martin's proposal to use the 25th and 75th percentiles to define an initial range excludes too many high damage values, is not fully representative of all the possible damage outcomes modeled by the IWG, and can be characterized as "data trimming." He noted that when the extreme values are a legitimate part of the distribution rather than being external to it (e.g., because of measurement error), trimming is not appropriate because it excludes data points that really belong in the distribution. Dr. Hanemann pointed out that in the climate change context, sound decision-making requires consideration of not only the typical or most likely outcomes, but also less likely outcomes that could have very large (or small, or even negative) damages (the tails of the distribution). Mr. Martin should have included the 95th percentile of the SCC distribution in his damage estimates, according to Dr. Hanemann, as is done in other regulatory contexts involving low risk but potentially catastrophic outcomes.

Polasky (CEO): Dr. Polasky disagreed with Martin's analysis in three main areas: (1) the reasons Martin rejects adoption of a set of single values; (2) Martin's use of the median rather than the mean; and (3) his method for determining a range. Dr. Polasky noted that the IWG addressed the adoption of single point values, such as the 95th percentile, and also the use of the mean rather than median in its response to comments. With regard to Martin's method of determining a range, he stated that it is inappropriate to choose two arbitrary end points (25th and 75th percentiles), and then average across three discount rates. He noted that this in fact creates a more subjective estimate of the SCC. The range between 25 percent and 75 percent can result in misleading representations of the SCC and therefore is less practical, and Dr. Polasky argued that a range between the 5th and 95th percentiles would provide a better description of the SCC distribution. The endpoints should not be selected based on whether the desired result is achieved. The IWG's choice to use the mean as the best measure was reasonable and represents the wide distribution; the Commission should avoid selecting an arbitrarily narrow range. Dr. Polasky argued that Mr. Martin's decision to average the results across the three discount rates to produce one range is clearly inappropriate and has no theoretical basis as we are not considering the entire range of possible discount rates, nor are we applying any probability distribution to the likelihood of any rate being the "true" social discount rate.

Mendelsohn (Peabody): According to Dr. Mendelsohn, Mr. Martin's methodology to use percentiles to define a range of values is subjective, arbitrary, and capricious, violating his own criteria for developing the CO_2 values. Also, Mr. Martin's decision to average the discount rates is logically inconsistent since the discount rates are not uncertain, they are simply controversial.

Wecker (Peabody): Dr. Wecker argued that Mr. Martin has failed to employ statistically sound methods, to apply his own stated criteria on a rigorous basis, and to provide any principled basis for the proposed CO_2 environmental cost values. Mr. Martin's proposed range is the product of entirely arbitrary subjective judgment. According to Dr. Wecker, Mr. Martin's testimony lacks

any reference to the large body of peer-reviewed research literature in the mainstream of statistics and applied mathematics, and instead relies on novel ad hoc procedures of his own invention. Choosing forms of descriptive statistics without any apparent consideration of the conceptual elements of the decision problem, as done by Mr. Martin, does not resolve but rather ignores the inherent uncertainty. Dr. Wecker noted that the equal treatment (averaging) of discount rates is inappropriate, because the discount rate is not a modeling parameter whose true value is uncertain, but reflects decision-making guided by theory and other normative considerations. He also pointed out that it was unnecessary and needlessly complicated to use bootstrapping, when Mr. Martin could have just applied his percentiles to the 450,000 SCC values produced by the IWG.

Bezdek (Peabody): According to Dr. Bezdek, Mr. Martin's methodology is based on the flawed IWG methodology and data, therefore his estimates are equally flawed and meaningless.

Smith (GRE/MP/OTP/MLIG): According to Dr. Smith, Mr. Martin first correctly rejected many of the IWG's subjective framing assumptions, only to then simply adopt those very same assumptions, and apply his own subjective judgments to narrow down a range of CO_2 values. Dr. Smith pointed out that there is no foundation in statistical theory or decision theory to support the way Mr. Martin derived a narrower range from the very wide range of raw SCC values. Dr. Smith argued that Mr. Martin used an *ad hoc* approach to select a range that suits a particular concept of "narrow enough" and claimed that this range is wide enough to meet an unspecified degree of "risk tolerance." She noted that Mr. Martin made another unreasonable decision when he equally weighted the discount rates of 2.5%, 3%, and 5% (making them each 33.3% probable); the IWG at least recognized that SCC estimates based on different discount rates should be reported separately in order to give SCC users the ability to decide themselves which of the three discount rates to emphasize for their decision-making purposes. According to Dr. Smith, there is no objective principle with which one can estimate the probability that the "true" value of the SCC will lie within any particular range that can be selected from the IWG's SCC distribution. The correct way to manage subjective uncertainty is to study the framing assumption options, choose appropriate assumptions for the decision context, and develop a distribution of estimates based on the chosen assumptions.

