BEFORE THE MINNESOTA OFFICE OF ADMINISTRATIVE HEARINGS
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FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
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Nancy Lange	Commissioner
Dan Lipschultz	Commissioner
John Tuma	Commissioner
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In the Matter of Further Investigation into Environmental and Socioeconomic Costs under Minnesota Statute 216B.2422, Subdivision 3	OAH Docket No. 80-2500-31888 MPUC Docket No. E-999/CI-14-643

INITIAL BRIEF OF THE MINNESOTA DEPARTMENT OF COMMERCE, DIVISION OF ENERGY RESOURCES AND MINNESOTA POLLUTION CONTROL AGENCY

CARBON DIOXIDE

Dated: November 24, 2015

Respectfully submitted,

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I. INTRODUCTION

The Minnesota Department of Commerce, Division of Energy Resources ("DOC-DER" OR "Department") and the Minnesota Pollution Control Agency ("MPCA") (collectively, "the Agencies") respectfully submit this Initial Brief in order to provide the Administrative Law Judges ("ALJs") and the Minnesota Public Utilities Commission ("Commission" or "MPUC") with analysis of the facts and law as to whether the federal Social Cost of Carbon ("federal SCC") is reasonable and the best available measure to determine the environmental cost of carbon dioxide ("CO_2") emissions.

II. SUMMARY OF AGENCIES' CONCLUSIONS AND RECOMMENDATIONS

The Agencies recommend that the ALJs determine that the federal SCC, developed by the federal government's Interagency Working Group ("IWG"),[1] is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422. Such a finding is consistent with the Commission's requirement that the parties to this proceeding evaluate the environmental cost of CO_2 using a damage cost approach, and that the Agencies' consultants use reduced-form[2] modeling to estimate damage costs.[3] It satisfies the Commission's obligation, with respect to CO_2, "to the extent practicable, [to] quantify and

[1] The IWG consisted of participants from the Council of Economic Advisers, Council on Environmental Quality, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and the Departments of Agriculture, Commerce, Energy, Transportation, and the Treasury. In March 2011, the Office of Energy and Climate Change joined the Domestic Policy Council. Agencies Ex. 800 at fn. 1 (Hanemann Direct).

[2] Dr. Hanemann explained that "an [Integrated Assessment Model] combines a reduced form representation of the carbon cycle and the climate system together with a reduced form representation of the economy, economic growth and the generation of GHG emissions and a reduced form representation of the impacts of climate change and how those impacts are valued (the external cost generated)." Agencies Ex. 800 at 23 (Hanemann Direct).

[3] MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643, *Notice and Order for Hearing* at 4-5 and 8 (October 15, 2014).

establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422, subd. 3.

Because the most recent update of the federal SCC occurred in 2013, the Agencies further recommend that the ALJs find the 2013 estimate of the federal SCC is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422.

III. PROCEDURAL HISTORY[4]

On February 10, 2014, the Commission issued an order in Docket No. E-999/CI-00-1636 reopening its investigation into environmental costs of different methods of generating electricity under Minn. Stat. § 216B.2422, subd. 3. The Commission determined that the investigation would be best resolved in the context of a contested case proceeding conducted by the Office of Administrative Hearings ("OAH").[5]

On October 15, 2014, the Commission issued its *Notice and Order for Hearing* in which it set forth the scope of the investigation, as follows:[6]

> The Commission will investigate the appropriate cost values for $PM_{2.5}$, SO_2, NO_x, and CO_2. … Because CO2 represents 99% of greenhouse gas emissions, an accurate environmental cost value for CO_2 will account for almost all greenhouse gas costs …. in light of the record so far, the Commission will ask the Administrative Law Judge to determine whether the Federal Social Cost of Carbon is reasonable and the best available measure to determine the environmental cost of CO_2 and, if not, what measure is better supported by the evidence.
>
> The Commission will require parties in the contested case proceeding to evaluate the costs using a damage cost approach, as opposed to (for example), market-based or cost-of-control values. … Where a damage cost can be reasonably

[4] A complete procedural history is appended hereto as Attachment A.
[5] MPUC Docket E-999/CI-00-1636, *Order Reopening Investigation and Convening Stakeholder Group to Provide Recommendations for Contested Case Proceeding* at 3 and 5, (February 10, 2014).
[6] *Notice and Order for Hearing, id.* at 4-5.

> estimated, it represents a superior method of valuing an emission's environmental cost. The Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it.

The Commission also authorized the Department, on a discretionary basis, to work with the Office of Management and Budget to retain a consultant under Minn. Stat. § 216B.62, subd. 8. If a consultant was retained, the Commission required that the consultant use reduced-form modeling to estimate damage costs. The Commission referred to OAH[7] the issue of whether the federal SCC is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422 and, if not, what measure is better supported by the evidence.

On March 27, 2015 the ALJ issued an *Order Regarding Burdens of Proof* that provides, in part, as follows:

> 1. A party or parties proposing that the Commission adopt a new environmental cost value for CO_2, including the Federal Social Cost of Carbon, bears the burden of showing, by a preponderance of the evidence, that the value being proposed is reasonable and the best available measure of the environmental cost of CO_2.
>
> 2. A party or parties proposing that the Commission adopt a new environmental cost value for one or more of the criteria pollutants – SO_2, NOx, and/or $PM_{2.5}$ – bears the burden of showing, by a preponderance of the evidence, that the cost value being proposed is reasonable, practicable, and the best available measure of the criteria pollutant's cost.

On September 15, 2015, ALJ Schlatter issued an Order[8] denying a motion to strike Dr. Hanemann's testimony which found, in part, that the Agencies had demonstrated that Dr. Hanemann's testimony would qualify under Minn. R. Evid. 702, "that the IWG process was reasonably transparent," and that the record "provided ample evidence to demonstrate that the

[7] *Notice and Order For Hearing, id.* at 5 and 8.
[8] *Order On Motions By Minnesota Large Industrial Group and Peabody Energy Corporation to Exclude and Strike Testimony* which denied motions of the Minnesota Large Industrial Group (MLIG) and Peabody Energy Corporation (Peabody).

Intergovernmental Panel on Climate Change ("IPCC") Reports are more than sufficiently reliable for the witnesses to rely on to form the foundations for their opinions."

On September 24 – 30, 2015, the evidentiary hearing was held in the Commission's large hearing room.

IV. ARGUMENT

The Commission is required "to the extent practicable, [to] quantify and establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422, subd. 3. Each electricity utility must use the environmental externality values in conjunction with other factors when evaluating resource options in all proceedings before the Commission. Minn. Stat. § 216B.2422, subd. 3(a). The most common application of environmental externalities is in electric utility Integrated Resource Planning ("IRP").[9] The Agencies conclude that the federal SCC is reasonable and the best available measure to determine the environmental cost of CO_2 emissions from electricity generation. It satisfies the Commission's obligation, "to the extent practicable, [to] quantify and establish a range of environmental costs associated with each method of electricity generation" as is required by Minn. Stat. § 216B.2422, subd. 3. The federal SCC was developed[10] using reduced-form modeling and a damage cost approach, which the Commission required to be used.

[9] The Commission has also applied the estimates of environmental externalities to other analyses such as in large energy facility certificates of need and in the determination of the "value of solar." In this latter instance, the Commission employed the IWG's SCC as one component in the methodology used to determine the appropriate rate that should be paid to distributed solar generation. Agencies Ex. 800 at 64 (Hanemann Direct).

[10] The federal SCC was initially published in 2010 and updated in 2013. Agencies Ex. 800 at WMH-2 (*Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government (February 2010) (IWG 2010 TSD Report)); Agencies Ex. 800 at WMH-3, p.1 (Hanemann Direct) (*Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government (May 2013) (IWG 2013 TSD Report)). A slightly revised TSD with

1. THE AGENCIES' EXPERT WITNESSES

The Agencies provided testimony from two experts, Drs. Michael Hanemann and Dr. Kevin Gurney. Dr. Hanemann is a leading expert in the field of economics known as environmental and resource economics. He provided testimony on the economic concept that is measured in the federal SCC, and his opinion that the estimated federal SCC is reasonable for use in Minnesota, and is the best estimate available at this time. Agencies Ex. 800 at 3, 74. (Hanemann Direct). Dr. Kevin Gurney provided testimony regarding atmospheric science, specifically the science of climate change, and the importance of relying upon peer-reviewed literature and the IPCC 5th Assessment Report. Agencies Ex. 803 at 1-2 (Gurney Rebuttal); Agencies Ex. 804 (Gurney Surrebuttal). He is an expert in ecology and the global carbon cycle. Agencies Ex. 803. (Gurney Rebuttal.)

Dr. Hanemann received his Ph.D. in Economics from Harvard University; his Doctorate work and subsequent teaching and research have been in the field of environmental and resource economics, focused on non-market valuation – the monetary valuation of the natural environment.[11] From 2002 to 2010, at the request of the California Energy Commission ("CEC") Dr. Hanemann founded and directed the California Climate Change Center at UC Berkeley, the purpose of which was to provide a multi-investigator assessment of the potential impacts of climate change on the State of California. Agencies Ex. 800 at 1-2 (Hanemann Direct). Dr. Hanemann testified that he is very familiar with the literature on Integrated Assessment Models ("IAMs"), the damages from climate change and the social cost of carbon.

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minor technical corrections was issued in November, 2013 (IWG November 2013 TSD Report). Xcel Ex. 600 at NFM-1, p. 22 (Martin Direct).

[11] The economic valuation of the natural environment, and changes in environmental quality, is an application of non-market valuation. Non-market valuation seeks to measure, in monetary terms, the value that people place on things they care for. This includes things that cannot be purchased through a market. It subsumes, and generalizes, the economic valuation of things that are bought and sold in markets. Agencies Ex. 800 at 13 (Hanemann Direct).

Agencies Ex. 802 at 3-4 (Hanemann Surrebuttal). He participated in perhaps the first conference on the economics of climate change in the United States, organized in 1980 by Professor Kerry Smith with funding from the National Oceanographic and Atmospheric Administration ("NOAA"). *Id.* at 3-4. Since approximately 2010, he has served as an advisor to the economics group in the European Union's ("EU") Joint Research Center which conducts the EU's economic assessment of the impacts of climate change on EU member countries. *Id*. at 5.

Dr. Hanemann was selected to assist in drafting the IPCC's 5th Assessment Report; he was a lead author in Working Group III, on the Committee drafting Chapter 3, which contains information on the economic impacts of climate change. He led the drafting of section 3.9, which considered the metrics of costs and benefits. During the course of the Committee's work between 2011 and 2014 he studied the literature on the costs and benefits of reducing greenhouse gas ("GHG") emissions. Agencies Ex. 800 at 1-2 (Hanemann Direct). Dr. Hanemann was invited to present the findings regarding the IPCC's 5th Assessment Report, Chapter 3, at a joint meeting of the United States and Mexican National Academies of Sciences on climate change in Mexico City in April, 2014. For the National Academy's Board on Environmental Change and Society, he co-organized a Workshop on Integrating Socio-Economic Factors with Abrupt Change and Extreme Events in Climate Models in Washington in June 2014. Agencies Ex. 802 at 5-6 (Hanemann Surrebuttal). The federal SCC is one of the topics on which Dr. Hanemann has taught, conducted research, and followed the literature for many years. *Id.* at 4.

Dr. Hanemann was inducted into the National Academy of Sciences ("NAS") in 2011. The NAS is an honorific society, membership of which is considered one of the highest academic honors accorded.

Dr. Gurney has a BA in environmental physics with a concentration in climate change from UC Berkeley, a Master of Science in atmospheric science from MIT, a Master in public policy from UC Berkeley and a Ph.D. in Ecology from Colorado State University. He has worked in climate change research for 30 years. He has performed research in think tanks and academia, focusing during the last 15 years on the global carbon cycle. His research on the global carbon cycle is performed through the use of observations and modeling to better understand how carbon flows through the Earth System and impacts the Earth's climate. His testimony responded to several witnesses, and he discussed the importance of scientific protocols, including reliance on peer-reviewed literature. Agencies Ex. 803 at 2 (Gurney Rebuttal). He explained that, permeating the testimony of certain Peabody witnesses was the persistent use of patterns of argumentation and reasoning that failed to comport with ordinary protocols of science,. Agencies Ex. 804 at 1 (Gurney Surrebuttal). Dr. Gurney noted that these witnesses' reasoning was misleading, biased, or otherwise flawed. *Id*. He discussed the importance of the IPCC 5th Assessment Report, and unfavorably compared the protocols followed by several Peabody witnesses with the much more appropriate protocols followed by the authors of the IPCC 5th Assessment Report. Agencies Ex. 803 at 2, 25-28 (Gurney Rebuttal).

2. CLIMATE CHANGE

Dr. Hanemann explained climate change, broadly, as follows: Carbon dioxide and other GHGs are being released through human activity and natural causes on Earth. Some of the GHGs released are absorbed into the ocean, and some remain in the atmosphere. This accumulation of gasses changes the energy balance in the atmosphere, eventually leading to changes in the climate worldwide. The changes in the Earth's climate can include changes in temperature and precipitation, melting of sea ice and ice sheets, sea-level rise, ocean acidification and other phenomena. Greenhouse gasses are released both by natural causes (for example,

volcanic eruptions or releases of methane from a swamp) and by human actions (including the burning of fossil fuels, deforestation, and land degradation). The resulting changes in climate have many economic and environmental consequences that affect the wellbeing of humans and natural ecosystems worldwide. In some cases, the effects can be beneficial; often they are harmful. Agencies Ex. 800 at 6-7 (Hanemann Direct).

3. EXTERNALITIES AND REMEDY FOR MARKET FAILURE

A. Externalities

Dr. Hanemann explained that an economic externality arises when an entity takes an action that imposes costs or benefits on others as a result of that action. A distinction thus arises between the private costs and benefits of the action, which accrue to the actor, and the external costs and benefits, which accrue to others. This distinction defines an externality. There is said to be a negative (harmful) externality when there is an external cost to others as a result of the action of an entity, but no offsetting external benefit. There is said to be a positive (beneficial) externality when there is an external benefit to others as a result of the action of an entity, but no offsetting external cost. From society's perspective, the social costs and benefits of an entity's action consists of the sum of the private costs and benefits and the external costs and benefits. If there is no externality, the private costs and benefits coincide with the social costs and benefits. If there is an externality, however, there is a divergence between the private and social costs of an action and/or between the private and social benefits. This divergence leads to a level of activity that is not optimal. Agencies Ex. 800 at 7-8 (Hanemann Direct).

If externality costs and benefits are not internalized, private actions are likely to lead to outcomes that are not in the best public interest. The presumption is that the actor pays attention to the private costs and benefits of his action but disregards the external costs and benefits. With a negative externality, the presumption is that too much of a harmful activity takes place because

the actor disregards the external costs. With a positive externality, the presumption is that too little of a beneficial activity takes place because the actor disregards the external benefits. Emissions of GHGs that cause harm to non-emitting entities are negative externalities. *Id*. at 10-11. When an action causes a negative externality, this does not necessarily mean that it should not be undertaken at all because there is still some private benefit from that activity. However, if an actor internalizes a negative externality to some extent, the presumption is that less of that action will occur. *Id.* at 8-9.

Greenhouse gasses like CO_2 are a stock externality: the harm comes from the effects of the accumulated stock of emissions, including past as well as present emissions. If no emissions occur over the course of a year, harm still occurs during that year due to the stock of pollutants which has accumulated from past emissions. With a stock pollutant, the harm continues for a span of time, until the stock of pollutants has dissipated. In the case of some GHGs it can take centuries before past emissions are removed through natural processes and cease to contribute to climate change and to cause harm. *Id.* at 11.

Greenhouse gasses also have a broad spatial scale. Greenhouse gasses emitted at a particular location on the Earth are rapidly mixed in the atmosphere with GHGs emitted from other locations on Earth. How GHG emissions influence climate, and the consequent impacts on environmental and human wellbeing, plays out on a global scale. A molecule of emitted GHG contributes to damages from climate change experienced everywhere around the globe, regardless of where it is emitted. *Id.* at 12.

Climate change can affect populations in different ways. Some populations may benefit; others may be harmed. There are numerous ways that populations can be impacted by climate change, and while many non-monetary metrics can be used to characterize particular components

of the impacts of climate change, they provide no unambiguous way to aggregate those metrics for the purpose of characterizing the overall change in human wellbeing. In principle, the economic theory of monetary valuation provides a way to perform this aggregation. *Id.* at 14.

B. Remedy for Market Failure

The existence of externalities and a divergence between private and social costs leads to what is known as a "market failure." In the case of a negative externality, the divergence between the private and social costs results in a burden placed on society through the actions of the private entity. The remedy is related to a concept known as "the polluter pays" principle, under which a party responsible for causing pollution is also responsible for paying for the damage caused by that pollution, thus internalizing the externality. Agencies Ex. 800 at 9 (Hanemann Direct). Taxing the party creating the negative externality at the marginal external cost of the damage that the party's action imposes can remedy a market failure and reduce the action to a socially optimal level. Through the tax,[12] a polluter pays for the damage the polluter's action causes. *Id.* Formalized mathematically, this analysis of externalities and beneficial taxation on cost-causers is part of the standard canon of microeconomics. *Id.* at 10.

Various levels of government in the United States and abroad have used taxes and market incentives as a means of shifting people's behavior in ways deemed in the public interest. Dr. Hanemann provided examples of such taxes. One example at the federal level in the United States is the excise tax on ozone-depleting chemicals introduced in 1989 to promote the policy goal of reducing the use of chlorofluorocarbons following the negotiation of the Montreal Protocol (Barthold, 1994). Additionally, the emissions trading scheme for sulfur dioxide ("SO_2") emissions, initiated in 1995 under Title IV of the 1990 Clean Air Act Amendments is another example of a market-based system for regulating a pollutant externality. Trading of SO_2

[12] Dr. Hanemann explained that the tax is referred to in economic theory as a "Pigouvian" tax. *Id.*

allowances had the (intended) effect of placing a price on emissions – an SO_2 price. At a regional level, Southern California's RECLAIM market is a cap and trade system for NOx emissions. Outside the United States, a number of countries have levied environmental taxes, including carbon taxes, in Denmark, Finland, Sweden, Ireland and France. The European Union has had a cap and trade system for CO_2 emissions since 2005 (World Bank, 2014). And, something akin to this type of tax, and based on a measurement of external cost, has been used for regulatory purposes. An example in the United States is the use of environmental adders by various state Public Utilities Commissions, including the Minnesota Commission. The adder is a measure of the external cost imposed on society by damages from emissions (those exceeding the optimal level from society's perspective) from the generation of electricity. The monetized value of the damage is added to the cost per kilowatt-hour ("kWh") of electricity to permit a comparison of the costs of available options, for example in the context of integrated resource planning.[13] Agencies Ex. 800 at 12-13 (Hanemann Direct).

C. Valuing Impacts on Human Wellbeing - Market and Non-market Valuation

Changes that affect human wellbeing are classified as *market* and *non-market*. Market effects involve changes in market prices, and changes in revenue and net income, in the quantity or quality of market commodities, or in the availability of commodities. Non-market changes are changes in the quantity, quality or availability of things that matter to people, even though they are not obtained through the market. Agencies Ex. 800 at 14-15. (Hanemann Direct).

The economic valuation of the natural environment, and changes in environmental quality, is primarily an application of *non-market valuation*. Non-market valuation seeks to measure, in monetary terms, the value that people place on things they care for that cannot be purchased through a market. It subsumes, and generalizes, the economic valuation of things that

[13] NRC (2010, pp. 26-28)

are bought and sold in markets. *Id.* at 13. In the case of climate harm, the willingness-to-pay measure of damage is the amount of an individual's income that the individual would be willing to give up to avoid the harm. This measure covers not only the income loss that might be incurred but also anything else that contributes to a reduction of the person's wellbeing. *Id* at 21. Non-market items that people value include health, quality of life, culture, environmental quality, natural ecosystems, wildlife, and aesthetics. A given change in a physical or biological system can generate both market and non-market damage to human wellbeing. *Id.* at 15.

3. MEASUREMENT OF THE SOCIAL COST OF CARBON (SCC) AND INTEGRATED ASSESSMENT MODELS

The SCC measures the external costs associated with an incremental unit of greenhouse gasses emitted now. These costs continue into the future. What is measured, therefore, is the discounted present value of the stream of additional external costs occurring as a consequence of emitting an incremental unit now. To the extent that changes in climate associated with greenhouse gas emissions are beneficial, the external cost is negative (i.e., a benefit) Empirical evidence and theoretical understanding indicate that, in aggregate, the net effect is harmful; therefore, the value of the SCC is a positive number. Agencies Ex. 800 at 21 (Hanemann Direct).

The SCC is thus a measure of the marginal external cost associated with the emission of an additional unit of greenhouse gasses today. This marginal external cost would be internalized if there were a "polluter pays" tax equal to the marginal external cost on that unit of emissions. The reference to "carbon" in the SCC reflects three things: (1) the dominance of carbon dioxide among the current greenhouse gasses; (2) the translation of non-CO_2 GHGs into CO_2-equivalent units, and (3) the use of "carbon" as shorthand for carbon dioxide and its equivalents. *Id.* at 22.

Dr. Hanemann explained how the SCC is estimated, indicating that, to estimate the marginal external cost associated with an additional unit of GHG emissions one needs to

estimate, in general terms: (1) how that emission changes the existing accumulation of GHGs in the atmosphere via the carbon cycle; (2) how that, in turn, changes the amount of energy stored in the Earth's system (the change in radiative forcing); (3) how the change in radiative forcing leads to changes in the climate worldwide; (4) how those changes in climate affect things that matter to humans, such as water supply and drought, crop production, disease and human health, outbreaks of wildfire, coastal flooding, and ecosystem functioning and the like; and (5) how humans value the changes in those things. *Id.* at 22.

4. INTEGRATED ASSESSMENT MODELS ARE "REDUCED-FORM" MODELS, AND EMPLOY A DAMAGE COST APPROACH, AS IS REQUIRED BY THE COMMISSION.

In referring to a contested case proceeding the question of whether the federal SCC is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422, the Commission required parties to use a damage cost approach.[14] The federal SCC satisfies this requirement, as the calculation of the SCC is conducted within the framework of what is known as an Integrated Assessment Model ("IAM" as noted above) which is a computable, numerical model that accounts for the five damage estimates noted above that are needed to calculate SCC. Agencies Ex. 800 at 22-23. (Hanemann Direct).

A. IAMs are Reduced-Form Models that Use a Damage Cost Approach (Issue 2)

IAMs are mathematical computer models that are based upon explicit assumptions about the behavior of a modeled system. They attempt to incorporate information from physical and social sciences that consider economic, political, and demographic variables in addition to the climate system to provide a coherent synthesis of different information that is available for use by decision makers. Agencies Ex. 800 at 23 (Hanemann Direct). Dr. Hanemann explained that

[14] MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643, Notice and Order for Hearing at 5 and 8 (October 15, 2014).

an IAM combines (1) a reduced-form[15] representation of the carbon cycle and the climate system together with (2) a reduced-form representation of the economy, economic growth and the generation of GHG emissions and (3) a reduced-form representation of the impacts of climate change and how those impacts are valued (the external cost generated). *Id.* at 23. The strength of an IAM is that it combines these three components in one integrated model – the representation of how economic activity generates emissions, the representation of how the emissions lead to climate change, and the representation of the economic cost of the resulting impacts. *Id.* at 24. The numerical computations are conducted period by period, starting in a base year (e.g., 2010) and continuing at least through 2100. *Id.* at 25-26.

The IAM output is a set of time paths (trajectories) for variables such as average annual Gross Domestic Product ("GDP") during each time period, average annual GHG emissions and abatement, average annual atmospheric GHG concentration, average annual change in global temperature, the average annual economic value of the impacts caused by the change in temperature, and the average annual carbon tax (social cost of carbon). The trajectories are typically reported through at least 2100. *Id.* at 26.

The economic valuation of the impacts of climate change is expressed using the "willingness-to-pay" measure of economic value. This measures the maximum amount that the public existing at that point in time would be willing to pay annually to avoid the harm at that time. This annual willingness to pay is expressed as an equivalent percentage of annual GDP at the time. It is intended to cover not only market impacts of climate change but also non-market

[15] In climate science, "reduced-form" models involve a simplified version of a larger model. The larger model ("the structural model") has equations characterizing physical or behavioral relationship ("structural equations") which, in the reduced-form model, are simplified into a smaller number of equations that summarize the outcome of interactions among the structural equations after variables have been solved out of them.

impacts, and not only changes in income but also changes in market prices and, more generally, any changes that are considered to affect public wellbeing as accounted for by the model. *Id.* at 26-27. The "damage function" of an IAM is the economic value associated with particular groups of impacts at a point in time as a function of the increase in global average annual temperature occurring at that time. The damage function, like the other components of an IAM, is represented through an algebraic equation. *Id.* at 27. Dr. Hanemann detailed the formula of equations used to represent the damage function. *Id.* at 27-29.

B. The DICE, PAGE, and FUND IAMs (Issues 17, 18, 19)

Dr. Hanemann explained that the three IAMs used by the IWG, namely the Dynamic Integrated Climate-Economy model (DICE)[16], Policy Analysis of the Greenhouse Effect (PAGE),[17] and Climate Framework for Uncertainty, Negotiation and Distribution (FUND),[18] are the three main such models in the literature. They were developed in the 1990s for the purposes of determining the benefits and costs of GHG mitigation and measuring the social cost of carbon. Agencies Ex. 800 at 31 (Hanemann Direct). These IAMs first appeared in 1993, 1994, and 1995, respectively, and were each used at that time to calculate a SCC for emissions of CO_2. *Id.* at 30. Dr. Hanemann described in detail the history of the three IAMs and explained how they have been revised over time. *Id.* at 31-33. The DICE, PAGE and FUND IAMs differ from each other in their representation of the carbon cycle, the climate system, and the damages associated with an increase in the global average annual temperature. Although the three economists who developed each of them had a similar purpose in mind, each IAM embodies each researcher's ideas as to how one should build a model. *Id.* at 34, 65. To Dr. Hanemann's knowledge, the IAM modelers have never collaborated or participated in a model inter-comparison exercise.

[16] Agencies Ex. 800 at 31 (Hanemann Direct).
[17] *Id.* at 32.
[18] *Id.* at 33.

Indeed, prior to the IWG's study, there had been no comparable IAM model inter-comparison exercise. *Id.* at 65-66.

1. Similarities among the DICE, PAGE and FUND IAMs

All three IAMs take the trajectory of population change over time as exogenous to the model (i.e., determined outside the model). Agencies Ex. 800 at 35 (Hanemann Direct). All three IAMs account for CO_2 emissions from land-use change as well as from the use of fossil fuel in electricity generation and industrial production (*Id.* at 38-39) and otherwise account for the effects of warming. *Id.* at 41-42.

The DICE, PAGE, and FUND IAMs all contain "simplified" representations of *economic* models, *climate* models, and *impact* models. As a result, they are appropriate for use in policy making, because simplified representations of the three underlying component models are necessary in order to combine those components together and enable rapid iteration of the IAM for policymaking purposes. *Id.* at 42.

The strength of IAMs like DICE, FUND and PAGE is that they combine climate models, economic models, and impact models within one integrated framework. Their climate model is a simplified representation of General Circulation Models ("GCMs"). Their model of economic activity and the generation of emissions is a simplified version of what is found in other economic models. Their representation of impacts is a simplified version of what is found in more detailed models of individual types of impact. *Id.* at 30.

2. Differences Between the DICE, PAGE and FUND IAMs.

Dr. Hanemann explained how the three models differ from one another. Agencies Ex. 800 at 34-42 (Hanemann Direct). The similarities and differences are summarized in Dr. Hanemann's Direct Testimony at Figure 2. *Id.* at 34, 36. Some important differences include

income growth over time,[19] the spatial scale,[20] and temporal scale.[21] With regard to income growth, an important difference between DICE, on the one hand, and FUND and PAGE, on the other, is that PAGE and FUND are simulation models, whereas DICE is formulated and solved as an "optimization" model. *Id.* at 37.

A simulation model proceeds through time period by period. In each period, inputs to the calculations for that period consist of variables determined inside the model from previous periods' computations plus inputs exogenous to the model. After the completion of computations for that period, some of the results are stored for use as inputs to future periods' computations. There is a separate set of computations for each period in sequence. *Id.* at 37.

In an optimization model, while each period is evaluated, there is a linkage between the determination of variables made for one period and those made for other periods, reflecting the optimization being conducted. In the case of DICE, the optimization takes the form of a standard economic growth model modified to account for a stock externality (namely, GHGs). *Id.* at 37. The essence of the optimization in an economic growth model 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

[19] PAGE and FUND take the growth of income over time as exogenous (i.e., determined outside the model). In DICE, by contrast, the per-capita income is endogenous (i.e., determined inside the model). This is because PAGE and FUND are simulation models, whereas DICE is formulated and solved as an optimization model.

[20] FUND divides the world into 16 regions. Economic activity, emissions, and impacts are modeled separately for each region. PAGE divides the world into 8 regions, with economic activity, emissions, and impacts modeled separately for each region. DICE models the world as a global entity. *Id.* at 34.

[21] FUND operates on an annual time step. DICE operates on a decadal time step. PAGE operates on a decadal time step from 2000 to 2060 and a 20-year time step between 2060 and 2100. *Id.* at 35.

individual period. The time span being considered in DICE – several centuries – contains many generations of people living on Earth. *Id*.

A common approach in the economic literature to attempting to predict these variables over several centuries, and the one adopted by DICE, is to represent the situation as though there was a single individual, representative of the entire population, who is alive over the entire span of time considered. The representative individual controls each period's economic variables (e.g., output, investment, consumption, and the generation of emissions). In each period, the representative individual's well-being benefits from consumption in that period but is harmed by the damage from warming in that period. The output available from production in a period, adjusted downwards for the damage from warming in that period, can be either consumed in that period, invested in productive capital, or applied to reduce GHGs (mitigation) from the production of output in the current period. The allocation of each period's output to consumption, investment and mitigation is determined so as to maximize the total discounted present value of the representative individual's wellbeing (utility) over the span of time considered. Being simulation models, PAGE and FUND do not embody this type of optimization. *Id*. at 37-38.

The economic impact of a climate catastrophe is not modeled separately in DICE or FUND. In PAGE it is represented by a damage function that kicks in with a positive probability when the increase in global average annual temperature exceeds 3^{o}C. *Id.* at 42.

Dr. Hanemann explained that DICE, FUND and PAGE each employ a simple "box" climate model approach to model the accumulation of GHGs in the atmosphere, in which the entire atmosphere may be modeled as one single reservoir ("box"); and the entirety of the oceans is modeled as one or two reservoirs. Although the three IAMs differ in what the boxes represent

in each IAM,[22] the key to this method is the ability to assign values for the model parameters governing the flow of carbon between the reservoirs. *Id.* at 39-41.

Dr. Hanemann explained that the impacts of warming (the global damage functions) are accounted for in the three IAMs in different ways. Starting with DICE 2007, DICE has had two categories of impact/global damage functions; one for the effects of sea-level rise, and the other for aggregate non-sea-level rise impacts. PAGE 2002 (used by the IWG in its 2010 Technical Support Document ("IWG 2010 TSD Report") had three categories of impact,[23] economic (i.e., market) impacts; non-economic (i.e., non–market) impacts; and discontinuity (e.g., abrupt change or catastrophe) impacts. PAGE 2009 (used by the IWG in its IWG 2013 TSD Report) adds a fourth category of impact for sea-level rise. FUND has fourteen categories of impact:[24] sea level rise, agriculture, forests, heating, cooling, water resources, tropical storms, extra-tropical storms, migration, biodiversity, cardiovascular disease, respiratory illness, vector-borne disease, and diarrhea.[25] *Id.* at 41. Dr. Hanemann testified that IAMs are appropriate for use in

[22] DICE uses a 3-box model to represent the flow of CO_2 in the Earth system. FUND takes an approach that is of the same general type as DICE but with different details. In FUND, the boxes are associated with five processes that represent removal of CO_2 from the atmosphere, the summation of which represents a total removal of CO_2 by the land/ocean. PAGE uses one box to represent removal of CO_2 from the atmosphere to the land and the ocean. As with DICE and FUND, this is designed to capture a number of processes in a compact mathematical form. Agencies Ex. 800 at 40-41 (Hanemann Direct).

[23] There are three regional damage functions for each of eight regions.

[24] There are fourteen regional damage functions for each of sixteen regions.

[25] There are differences in the models as to the damage due to sea-level rise and non-sea-level rise. In the case of sea-level rise, the damage is modeled as a function of the rise in global mean sea level, which, in each model, is projected as a function of temperature and lagged temperature. In DICE the global damage is expressed as a quadratic function of the rise in mean sea level. In PAGE and FUND, with their regional spatial resolutions, factors such as regional coastal length or topography are used in the calibration of the regional sea-level rise damage function. In PAGE, the function is a power function of projected global sea-level rise. In FUND, a more elaborate formula is employed. Similarly, the non-sea-level rise damage function is a quadratic function of temperature in DICE and a power function in PAGE. In FUND, there is a different formulation of the damage function for each category of impact. *Id.* at 41-42.

estimating the SCC and, because of the constraints of computing capacity, it is essential to use simplified models such as the DICE, PAGE, and FUND models, in order to be able to combine all three elements – emissions, climate change and impacts – in a unified assessment. *Id.* at 42, 44.

5. THE FEDERAL INTERAGENCY WORKING GROUP AND INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC).

The Interagency Working Group was created in response to a 2008 Order resulting from a lawsuit brought against the Federal Transportation Administration. The federal Ninth Circuit Court of Appeals ordered executive branch agencies to include the climate benefits of any significant regulatory action in their federal benefit-cost analyses ("BCA") in order to comply with Executive Order 12866.[26] Agencies Ex. 800 at 44 (Hanemann Direct). In 2009, the Council of Economic Advisers and the Office of Management and Budget, with participation by the Council on Environmental Quality, the National Economic Council, the Office of Energy and Climate Change, the Office of Science and Technology Policy, the Environmental Protection Agency and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury convened the IWG to review and develop estimates of the SCC. Agencies Ex. 800 at 3, 45 (Hanemann Direct).

The IWG convened on a regular basis between 2009-2010 to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. The result is a report known as the IWG 2010 Technical Support

[26] As a result of that ruling, in 2008 and 2009, the U.S. Department of Transportation ("USDOT"), U.S. Environmental Protection Agency ("USEPA") and U.S. Department of Energy ("USDOE"), began applying estimates of the SCC. The individual agencies developed separate estimates of the SCC based on their interpretation of the academic literature. Initial applications of the SCC in regulatory impact analyses ranged from $0 to $159 per metric ton of CO_2 emitted (GAO, 2014). See Agencies Ex. 800 at WMH-6 (Hanemann Direct). The IWG was convened, in part due to the inconsistent application of estimates of the SCC, to review and develop estimates of the SCC that could be applied consistently. *Id.* at 45.

Document ("TSD") Report. *Id.* at 45; Agencies Ex. 800 at WMH-2 (Hanemann Direct). The stated objective was to "develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of IWG's SCC estimates used in the rulemaking process." *Id.* at 1.

The Intergovernmental Panel on Climate Change is an intergovernmental scientific body under the auspices of the United Nations, established in 1988 at the request of member governments. It was originally formed under the auspices of the World Meteorological Organization ("WMO") and the United Nations Environment Program ("UNEP"), and was later formally recognized by the United Nations General Assembly. Countries which are members of the IPCC are also members of the WMO and UNEP. The IPCC is tasked with producing reports that support the United Nations Framework Convention on Climate Change ("UNFCCC"), which is the main international treaty on climate change. *Id.* at 33-34.

Dr. Gurney explained why the IPCC is a reliable source of scientific information. The IPCC is an international collective of scientists with acknowledged expertise in the broad topical umbrella of climate change.[27] During the nearly three decades during which the IPCC has functioned, it has had the voluntary involvement of thousands of experts within the climate change discipline. The most important function of this large international collective, and its founding intent, was to prepare a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change, the social and economic impact of

[27] The authors of the IPCC reports are working scientists who volunteer their time to review the science. They often work in teams on particular chapters or report sections. The IPCC Secretariat itself is composed of a very small staff with no modeling or research capability. The Secretariat staff serve a predominantly clerical function. Agencies Ex. 804 at 13 (Gurney Surrebuttal).

climate change, and possible response strategies and elements for inclusion in a possible future international convention on climate. Agencies Ex. 803 at 26-27 (Gurney Rebuttal) (*citing www.ipcc.ch/organization/organization_history.shtml*). Comprehensive assessment is an absolute necessity in order to arrive at a reasonable understanding of a topic at hand. This is one of the goals of the IIPCC in forming and generating the series of multivolume assessment reports since the 1990s. Agencies Ex. 804 at 6 (Gurney Surrebuttal). The IPCC Assessment Reports have been produced roughly every six years and now include multiple volumes, technical summaries, and a summary for policymakers. Agencies Ex. 803 at 27 (Gurney Rebuttal).

The IPCC Assessment Reports contain no original research; rather, the reports review the existing peer-reviewed literature and synthesize the information into an assessment of the current state of scientific knowledge on the topic of climate change. Agencies Ex. 804 at 13 (Gurney Surrebuttal). The volunteer scientist-reviewers aim to comprehensively examine every aspect of climate change and its impacts. On any topic within the multivolume assessments, there are often tens to hundreds of peer-reviewed papers. Papers can often have conflicting or incomplete results. Rather than "cherry-picking" a result by selecting a particular subset of papers, the Assessment Reports strive to synthesize all research, identifying those areas that remain uncertain or for which conflicting results have been published in order to arrive at an objective, unbiased assessment of what is known and not-known about climate change. *Id.* at 26 The Assessment Reports themselves are reviewed by experts. *Id.*

Finally, the Assessment Reports assign different levels of confidence and likelihood to key conclusions regarding areas of study within the assessment. *Id.* at 27 (*citing* IPCC 5th Assessment Report). As a result, the IPCC assessments are the best resource for providing a comprehensive syntheses of what is known and not known about climate change. It provides an

extensive bibliography citing the thousands of papers reviewed for the Report. All authors, contributing authors, editors, reviewers are publicly listed and the reports go through extensive editing to ensure readability, accuracy, and objectivity. *Id.* at 28.

Dr. Hanemann explained that IPCC Assessment Reports are internationally regarded as authoritative on the topics covered. Agencies Ex. 800 at 34. The IPCC Assessment Reports are a source of scientific information used in the IAMs. *Id.* at 32, 52, 56, 74. For example, the synthesis supplied by the IPCC is the best comprehensive review of global temperature records. Agencies Ex. 804 at 16 (Gurney Surrebuttal). The IPCC has published five comprehensive assessment reports reviewing the latest climate science. Each assessment report is in three volumes, produced by Working Group I (The Physical Science), Working Group II (Impacts), and Working Group III (Mitigation). The First Assessment Report was published in 1990, the 2nd in 1995, the 3rd in 2001, the 4th in 2007, and the 5th in 2014. The findings of DICE, PAGE and FUND are cited by Working Groups II and III in the 2nd, 3rd and 5th Assessment Reports. Agencies Ex. 800 at 34 (Hanemann Direct).

6. THE FEDERAL SCC DEVELOPED BY THE IWG IS THE BEST AVAILABLE ESTIMATE OF THE ENVIRONMENTAL COST OF CARBON.

It is reasonable for the MPUC to use the SCC to measure the environmental cost of CO_2, because, at the present time, this is the best available estimate of the environmental damage cost of an additional ton of CO_2 emissions. Agencies Ex. 800 at 74 (Hanemann Direct). Dr. Hanemann's Direct Testimony detailed, and independently evaluated, the choices and actions taken by the IWG to develop its initial IWG 2010 TSD Report 2010 and subsequent IWG 2013 TSD Report. In his opinion, each aspect of these choices and actions, as discussed more fully below, was appropriate and reasonable.

A. The IWG Appropriately Selected the DICE 2007, FUND 3.5, and PAGE 2002 Models to Use in its IWG 2010 TSD Report. (Issues 17, 18, 19)

To estimate the SCC in the IWG 2010 TSD Report, the IWG did not undertake a new climate modeling effort nor did it try to develop a new IAM. Instead, it used the current versions of the three best known and most widely cited IAMs in the literature: DICE 2007; FUND 3.5; and PAGE 2002. Agencies Ex. 800 at 46 (Hanemann Direct). Dr. Hanemann testified that, in his opinion, it was appropriate for the IWG to use these three models because they are well known and have been widely cited in the economic literature on climate change and mitigation policy for the last two decades. He explained that, to most people familiar with the economic literature on climate change and mitigation policy, it would have been surprising had the IWG not used DICE, PAGE and FUND. *Id* at 65. Although other, less widely known and cited IAMs exist, they either were out of date relative to the version of DICE used by the IWG, lacked adequate or reasonable representation of damages, or had incompatibility issues with DICE, FUND and PAGE, which are widely known, respected, and are commonly cited, including in the IPCC's 4th Assessment Report. *Id.* at 70-73.

The IWG, essentially, ran the models side by side and averaged the results. *Id.* at 46, 64. This had never been done before because two of the models were – and still are – not readily available for use by anyone other than the model-builders and their collaborators. DICE is readily available; the model code and full instructions for running it have been posted on the web since the initial publication of DICE 1993. As a result, many academic papers have been published over the past 10-15 years by other researchers who use DICE, make changes to it, and/or run probabilistic simulations in the same manner as the IWG. The same is not true for PAGE and FUND. The IWG was the first entity to have independent access to all three models. Dr. Hanemann explained that, since then, only the Electric Power Research Institute ("EPRI"),

the electric industry's research arm, has had independent access to all three models. *Id* at 64. The IWG study stands out, therefore, and represents an important development. *Id.* at 66.

B. The IWG Appropriately Standardized the DICE, PAGE, and FUND Models (Issue 14)

Dr. Hanemann 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.[28] Agencies Ex. 800 at 46 (Hanemann Direct). He explained that this is a standard practice in model inter-comparison exercises. He testified that, in his expert opinion, it would have been unreasonable if the IWG had *not* done this. *Id.* at 47, 66; Agencies Ex. 802 at 30 (Hanemann Surrebuttal).

1. The IWG Appropriately Modified DICE to Convert it to a Simulation Model

The IWG's standardization necessitated a change in the structure of DICE because, while PAGE and FUND are simulation models, DICE is an optimization model. The standardization made by the IWG converted DICE into a simulation model, so that it was on a common footing with the other two models. Without making the change, differences between optimization and simulation would have confounded the model comparison. Agencies Ex. 800 at 47 (Hanemann Direct). Dr. Hanemann testified that, in his expert opinion, it was appropriate for the IWG to change the structure of DICE to make it a simulation model rather than an optimization model. This change was required in order to standardize the income and emission inputs into DICE and to render it more directly comparable with the other two IAMs used by the IWG. It was also required in order to standardize the discount rate across the three models.[29] *Id.* at 67.

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[28] The IWG preserved how 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. *Id.* at 47.

[29] Dr. Hanemann explained that the only other modification, for the purposes of model comparisons, that the IWG could have made to these models for its IWG 2010 TSD Report was to recode the three models in a common programming language. It used each of the three

2. The IWG Appropriately Standardized Model Inputs and Non-CO_2 Radiative Forcing

Dr. Hanemann detailed how the IWG standardized external model inputs (the "drivers") of future population, income, and emissions, as well as parameters for non-CO_2 radiative forcing and the climate sensitivity[30] value. Agencies Ex. 800 at 46 (Hanemann Direct). To standardize projections of income, population, emissions, and non-CO_2 radiative forcing, the IWG used results of the highly authoritative Energy Modeling Forum's ("EMF")[31] 22nd model inter-comparison study (Clarke *et al*., 2009). *Id.* at 49-51; Agencies Ex. 801 at 17 (Hanemann Rebuttal). Dr. Hanemann testified that, in his opinion, it was appropriate for the IWG to draw the standardized values of the socioeconomic/emissions inputs from the EMF-22 model inter-comparison exercise, which had just been completed prior to the IWG 's study. He explained that the EMF model inter-comparison exercises are seen as authoritative in the economic literature on climate change and mitigation policy. *Id.* at 50, 66-67. In Dr. Hanemann's expert opinion, it was also appropriate for the IWG to standardize the non-CO_2 radiative forcing across the three models. Non-CO_2 emissions constitute a relatively small part of total GHGs. By harmonizing their treatment, this made the models more readily comparable. *Id.* at 67.

Dr. Hanemann summarized the standardized IAM inputs in his Figure 4. *Id.* at 49. To standardize income, the IWG removed the optimization performed by DICE, and made income

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models in its native code, while standardizing elements of the model structure and harmonizing the model inputs. Subsequently, EPRI, the electricity industry's research arm, recoded all three models in a common programming language (EPRI, 2014). Dr. Hanemann explained that this was an arduous and time-consuming task, and he doubted that the IWG would have had the time to do this when conducting its studies in 2010 and 2013. *Id.* at 69

[30] Equilibrium Climate Sensitivity is a key parameter that characterizes how a doubling of the atmospheric concentration of CO_2 translates into an increase in global average annual temperature. *Id.* at 46.