IV.   Adoption of a Single Point or Range (Issue 31)

Record Citations:
Hanemann Direct at 73
Hanemann Rebuttal at 87-88
Hanemann Surrebuttal at 39, 41-42, 46
Polasky Rebuttal at 32-35
Polasky Rebuttal Schedule 1 (OMB Response to Comments) at 25-26
Mendelsohn Direct at 14-15
Bezdek Rebuttal, Ex. 1, at 48
Wecker Rebuttal, Ex. 2, at lines 119-289, 341-362
Smith Direct at 33-34, Ex. 2, at 10-13, 45-48, Table 5
Gayer Direct at 6-10, Expert Report at 2-18
Gayer Surrebuttal at 19-20
Martin Direct at 3-4, 28-29, 52

Martin Rebuttal at 13, 29, 35, Schedules 2 and 3
Martin Surrebuttal at 36-38, 40

Hanemann (Agencies): Dr. Hanemann stated that the range of values that the IWG used for the discount rate – 2.5%, 3% and 5% – reasonably spans the values found in the existing peer-reviewed literature on the economics of climate change which range from 1.4% to 5.5%. He would recommend the range of estimates presented by the IWG corresponding to the alternative discount rates it considered – 2.5%, 3% and 5%. The range for the 2015 SCC is from $11 (5%) to $56 (2.5%). The range for the 2020 SCC is from $12 (5%) to $62 (2.5%). He believe the IAM damage functions used by the IWG are likely to understate the SCC, that 5% is likely to be too high as an estimate of the social consumption rate of discount because the marginal utility factor which it reflects is likely to be overstated. Dr. Hanemann opposed the ranges proposed by Drs. Smith and Mendelsohn because the ranges are so low and narrow that they do not capture much of the inherent uncertainty and reflect an inappropriately high level of risk tolerance.

Polasky (CEO): Dr. Polasky disagreed that adoption of a set of single values for the SCC would be inappropriate. Ultimately, in a particular case, he argued it will be necessary to decide on a single estimate for the SCC. It was appropriate for the IWG to report four single SCC values. Dr. Polasky argued that it would also be reasonable for the Commission to adopt the full range of SCC values across the three discount rates and the 95th percentile value for the purposes of this proceeding. He stated that having a range of values would provide the Commission with more information, allowing for a central value (at 3 percent discount rate) along with sensitivity values. By adopting this range of values the Commission would also avoid the "false precision" that is central to Mr. Martin's objection. The IWG also explained how the set of individual values represents the central tendency of SCC estimates across scenarios.

Mendelsohn (Peabody): Dr. Mendelsohn stated that a range of values is appropriate because it is not possible to identify a single value of the SCC given the wide uncertainty about future events. The range of values illustrates the uncertainty surrounding the estimate given our current scientific and economic understanding. Dr. Mendelsohn recommended three ranges: $4 to $6/ton if ECS is assumed to be 3°C; $0.30 to $0.80 per ton if ECS is assumed to be 1.5°C; and $1.10 to $2.00 per ton if ECS is assumed to be 2°C.

Bezdek (Peabody): Dr. Bezdek recommended keeping the CO_2 environmental cost range at the inflation-adjusted level where it was set originally, which he calculates to be $0.42 to $4.43 per ton; or reducing it to $0.20 to $2.00 per ton or lower.

Wecker (Peabody): Dr. Wecker testified that Mr. Martin's arbitrary use of 25%/75% cutoffs for an SCC range ignored authoritative statistical literature on decision analysis, substituting his own risk tolerance for that of policymakers. Further, Mr. Martin's bootstrap method of calculating the endpoints of his range is unnecessarily complicated, introducing a further source of error.