[31] Based at Stanford University, the EMF organizes structured forums for discussing important modeling issues regarding the economics of energy and climate change. It was established in 1976 and is considered the premiere forum for objective discussion within the energy/economic modeling community. *Id.* at 49, note 34.

exogenous to DICE in the same manner as PAGE and FUND.[32] The IWG used the same income projections for all three models. *Id.* at 48. For population, the three models use slightly different exogenous projections. As part of the standardization, the IWG used a common population projection for all three models. *Id*. Finally, the three models treat non-CO_2 greenhouse gasses slightly differently. The IWG standardized the treatment of non-CO_2 greenhouse gasses the same, so as to place PAGE on the same footing as DICE. *Id.*

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. Peabody Ex. 238 at RSJT-2, pp. 6-7 (Tol Rebuttal).

Dr. Hanemann was not surprised that FUND, as run by the IWG, produced different results than FUND in its native form. The IWG standardized the external model inputs for the IAMs and used different drivers for emissions than those native to FUND. This standardization was reasonable. For example, when projecting emissions, FUND uses projections from EMF-14 which the IWG replaced with projections from the more recent EMF-22. The standardization was necessary in order to put the three models on a common footing and to make them more comparable. Agencies Ex. 802 at 30 (Hanemann Surrebuttal); Tr. Vol.2B at 78, lines 16-120.

3. The IWG Appropriately Standardized the Equilibrium Climate Sensitivity

Dr. Hanemann explained how the value of the equilibrium climate sensitivity ("ECS") was standardized across all three models in each model run. To accommodate the scientific

[32] In all three models, income (production) is a determinant of GHG emissions. While income is determined outside PAGE and FUND, it is determined within DICE as part of the optimization performed by that model. *Id.* at 48.

uncertainty regarding this key parameter, the IWG incorporated the ECS parameter in the three IAMs not as a single fixed value but as a random value sampled from a probability distribution. In Dr. Hanemann's expert opinion, it was appropriate for the IWG both to standardize the ECS parameter and to make it a random variable with the same probability distribution across all three models. Making the ECS parameter a random parameter has been done before in the literature and is not unusual or novel. Agencies Ex. 800 at 67-68 (Hanemann Direct).

In standardizing the value of the ECS, the IWG used the Roe and Baker (2007) probability distribution for the value of the climate sensitivity. This distribution is often used in the scientific literature. It was selected by the IWG after consulting with several lead authors of the relevant chapter in the 2007 IPCC 4th Assessment Report, and after considering three other alternative distributions. The Roe and Baker distribution was chosen because it was the only one based on a theoretical understanding of the climate system's response to increased GHG concentrations, and it better matched the IPCC's judgment regarding the distribution of climate sensitivity values. *Id.* at 52. In Dr. Hanemann's opinion, it was appropriate for the IWG to use the Roe and Baker distribution as the common probability distribution of the climate sensitivity, because it is based on a theoretical understanding of the climate system's response to increased radiative forcing and widely cited in the literature. *Id.* at 68.

4. The IWG Appropriately Calculated Annual Estimated Damages

To implement its choice of common probability distribution of the climate sensitivity value, and determine annual estimated damages, the IWG used a numerical simulation procedure. It randomly drew 10,000 possible values of the climate sensitivity in a manner that conformed to the Roe and Baker distribution. Each value drawn was then applied to all three

IAM models in common. Agencies Ex. 800 at 52 (Hanemann Direct). DICE, PAGE and FUND were each run five times using the five common sets of EMF inputs. *Id.* at 51.

While DICE itself has no randomly sampled parameters, PAGE and FUND both do contain some components with particular probability distributions for certain model parameters – ten random parameters in the case of PAGE, and eleven random parameters in the case of FUND. The IWG preserved the existing random components in PAGE and FUND, while adding the random component associated with the climate sensitivity parameter. Thus, in the case of PAGE and FUND, the IWG ran 10,000 replications of those models which also included draws from the probability distributions of the random parameters native to them. *Id.* at 51-52.

Dr. Hanemann explained that, with five socioeconomic/emissions scenarios and 10,000 replications of the random parameters, for each model there were 50,000 sets of output. These outputs of the models contained the estimates of the annual damages over the period 2010 through 2100 due to warming induced by an emissions scenario. *Id.* at 53.

5. The IWG Appropriately Used a Common Discount Rate Across All Three Models When Aggregating Annual Damages into a Discounted Present Value.

Once annual damages for the time horizon are calculated, the SCC can be calculated by standardizing the discount rate--using the same discount rates--in the three models, then aggregating annual damages and converting them to a present value. Agencies Ex. 800 at 46 (Hanemann Direct). To determine the present SCC, the IWG aggregated the annual damages over the period 2010 through 2100. Such damages are conventionally expressed as a *discounted present value*, with each year's damages discounted back to 2010 and summed. *Id.* at 53.

Dr. Hanemann explained that, because of the unusually long span of time at issue when calculating the environmental cost of CO_2 emissions, the discount rate used for this purpose has a huge impact on the result. The discount rate represents the extent to which the value of future

costs and benefits are reduced relative to present costs and benefits. Thus, a lower discount rate yields a larger discounted present value, while a higher discount rate yields a smaller discounted present value. For example, the present value in 2010 of $100 of damage occurring in 2100 is just $10.83 using an annual discount rate of 2.5 percent. Using an annual discount rate of 5 percent, it is $1.24. 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. *Id.* at 53.

To aggregate annual damages into a discounted present value, the IWG standardized the discount rates it used, applying the same rate to all three of the DICE, PAGE and FUND models. Dr. Hanemann testified that, in his expert opinion, it was appropriate for the IWG to employ a common discount rate across all three models when aggregating the annual damages projected by the models into a discounted present value. He explained that, had the IWG not done this, it would have been pointless to make a comparison of SCC estimates across the models. *Id.* at 68.

C. The IWG Appropriately Selected Annual Discount Rates of 2.5 Percent, 3 Percent and 5 Percent (Issue 12)

The IWG chose to use three alternative values for the annual discount rate: 2.5 percent, 3 percent and 5 percent. Agencies Ex. 800 at 54 (Hanemann Direct). This was a policy judgment by the IWG, which determined that those three rates "reflect reasonable judgments under both descriptive and prescriptive approaches" to determining an appropriate rate of discount. Agencies Ex. 800 at WMH-2, p. 23 (Hanemann Direct) (IWG 2010 TSD Report). *Id.* at 54. The IWG also selected the 3 percent value for the central estimate. *Id.* at 68. Dr. Hanemann testified that, in his expert opinion, it was appropriate for the IWG to use the three values and to consider the 3 percent value the central estimate. He stated that these values are consistent with the values used in the existing literature on the economics of climate change and of GHG mitigation. He

explained that a major study, the Stern (2006) Review, conducted for the United Kingdom, used a discount rate of 1.4 percent, and that, for DICE, Nordhaus uses 5.5 percent. Dr. Hanemann knows of no values higher than 5.5 percent or lower than 1.4 percent being used in the existing literature on the economics of climate change. *Id.* at 68-69, 73.

D. The IWG Appropriately Averaged the Results Obtained from the Three Models to Calculate the Discounted Present Environmental Cost Values (Issue 20)

With discount rates determined, the IWG calculated the SCC as follows: For each choice of discount rate and each IAM, there were 50,000 (= 5 socioeconomic/emissions scenarios*10,000 draws of random parameters) estimates of the value of the SCC in a given year. Dr. Hanemann referred to these as "baseline discounted present values." *Id.* at 54. Pooling the results of the three IAMs yielded 150,000 estimates of the value of the SCC in that year for each discount rate. *Id.* at 55.

The IWG calculated the resulting estimates of the SCC for that year as the *average value* across the 150,000 replications of the three models combined, for each separate value of the discount rate (2.5 percent, 3 percent and 5 percent). In addition, for the 3 percent discount rate, the IWG presented the upper 95th-percentile of the 150,000 replications. The SCC values were calculated in this manner for years 2010, 2020, 2030, 2040, and 2050. *Id.* at 55 (*citing* Agencies Ex. 800 at WMH-3, p. 12 (Hanemann Direct) (IWG 2013 TSD Report). The SCC values for years in between were calculated using straight-line projections. *Id.* at 55.

The IWG's estimate of the SCC increases over time because, over time, there is a greater accumulation of CO_2 in the atmosphere, and higher future levels of population, global output, and emissions, and thus a higher total willingness to pay to avoid climate change damages. As explained in the IWG 2010 TSD Report: "The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become

more stressed in response to greater climatic change." Agencies Ex. 800 at 56; WMH-2, p. 28 (Hanemann Direct) (IWG 2010 TSD Report).

E. The Commission Should Adopt The IWG's 2013 Estimate of The SCC

The IWG's 2013 estimate of the SCC, across the range of discount rates, is at this time the best available measure of the environmental cost of an additional ton of CO_2 emissions. Agencies Ex. 800 at 74 (Hanemann Direct). The IWG's 2013 estimate differs from the 2010 estimate in that it used updated versions of DICE, PAGE and FUND, which accounted for more recent scientific information. Dr. Hanemann explained that in its 2013 update to the IWG 2010 TSD Report, the IWG in all other respects retained the methodology it had used in 2010.[33] Agencies Ex. 800 at 57, 59 (Hanemann Direct). The updates to the IAMs by the three model developers, which the IWG incorporated, were:

- An update to PAGE 2009, replacing PAGE 2002, the version used in the IWG 2010 TSD Report. The update was intended to take account of the latest scientific information primarily in the IPCC's 4th Assessment Report.

- An update to DICE 2010, replacing DICE 2007, the version used in the IWG 2010 TSD Report. The update, similarly, incorporated information from the 4th Assessment Report which was partially available when DICE 2007 was being finalized.

- An update to FUND 3.8, replacing the version used in the IWG 2010 TSD Report, FUND 3.5.

[33] Dr. Hanemann explained (*Id.* at 59) that the retained methodology included:
- The overall experimental design was unchanged.
- The comparison of the three IAMs was not changed.
- The five socioeconomic/emission projections were unchanged.
- The methodology for extending the socioeconomic/emissions assumptions after 2100 was unchanged.
- The probability distribution used for the climate sensitivity parameter was unchanged.
- The types of uncertainties considered and their specifications, both standardized and model-specific, were unchanged (except as those were affected by the updates made by the model developer.
- The treatment of discounting was unchanged.

Id. at 32-33, 56-67.

According to an analysis of the EPRI, "[f]or DICE, the carbon cycle was revised with weaker ocean uptake. For FUND, the transient temperature response was unchanged and indirect radiative forcing from methane was added. For PAGE, the carbon cycle/ocean carbon uptake was revised, as was scaling to regional temperatures. For DICE and FUND, the climate modeling revisions, all else equal, resulted in higher SCC estimates. For PAGE, it is unclear." *Id.* at 57.

Dr. Hanemann's Direct Testimony detailed the changes to the three IAMs used by the IWG in 2013 and described the import of those changes in his Figure 6. *Id.* at 58, 61. He testified that, in his expert opinion, the Commission should use the IWG's 2013 estimate of the SCC, rather than the IWG's 2010 estimate. He explained that the 2010 estimate of the SCC differs from the 2013 only because it used what are outdated versions of DICE, PAGE and FUND. The updated versions of the IAMs used for the IWG's 2013 study took account of more recent scientific information, including information from the IPCC 4th Assessment Report. It would be unreasonable to base a current estimate of the SCC on earlier versions of the IAMs, just as it would be unreasonable to base a scientific assessment of climate change on an old IPCC Assessment Report rather than the current Assessment Report. *Id.* at 74.

The present federal SCC estimates can be updated annually using the GDP deflator index as recommended by the IWG. Furthermore, as newer versions of the IAMs become available, what was done by the IWG could be repeated. As the federal government updates their estimates of the SCC, those estimates would be available for use by the State of Minnesota in determining the environmental externalities associated with CO_2 emissions. *Id.* at 61.

F. IWG's 2013 Estimate of The SCC

The most recent estimate of the federal SCC is in the IWG 2013 TSD Report, where the IWG presented annual SCC estimates through 2050 for the three discount rates and the 95th percentile of the 3 percent discount rate. These estimates are in 2007 dollars. The IWG recommended adjusting these numbers to current-year dollars using the GDP deflator index. *Id.* at 59.

Dr. Hanemann's Direct Testimony, at Figure 7 set out the IWG's present SCC:

Figure 7: Annual SCC Values: 2010-2050 (2007$/metric ton CO2)

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	**Avg**	**Avg**	**Avg**	**95th**
2010	11	32	51	89
2011	11	33	52	93
2012	11	34	54	97
2013	11	35	55	101
2014	11	36	56	105
2015	11	37	57	109
2016	12	38	59	112
2017	12	39	60	116
2018	12	40	61	120
2019	12	42	62	124
2020	12	43	64	128
2021	12	43	65	131
2022	13	44	66	134
2023	13	45	67	137
2024	14	46	68	140
2025	14	47	69	143
2026	15	48	70	146
2027	15	49	71	149
2028	15	50	72	152
2029	16	51	73	155
2030	16	52	75	159
2031	17	52	76	162
2032	17	53	77	165
2033	18	54	78	168
2034	18	55	79	172
2035	19	56	80	175
2036	19	57	81	178
2037	20	58	83	181
2038	20	59	84	185
2039	21	60	85	188
2040	21	61	86	191
2041	22	62	87	194
2042	22	63	88	197
2043	23	64	89	200
2044	23	65	90	203
2045	24	66	92	206
2046	24	67	93	209
2047	25	68	94	211
2048	25	69	95	214
2049	26	70	96	217
2050	26	71	97	220

Dr. Hanemann testified in Direct Testimony that, in his expert opinion, the 2013 IWG estimates of the SCC, across the range of discount rates, is at this time, the best available measure of the environmental cost of an additional ton of CO_2 emissions. *Id.* at. 74.

In his Rebuttal Testimony, Dr. Hanemann affirmed his opinion, indicating that the additional information he discussed in his Rebuttal left his recommendations unchanged. Agencies Ex. 801 at 88 (Hanemann Rebuttal).

G. Use of the Federal SCC In Regulatory Proceedings. (Issue 3)

Minnesota Statute § 216B.2422, subd. 3 requires that "[a] utility shall use the values established by the commission in conjunction with other external factors, including socioeconomic costs, when evaluating and selecting resource options in all proceedings before the commission, including resource plan and certificate of need proceedings." The IWG's estimate of the SCC was developed for use in cost-benefit analysis. The Agencies recommend use of the federal SCC, because there is no material difference between cost benefit analyses and the uses required by Minnesota Statute that would preclude the use of the federal SCC as the Commission's CO_2 externality value range.

Xcel Energy's ("Xcel") Mr. Martin contested the applicability of the federal SCC to Minnesota's resource planning, arguing that the SCC was developed for a specific and limited purpose as a component of a cost-benefit analysis of proposed federal regulations performed as part of the regulatory impact analysis required by the White House's Office of Management and Budget ("OMB") under Executive Order 12866. Mr. Martin generally asserted that there is an important difference between using the SCC for its intended purpose and using the SCC in integrated resource planning and other Commission decisions. Agencies Ex. 801 at 16 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 12 (Martin Direct).

Dr. Hanemann disagreed with Mr. Martin, explaining that resource planning is a form of cost-effectiveness analysis. A cost-effectiveness analysis seeks to identify the least-cost means of achieving a given target or goal. As such, a cost-effectiveness analysis is a particular type of cost-benefit analysis, where the alternatives all have the same benefit. In that case, maximizing the net benefit (the object of a cost-benefit analysis) is equivalent to minimizing the cost (the object of cost-effectiveness analysis). Agencies Ex. 801 at 17 (Hanemann Rebuttal).

Federal agencies similarly use the federal SCC in regulatory impact analyses ("RIA") to evaluate the benefits and costs of proposed rulemakings in a manner that accounts for the impact of GHG emissions. Some of these rulemakings have directly targeted CO_2 emissions, such as the car and truck standards, whereas others have set standards for conventional or toxic pollutants that indirectly affect CO_2 emissions, such as the Mercury and Air Toxics Standard ("MATS"). *Id.* at 61.

The federal government uses the federal SCC in other analyses. For example, the US DOT requires grant applicants for their Transportation Investment Generating Economic Recovery ("TIGER") program to use the IWG's SCC in documenting the benefits of proposed projects. The U.S. DOT Federal Railroad Administration requires applicants for high-speed rail grants to value reduced CO_2 emissions using the IWG's SCC. In a planning process somewhat analogous to electric utility integrated resource planning efforts, the Federal Aviation Administration Environmental Design and Portfolio Management Tools incorporate estimates of reduced CO_2 from alternative airport configurations, flight operations approaching and leaving airports, flight routing and trajectories, and fuel composition emissions using the IWG's SCC. *Id.* at 62.

Various states' agencies have adopted using the IWG's SCC estimates. On April 22, 2014, Montgomery County, Maryland, revised its County Code 18A on environmental sustainability to require the SCC to be incorporated into return on investment calculations for energy efficiency and sustainability decisions. *Id.* at 62. The Minnesota Public Utilities Commission has previously applied the estimates of environmental externalities to other analyses such as in large energy facility certificates of need and in the determination of the "value of solar." In the latter instance, the Commission employed the IWG's SCC as one component in the methodology used to determine the appropriate rate that should be paid to distributed solar generation.[34] *Id*. at 64.

The use of an estimate of the SCC is currently a component of numerous integrated resource plans across the nation. For example, Puget Sound Energy, Portland General Electric, Tennessee Valley Authority, and NV Energy are among the many utilities incorporating the IWG's SCC estimates in their recent planning documents. *Id.* at 62-63.

7. ARGUMENTS AGAINST COMMISSION USE OF THE FEDERAL SCC

A. Criticism that SCC Estimates Should Not be Based on the Marginal "Last Ton" (Issue 11)

The conventional manner by which an SCC estimate is created is as follows: To generate the SCC value for 2020, say, one introduces a small increment (one marginal ton) into CO_2 emissions for 2020. Given the one-time increment in emissions, one calculates:

(i) the annual atmospheric concentration of CO_2 for each year following 2020,

[34] *See In the Matter of Establishing a Distributed Solar Value Methodology under Minn. Stat. § 216B.164, subd. 10 (e) and (f)*, MPUC Docket E999/M-14-65, "Minnesota Value of Solar: Methodology" at 40 (April 1, 2014) published at https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={3F6F9D30-11CF-460D-8FE7-D9F101F66694}&documentTitle=20144-97891-02 (minutes of meeting approving Minnesota Value of Solar methodology, January 31, 2014) published at https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={0B857F78-7E77-453B-9653-DF10A735E24A}&documentTitle=20145-99180-03.

(ii) the annual degree of global warming for each year following 2020, and

(iii) the annual damage associated with that annual warming for each year after 2020. Agencies Ex. 801 at 27 (Hanemann Rebuttal).

The annual damages for each year after 2020 are compared with the annual damages over the same period in the baseline run with no incremental increase of emissions in 2020. The differences between the baseline and baseline-plus-incremental-increase damage trajectories measure the additional annual damages arising from the one-time emissions addition in 2020. To obtain the 2020 SCC, one discounts and sums those annual damage increments back to a present value in 2020. *Id.* This approach is what Dr. Smith referred to as the "last ton" approach to calculating the SCC. *Id.*

As noted above, the warming in any future year – say, 2075 – depends on emissions that have already occurred before today as well as on emissions that will occur between today and 2075. Those emissions all mix and contribute to the atmospheric concentration of CO_2 in future years, and therefore to the warming that occurs in future years. Therefore, damages associated with emissions that have already occurred affect both the baseline trajectory and the trajectory of damages associated with an incremental emissions increase used to calculate the 2020 SCC. *Id.* at 27-28. Or, to state it more directly, the estimate of the 2020 SCC depends on both past emissions and future emissions. *Id.* at 28.

1. Smith's Alternative "First Ton" Proposal is Not Reasonable.

Dr. Smith proposed an alternative to the last ton approach, which she called the "first ton" approach. Agencies Ex. 801 at 28 (Hanemann Rebuttal) (*citing* GRE,MP,OTP,MLIG Ex. 300 at 33 (Smith Direct)). Under this approach to calculating a SCC value for 2020, she assumed that no anthropogenic emissions occur after 2020. This became her baseline scenario. *Id*. at 28.

Dr. Smith then imposed an incremental emission increase in 2020 on that baseline, and proceeded to compare the damages with and without the 2020 incremental emission increase in the manner as described above. *Id.*

Dr. Hanemann testified that Dr. Smith's first ton approach is not a reasonable way to proceed because the baseline for the first ton approach assumes that no emissions of CO_2 occur anywhere in the world after 2020. *Id.* at 29. Dr. Hanemann stated that, in his opinion, that is a "ridiculous assumption" and it is not a reasonable foundation on which to base an estimate of the SCC. *Id.*

B. The IWG's Projection of Future Emissions and Criticisms of the IWG's Modeling Horizon (Issue 10)

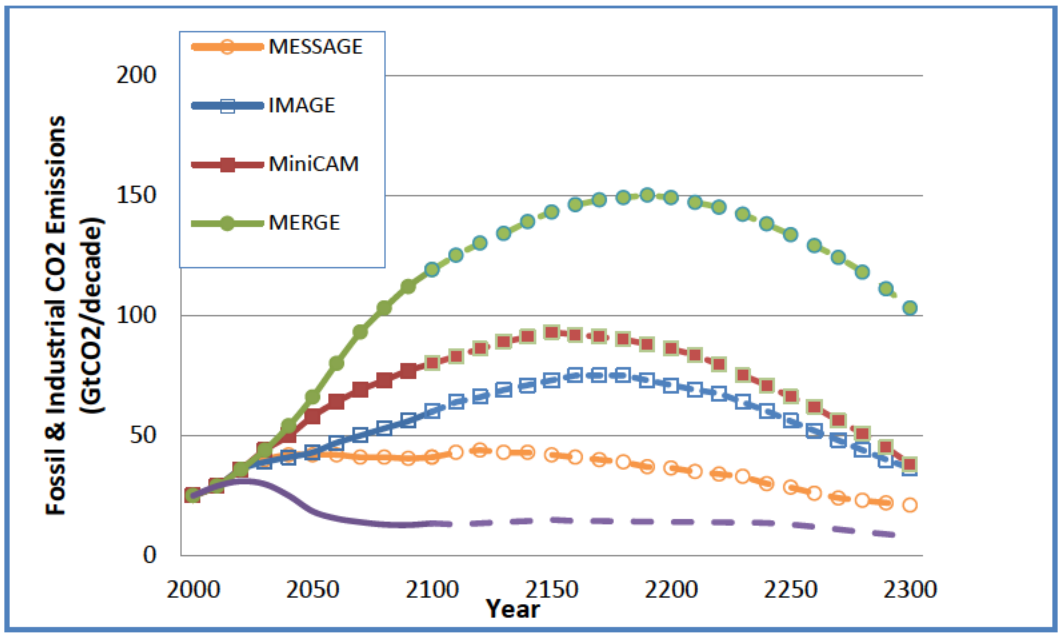
The degree of global warming between now and 2300 – the period considered by the IWG[35] – depends on both past GHG emissions and future emissions occurring through 2300.

As discussed above,[36] the IWG needed a standardized set of future emissions to feed into the three IAMs it was using in simulation mode. For an authoritative source, it drew on emission projections from the EMF's twenty-second model inter-comparison exercise ("EMF-22"). That exercise projected emissions through 2100, and the IWG made some assumptions to extend the projections through 2300. Agencies Ex. 801 at 17 (Hanemann Rebuttal). The IWG's

[35] The IWG explained in its IWG 2010 TSD Report that "each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. A more detailed discussion of these assumptions is included in the Appendix to the IWG 2010 TSD Report. Agencies Ex. 800 at WMH-2, p. 25 (Hanemann Direct).

[36] The IWG's process to standardize future emissions is discussed in above section 6.B.2., entitled, "The IWG Appropriately Standardized Model Inputs and Non-CO_2 Radiative Forcing."

projections of emissions through 2300 (reproduced below) are found in Hanemann Rebuttal, Figure 1B. Agencies Ex. 801 at 19 (Hanemann Rebuttal).



As is seen, the IWG assumed that emissions level off and then decline. *Id.* at 23.

The emission projections used by the IWG drew criticism from Dr. Smith.[37] *Id.* at 17, 20-22. One concern of Dr. Smith was that there was "no provision in any of the IWG scenarios for societal response to the worst-case levels" of climate sensitivity. GRE,MP,OTP,MLIG Ex. 300 at AES-D-2, p. 30 (Smith Direct). Dr. Smith was concerned that "[t]he IWG's analysis forces the emissions projections that drive those very high temperature outcomes to remain unchanged through the entire 300-year modeling horizon." *Id.* Dr. Hanemann stated, in response, that, in fact, the IWG placed a 20 percent weight on the emission projection keyed to climate stabilization at 550 parts per million ("ppm");[38] this is the low trajectory in the above

[37] Mr. Martin saw these projections as a source of uncertainty. Agencies Ex. 801 at 17 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 30 (Martin Direct). This initial Brief will address Mr. Martin's concerns with other criticisms concerning uncertainty as "Issue 22."

[38] In 2002, the United Nations Framework Convention on Climate Change (UNFCCC), an international organization established by treaty in 1992, formally adopted the goal of avoiding

Figure 1B. Further, the emissions projections are not unchanged, but, as is seen in Figure 1B, emission projections level off and then decline for each scenario.

Second, Dr. Smith attributed some significance to the fact that, whereas the EMF-22 terminated its projections in 2100, the IWG made projections through 2300. Dr. Smith implied that this difference arose because the EMF modelers – unlike the IWG – "know that the uncertainty in any projections they can make expands as those projections go further in time, until at some point the projections are not useful or meaningful." GRE,MP,OTP,MLIG Ex. 300 at AES-D-2, p. 69 (Smith Direct). Dr. Hanemann explained that this is not the reason for the difference. The reason is that EMF-22 had a different objective than the IWG. EMF-22 was not a cost-benefit analysis of climate mitigation policies. It did not consider damages from climate change. Instead, it focused on cost minimization in reducing emissions to meet targets being considered in current climate policy debates. Those climate targets were atmospheric concentrations of CO_2 of 450 ppm, 550 ppm or 650 ppm in 2100. The focus of the EMF-22 was to look at abatement costs to meet a goal specifically in 2100. EMF-22 did not consider damages either before or after 2100. It therefore sheds no light on the relative merits of damage projections that terminate before or after 2100. Agencies Ex. 801 at 24-25 (Hanemann Rebuttal).

A third concern identified by Dr. Smith was that the IWG projections beyond 2100 were not "evidentiary-based" and/or supported by "facts, available evidence, or peer-reviewed analyses." GRE,MP,OTP,MLIG Ex. 300 at 67, 68 (Smith Direct). By implication, it appeared she was suggesting that the EMF-22 projections are supported by facts, available evidence, and

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dangerous climate change. Dangerous climate change was widely considered to be warming in excess of 2°C. The precise limit on atmospheric concentrations of CO_2 required to avoid this warming depends on the climate sensitivity. In the policy debates of the 1990s, the focus was on avoiding a CO_2 concentration in excess of 550 ppm -- roughly a doubling of the pre-industrial concentration -- as the condition for avoiding more than 2°C warming. Agencies Ex. 801 at 23-24 (Hanemann Rebuttal).

peer-reviewed analyses. Dr. Hanemann responded that that is not the case. There is no way to support a projection of anything to 2100 through "facts" or "available evidence" prior to 2100; that would be a meaningless criterion. By the very nature of projections into the far future, they cannot be evidentiary or fact based, but instead, can be based only on reasonable assumptions. Agencies Ex. 801 at 24-25 (Hanemann Rebuttal).

A fourth assertion made by Dr. Smith was that "society" would not allow levels of emissions that generate high levels of warming. GRE,MP,OTP,MLIG Ex. 300 at 72-73 (Smith Direct).[39] Dr. Hanemann did not agree. He initially observed that there was some degree of paradox in Dr. Smith arguing for Minnesota to adopt a relatively lax regulation of GHG emissions on the grounds that "society" will choose to avoid high levels of GHG emissions. Further, there were two reasons not to share Dr. Smith's optimism regarding future emissions: (a) There is a time lag of decades before the effects of today's emissions are translated into future warming; accordingly, "society" may be slow to act; and (b) global emissions are not determined by "society" as stated by Dr. Smith. They are determined by the 196 members of the UNFCCC, who each have their own interests and concerns. Reduction of global CO_2 emissions is an exercise in global collective action, and it is well known that collective action can be fraught with problems. Dr. Hanemann explained that, as time passes, and we learn more about the likely trend of emissions during the coming decades, the new information can – and should – be used to update future estimates of the SCC. Agencies Ex. 801 at 26 (Hanemann Rebuttal).

[39] As noted in this Initial Brief, in above section IV.7.A.1, entitled "Smith's Alternative "First Ton" Proposal is Not Reasonable," Dr. Smith's baseline scenario to calculate an SCC value for 2020 assumed that no anthropogenic emissions occur after 2020.

C. Criticisms Supposing that CO_2 Emissions are "Net Beneficial" Due to Carbon Fertilization (Issue 16)

Peabody Witnesses, Dr. Bezdek, Dr. Mendelsohn, and Dr. Happer in their direct testimonies made assertions that CO_2 emissions are a net benefit. Dr. Bezdek made the assertion on the basis of (a) increased crop yields associated with elevated atmospheric concentrations of CO_2 (including "carbon fertilization"); and (b) higher economic growth historically associated with the availability of cheap energy from fossil fuel sources. Agencies Ex. 801 at 2-3 (Hanemann Rebuttal) (*citing* Peabody Ex. 228 at 9 (Bezdek Direct)). Dr. Mendelsohn's assertion is based on (a) alone. *Id.* at 3 (*citing* Peabody Ex. 214 at 9 (Mendelsohn Direct)).

Dr. Hanemann is familiar with the literature on this topic, having first reviewed the literature on agricultural impacts, including carbon fertilization, in preparation of his 2005 paper[40] that disproved Mendelsohn's econometric methodology and empirical conclusions. *Id.* Dr. Hanemann's opinion is that, Dr. Mendelsohn and Dr. Bezdek's suppositions notwithstanding, it is not plausible that generating CO_2 emissions per se benefits humankind. *Id* at 8.

As an initial matter, Dr. Hanemann observed that the IAMs used in the SCC allow for carbon fertilization. The developers of DICE and FUND both acknowledge the existence of a CO_2 fertilization effect, and account for it within the modeling. It is not clear whether that effect is accounted for in PAGE. Agencies Ex. 801 at 4 (Hanemann Rebuttal).

Dr. Hanemann provided his further assessment of carbon fertilization, explaining that, for most but not all plants, photosynthesis increases when CO_2 rises. Whether this translates into increased crop growth, and increased yield of economically valuable plant products (e.g., seed, fruits), and just how much, are less certain. The fertilization effect varies not only by plant but

[40] Agencies Ex. 801 at 3, fn. 2. (Hanemann Rebuttal) (*citing* Schlenker, Hanemann and Fisher, "Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach," *American Economic Review* (March 2005) 395-406.

also with temperature, ozone concentration, soil moisture, nutrient availability and microclimate. There are interactions with other factors that affect plant growth, including weeds, which could also respond to CO_2. The overall effect is complex and is likely to be quite variable. It is hard to tease out the effect on any large spatial scale through statistical analyses. At a given point in time, there is little cross-section variation in CO_2 levels. With time-series data, increasing levels of atmospheric CO_2 are confounded with other changes occurring over time that can also affect crop yield. As a consequence, the existing evidence comes largely from small-scale experiments, either through Free Air Concentration Enrichment ("FACE") experiments[41] or non-FACE experiments involving greenhouses or controlled or open-top chambers. How well small-scale experimental results from FACE or chamber studies generalize on a field level and at large scale is not well known and is subject to much debate. *Id.* at 3-4.

1. Bezdek

Dr. Gurney criticized the "scientific" testimony of Dr. Bezdek on CO_2 fertilization. He testified that Dr. Bezdek's testimony did not ask the relevant question. The relevant question when assessing the SCC should not be centered on whether or not there is a CO_2 fertilization effect, but rather, on assessing the total net impact on plants, particularly food crops, from anthropogenic climate change. The assessment should include the CO_2 fertilization effect, along with other climate change impacts. Agencies Ex. 803 at 4 (Gurney Rebuttal).

Dr. Gurney provided an example of a recent peer-reviewed study that reviewed the CO_2 fertilization effect for the specific case of food crops (crops particularly relevant for assessing the SCC) in order to quantify the regional impact expected from a 100 ppm increase in atmospheric CO_2 concentration, a concentration that is equivalent to a 25 percent increase over current levels.

[41] In a FACE experiment, pipes that emit CO_2-enriched air (and/or nitrogen-enriched air) encircle an experimental plot. Sensors control the concentration of CO_2, or nitrogen, in order to maintain it at the level desired for the experiment. *Id.* at 4, fn. 4.

Model results in that study found a crop-yield response ranging from 5 to 17 percent at the regional level. There was greater variation in the CO_2 fertilization response within the regions and among various crop types, and this variation, as well as the variation across the regions, was dependent upon a wide variety of factors such as nutrient availability, species, water availability, and the like. *Id.* at 4-5.

Dr. Gurney addressed further problems in the Bezdek Direct Testimony. He summarized the two main topics of the Bezdek Direct, which were, first, whether there is a CO_2 fertilization effect and if so, how big might it be (Agencies Ex. 803 at 2 (Gurney Rebuttal) (*citing* Peabody Ex. 228 at 9-10 (Bezdek Direct) and Peabody Ex. 230 at RHB-2, pp. 49-52 (Bezdek Direct))) and second, Dr. Bezdek's limited assessment of the net impact of CO_2 fertilization within the context of climate change. Agencies Ex. 803 at 2-3 (Gurney Rebuttal).

Dr. Gurney, as an initial matter, explained that all available scientific evidence supports the general concept of a CO_2 fertilization effect; and that it is well understood and quantified at the individual leaf/plant scale in controlled or laboratory conditions. He explained that studies in real-world applications --in the field--and those that attempt to quantify CO_2 fertilization at the population to ecosystem scale, arrive at much more variable and conflicting results. The magnitude of CO_2 fertilization in real-world conditions is therefore extremely variable and dependent upon a wide array of factors such as nutrient availability, water availability, species, soil type/condition, light levels, etc. *Id.* at 3.

Dr. Gurney harshly criticized Dr. Bezdek's testimony, which heavily relied on non-peer-reviewed resources. *Id.* He explained that, to the best of his knowledge, Dr. Bezdek has never published within the peer-reviewed literature on the topic of CO_2 fertilization or the impact of climate change on food crops or agricultural productivity. *Id.* at 7. In his Direct Testimony, Dr.

Bezdek relied on a non-peer-reviewed report, which presented a compilation of individual responses of plants to CO_2 increases, the majority of which were under controlled or laboratory conditions. Dr. Gurney offered his expert opinion that this report is an unreliable assessment of the impact of increasing CO_2 concentration on plants in real-world conditions. *Id.* at 3.

Further, Dr. Bezdek's Direct Testimony also referred to the testimony of Dr. Happer, another non-peer-reviewed source, as support for an assertion that the planet has already experienced "greening" as a result of CO_2 fertilization. *Id.* (*citing* Peabody Ex. 228 at 10 (Bezdek Direct). Dr. Bezdek's Direct reproduced a figure from Dr. Happer's Direct with the title, "Figure 17-1: Global Greening from CO_2 Fertilization: 1982-2010." *Id.* (*citing* Peabody Ex. 228 at 10) (Bezdek Direct).

Dr. Gurney criticized both of Dr. Happer's and Dr. Bezdek's testimony regarding this figure, because the figure was incorrectly cited and described in Dr. Happer's testimony, and because Dr. Bezdek's Direct furthered the misrepresentation of the figure by implying that it represented "Greening from CO_2 Fertilization." *Id* at 4. Dr. Gurney testified that this testimony was factually incorrect and was a misleading representation of the CO_2 fertilization effect. Dr. Gurney testified that, in his expert judgment, this represented a fundamental misunderstanding regarding the role of CO_2 fertilization within the wider topic of planetary greening. *Id.*

Dr. Gurney stated that Dr. Bezdek's testimony regarding CO_2 fertilization within the context of anthropogenic climate change, in addition to the above concerns, inappropriately isolated the CO_2 fertilization effect within the larger issue of climate change impacts on plants, particularly food crops, which "results in an incomplete and misleading assessment" *Id.* at 5 (*citing* Peabody Ex. 228 at 16 (Bezdek Direct)); this is because the question is not whether there is a CO_2 fertilization effect, but rather, whether CO_2 fertilization is accurately included in the

assessment of impacts routinely undertaken in scientific study and included in institutional reviews of climate change impacts. *Id.*

To support his expert opinions that: (1) to understand and quantify the impact of climate change on crop productivity, all known negative and positive impacts must be included in an assessment, and (2) the CO_2 fertilization effect is already appropriately included in the literature on climate change impacts on plants, and food crops in particular, Dr. Gurney pointed to the results discussed in the IPCC 5th Assessment Report. *Id.* at 6. He stated that the IPCC 5th Assessment Report represents the most comprehensive assessment of research on this topic to date. *Id.* at 7.

The IPCC 5th Assessment Report includes an extensive review of the impact of climate change on crop productivity with CO_2 fertilization effects considered. *Id.* at 5 (*citing* IPCC 5th Assessment Report, Working Group II, chapter 7, p. 506 and Figure 7-7). The IPCC 5th Assessment Report states that a "summary of studies that quantify the impact of climate and CO_2 changes on crop yields" is included in the IPCC review results. Id. at 6. The 5th Assessment Report shows that there is a *net negative impact* on crop yields, inclusive of the CO_2 fertilization effect. *Id.* at 6. The net effect of climate and CO_2 changes on crop productivity is negative at both the global scale and the regional scale. In addition to the long-term mean negative impact, the variability of crop yields is projected to increase. Dr. Gurney noted, however, that uncertainty is large, this area of research remains very active, and the 5th Assessment Report acknowledged the need for additional research. *Id.* at 6-7.

In summary, the evidence presented by the Agencies' witness Dr. Gurney is that the academic community has properly accounted for the CO_2 fertilization effect in their assessment of the impact of anthropogenic climate change on plants, particularly food crops in real world

conditions. The CO_2 fertilization effect is highly variable and dependent upon a number of complicating factors that cannot be represented adequately by experiments carried out in small scale, controlled conditions. Further, research that reflects real-world environments and incorporates a more comprehensive treatment of the impacts of climate change on food crops (including CO_2 fertilization), finds a net negative response of crop yields to anthropogenic climate change. *Id.* at 7.

Dr. Hanemann also critiqued the Direct Testimony of Dr. Bezdek, explaining that, for his testimony on the global impact of CO_2 fertilization, Dr. Bezdek relied on a 2013 report that has never been published in a peer-reviewed journal. Agencies Ex. 801 at 4-5, 6 (*citing* Peabody Ex. 230 at RHB-2, pp. 49-60 (Bezdek Direct). That report used a database of plant-specific CO_2 growth-response factors compiled from various small-scale experiments found in the literature. For each crop, the average value of the growth-response factor in the data base is combined with projections of increased atmospheric concentrations of CO_2, and then applied to the global production of that crop. This generates an estimate of the increase in gross revenue that Dr. Bezdek then counted as a benefit from CO_2. *Id.* at 5 (*citing* Peabody Ex. 230 at RHB-2, p. 5 (Bezdek Direct).

Dr. Hanemann explained basic errors in Dr. Bezdek's testimony. Gross revenue is not an accepted economic metric of wellbeing. The accepted metric is net revenue, which is roughly an order of magnitude smaller than gross revenue in the case of agricultural commodities. *Id.* at 5.

Further, Dr. Bezdek's testimony that carbon fertilization dominates all other impacts of climate change on global agriculture fails to comport with assessments in the generally-accepted literature. The most authoritative contemporary source is the IPCC's 5th Assessment Report, which states, with high confidence, that "[b]ased on many studies covering a wide range of

regions and crops, negative impacts of climate change on crop yields have been more common than positive impacts." *Id.* (*citing* IPCC, Working Group II, *Climate Change 2014: Impacts, Adaptation and Vulnerability Part A: Global and Sectoral Aspects*, p. 47).

Dr. Hanemann stated that other researchers have demonstrated the weaknesses in Bezdek's position, and demonstrated that the estimate for global productive capacity change including carbon fertilization is a decrease of about three percent. *Id.* at 6 (*citing* Cline, "Global Warming and Agriculture: Impact Estimates by Country," *Peterson Institute*, Washington 2007 (pp. 95-96)) (Cline 2007). Dr. Hanemann discussed favorably the Cline 2007 critique of Bezdek's position, which indicated that a three percent decrease probably understates potential losses. The models (such as Mendelsohn, Nordhaus and Shaw (1994)) probably err in the direction of optimism by implicitly counting on availability of more water for irrigation under circumstances in which there could easily be less water. Neither these models nor other crop models deal explicitly with increased damage from pests or more frequent and more severe extreme weather events such as floods and droughts. *Id.*

Dr. Hanemann concluded that, in the absence of hard evidence of the external validity of the data relied upon by Dr. Bezdek in demonstrating that the data reliably applies under field conditions and on a global scale, and in the absence of a full peer review of that analysis, Dr. Bezdek's analysis lacks credibility. *Id.*

With respect to Dr. Bezdek's further assertions regarding the effect of CO_2 emissions on economic growth, Dr. Hanemann observed that since the beginning of the Industrial Revolution, the global use of fossil fuels has increased enormously, as have the world population, per capita income, and human wellbeing. Dr. Bezdek's testimony correlates the growth in world GDP with the growth in world energy consumption or carbon utilization over the period from about 1820 to

about 2010. *Id.* at 7 (*citing* Peabody Ex. 230 at RHB-2, pp. 70-75 (Bezdek Direct). Dr. Hanemann observed that "correlation" is not the same as causation, and neither of the regression analyses cited by Dr. Bezdek included any controls for other factors that may have changed in the world between 1800 and 2010, such as changes in human lifespan, education, scientific and technical knowledge, or the stock of physical capital. *Id.* Dr. Hanemann explained that, for these reasons, the regressions cited by Dr. Bezdek are misspecified (meaning they are missing key significant variables resulting in adverse impacts to the predictive ability of the model), and have no scientific validity. *Id.*

Dr. Hanemann also explained and sharply criticized Dr. Bezdek's conclusions that focused on global CO_2 emissions and GDP. Dr. Bezdek calculated the ratio of world GDP to global CO_2 emissions in 2010, which amounts to $2,400 per ton of CO_2 (in 2007 dollars). *Id.* at 8 (*citing* Peabody Ex.228 at 76 (Bezdek Direct)). Dr. Bezdek took this value as a measure of the "indirect" benefit of CO_2 emissions and compared it to the social cost of CO_2 emissions implied by the IWG's 2010 and 2013 SCC estimates. Based on this analysis, Dr. Bezdek testified that the benefit-cost ratios are vastly greater than unity (i.e., he found that benefits are far greater than costs). *Id.* (*citing* Peabody Ex. 228 at 78-79 (Bezdek Direct)). Dr. Bezdek's testimony implies that humankind obtains benefits from CO_2 emissions directly, rather than from the use of carbon-emitting energy resources. *Id.*

Dr. Hanemann bluntly offered his opinion that it is not plausible that generating CO_2 emissions per se benefits humankind. *Id.* Dr. Hanemann stated that Dr. Bezdek's estimate of the benefits of CO_2 failed to control for other explanatory factors that may affect global GDP, such as stocks of physical, natural or human capital, scientific knowledge, prices, economic policies

or cultural factors. Because of the lack of controls, Dr. Bezdek's estimate is meaningless. It has no scientific validity. *Id.* at 9.[42]

Furthermore, even if Dr. Bezdek's testimony on net benefits of CO_2 had some scientific validity, it would it be irrelevant for the proceeding at hand because it does not concern the environmental externalities that are at issue in this proceeding. Dr. Bezdek's estimate – if it were meaningful – would be picking up the effect on GDP of the cheap sources of energy that became available with the expanded use of fossil fuels. It is an effect mediated through reductions in the price of an input used for production, an effect which is known in economics as a (beneficial) "pecuniary externality." *Id.*

The difference between a "pecuniary externality" and the environmental externality values the current docket is meant to address is this: a real "externality" prevents competitive markets from producing an outcome in the best public interest—it represents a market failure—and calls for governmental intervention. A "pecuniary externality," in contrast, does not interfere with the social optimality of market outcomes in a competitive economy and does not call for governmental intervention. *Id.* at 10. A pecuniary externality occurs when one actor affects the well-being of another, precisely through the working of the price system in a

[42] Dr. Hanemann further observed that Dr. Bezdek's testimony implicitly assumed that a unit of emissions causes the same increment of benefit regardless of the energy source being used and regardless of where on the Earth, or how, the emission was generated. That is, he failed to allow for any spatial or temporal variation in what he sees as the beneficial effect of CO_2 emissions on economic growth; instead, he treated the benefit of CO_2 emissions as constant. His estimate implied than the emission of one ton of CO_2 raises global GDP (in 2007 dollars) by an average of $2,400 anywhere on the globe. He compared that value with the IWG's estimate of the federal SCC. With the federal SCC, because of the global mixing of CO_2 in the atmosphere, it is reasonable to assume that a unit of emissions causes the same increment of damage regardless of where in the world it was emitted. By comparing the SCC value to his value estimate of $2,400, Dr. Bezdek also assumed that a unit of emissions causes the same increment of benefit throughout the globe, regardless of the energy source being used and regardless of where, or how, the emission was generated. *Id.* at 8-9.

competitive market, by directly influencing a supply or demand for a thing. *Id.* The existence of a beneficial pecuniary externality has no bearing on the remedy called for by a harmful environmental externality, namely a tax on the actor that internalizes the social cost imposed on others by the environmental externality. In other words, the market cannot correct for an environmental externality without the imposition of a tax at the level of damages, or through the imposition of regulation to reduce external damages. For this reason, even if Dr. Bezdek's estimate of $2,400 per ton of CO_2 emissions (in 2007 dollars) were meaningful it would be irrelevant to the issue in this proceeding. *Id.* at 11.