Smith (GRE/MP/OTP/MLIG): Dr. Smith recommended a range of values based on the lowest and highest SCC that resulted from all of the combinations of the four framing assumptions involved in the SCC. Her recommended range is $1.62 to $5.14 (in 2014 dollars per net metric ton, for emission year 2020). The low value is based on modeling damages from the first ton

emitted, 5 percent discount rate, U.S. damages, and a modeling horizon to year 2100. The high value is based on the average of first ton and last ton emitted, 3 percent discount rate, U.S. damages, and a modeling horizon to year 2140. Dr. Smith also provided separate estimates of the respective non-U.S. damages for each combination of framing assumptions, and noted that this information could be used by the Commission to adjust her recommended values if it wishes to incorporate a greater degree of altruistic value into the range.

Gayer (MLIG): Focusing only on the global aspect to the IWG's SCC, without endorsing any aspect of the IWG's SCC calculations, and accepting the IWG's estimates in the February 2010 TSD that U.S. damages range from 7 percent (based on the FUND model's regional damages) to 23 percent (based on the U.S. share of the global GDP) of global damages, Dr. Gayer proposed using these percentages as conversion factors to derive U.S. damage values from the four Federal SCC executive summary values. Applying these adjustment factors to the IWG's November 2013 four SCC executive summary values for discount rates of 5%, 3%, 2.5%, and the 95th percentile of SCC estimates across the three IAM models at a 3% discount rate, Dr. Gayer arrived respectively at CO_2 environmental cost values of $0.77-$2.53, $2.24-$7.36, $3.57-$11.73, and $6.23-$20.47 (2010 damage value in 2007 dollars).

Dr. Gayer also proposed a Minnesota-damages-only value, which would be approximately 0.4 percent of the SCC based on Minnesota's GDP as a share of global GDP. Applied only to the 95th percentile SCC value yielded a high-end Minnesota damages estimate of $0.37 per metric ton of CO_2 (November 2013 TSD, 2010 damage values in 2007 dollars).

The same 0.4% factor can be applied to the global values found by Dr. Smith using her various adjustments to the IWG's SCC if those adjustments, or any of them, are accepted by the Commission.

Martin (Xcel Energy): According to Mr. Martin, there are several reasons why the Commission should select a range and not adopt a single point estimate or value: 1) a range is a requirement of Minn. Stat. § 216B.2422, subd. 3(a); 2) the SCC was not developed for state-level resource planning purposes, in the context of which false precision is of more concern than in federal regulatory impact analysis; 3) the SCC methodology is inherently uncertain; 4) the SCC modeling produced 450,000 values instead of a single point estimate; 5) the SCC estimates broad global damages, but the direct costs resulting from the Commission decisions using the SCC would be borne by Minnesota utility customers; and 6) a range provides more information for resource planning than a single value. Mr. Martin stated that a single CO_2 value cannot accurately represent the amount of future climate damages. He pointed out that the four summary SCC values do not represent a true range; they are four point estimates that are subject to the same false precision as one point estimate. It would be particularly unreasonable to label one value (the 3 percent discount rate average value) as "central" and privilege this over others, since doing so would imply that the SCC is known with precision and that consensus exists around using a discount rate of 3 percent, neither of which is the case. According to Mr. Martin, the low and narrow ranges proposed by Drs. Smith and Mendelsohn do not adequately capture the inherent uncertainty in predicting climate damages and imply an inappropriately high level of risk tolerance. The range that Mr. Martin proposes, based on a balancing of his eight proposed criteria, is $12.13 to $41.40 (2014 dollars per short ton) for emissions in 2020, with corresponding ranges for all years 2010 to 2050 provided in 2014 dollars and nominal dollars.

CERTIFICATE OF SERVICE

I, Jim Erickson, hereby certify that I have this day served copies of the foregoing document on the attached list of persons.

    <u>xx</u>   by depositing a true and correct copy thereof, properly enveloped with postage paid in the United States mail at Minneapolis, Minnesota; or

    <u>xx</u>   by electronic filing.

MPUC Docket No: E-999/CI-14-643

Dated this 12th day of November 2015.

/s/

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