2. Mendelsohn

Turning to Dr. Mendelsohn's Direct Testimony, Dr. Hanemann criticized Dr. Mendelsohn's apparent belief that he can infer the net global effect of warming based on his reading of the agricultural and forestry literatures. *Id.* at 12.

Dr. Mendelsohn testified that:

> . . .carbon fertilization has increased crop yields by a far larger amount across the entire world (Kimball 1983) suggesting a sizable net benefit. … the carbon fertilization of trees has also led to an overall increase in ecosystem productivity and standing biomass (Gerber *et al*. 2004) which is an overall net benefit for ecosystems.

Id. at 11 (*citing* Peabody Ex. 214 at 12 (Mendelsohn Direct)).

Dr. Hanemann explained that the authorities on which Dr. Mendelsohn's testimony relied, Kimball (1983) and Gerber *et al.*, (2004) in his Direct are not convincing evidence that the net impact of CO_2 emissions on human wellbeing is positive due to the magnitude of carbon fertilization effect. Notably, the phrase "net benefit" appears nowhere in Gerber *et al*. (2004). Rather, that paper is about carbon sequestration in vegetation and how this might change with an increase in atmospheric CO_2. It contains no assessment of benefits to ecosystems. Similarly,

Kimball (1983) is a paper saying that, based on studies performed in greenhouses or growth chambers, CO_2 fertilization will increase yields, while recognizing that results in open fields could be different. *Id.* at 11-12. Dr. Hanemann chastised Dr. Mendelsohn on this point, stating;

> "given that climate change can also affect sea-level rise, inland flooding, water supply and demand, energy supply and demand, transportation systems, various aspects of human health such as vector-borne disease, diarrhea, and cardiovascular and respiratory illness, labor productivity, violence and social strife and unrest, migration, biodiversity and ecosystems, Professor Mendelsohn's apparent belief that he can infer the net global effect of warming based on his reading of the agricultural and forestry literatures is unfounded.

Id. at 12.

3. Happer

Dr. Happer inaccurately testified that "[m]ore atmospheric CO_2 will substantially increase plant growth rates and drought resistance." Agencies Ex. 803 at 19 (Gurney Rebuttal) (*citing* Peabody Ex. 200 at 10 (Happer Direct)). Dr. Gurney rebutted this assertion in a manner similar to his rebuttal of Dr. Bezdek, explaining that CO_2 fertilization and the potential for increased CO_2 to increase drought tolerance is theoretically well understood, but quantification of these effects is uncertain, particularly outside of controlled laboratory conditions. *Id.* Dr. Gurney reiterated that the IPCC 5th Assessment Report, which is the most comprehensive assessment of research on the issue of CO_2 fertilization and the role of CO_2 fertilization within climate change, states:

> Elevated atmospheric CO_2 concentrations lead to higher leaf photosynthesis and reduced canopy transpiration……The increase in leaf photosynthesis with rising CO_2, the so-called CO_2 fertilization effect, plays a dominant role in terrestrial biogeochemical models……These physiological changes translate into a broad range of higher plant carbon accumulation in more than two-thirds of the experiments….However, FACE experiments also show the diminishing or lack of CO_2 fertilization effect in some ecosystems and for some plant species……

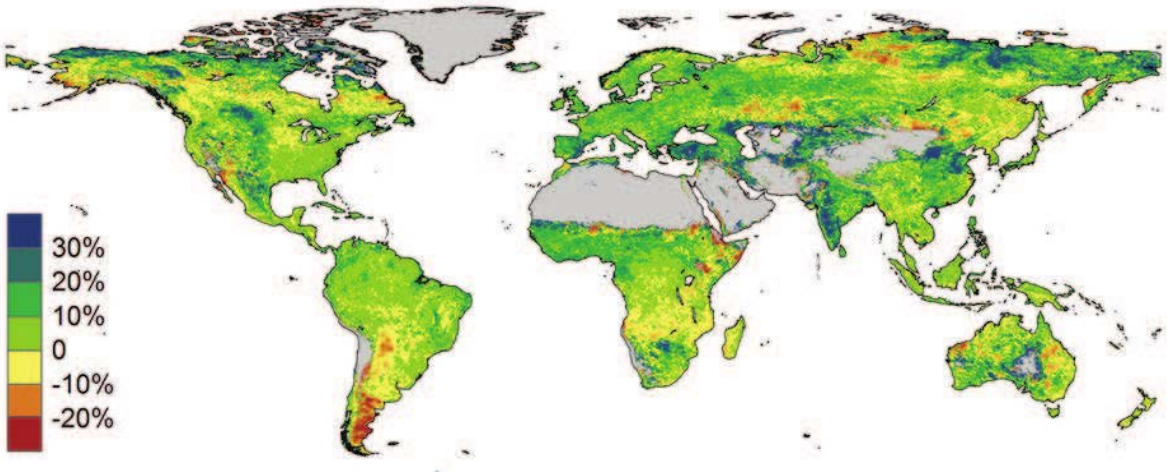
> Nutrient limitation is hypothesized as primary cause for reduced or lack of CO_2 fertilization effect observed on NPP in some experiments.

Id. at 19-20 (*citing* IPCC 5th Assessment Report, Working Group I, Ch. 6, p. 502).

Furthermore, said Dr. Gurney, reiterating his critique of Dr. Bezdek's Direct, the impact of climate change on plants must necessarily include the entire suite of impacts in order to understand how plants will respond. If one were to isolate one element within this larger suite of impacts, results would be incomplete and potentially misleading. *Id.* at 20.

The more reliable evidence on this topic is the IPCC 5th Assessment Report, which, as noted in Dr. Gurney's rebuttal of Dr. Bezdek's Direct, found "that there is a net negative impact on crop yields, inclusive of the CO2 fertilization effect. The net effect of climate and CO2 changes on crop productivity is negative at the global scale and the regional scale. In addition to the long-term mean impact, the variability of crop yields are projected to increase." *Id.* at 20-21. (*citing* IPCC 5th Assessment Report, Working Group II, Ch. 7, p. 506).

Dr. Gurney even more sharply criticized Dr. Happer for the misrepresentations in his so-called "Greening of the Earth" testimony. As evidence for his claim that additional CO_2 provided a worldwide "growth stimulation" to plants, Dr. Happer included in his Direct Testimony a map entitled "Figure 8: Greening of the Earth as observed by satellites," purportedly reproduced from a peer-reviewed paper for the proposition that, "[s]atellite observations like those of Fig. 8 from R.J. Donohue [19] have shown a very pronounced 'greening' of the Earth…." Agencies Ex. 803 at 21 (Gurney Rebuttal) (*citing* Peabody Ex. 202 at WH-2, p. 11 (Happer Direct)). The figure presented in the Happer Testimony is the following:



Dr. Gurney observed that this portion of Dr. Happer's Direct Testimony is false. The paper Dr. Happer referenced, Donohue *et al* (2013)[43] contains no such figure. *Id.* at 22. Furthermore the Donohue *et al*. paper arrives at a far narrower set of conclusions regarding CO_2 fertilization; it concludes that a "….14% increase in atmospheric CO_2 (1982-2010) led to a 5 to 10% increase in green foliage cover *in warm, arid environments*." *Id.* at 22 (emphasis added). Dr. Happer's testimony of supposed worldwide greening due to CO_2 fertilization is not supported by his citation nor the IPCC Assessment Report on the topic. *Id.*

Dr. Gurney stated that Dr. Happer more likely reproduced Figure 8 from data consisting of satellite observations of the change in a metric of vegetation cover, the most common of which is the Normalized Difference Vegetation Index metric ("NDVI"). *Id.* at 22. Dr. Gurney explained that the mechanisms driving the well-established "greening" of the planet over the last few decades remains a topic of research, in which CO_2 fertilization is considered one contributing factor. The IPCC 5th Assessment Report provides a reasonable overview of the

[43] *Id.* (*citing* R. J. Donohue, M. L. Roderick, T. R. McVicar, and G. D. Farquhar, "Impact of CO_2 fertilization on maximum foliage cover across the globe's warm, arid environments," *Geophysical Research Letters* 40, 3031-3035 (2013)).

processes, which are hypothesized to transfer CO_2 from the Earth's atmosphere into the land (referred to as "increased storage"):

> This increased storage in terrestrial ecosystems not affected by land-use change is likely to be caused by enhanced photosynthesis at higher CO_2 levels and nitrogen deposition, and changes in climate favouring carbon sinks such as longer growing seasons in mid-to-high latitudes. Forest area expansion and increased biomass density of forests that result from changes in land-use change are also carbon sinks, and they are accounted … as part of the net flux from land use change.

Id. at 23 (*citing* IPCC 5th Assessment Report, Working Group I, Ch. 6, pp. 487-488). In this view, summarized in the IPCC 5th Assessment Report, CO_2 fertilization is only one contributor to the global "greening" observed from satellites and inferred from other measurement and modeling approaches. *Id.* at 23.

Dr. Gurney expressed his opinion that Dr. Happer's confusion over the presented figure, its citation, and the general misinterpretation of the CO_2 fertilization effect raise serious questions about the reliability of Dr. Happer's testimony on the topic of CO_2 fertilization and its relationship to anthropogenic climate change. He observed that Dr. Happer appears to have limited expertise in the subject of climate science or economics, as he has published no peer-reviewed papers in climate science nor economics and has performed no research related to climate modeling, the carbon cycle, or temperature measurements - all topics on which he has provided testimony. Agencies Ex. 804 at 14 (Gurney Surrebuttal) (*citing http://physics.princeton.edu/atomic/happer/Publications.html).*

D. Criticism of the Global Geographic Scope of CO_2 Emission Impacts, Which are Reasonably Accounted for in the Federal SCC. (Issue 13)

The Agencies recommend adoption of the federal SCC set out in the IWG 2013 TSD Report, under which the geographic scope of impacts resulting from CO_2 emissions are taken into account when determining the SCC value.

This recommendation is supported by the testimony of Dr. Hanemann, who explained that GHGs differ from criteria air pollutants in both the temporal and spatial scales of their impacts. Agencies Ex. 801 at 13 (Hanemann Rebuttal) (*citing* Agencies Ex. 800 at 12 (Hanemann Direct). With regard to spatial scale, GHGs emitted at a particular location on the Earth mixes in the atmosphere with GHGs emitted from all other locations on Earth. A molecule of emitted GHG contributes to damages from climate change experienced everywhere around the globe, regardless of where it is emitted. The impacts on human well-being play out on a global scale. *Id.*

The IWG determined in the federal SCC that this distinctive feature of GHGs should be recognized when assessing the social cost of CO_2 emissions, and thus considered the global impact of GHGs when calculating the federal SCC. *Id.*

1. Gayer and Smith

The Agencies disagree with Dr. Gayer and Dr. Smith, who testified that the global impact of CO_2 should be disregarded by the Commission. *Id.*

Dr. Gayer argued that the IWG's estimates of SCC should be adjusted to state level. Doing so would result in estimates that are approximately 0.4 percent of the global value in magnitude, suggesting extremely small damage estimates, with a high-end estimate of $0.37 per metric ton of CO_2. *Id.* (*citing* MLIG Ex. 400 at 10 (Gayer Direct)). Dr. Gayer based his testimony on the following argument, which acknowledged that the issue is a policy choice. He nevertheless offered the following thoughts:

> The CO_2 policy under consideration by the Commission is a unilateral policy. It is not coordinated in either a national or global way with any other political entities. In other words, there is no explicit reciprocity by other states or nations. In considering a policy that accrues costs on Minnesotans but absent explicit reciprocity from the world for Minnesota's actions, it would be outside the typical practice of benefit-cost analysis for Minnesota to consider environmental benefits

> to the entire global population and to place equal weight on benefits to everyone in the global population as it does for Minnesotans.

Id. at 14 (*citing* MLIG Ex.400 at 9 (Gayer Direct)).

> Dr. Smith testified:
>
> …the IWG's SCC values are based on global damages, not Minnesota damages or U.S. damages. This is inappropriate in the case of an individual state's investment decisions when there are no reciprocal agreements with major emitting nations to also adopt that same SCC.

Id. at 14 (*citing* GRE,MP,OTP,MLIG Ex. 300 at 15 (Smith Direct)).

Dr. Smith elaborated on this position as follows:

> It might make sense for the Federal government to consider global damages when calculating the SCC, because the Federal government, unlike the individual states, has authority to negotiate international agreements to reduce global carbon emissions. For the Federal government, nationwide domestic policies may support its positions in those negotiations. Minnesota, however, lacks authority under the U.S. Constitution to enter into international treaties. Moreover, any unilateral changes Minnesota makes in its own emissions will have, at best, de minimis impacts on climate change, even putting aside issues of leakage that I discuss in my report. It is most appropriate, therefore, to consider the benefits to Minnesotans from Minnesota's actions to reduce CO_2.

Id. at 14-15 (*citing* GRE,MP,OTP,MLIG Ex. 300 at 27 (Smith Direct)).

Dr. Smith thus initially appeared to agree that this choice to adopt the federal SCC—which includes global impacts—is a policy decision. However, referencing the assumptions with which she disagrees, one of which is the use of global impacts, she stated:

> The list of five assumptions that I conclude should be made differently for Minnesota (if it is to use IAMs) are not objective issues that can be tested by scientific methods. Rather, they reflect the judgments of the analysts who use the IAMs on behalf of policy makers.

Id. at 15 (*citing* GRE,MP,OTP,MLIG Ex. 300 at 16 (Smith Direct)).

Dr. Smith thus appeared incorrectly to imply that the choice of geographical scope and other such decisions made by the IWG were not policy decisions by the United States government. Instead, they were policy decisions made by "analysts" working for the United States government. Dr. Hanemann explained that that is a distinction without a difference. *Id.* at 15.

Dr. Hanemann explained that the geographical scale on which to consider impacts is a policy decision. While it has economic implications, economic theory per se cannot prescribe what spatial scope should be employed when considering policy decisions regarding climate change. *Id.* at 15. Because economic theory per se cannot prescribe what spatial scope to employ, the Commission should carefully consider whether to place any weight on the opinions of Smith and Gayer.

E. Criticisms of the IAM Damage Functions (Issue 9)

1. Bezdek, Smith and Martin

Dr. Bezdek quoted Pindyck (2013), in Peabody Ex. 228 at 7, 26-27 (Bezdek Direct)[44] that: "these [IAM] models have crucial flaws that make them 'close to useless' as tools for policy analysis."[45] Dr. Smith and Mr. Martin raised similar arguments. Agencies Ex. 801 at 34-36 (Hanemann Rebuttal).

Professor Robert Pindyck, Professor of Economics at the Massachusetts Institute of Technology, is an eminent economic theorist who has written papers relating to climate change. *Id*. 36. Dr. Hanemann explained that, despite these quotations, Professor Pindyck endorses the use of the IWG estimates of SCC. Unlike Dr. Bezdek, Professor Pindyck holds the view that

[44] Dr. Bezdek repeats Pindyck's phrase "close to useless" in Peabody Ex. 230 at RHB-2, pp. 5, 7, 95, 115, 106, 116, and 117 (Bezdek Direct) and in Peabody Ex. 231 at RHB-3, pp. 170 and 174 (Bezdek Direct).

[45] GRE,MP,OTP,MLIG Ex. 300 at 1, 2 3, 5, 22, 30 (Smith Direct); Xcel Ex. 600 at 48 (Martin Direct).

fossil fuels generate a positive external cost. Professor Pindyck has written: "Burning carbon has an external cost because it produces CO_2 and other greenhouse gasses (GHGs) that accumulate in the atmosphere, and will eventually result in unwanted climate change." *Id.* With regard to the SCC, Pindyck states the following conclusion:

> My criticism of IAMs should not be taken to imply that, because we know so little, nothing should be done about climate change right now, and instead we should wait until we learn more. Quite the contrary. One can think of GHG abatement policy as a form of insurance: society would be paying for a guarantee that a low-probability catastrophe will not occur (or is less likely). As I have argued elsewhere, even though we don't have a good estimate of the SCC, it would make sense to take the Interagency Working Group's $21 (or updated $33) number as a rough and politically acceptable starting point and impose a carbon tax (or equivalent policy) of that amount. This would help to establish that there is a social cost of carbon, and that social cost must be internalized in the prices that consumers and firms pay. (Yes, most economists already understand this, but politicians and the public are a different matter.) Later, as we learn more about the true size of the SCC, the carbon tax could be increased or decreased accordingly.

Agencies Ex. 801 at 36-37 (*citing* Pindyck (2013a)[46] at 870).

Professor Pindyck has further written:

> If we focus on "most likely" scenarios for which temperature increases are moderate and effects are small, the SCC is probably in the $10 to $40 range, justifying only a small tax on carbon emissions. But, the "most likely" scenarios are not the ones that should be of major concern. We should focus more on the unlikely but devastating scenarios, i.e., the possibility of a climate catastrophe. Depending on their probability, potential effect, and timing, that might lead to an SCC as high as $200 per ton (although I have not actually tried to actually estimate the number.)
>
> That leaves us with two policy priorities. First, we should take the $20 Interagency Working Group estimate as a rough and politically acceptable lower bound and impose a carbon tax (or equivalent policy) of that amount. Of course, climate change is a global problem and we should pressure other countries to

[46] Robert S. Pindyck, "Climate Change Policy: What Do Models Tell Us?" (2013a) *Journal of Economic Literature* 51(3), 860-872.

> adopt a similar abatement policy… The second policy priority relates to climate change research. … What matters is the possibility of a catastrophic outcome, which does not simply mean a very high increase in temperature and rising sea levels, but rather an economic effect of those physical changes that is catastrophic. We need to develop plausible estimates of probabilities of extreme climate outcomes and plausible estimates of the impacts of those outcomes.

Agencies Ex. 801 at 37-38 (Hanemann Rebuttal) (Pindyck (2013b)[47] at 46).

These quotations demonstrate that Professor Pindyck does not reject the use of the IWG's SCC estimate as characterized by other witnesses, and in fact, Pindyck believes that the true SCC may be considerably higher.

Dr. Hanemann addressed further assertions that Dr. Bezdek made while falsely claiming to refer back to the same Pindyck quotation in Bezdek's Exhibit 3.[48] Dr. Bezdek's testimony, in reference to the Pindyck citation, stated, "IAM damage functions tend to place too much value ('willingness to pay') on abatement because they track absolute levels of GDP rather than growth rate." Peabody Ex. 231 at RHB-3, pp. 168-169 (Bezdek Direct). Dr. Hanemann explained that, "[i]n fact, this sentence is *not* something that Pindyck says – it is what Dr. Bezdek says. And, *it is absolutely wrong*." Agencies Ex. 801 at 56 (Hanemann Rebuttal) (emphasis added). Dr. Hanemann pointed to explanatory research by Dell Jones and Olken (2014) regarding growth effects versus level effects:

> Growth effects, which compound over time, have potentially first-order consequences for the scale of economic damages over the longer run, greatly exceeding the level effects on income, and are thus an important area for further modeling and research.

[47] Robert S. Pindyck, "Pricing Carbon When We Don't Know the Right Price" (2013b) *Regulation* Summer 2013, 43-46.

[48] This appears in a subsection of the table with the heading "Damage Functions Used in IAMs Consistently Overestimate the Damage from Warming." Agencies Ex. 801 at 56 (Hanemann Rebuttal).

Id. Dr. Hanemann explained that the point is that reducing the *rate* of growth of GDP rather than its *level* in a given year is more damaging over time. To the extent that the IAM damage functions represent warming in a period as affecting the *level* of GDP in that period, rather than the *growth rate* (or, say, the capital stock) this leads them to understate the damages from warming.

2. Smith

a. Circularity and Foundation in Economic Theory

A second criticism of Dr. Smith concerned her note of remarks by Professor Pindyck asserting a degree of "circularity" in the IAM damage functions. Agencies Ex. 801 at 38 (Hanemann Rebuttal) (*citing* GRE,MP,OTP,MLIG Ex. 300 at 24 (Smith Direct)). Dr. Hanemann rebutted this criticism, explaining that, while Professor Pindyck's remark holds for DICE, it does not hold for PAGE or FUND. Dr. Hanemann explained that the damage functions in PAGE and FUND do not reveal evidence of being calibrated to damages in one another or to those in DICE. They are based on independent estimates of sectoral impacts for the sectors covered by those models. In the versions of DICE through DICE 1999, the damage function was based explicitly on a consideration of sectoral impacts. In subsequent versions, starting with DICE 2007, the disaggregation into impacts on individual sectors seems to have been abandoned and the focus was mainly on aggregate impacts across all sectors. In calibrating the damage function in these later versions of DICE, attention seems to have been paid to some summaries of estimates of aggregate damages appearing in the literature. Agencies Ex. 801 at 38-39 (Hanemann Rebuttal).

Dr. Hanemann also disagreed with Dr. Smith's criticism that the damage functions lack an adequate "foundation in economic theory." *Id.* at 39. He explained that the nature and magnitude of the impacts from climate change are empirical and quantitative—factual—questions. Economic theory, in contrast, typically provides qualitative predictions, based on

assumptions. Dr. Hanemann testified that it is not appropriate to expect that economic theory would be informative about how much people will be affected by wildfire, say, or flooding, or drought, or crop failure, or increased incidence of malaria. Thus, the asserted lack of foundation in economic theory is irrelevant, in practice, in assessing the validity of damage functions. *Id.* at 39.

b. Dose-Response Functions

Dr. Hanemann similarly rejected a criticism of Dr. Smith, that the IAM damage functions are invalid because they are not dose-response functions. *Id.* at 39. He explained that dose-response functions are typically formulated for narrowly defined outcomes, whether health outcomes or otherwise. Dose-response functions apply to particular outcomes, such as malaria, rather than waterborne diseases in general, and they are calibrated to specific conditions. *Id.*

Dr. Hanemann knew of no dose-response functions that exist for the multiplicity of outcomes of impacts likely to be associated with climate change, on the spatial and temporal scales required. He maintained that although the DICE, PAGE, and FUND IAMs contain simplified representations of economic models, climate models, and impact models, they remain appropriate for use in policymaking. A simplified representation of the three underlying component models is necessary in order to combine those components together and enable rapid iteration of the model for policymaking purposes. Without some simplification, the components could not be combined because of the extreme differences in their spatial and temporal scales. Furthermore, the computer infrastructure and time required to run complete Earth System models is prohibitive in a policymaking setting. Agencies Ex. 800 at 42 (Hanemann Direct); Agencies Ex. 801 at 39-40 (Hanemann Rebuttal).

Dr. Hanemann concluded 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, and therefore, Dr. Smith's argument lacks merit. Agencies Ex. 801 at 40 (Hanemann Rebuttal).

c. SCC Estimates may Underestimate Damages

Dr. Hanemann's third criticism of Dr. Smith's testimony on the damage function concerned her failure to acknowledge the existence of factors that could lead the IWG estimate of the SCC to be an underestimate, or to acknowledge that the IWG explicitly warned that the IAM damage functions omit important damages. Agencies Ex. 801 at 57 (Hanemann Rebuttal). Dr. Hanemann stated that the IWG acknowledged various limitations of the analysis. For example:

> Current IAMs do not assign value to all of the important physical, ecological and economic impacts of climate change recognized in the climate change literature … because of lack of precise information on the nature of the damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, *a number of potentially significant damage categories will remain non-monetized*. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Agencies Ex. 801 at 57-58 (Hanemann Rebuttal) (*citing* Agencies Ex. 800 at WMH-2, p. 29 (Hanemann Direct) (IWG 2010 TSD Report) (emphasis added)). Importantly, just this past summer, the IWG recently cautioned:

> Based on the current scientific understanding of climate change and its impacts, and on the limitations of the IAMs in quantifying and monetizing the full array of potential catastrophic and non-catastrophic damages, the IWG concluded that the distribution of *SCC estimates may be biased downwards* [underestimate damages]. Since then, the peer-reviewed literature has continued to support this conclusion.

Agencies Ex. 801 at 57-58 (Hanemann Rebuttal). (*citing* CEO Ex. 101 at Sched. 1, p. 26) (Polasky Rebuttal) (Response to Comments, Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group (July 2015)) (emphasis added)).

Dr. Smith did not acknowledge this observation by the IWG.

d. The IWG Acknowledges that the SCC Estimate Fails to Account for Climate Tipping Points

A fourth criticism Dr. Hanemann levied against Dr. Smith's testimony regarding the damage function is for her failure to acknowledge the IWG's long-standing observation that its SCC estimate fails to account for the possibility of "climate tipping points" which would raise the SCC estimate. Agencies Ex. 801 at 58 (Hanemann Rebuttal). Dr. Hanemann explained that the IWG 2010 TSD Report noted that the SCC estimate may not capture the economic effects of all possible adverse consequences of climate change, including "potentially discontinuous 'tipping point' behavior in Earth systems." *Id.* (*citing* Agencies Ex. 800 at WMH-2, p. 31 (Hanemann Direct) (IWG 2010 TSD Report)).

A climate tipping point is a threshold beyond which abrupt, irreversible and damaging climate outcomes may occur. Examples include boreal forest dieback, Amazon rainforest dieback, loss of Arctic and Antarctic sea ice and melting of the Greenland and Antarctic ice sheets, disruption of the Indian and West African monsoon, disruption of the Atlantic thermohaline circulation[49], and loss of permafrost leading to methane release. The IWG 2010

[49] The NOAA defines thermohaline circulation as follows: "Winds drive ocean currents in the upper 100 meters of the ocean's surface. However, ocean currents also flow thousands of meters below the surface. These deep-ocean currents are driven by differences in the water's density, which is controlled by temperature (thermo) and salinity (haline). This process is known as thermohaline circulation. In the Earth's polar regions ocean water gets very cold, forming sea ice. As a consequence the surrounding seawater gets saltier, because when sea ice forms, the salt is left behind. As the seawater gets saltier, its density increases, and it starts to sink. Surface

TSD Report notes: "Many of these tipping points are estimated to have thresholds between about 3°C and 5°C." *Id.* at 59. The IPCC 5th Assessment Report also noted that the risk associated with crossing these tipping points increases with rising global temperature, but that the precise location of the tipping point is uncertain. *Id.*

Dr. Hanemann observed that the damage function in DICE 1999 contained a component intended to measure the risk premium to avoid a global tipping point (such as disruption of the thermohaline circulation) but that is not an individual component of the damage functions in DICE 2007, 2010 or 2013. PAGE contains a specific element representing discontinuity impacts (i.e., abrupt change or catastrophe). FUND has no specific component representing catastrophic climate change. *Id.*

Dr. Hanemann also observed that, even if tipping points are reflected in the IAM damage functions, there is no allowance for uncertainty about the location of the tipping points. *Id.* Dr. Hanemann discussed recent research[50] (using an analogy of a bicyclist approaching a curve who slows his speed until he sees how bad the curve is) that demonstrates that, when approaching an uncertain hazard, a sound response would boost mitigation efforts while the uncertainty for a tipping point existed, and, once the tipping point danger is resolved, the pace of mitigation may fall back (unless another uncertain threshold for a tipping point lies ahead). *Id.* at 59-60.

There is a parallel impact on the SCC estimate: the existence of an uncertain threshold for a tipping point lying ahead is shown to raise the current SCC value. Once the tipping point

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water is pulled in to replace the sinking water, which in turn eventually becomes cold and salty enough to sink. This initiates the deep-ocean currents driving the global conveyer belt." *http://oceanservice.noaa.gov/education/tutorial_currents/05conveyor1.html*

[50] Derek Lemoine and Christian Traeger, "Watch Your Step: Optimal Policy in a Tipping Climate," *American Economic Journal: Economic Policy* 2014 6(1) 1-31; Yongyang Cai *et al*. "Environmental Tipping Points Significantly Affect the Cost-Benefit Assessment of Climate Policies," *Proceedings of the National Academy of Sciences* Vol. 112, no. 15, April 14, 2015, 4606-4611.

danger is resolved, the SCC value drops down. Dr. Hanemann concluded that this research overturns the conventional pattern in which the SCC starts out low and rises over time: with tipping point uncertainty, the SCC would start out high. Agencies Ex. 801 at 60 (Hanemann Rebuttal). Dr. Hanemann criticized Dr. Smith for her failure to acknowledge that tipping points could raise the IWG estimate of the SCC. *Id.* at 60.

e. The IWG has Stated that Regulation of GHGs Should Possibly Include a Degree of Risk Aversion

A fifth criticism Dr. Hanemann levied against Dr. Smith's testimony regarding the damage function was for her failure to acknowledge the IWG's observation that regulation of GHGs should possibly include a degree of risk aversion.[51] *Id.* at 60. Dr. Hanemann observed that the IWG noted the issue of risk aversion in its IWG 2010 TSD Report. It pointed out: "Even if individuals are not risk averse for such scenarios, it is possible that regulatory policy should include a degree of risk aversion." Agencies Ex. 801 at 62 (Hanemann Rebuttal) (*citing* Agencies Ex. 800 at WMH-2, p. 30 (Hanemann Direct) (IWG 2010 TSD Report)).

3. Mendelsohn, Gayer and Smith

Dr. Hanemann also rebutted Dr. Mendelsohn's claim that the damage function in DICE needs to be changed.[52] Agencies Ex. 801 at 41 (Hanemann Rebuttal). Dr. Mendelsohn asserted

[51] Dr. Hanemann explained the economic concept of risk aversion, and how a "risk premium" applies to risks with non-monetary outcomes as well as those with purely financial outcomes, such as a risk-averse water user facing an unreliable water supply, who would be willing to pay a risk premium to improve the reliability of his supply. Agencies Ex. 801 at 60-62 (Hanemann Rebuttal).

[52] The damage function in DICE implies that, for any degree of warming above preindustrial temperature, there is some amount of damage (measured as a reduction in GDP), however small. Dr. Mendelsohn disagrees with the author of DICE, Professor William Nordhaus, and feels it appropriate to modify this. He implemented two alternative modifications. In each there is no damage – no effect, negative or positive – from warming below a threshold level. In one case, he set that threshold at 1.5°C above preindustrial global temperature. In the other case, he set it at 2°C above pre-industrial global temperature. Agencies Ex. 801 at 40 (Hanemann Rebuttal).

that the empirical evidence justifies the change. The "empirical evidence" on which Dr. Mendelsohn relied, however, was only the following:

> Global temperature today is about 0.8°C warmer than the pre-industrial temperature. According to DICE 2013, there should already be a global damage from climate change in 2015 equal to $173 billion annually. Clearly damage this great would be conspicuous. In practice, however, it is very difficult to detect this global damage today, even with careful scientific measurements.

Id. (*citing* Peabody Ex. 216 at ROM-2, p. 11 (Mendelsohn Direct)).

According to Dr. Mendelsohn's spreadsheet,[53] annual global GDP in 2015 amounts to about $75 trillion. Thus, annual damage of $173 billion amounts to about 0.23 percent of global GDP. *Id.*

Dr. Hanemann explained that the "empirical evidence" on which Dr. Mendelsohn relied is far from powerful, observing that the amount is so small as to be "within the range of noise" and any failure to detect it does not discredit Professor Nordhaus' damage function.[54] Dr. Hanemann testified that Dr. Mendelsohn's argument--that Nordhaus' damage function in DICE must be wrong because nobody yet notices the effects of the warming that has occurred since pre-industrial times--is a specious argument. *Id.* at 42. Dr. Hanemann explained that the damage function formula in DICE was chosen by Professor Nordhaus, and if he had wished to use a different formula, he would have. Dr. Hanemann concluded that while Dr. Mendelsohn may disagree with Professor Nordhaus' choice of formula, if Dr. Mendelsohn wants others to accept his modification, he needs to present solid evidence showing that he is right and Professor Nordhaus is wrong, which he has failed to do. *Id.* at 42.

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[53] Agencies Ex. 801 at WMH-R-1 (Hanemann Rebuttal) (Mendelsohn's "Basic DICE Runs.xlsx")

[54] Professor William Nordhaus, Sterling Professor of Economics at Yale University, is an eminent economist who is regarded as the father of climate change economics. He created the first version of an economic growth model that contained a constraint on CO_2 emissions in 1977, and he created the first IAM model with climate damages – the DICE model -- in 1991. He is a member of the US National Academy of Sciences. Agencies Ex. 801 at 41 (Hanemann Rebuttal).

Dr. Hanemann also observed that, contrary to his factual claim--that nobody yet notices the effects of the warming that has occurred since pre-industrial times—Dr. Mendelsohn testified that there have been detectable changes since pre-industrial times:

> there are detectable physical effects associated with the 0.8°C warming since pre-industrial times" and "warmer temperatures are encouraging ecosystems to move poleward (IPCC 2013b) which is a change that may lead to damage in some places. For example, plants have flowered earlier, birds have arrived sooner after winter, and birds have over wintered in more northern locations in the northern hemisphere.

Agencies Ex. 801 at 42 (Hanemann Rebuttal) (*citing* Peabody Ex. 216 at ROM-2, p. 11 (Mendelsohn Direct)).

Dr. Hanemann also criticized additional changes to the federal SCC IAM damage functions proposed by Dr. Mendelsohn. Dr. Hanemann explained that Dr. Mendelsohn used only DICE, not PAGE or FUND. And, whereas the IWG 2013 TSD Report used DICE 2010, Dr. Mendelsohn used DICE 2013. In addition, he used DICE in its native optimization format and he set aside the standardized inputs on population, income and emissions that the IWG fed into PAGE and FUND along with the non-optimization (simulation) version of DICE. He also conducted a deterministic analysis (i.e., an analysis with no randomness), rather than using probabilistic versions of the climate sensitivity and other model parameters. *Id.* at 42.

Dr. Hanemann explained that it makes a difference whether one uses DICE as an optimization or in a simulation format. In the optimization version, global emissions of CO_2 are modeled as though they were determined by a single decision maker who controls emissions made around the world.[55] Dr. Hanemann stated that, while this assumption simplifies the mathematical analysis and is common in the theoretical literature in economics, this assumption

[55] See discussion in this Initial Brief in above section VI.4.B.2., entitled "Differences Between the DICE, PAGE and FUND IAMs."

is unrealistic. The United Nations Framework Convention on Climate Change has 196 members – all the UN member states plus Cook Island, Niue, and the European Union. To represent UNFCCC actions as though all members spoke with one voice is not a reasonable way to characterize how the world will proceed in dealing with climate change. Further, the simplifications embedded in the optimization version of DICE are not innocuous. They 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 the damages are smaller than is likely in the real world. The simplifications, therefore, generate a lower estimate of the social cost of carbon than is likely to occur in the real world. This is one factor causing a difference between the IWG's estimate of the SCC and that of Dr. Mendelsohn. Agencies Ex. 801 at 43-44 (Hanemann Rebuttal).

Dr. Mendelsohn's revised damage function significantly affects his proposed estimate of the SCC. Dr. Hanemann prepared Table 1, based on the spreadsheet of Mendelsohn's output results. He explained that Dr. Mendelsohn ran DICE 2013 in the following modes: optimization using DICE's default damage function; optimization using his alternative damage functions modified so that there is no effect of global warming until it reaches 1.5°C or 20°C; and a non-optimizing version where global emissions follow a business-as-usual ("BAU") trajectory. *Id.* at 45. Those modes are reflected in the four rows in Table 1 below. The columns show the projected year in which the highest atmospheric concentration of CO_2 occurs and the level in that year; the year in which the greatest warming occurs and the amount of warming in that year; and the degree of warming projected for 2200 and 2300. *Id.*

Table 1: DICE WITH ALTERNATIVE DAMAGE FUNCTIONS							
	Peak CO_2 (ppm)		Peak Warming (C)		Warming (C) in 2200	Warming (C) in 2300	Social Cost of Carbon 2015 ($)
DICE DAMAGE FUNCTION	Year Attained	Level	Year Attained	Level			
OPTIMIZATION							
Nordhaus	2100	602	2130	3.38	2.5	0.3	$18.60
Mendelsohn – 1.5 C	2120	700	2150	4.07	3.49	2.1	$6.90
Mendelsohn –2 C	2125	740	2160	4.32	3.96	2.39	$4.45
BUSINESS AS USUAL							
Nordhaus	2225	1275	2290	6.85	6.44	6.85	$19.04

Agencies Ex. 801 at 46 (Hanemann Rebuttal).

Table 1 illustrates the effect of the assumption of optimization by a single decision maker who controls global emissions. In the absence of such a decision maker, climate outcomes would be more adverse – worse than under the three optimization scenarios, although probably not quite as bad as the BAU scenario. Dr. Hanemann testified that the BAU scenario is very concerning: by 2100, the atmospheric concentration of CO_2 would be three times the pre-industrial level of 280 ppm, and by 2150 four times that level. Warming would exceed 6°C by 2175. Agencies Ex. 801 at 46 (Hanemann Rebuttal).

Modifying the damage function to make it less damaging, as Dr. Mendelsohn proposed, has two effects. It lowers the SCC and it reduces the incentive to reduce emissions, so that atmospheric CO_2 reaches higher levels and there is more warming before – under optimization – abatement efforts kick in. Dr. Mendelsohn's analysis using DICE's default damage function generated an SCC of $18.60 in 2015. Dr. Mendelsohn's changes to that damage function lowered the SCC by two-thirds or more, to $6.90 or $4.45. Dr. Hanemann explained that this

was a very large alteration to the specifications of DICE based on very little evidence to show that such alteration is reasonable. *Id.* at 45.[56]

Dr. Hanemann observed that other witnesses' testimonies also relied on the idealized but unrealistic assumption of a single, infinitely-lived maker who controls global emissions:

- Dr. Gayer and Dr. Smith also relied on the idealized but unrealistic assumption of global emissions being determined by a single, infinitely lived, optimizing decision maker.

- Dr. Gayer relied on this assumption for the discussion of the efficient provision of environmental quality on p. 3 of Gayer and Viscusi, "Determining the Proper Scope of Climate Change Benefits," appended to his Direct Testimony.

- Dr. Smith relied on this assumption for her discussion of the optimal level of emissions in GRE,MP,OTP,MLIG Ex. 300 at AES-D-2, pp. 55-56 (Smith Direct).

Dr. Hanemann concluded that, because the assumption is highly unrealistic, it casts doubt on the arguments of Drs. Mendelsohn, Gayer and Smith. Agencies Ex. 801 at 44 (Hanemann Rebuttal).

4. Martin

Mr. Martin stated that the designers of IAMs lacked an empirical basis on which to base these key model functions (i.e., the damage function). Agencies Ex. 801 at 46 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 48 (Martin Direct)). Dr. Hanemann responded that Mr. Martin's statement is incorrect, and that a more accurate statement is that the IAM designers

[56] Dr. Hanemann also observed that Dr. Mendelsohn testified that he utilized DICE2013 which is the most recent version of DICE and is the version used in *The Climate Casino* (Nordhaus 2013). Agencies Ex. 801 at fn. 27 (Hanemann Rebuttal) (*citing* Peabody Ex. 216 at ROM-2, p. 10 (Mendelsohn Direct)). Dr. Hanemann observed, however, that the value Nordhaus *actually* gives in that book for the social cost of carbon is "about $25." *Id.* (*citing* Nordhaus, *Climate Casino,* Yale University Press, p. 229). Nordhaus refers directly to the IWG's (2010) estimate of the SCC, and he endorses it. He writes: "*There are currently many estimates of the social cost of carbon. A U.S. government report provided the best estimate of about $25 per ton of* CO_2 *for 2015." Id.* (*citing* Climate Casino, p. 228) (emphasis added).

drew on empirical literature mainly from the 1990s for their damage functions. Dr. Hanemann observed, and the EPRI (2014) noted:

> [T]he models draw directly and indirectly on older literature, some dating back to the 1990s. Scientific impacts knowledge has progressed since, as summarized in synthesis products like IPCC (2007, 2014). However this knowledge is not reflected in the current SCC model damage formulations.

Agencies Ex. 801 at 47 (Hanemann Rebuttal) (c*iting* Agencies Ex. 800 at WMH-5, p. 6-8, Table 6-2 (Hanemann Direct) (EPRI (2014)).[57]

Dr. Hanemann stated that, in the case of DICE, a detailed accounting of individual sectoral impacts based on the citation of specific impact studies ends with DICE (2000). In the case of FUND, EPRI identifies thirty-two studies which form the information base for FUND's damage functions, only four of which appeared after 2002. EPRI identifies eight studies that form the information base for the damage functions in PAGE, seven of which date from the period 2006-2009. *Id*. In total, fewer than fifty studies form the information base on which these IAMs draw. Dr. Hanemann stated that that number represents a small fraction of the information now available in the economic literature on climate change impacts, and a minuscule fraction of what is available in the larger impact literature. Agencies Ex. 801 at 47 (Hanemann Rebuttal). Dr. Hanemann concluded by stating that the literature, while still highly incomplete, is not quite as non-existent as Mr. Martin suggested. *Id.* at 48.

[57] Agencies Ex. 800 at WMH-5 (Hanemann Direct) (Electric Power Research Institute, Inc., *Understanding the Social Cost of Carbon A Technical Assessment 3002004657 Technical Update*, October 2014 (EPRI (2014)).

5. Summary: Although the IAMs' Damage Functions Likely Understate the Actual SCC, They Are the Only Damage Functions Currently Available. The IWG's Decision to Use the IAMs is Reasonable, and the Commission Should Adopt the Federal SCC.

Dr. Hanemann explained that, contrary to the testimony of Bezdek, Smith, Martin, Gayer and Mendelsohn, the damage functions in DICE, FUND and PAGE likely understate the actual SCC because they do not well reflect the current empirical literature on climate change impacts. In addition, the theoretical literature has developed mathematical modifications of the damage function formula that can account for certain considerations (discussed below) and has demonstrated their application to DICE. Agencies Ex. 801 at 63 (Hanemann Rebuttal).

Dr. Hanemann's assessment of the newer literature is that they generally indicate more severe damages than the earlier literature. Agencies Ex. 801 at 63 (Hanemann Rebuttal). He stated that it is important to recognize that these damage functions are likely to understate the actual social cost of carbon. *Id.* At present, however, the damage functions in DICE, FUND and PAGE are the only damage functions currently available for use in a model inter-comparison exercise. *Id.* Dr. Hanemann offered his expert opinion that the decision by the IWG to use those models was reasonable at the time and is still reasonable today. *Id.* at 63. His opinion that the damage functions in the IAMs likely understate the actual SCC does not change his recommendation that the Commission should adopt the federal SCC. *Id.*

Dr. Hanemann explained that the damage functions in DICE, FUND and PAGE fairly accurately reflected the economic literature on climate impacts as of about 2001. However, the empirical literature has exploded since then, and the IAM developers have failed to keep up with it. His assessment of the newer literature is that these studies generally indicate more severe damages than the earlier literature and thus, if anything, the damage estimates in the IWG SCC are too low. Agencies Ex. 801 at 48 (Hanemann Rebuttal). In addition to there being a much

larger volume of studies than existed fifteen years ago, an important feature of the newer studies is that they are becoming more granular with regard to the spatial and temporal scales at which impacts are assessed. *Id.*

Dr. Hanemann explained that the more severe damage estimates in newer literature come about partly because of increased granularity of the General Circulation Models ("GCMs" as noted above) used to make projections of climate change on a global scale, and partly because the GCM analyses are increasingly being supplemented by what is known as "spatial downscaling." The downscaling (or spatial disaggregation) translates the GCM projections from the relatively coarse native spatial grid scale of the GCMs to a finer spatial scale. *Id.* at 49.

Because of what is known as the "convexity" of the damage functions, the development of a more granular analysis, whether through spatial or temporal disaggregation, is typically likely to generate higher estimates of damages. This is an important reason why the new literature, being more granular, tends to come up with higher estimates of damages. *Id.* at 49.

Dr. Hanemann described convexity of the damage function as a mathematical property that relates to the behavior of the marginal damage as the degree of warming increases. The concept of marginal damage is closely related to the concept of the social cost of carbon. The damage function in the IAMs expresses the damage occurring during a period as a function of the degree of warming occurring at that time. The marginal damage measures the increment in damages during a period associated with a unit increment in warming – it is the extra damage per degree increase in warming. Of interest is how the marginal damage varies as the temperature becomes warmer. If the marginal damage does not change when it is warmer or cooler, the damage function is linear in temperature. If the marginal damage is larger when it is warmer, the

damage function is said to be convex. The more sharply the marginal damage increases as temperature increases, the more convex the damage function. *Id.* at 49-50.

Dr. Hanemann explained that a similar effect occurs with temporal averaging, for example when using the warming of annual temperature rather than the warming of seasonal temperatures taken separately. Due to the convexity of the damage function, disaggregating temperature change by seasons, or even more finely, would raise the estimate of aggregate damage. *Id.* at 53. Dr. Hanemann's Rebuttal Testimony, Figures 2, 2a and 3 illustrated how disaggregation and the convexity of the damage function influences the damage estimate (*Id.* at 50-52), provided specific examples to describe these effects (*Id.* at 53-54), and explained how DICE, PAGE and FUND are likely to understate the damage function because their high degree of aggregation masks the granularity of what actually occurs. *Id.* at 55.[58]

Dr. Hanemann also offered his expert opinion that the sum of the concerns he raised regarding Dr. Smith's opinion regarding the damage functions, discussed above,[59] also cause the IWG estimates of the SCC to be biased downwards. *Id.* at 57-62.

F. Criticisms of Earth Temperature Data and a Claimed Lack of Warming Trend Between 1998 and 2014 (Issue 7)

Dr. Happer's testimony included a claim that recent observations show no warming. Agencies Ex. 803 at 9 (Gurney Rebuttal) (*citing* Peabody Ex. 200 at 8 (Happer Direct)). Dr.

[58] Dr. Hanemann stated that the IAM damage functions understate the effects of climate change in a second way: the IAMs exclude all aspects of changes in climate apart from average annual temperature. They do not account for precipitation, which is an important factor for flooding, water-borne disease, impacts on vegetation and ecosystems, and other types of impacts. To the extent those impacts do not co-vary (i.e., tend to move in the same direction) with average annual temperature, they are not accounted for by the IAM damage functions. While changes in *average* temperature are included in the IAMs, *extreme temperature events* are thus not accounted for in the IAM damage functions. Agencies Ex. 801 at 55 (Hanemann Rebuttal).

[59] These are his third, fourth, and fifth criticisms of Dr. Smith, more fully discussed in this Initial Brief in above section IV.7. E. 2., entitled, "Criticisms of the IAM Damage Functions (Issue 9)-Smith."

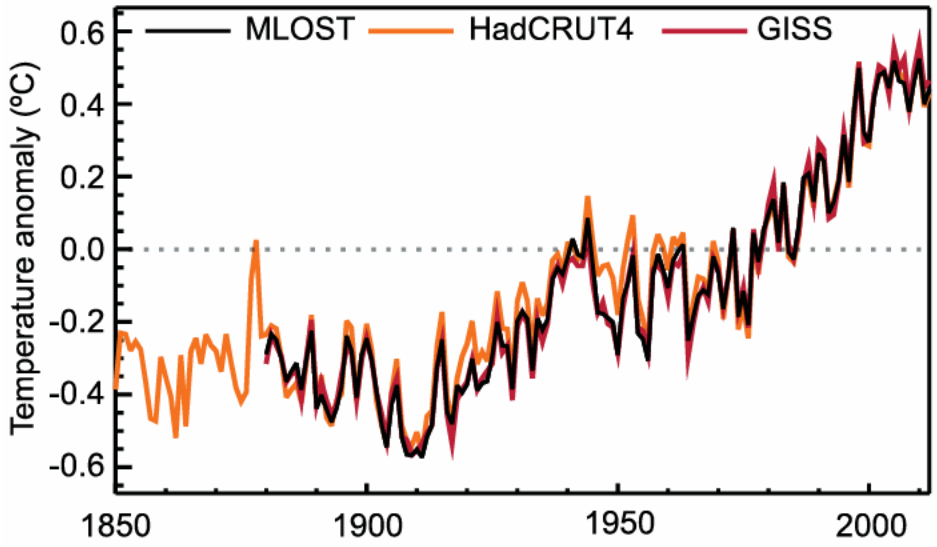
Happer asserted that "[g]lobal warming basically stopped about the time of the last large El Nino event in 1998 [and] [t]here has been no significant warming since," that "[g]round-based observations show virtually no warming since 1998," and "satellite measurements indicate that the lower atmosphere has had no warming for at least 20 years." *Id.* at 10 (*citing* Peabody Ex. 200 at 6, 8 (Happer Direct). Dr. Gurney observed, first, that the latter of these claims, that "satellite measurements indicate that the lower atmosphere has had no warming for at least 20 years" cited, and appears to be based upon, information published on a website rather than a peer-reviewed scientific paper. This is but one of many instances in which Peabody witnesses failed to rely upon peer-reviewed scientific literature and instead relied on information from websites or other grey literature sources that have not undergone the critical review process associated with academically respected literature. *Id.* at 10.

Dr. Gurney rebutted Dr. Happer's claims by explaining what the larger opinion currently is, as found in academic organizations or peer-reviewed literature, regarding recent temperature trends. Dr. Gurney stated that the particular time period referred to in the Happer Direct Testimony ("since 1998," "20 years") refers to the span starting in 1998 and ending presumably in 2014, a span of 17 years that begins, significantly, at a very large El Nino year (1998) which saw an unusually high global mean temperature. *Id.* at 11.

Dr. Gurney explained that this time period in the observed temperature record has been discussed regularly in the peer-reviewed literature and in the most recent IPCC 5th Assessment Report. This time period is often referred to as a warming "hiatus."[60] The global mean surface temperature record shows a decadal trend of 0.04 °C increase per decade during this period.

[60] Because of the timing of the production and review process involved in all IPCC reports, this period is described in the most recent IPCC 5th Assessment Report as a 15-year timespan (1998 – 2012). *Id.* at 11.

When compared to a more appropriate climatological span (1951 – 2012), a much-reduced trend estimate of 0.106 ± 0.027 °C per decade is estimated. Dr. Gurney provided the IPCC 5th Assessment Report's presentation of the global mean surface temperature trends from three different temperature databases, each of which represents an exhaustive, bias-corrected review of the data, including the following graphical presentation:



Id. at 12 (*citing* IPCC 5th Assessment Report, Working Group I, Chapter 2, p. 193).

Dr. Gurney explained that the temperature trend records shown in this graph represent statistically significant trends greater than that claimed for the short, recent warming "hiatus." The short time period emphasized in the Happer Direct, however is only the very end portion of the 162-year record, for which the general trend behavior slows. *Id.* at 12. Dr. Gurney explained that trends over periods as short as 15 years are neither reliable nor a reflection of long-term

change in climate. *Id*. at 13. He explained that the topic is addressed in the IPCC 5th Assessment Report:

> Owing to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998 – 2012; 0.05 [–0.05 to +0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951 – 2012; 0.12 [0.08 to 0.14] °C per decade). Trends for 15-year periods starting in 1995, 1996, and 1997 are 0.13 [0.02 to 0.24], 0.14 [0.03 to 0.24] and 0.07 [–0.02 to 0.18], respectively.

Id. at 13.

Dr. Gurney stated his opinion that Dr. Happer's reference to trends in this short time period is not relevant to an assessment of the observational evidence for anthropogenic climate change, nor is it sufficient grounds to make a statement regarding the long-term trend of the climate in one direction or another. *Id.* at 13 (*citing* Peabody Ex. 200 at 8 (Happer Direct)).

Dr. Gurney further observed that he is unaware of any peer-reviewed journal that has published work in which Dr. Happer argues that there has been no warming trend over the past 15 years. Agencies Ex. 803 at 9 (Gurney Rebuttal).

In his Surrebuttal, Dr. Gurney also critiqued Dr. Bezdek's Rebuttal Testimony regarding assertions made regarding the state of global warming. In his Rebuttal Testimony, Dr. Bezdek purported to quote a study by Steinkamp and Hickler, and claimed that the study is "further evidence that 'global warming has ceased.'" Agencies Ex. 804 at 18 (Gurney Surrebuttal) (*citing* Peabody Ex. 233 at RHB-1, lines 208-211 (Bezdek Rebuttal). Dr. Gurney examined this paper, however, and found that it neither contains the statement nor implies such a conclusion. Indeed, the synthesis statement in the abstract of the paper states:

> Synthesis. Our results indeed suggest that dry forests have been experiencing increasing drought-induced mortality. However, this does not apply to forests in general and the spatial variability has been large. The poor

> correspondence between the simulated and reported mortality events indicates that models like LPJ-GUESS driven by standard climatologies, and soil input data do not represent drought-induced mortality well. But the poor detection of the reported drought events in our climate indices also suggests that drought stress might not be the main driver of all the reported drought- mortality events.

Agencies Ex. 804 at 18 (Gurney Surrebuttal).

Dr. Gurney testified that he reviewed and found nothing in this paper that supports Dr. Bezdek's claim. This statement from the study by Steinkamp and Hickler indicates that dry forests are experiencing increased mortality from drought and that the biological models employed ("LPJ-GUESS") do not do a good job at representing this type of mortality. Dr. Gurney explained that it is unclear what Dr. Bezdek might have been quoting, but it was not the study by Steinkamp and Hickler. *Id.* (*citing* Peabody Ex. 233 at RHB-1, lines 208-211 (Bezdek Rebuttal).

Dr. Gurney's Surrebuttal stated that Dr. Bezdek mischaracterized the consensus around anthropogenic climate change as a "manufactured myth." Agencies Ex. 804 at 18 (Gurney Surrebuttal) (*citing* Peabody Ex. 233 at RHB-1, line 213 (Bezdek Rebuttal)). Dr. Gurney observed that, as support for his characterization, Dr. Bezdek relied on mostly non-peer-reviewed research. Further, the peer-reviewed studies upon which he relied as purported support for his characterization are both misquoted and misunderstood.[61] *Id.* at 18-19.

Dr. Gurney observed that Dr. Bezdek reiterated in his Rebuttal Testimony his assertion of a pause in warming and the biases present in temperature records. *Id.* at 19 (*citing* Peabody Ex. 233 at RHB-1, lines 276-336 (Bezdek Rebuttal). As support for his assertion, Dr. Bezdek provided no evidence based on peer-reviewed research, and instead presented figures presumably

[61] This topic is addressed separately in this Initial Brief, in the below section IV.7.K.2 entitled, "Misunderstanding of Science or Cited Literature."

derived from newspaper stories and magazines such as Forbes. Agencies Ex. 804 at 19 (Gurney Surrebuttal) (*citing* Peabody Ex. 233 at RHB-1, lines 306-309 (Bezdek Rebuttal)).

Finally, the remainder of Dr. Bezdek's Rebuttal Testimony that related to issues in physical or biological science reiterated the assertion made in his Direct Testimony that agriculture will benefit from CO_2 and warming. Agencies Ex. 804 at 1(Gurney Surrebuttal) (*citing* Peabody Ex. 233 at RHB-1, lines 393-540 (Bezdek Rebuttal)). This is a straw-man argument, separately responded to in this Initial Brief in the below section IV.7.K.3 entitled, "Straw Man Argumentation." The Agencies and Dr. Gurney suggest that the ALJ should not adopt the Bezdek Rebuttal Testimony as to any of the six topics in Dr. Bezdek's Rebuttal that relate to issues in physical or biological science.

G. Criticisms of the Model Calibration and Supposed "Over-Estimating" Warming (Issue 7)

Dr. Happer claimed that models used as the calibration to the IAMs (and their subsequent SCC results) do not agree with observations. Agencies Ex. 803 at 9 (Gurney Rebuttal) (*citing* Peabody Ex. 200 at 8-9 (Happer Direct)). Dr. Happer's Direct Testimony specifically claimed that:

> Nearly all of the IPCC climate models have predicted several hundred percent more warming over the past twenty years than has actually been observed.
>
> [C]limate models do not agree with observed temperatures. Climate models predicted far more warming than has actually been observed.

Id. at 13-14 (*citing* Peabody Ex. 200 at 6 (Happer Direct)).

> Models predict that the lower atmosphere (the troposphere) should warm more rapidly than the Earth's surface, the opposite of what has been observed.

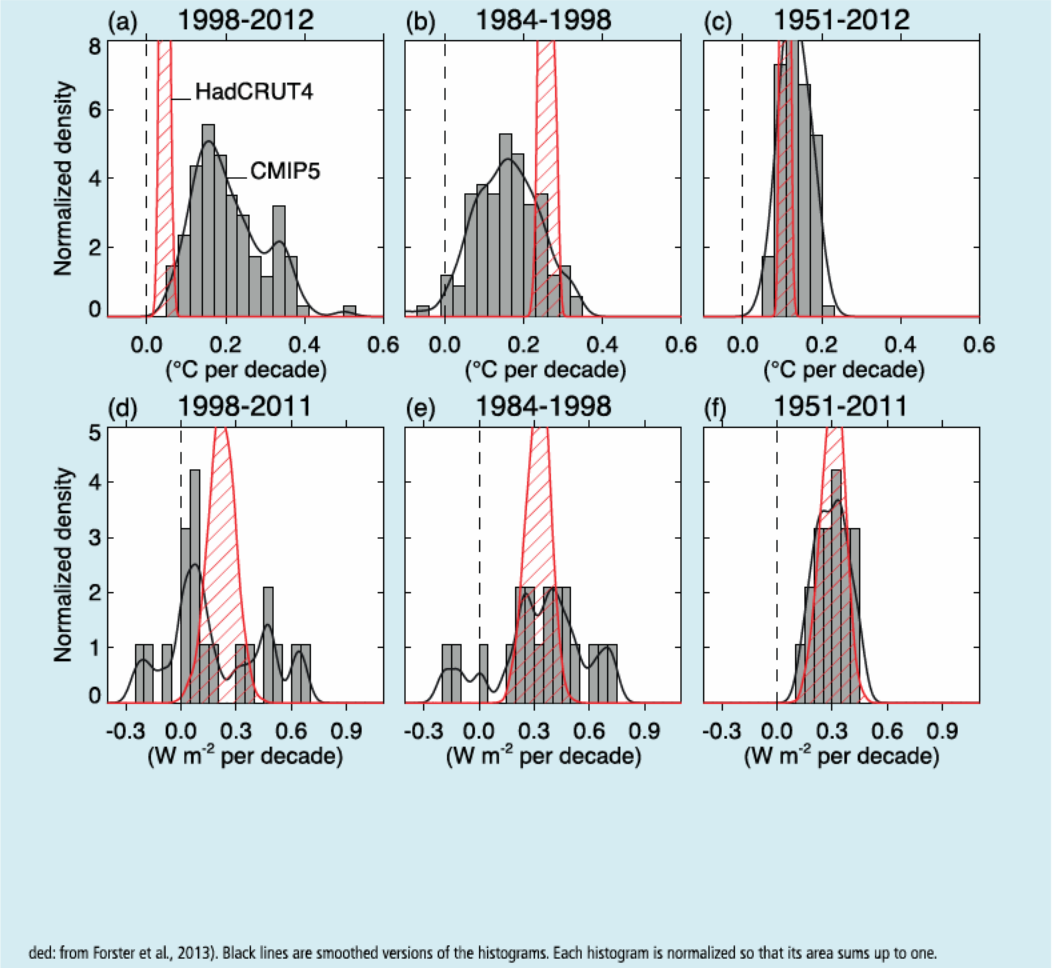
Id. at 14 (*citing* Peabody Ex. 202 at WH-2, p. 6 (Happer Direct)).

Technical support for these assertions was presented by Dr. Happer in Figures 4 and 5 in Peabody Ex. 202 at WH-2, p. 6-7 (Happer Direct).

In his rebuttal of Dr. Happer's claim, Dr. Gurney first criticized Dr. Happer's reliance on Figure 4, which was from congressional testimony, rather than a peer-reviewed scientific source. As a result, it was difficult for Dr. Gurney to comment on the content of Figure 4, as there are many questions of clarification and context that would be needed be answered to establish scientific reliability before Figure 4 could be considered legitimate as support. Figure 5 was from a peer-reviewed study but provided an incomplete assessment of the difference between the observations and climate models. *Id.* at 14.

Dr. Gurney explained that the discrepancy between the IPCC models and observed global mean temperature occurs over the above-discussed 15-year period and has received considerable analysis and description in the latest IPCC 5th Assessment Report. Dr. Gurney provided a more complete view of the topic by showing the following figure from the IPCC 5th Assessment Report.

The following figure shows that there is little discrepancy between the model and observed temperature trends when comparison is performed over appropriately long time periods, panel c: the 1951-2012 time period, as opposed to shorter time periods, panels a and b: 1998-2012 and 1984-1998, respectively. Agencies Ex. 803 at 15 (Gurney Rebuttal) (*citing* IPCC



5th Assessment Report, Working Group I, Technical Summary, p. 63).

Dr. Gurney criticized Dr. Happer's Direct Testimony for its failure to show panel c. He explained that the figure in panel c demonstrates the importance of considering sufficiently long periods of time in order to establish climate trends and/or the ability of models to simulate long-term climate trends. Shorter periods of less than three decades are not long enough to assess climate trends or model veracity. *Id.* at 16.

Dr. Gurney also explained that although short periods cannot establish long-term trends, the discrepancy noted in this figure is a topic of active research within the climate science community,[62] for which a complete discussion can be found in the IPCC 5th Assessment Report. *Id.* at 16 (*citing* IPCC 5th Assessment Report, Technical Summary, pp. 61-63).

Dr. Gurney reiterated that anthropogenic climate change, and the simulation of anthropogenic climate change, must be assessed over sufficiently long time periods to avoid misinterpretations due to short-term variability. The IPCC models perform well over the longer, climate-relevant time periods, which carries greater weight than discrepancies in shorter-term variability. *Id.*

H. Criticism of the Earth Temperature Data and Claimed "Measurement Errors" (Issue 4)

Dr. Happer's Rebuttal Testimony raised an issue that he referred to as measurement error. According to Dr. Happer, as a result of measurement error, surface measurement records are biased due to urbanization and the loss of measurement stations. Agencies Ex. 804 at 15 (Gurney Surrebuttal) (*citing* Peabody Ex. 204 at WH-1, p. 5 (Happer Rebuttal)) and (Peabody Ex. 205 at WH-2, pp. 19-20 (Happer Rebuttal)).

Dr. Gurney observed, first, that the Happer Rebuttal cited nine papers to support his claim, of which three are from the peer-reviewed literature. Of those three, one (a paper also cited by Peabody Witness Dr. Spencer) is a paper on corrections applied to surface temperature measurements in New Zealand (less than 0.2 percent of the land surface of the Earth) and one reports on the influence of urbanization in the temperature measurements in eastern China. The

[62] *Id.* at 16. Dr. Gurney explained that the source of the discrepancy between the IPCC models and observed global mean temperatures over the referenced 15-year period has been given attention, for example, in the recent paper by Dai *et al*. (2015) and is broadly attributed to the difficulty of large-scale atmospheric models to capture internal climate variability, particularly in regions such as the tropical Pacific, associated with El Nino activity.

final peer-reviewed paper (Wang *et al*.) has no content related to either urbanization or measurement station loss. Agencies Ex. 804 at 15 (Gurney Surrebuttal).

Second, the issue of urbanization and other conditions impacting surface measurement locations have been extensively researched and thorough corrections applied. *Id*. Dr. Gurney noted that CEO Ex. 103 at 13-14 (Dessler Rebuttal) and CEO Ex. 102 at 23-24 (Abraham Rebuttal) offered a series of peer-reviewed publications that cover the extensive effort that goes into correcting for urbanization and other effects. In short, the scientific community has accounted for these effects in the temperature records used to support the observational evidence for anthropogenic climate change. Agencies Ex. 804 at 15 (Gurney Surrebuttal).

With respect to the issue of urbanization and other conditions impacting surface measurement locations, Dr. Gurney testified that the synthesis supplied by the IPCC is the best comprehensive review of the temperature records. Chapter 2 of the IPCC 5th Assessment Report (section 2.4, particularly section 2.4.1.3) attached to Dr. Gurney's Surrebuttal as Attachment KG-S-1, provides an extensive review of all the temperature records and discusses the siting issues, urbanization effects, and a long list of peer-reviewed papers that provide the methodological details and analysis. *Id*. at 16. Dr. Gurney, and the Agencies, recommend that the ALJ reject the assertion of Dr. Happer regarding what he referred to as measurement error. Agencies Ex. 804 at 16 (Gurney Surrebuttal).

Dr. Gurney also responded to the Rebuttal Testimony of Dr. Lindzen with respect to the one new item he identified in Rebuttal. *Id*. That new topic purported to be a critique of a recent peer-reviewed paper that revised (very slightly) NOAA's temperature trend analysis. *Id.* (*citing* Peabody Ex. 211 at RSL-1, lines 33-69 (Lindzen Rebuttal)). Dr. Gurney observed that Dr. Lindzen provided no peer-reviewed support for his critique of his analysis. Rather, his critique

appeared to be a general statement about the motivation of researchers involved in analyzing the temperature records. Such a general statement without pertinent supporting evidence is immaterial to the matters at issue in this proceeding (whether the federal SCC is the best measure for determining the cost of carbon). *Id.* at 16-17.

I. Criticisms of the IWG's Equilibrium Climate Sensitivity (Issue 5)

The equilibrium climate sensitivity, usually abbreviated to "climate sensitivity" or ECS, is a parameter that measures the increase in global average annual temperature, at the steady-state equilibrium, as compared to the pre-industrial temperature, when atmospheric concentration of CO_2 is doubled. Agencies Ex. 801 at 31 (Hanemann Rebuttal).

In his Direct Testimony, Xcel's witness Mr. Martin cited Professor Pindyck (Pindyck 2015)[63] on the uncertainty regarding the climate sensitivity.

> We know very little about climate sensitivity, i.e., the temperature increase that would eventually result from a doubling of the atmospheric CO2 concentration, but this is a key input to any IAM. The problem is that the physical mechanisms that determine climate sensitivity involve crucial feedback loops, and the parameter values that determine the strength (and even the sign) of those feedback loops are largely unknown, and are likely to remain unknown for the foreseeable future. As Freeman, Wagner and Zeckhauser (2015) have shown, over the past decade our uncertainty over climate sensitivity has increased.'

Agencies Ex. 801 at 31-32 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 39 (Martin Direct)).

Mr. Martin correctly quoted Pindyck (2015)[64] to the effect that uncertainty over climate sensitivity has increased; however, it is not a persuasive argument against the Commission's adoption of the federal SCC. Mr. Martin failed to point out the implication that Freeman *et al*. drew from this increase in uncertainty. Dr. Hanemann explained that the economic implication

[63] Robert S. Pindyck, The Use and Misuse of Models for Climate Policy (2015), *NBER Working Paper 21097*, April 2015.
[64] Robert S. Pindyck, "The Use and Misuse of Models for Climate Policy" (2015), *NBER Working Paper 21097*, April 2015.

of the increase in the uncertainty regarding climate sensitivity is that it *raises the SCC* in Pindyck's economic model of climate change. Agencies Ex. 801 at 33 (Hanemann Rebuttal). [65] Mr. Martin is silent on this fact.

Dr. Hanemann described why the uncertainty regarding climate sensitivity increases the SCC in Professor Pindyck's economic model of climate change. Dr. Hanemann stated that Freeman *et al*. observed that, while a decrease in the minimum possible climate sensitivity "is undoubtedly good news for the planet," it also implied a widening of the range of uncertainty. Using Pindyck's (2012[66], 2013c[67]) mathematical model, Freeman *et al*. demonstrated that, because of the risk aversion and convexity[68] of the damage function in Pindyck's model, the widening of the uncertainty generally increases the "willingness to pay" ("WTP") value of avoiding climate change. Essentially, as the uncertainty surrounding outcomes of climate change

[65]Dr. Hanemann discussed the context of the increased uncertainty, explaining that the First, Second and Third IPCC Assessment Reports gave the range of values for climate sensitivity as 1.5°C - 4.5°C. In 2007, the 4th Assessment Report changed the range to 2°C - 4.5°C. In 2013, the 5th Assessment Report changed the range back to 1.5°C - 4.5°C. In addition, whereas the 4th Assessment Report gave a "best estimate" for climate sensitivity of 3°C, the 5th Assessment Report provided no "best estimate." The first change extended the range of uncertainty, albeit in the low direction (less climate sensitivity, hence less warming). The second change implied a less highly "peaked" probability distribution of values. Freeman *et al*. used Pindyck's simplified IAM model from Pindyck (2012, 2013c) to analyze the impact of these changes on the estimate of society's willingness to pay (WTP) out of current consumption to avoid climate damages in the future, the metric used by Pindyck which is directly related to the SCC. Agency Ex. 801 at 32-33 (Hanemann Rebuttal).
Pindyck (2013c) is: Robert S. Pindyck, "The Climate Policy Dilemma," (2013c) *Review of Environmental Economics and Policy* 7(2) 219-237.
Pindyck (2012) is: Robert S. Pindyck, "Uncertain Outcomes and Climate Change Policy," (2012) *Journal of Environmental Economics and Management,* Vol. 63, 289-303.
[66] Robert S. Pindyck, "Uncertain Outcomes and Climate Change Policy," (2012) *Journal of Environmental Economics and Management,* Vol. 63, 289-303.
[67] Robert S. Pindyck, The Climate Policy Dilemma (2013c) *Review of Environmental Economics and Policy* 7(2) 219-237.
[68] These topics, risk aversion and convexity, are discussed above in this Initial Brief, at sections IV.7. E.2.e., entitled, "Criticisms of the IAM Damage Functions" and IV.7.I., "Criticisms of the IWG's ECS" (Issue 5) (risk aversion); and IV.7.E.5, entitled, "Summary: Although the IAMs' Damage Functions Likely Understate the Actual SCC…" (Issue 9) (convexity).

increases, one is willing to pay a higher premium to avoid exposure to that increasingly uncertain risk. Freeman *et al*. also demonstrated that reducing the peakedness of the climate sensitivity distribution increased the WTP value of avoiding climate change. *Id.* at 32-33. The economic implication of the increase in the uncertainty regarding climate sensitivity, therefore, is that it raises the SCC in the Pindyck economic model of climate change. *Id.* at 33.

A second critique raised regarding ECS is Dr. Happer's assertion that the models reviewed by the IPCC 5th Assessment Report have ECS values that are too large. Agencies Ex. 803 at 17 (Gurney Rebuttal) (*citing* Peabody Ex. 200 at 8 (Happer Direct)). Dr. Happer's opinion is that a mean value of S = 1 K is the correct value. Dr. Happer's testimony relied on the assertion that the ECS is most accurately assessed without any climate feedbacks:

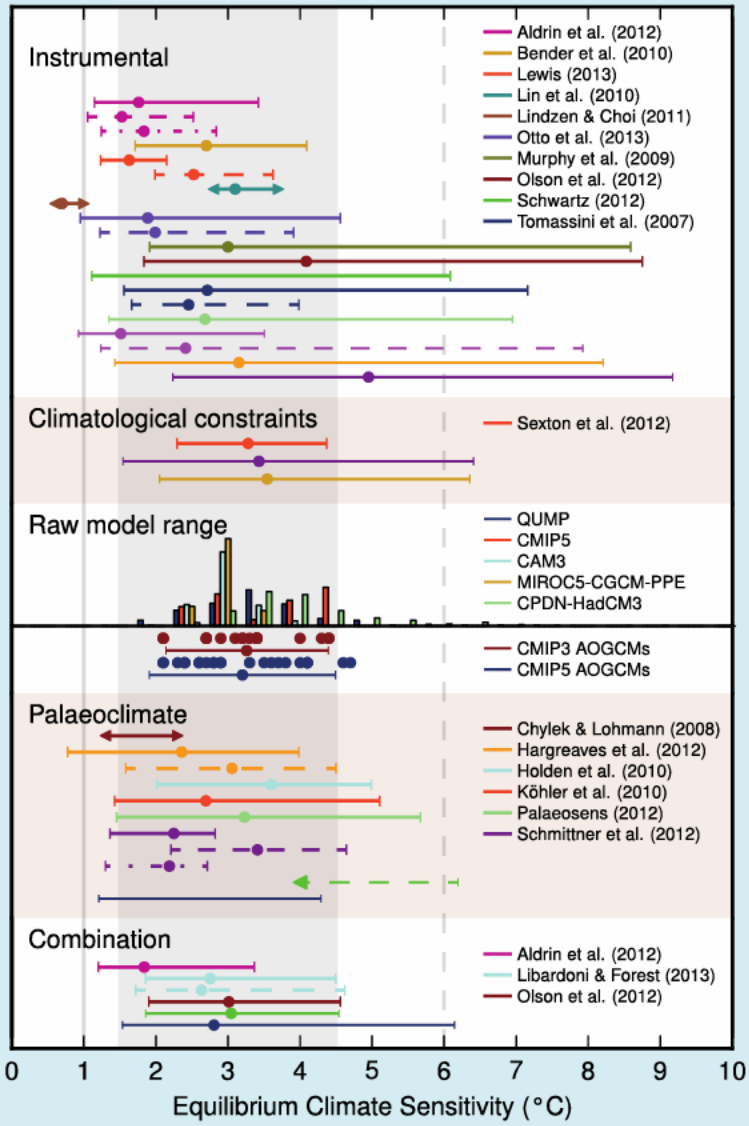
> If one assumes negligible feedback, that is, that other properties of the atmosphere change little in response to additions of CO_2, the doubling efficiency can be estimated to be about S = 1 K. The much larger doubling sensitivities claimed by the IPCC, which look increasingly dubious with each passing year, come from large positive feedbacks.

Id. (*citing* Peabody Ex. 202 at WH-2, p. 7 (Happer Direct)).

Dr. Gurney rebutted this assertion, noting, first, that the IPCC does not "make claims." *Id.* at 17. The IPCC consists of a group of scientists who volunteer to review, synthesize, and summarize existing peer-reviewed research. The doubling ECS range reported in the IPCC 5th Assessment Report (1.5 °C – 4.5 °C) is a range of values representative of the large body of peer-reviewed scientific literature on the topic. *Id.*

The IPCC 5th Assessment Report includes a thorough and comprehensive review of this important metric of the climate system; different aspects are discussed in at least three different chapters. *Id.* The reported range of ECS values are based on multiple lines of evidence,

including paleoclimate, model simulations, and instrumental measurements, as is demonstrated in the following figure from the IPCC 5th Assessment Report:



Box 12.2, Figure 1 | Probability density functions, distributions and ranges for equilibrium climate sensitivity, based on Figure 10.20b plus climatological constraints shown in IPCC AR4 (Meehl et al., 2007b; Box 10.2, Figure 1), and results from CMIP5 (Table 9.5). The grey shaded range marks the *likely* 1.5°C to 4.5°C range, and the grey solid line the *extremely unlikely* less than 1°C, the grey dashed line the *very unlikely* greater than 6°C. See Figure 10.20b and Chapter 10 Supplementary Material for full caption and details. Labels refer to studies since AR4. Full references are given in Section 10.8.

Id. at 17-18 (*citing* Hearing Ex. 405 (IPCC 5th Assessment Report, Working Group I, Chapter 12, p. 1110, box 12.2, Figure 1)).

This figure and the types of studies referenced in the figure were explained in detail during the evidentiary hearing. *See, e.g.,* Tr. Vol. 3 at 18- 22. As is noted in the annotation to the figure, the gray shaded area represents the *likely* 1.5 to 4.5^{o}C range of equilibrium climate sensitivity (*see also* Tr. Vol. 3 at 20, line 13 25) and the gray solid line represents the *extremely unlikely* less than 1^{o}C. Dr. Gurney explained that the available evidence, as represented by the IPCC 5th Assessment Report, does not support Dr. Happer's conclusion. *Id*. at 18.

J. Criticisms Concerning the Relationship of Emissions and Atmospheric CO_2 Concentration (Issue 6)

Although it is well established through multiple lines of scientific evidence that the long-term secular rise of CO_2 concentration in the Earth's atmosphere is driven by the combustion of fossil fuels, Dr. Lindzen incorrectly claimed that there is an ambiguous relationship between emissions and atmospheric CO_2 concentration. Agencies Ex. 803 at 7 (Gurney Rebuttal) (*citing* Peabody Ex. 207 at 6 (Lindzen Direct); Peabody Ex. 209 at RSL-2, lines 488-540)). Dr. Lindzen stated that the connection of fossil fuel emission to atmospheric CO_2 levels is open to question. *Id.* at 8. The Agencies also recommend that the ALJs not adopt Dr. Lindzen's markedly inaccurate testimony on this topic.

The increase in atmospheric CO_2 during the instrumental record is largely due to the increase in the combustion of fossil fuels and the alteration of vegetation at large scales (e.g. tropical deforestation). Dr. Gurney explained that this has been conclusively established through the measurement of ^{14}CO2. ^{14}CO2 is a small amount of atmospheric CO_2 for which the CO_2 molecule has a slightly heavier carbon atom. Fossil fuel-derived CO_2 contains none of this rare CO_2 due to its natural radioactive decay and the fact that it's half-life--the time it takes to decay--

is far less than the time required for carbon to transition to fossilized form. By contrast, the atmosphere has a well-measured amount of CO_2 in the $^{14}CO2$ form. The dilution of this well-known amount of $^{14}CO2$ can be quantitatively tied to the emission of fossil fuel CO_2 into the Earth's atmosphere at levels consistent with the records of coal, oil, and natural gas consumption worldwide. This is referred to as the "Suess" effect and is well established. *Id.* at 8.

Roughly one-half of the emissions due to fossil fuel combustion and deforestation are removed from the atmosphere on an average basis and the removal processes in the ocean and land biosphere are relatively well quantified. The short-term (year-to-year) modulation of global emissions remains an area of active research. *Id.* Dr. Gurney explained that it is well established through multiple lines of evidence, however, that the long-term secular rise of CO_2 concentration in the Earth's atmosphere is driven by the combustion of fossil fuels. *Id.*

The Agencies also recommend that the ALJs not adopt Dr. Lindzen's Direct Testimony on this topic for the second reason that Dr. Lindzen mischaracterized the basic science on this topic, stating that "[t]he usual rule of thumb is that half of emitted CO_2 appears as atmospheric CO_2 *based on the Bern model* for CO_2 geochemistry." Agencies Ex. 803 at 8 (Gurney Rebuttal) (*citing* Peabody Ex. 209 at RSL-2, lines 523-528 (Lindzen Direct) (emphasis added).

Dr. Gurney explained that Dr. Lindzen's Direct Testimony is simply inaccurate. The relationship between emissions and atmospheric CO_2 concentration is *not* based on a model. *Id*. at 9. Instead, Dr. Gurney testified, the "rule of thumb" refers to something quite different, called the "airborne fraction" – the fact that when averaged over decade timescales, slightly over ½ of the fossil fuel CO_2 emitted to the Earth's atmosphere is removed by processes in the ocean and land biosphere. This is not the outcome of a model but an observed, actual quantity, with

decades of instrumental support. This instrumental support precludes the notion that something other than fossil fuel CO_2 emissions are driving the secular trend in atmospheric CO_2 levels. *Id.*

K. The Persistent Failure of Peabody Witnesses to Employ Such Ordinary Scientific Protocols as Peer Review (Issue 24)

Dr. Gurney explained certain common protocols have been adopted as part of the standard scientific process, but these protocols have not been followed in the testimony of several Peabody witnesses. Agencies Ex. 803 at 24-25 (Gurney Rebuttal); Agencies Ex. 804 at 1-13 (Gurney Surrebuttal).

The communication and dissemination of advances in scientific research is performed through a process referred to as scholarly peer review. Agencies Ex. 803 at 24 (Gurney Rebuttal). This process subjects an authored work to the scrutiny of others who are expert in the particular subject matter under consideration. Scholarly peer review is considered mandatory in most academic journals, which are the primary means of communicating research results and advancing the scientific body of knowledge. *Id.* Typically, in the process of peer review, academics submit a written record of scientific work--a manuscript--to a peer-reviewed journal. The work is scrutinized by, typically, 2 to 4 experts within the manuscript's specialized area of research. The reviewers may choose to remain anonymous. Though the exact metrics used to judge the work vary somewhat among journals, the generally-accepted metrics are scientific originality, integrity, accuracy and clarity of communication. Reviewers can reject the manuscript, with detailed reasoning and supporting information when necessary, or they may request revisions of a minor or major caliber. The author(s) of the manuscript have the opportunity to respond, make corrections, or withdraw the work. This can proceed through multiple rounds of review with the same set of reviewers. The goal is to remain impartial and to generate a process of self-correcting advance of knowledge and information. *Id.* at 24. An

essential component of higher education within academia typically includes learning the peer-review process and the importance of maintaining impartiality, high quality, and adherence to strict scientific principles such as hypothesis generation and experimentation. *Id.* at 25.

Peer-reviewed sources, citations, and publications are given greater weight than those that have not been peer reviewed. Given the importance of peer review within scientific research, it is considered an expected standard when assessing information scientifically. As a result, when communicating to the scientific community or to the public on scientific topics, the use of peer-reviewed literature as support is considered essential. Reliance on literature that has not gone through the peer-review process is considered of unknown reliability and in practice, handled with suspicion. *Id.*

Dr. Gurney explained that several Peabody witnesses failed to rely on peer-reviewed literature to support their testimony in this proceeding.

For example, in examining Dr. Bezdek's Direct Testimony, Dr. Gurney reported that, of fifty-four citations provided by Dr. Bezdek, only one was peer-reviewed research, and one was a national academy report; all other sources were either federal agency reports, grey literature or popular literature. *Id.* (*citing* Peabody Ex. 228 at 37 (Bezdek Direct)).

Dr. Gurney, in his Surrebuttal Testimony, more generally explained other similar patterns of flawed and non-scientific argumentation practices that were persistently employed in certain Peabody witnesses' testimony. Agencies Ex. 804 at 1-13 (Gurney Surrebuttal). Dr. Gurney said that these Peabody witnesses used a series of argument patterns throughout their testimony that he has seen repeatedly over the last 30 years regarding anthropogenic climate change ("ACC"). These argument patterns reflect biased or flawed reasoning. Agencies Ex. 804 at 1-2 (Gurney Surrebuttal). Dr. Gurney explained that it is important that the Administrative Law Judges and

Commission understand these argument patterns, because, to audiences outside the climate science community, the arguments presented by these Peabody witnesses may appear legitimate.

Dr. Gurney explained that these argument patterns, in and of themselves, are logically flawed. Understanding the basic lack of scientific reasoning in these Peabody witnesses' testimony is important because it helps the reader to assess the technical merits, which can often be extremely difficult due to the volume of information and its technical nature. *Id.* at 2. Dr. Gurney explained that the patterns of argumentation in the Peabody witnesses' testimony can be classified into four categories. *Id.*

1. Selective Citation by Drs. Lindzen, Bezdek, Spencer and Happer.

The first non-scientific pattern of argumentation involves the witnesses' use of selective citation. Agencies Ex. 804 at 2 (Gurney Surrebuttal). Selective citation is commonly referred to as "error by omission" or "cherry-picking" and involves presenting information to support a predisposed conclusion. This has been relied upon to a great extent in discussion of ACC. The selective citation pattern has two variations, both of which are used by the Peabody witnesses in their direct and rebuttal testimonies. *Id.* The first variation is the failure to rely on peer-reviewed research, discussed above. The second variation of selective citation is "narrow citation." This is where the witness relies on peer-reviewed literature to support arguments but presents only an inappropriately narrow slice of the work on a topic, rather than the breadth of peer-reviewed research on a topic. *Id.* at 2, 5.

In his criticism of the selective citation practice of certain Peabody witnesses, Dr. Gurney reiterated that, to be a valid scientific assessment, a review must rely on peer-reviewed academic literature. Mere arguments that rely on non-peer-reviewed literature are considered unreliable and potentially biased. In Dr. Gurney's opinion, heavy reliance on non-peer-reviewed literature

is typically met with suspicion by the scientific community and often considered a deliberate attempt to obfuscate mainstream scientific thought. *Id.* at 3.

Dr. Gurney observed that large portions of the Rebuttal Testimony of Dr. Bezdek relied almost completely on non-peer-reviewed literature, a fact Dr. Bezdek apparently attempted to conceal by providing false and misleading characterizations of his testimony. For example, when Dr. Bezdek purported to rebut Dr. Polasky, he falsely testified that he was providing a refutation of ACC in "peer-reviewed international scientific journals…" Agencies Ex. 804 at 3 (Gurney Surrebuttal) (*citing* Peabody Ex. 233 at RHB-1, lines 97-136 (Bezdek Rebuttal). However, nine of the thirteen examples Dr. Bezdek identified were not peer-reviewed papers, but rather, a mixture of opinion pieces, institute reports, and online blog content. *Id.* at 3. Of the three peer-reviewed papers, one was in the "Forum" portion of the peer-reviewed journal (Bull. Am. Meteorological Soc.), a section intended for opinion pieces. The remaining two papers were authored or co-authored by fellow Peabody witnesses (Drs. Tol and Lindzen). None of the thirteen papers listed were from either Science or Nature (two of the highest regarded journals in science) even though Dr. Bezdek testified that refutation of ACC had appeared in these two important journals. *Id.* at 4 (*citing* Peabody Ex. 233 at RHB-1, line 92 (Bezdek Rebuttal)).

On the topic of "scientific consensus" in his Rebuttal Testimony, Dr. Bezdek cited eleven papers (in his RHB-1, lines 213-258). Only two of these are peer-reviewed papers, and those were the papers that he was attempting to refute. None of the nine papers Dr. Bezdek relied upon to support his Rebuttal Testimony were peer-reviewed. Agencies Ex. 804 at 4 (Gurney Surrebuttal).

Dr. Bezdek's Rebuttal Testimony purported to provide "empirical evidence" that counters ACC (in RHB-1, line 168). That so-called empirical evidence consisted, however, of an

unreferenced figure (in RHB-1, lines 178-179) and congressional testimony (in RHB-1, line 182) rather than peer-reviewed research. Agencies Ex. 804 at 4 (Gurney Surrebuttal). Similarly, when Dr. Bezdek asserted that there is a "divergence between observations and climate model projections…" (in RHB-1, line 190), the support for this assertion relied on a single instance of congressional testimony rather than peer-reviewed literature. *Id.* Finally, of the fifty-four endnotes to the *entirety* of the Direct Testimony of Dr. Bezdek, all but two were non-peer-reviewed. *Id.*

Dr. Gurney explained that other Peabody witnesses' reliance on non-peer-reviewed literature can be seen, for example, in the Rebuttal Testimony of Dr. Lindzen, where he listed elements of his critique of the recent paper by Karl *et al*. (2015). There, Dr. Lindzen cited a non-peer-reviewed Cato Institute report and "numerous others," the latter of which are not identified. Agencies Ex. 804 at 5 (Gurney Surrebuttal) (*citing* Peabody Ex. 211 at RSL-1, lines 51-59 (Lindzen Rebuttal)).

Regarding the second variation of selective citation, "narrow citation," the witness cites peer-reviewed literature to support arguments but uses only a very narrow slice of the work on a topic. Dr. Gurney testified that the narrow citation approach might be seen where the witness relies only on those papers that support the witness's predisposed position, cites papers that were later refuted without including the refutation literature, or cites papers without the context that would demonstrate their limited utility. Examples of narrow citation often show a preponderance of self-authored papers or a form of "circular" citation where a small group of ACC authors refer to a small set of papers authored by the same group of ACC authors, giving the impression that there is a large body of literature when, in reality, the number of papers is

small relative to a more comprehensive treatment of the literature on a subject. Agencies Ex. 804 at 5 (Gurney Surrebuttal).

Dr. Gurney explained that the practice of narrow citation diminishes the reliability of scientific claims and testimony. In order to accurately assess the fact of a scientific topic and produce a reliable analysis, all the peer-reviewed literature on the scientific topic must be included, assessed and synthesized. Agencies Ex. 804 at 5 (Gurney Surrebuttal); Agencies Ex. 803 at 26-27 (Gurney Rebuttal). Because the role of peer-reviewed publication is aimed at extending the boundaries of what is known, there is often a spectrum of evidence on any given topic. For this reason, comprehensive assessment is an absolute necessity in order to arrive at a reasonable understanding of a topic at hand.

Dr. Gurney unfavorably compared the approach of certain Peabody witnesses with the IPCC Assessment Reports, explaining that one of the goals of the IPCC in forming and generating the Assessment Reports since the 1990s was to include, assess and synthesize all the research on each pertinent scientific topic. The workforce to produce the Assessment Reports is entirely voluntary and comprised of scientists with specific expertise in the many sub-topics covered in the assessment reports. Agencies Ex. 804 at 6 (Gurney Surrebuttal). Several Peabody witnesses relied heavily on the narrow citation approach. It is seen, for example, in the testimony of Drs. Lindzen, Bezdek, Spencer and Happer. *Id.*

Narrow citation was employed by Drs. Lindzen and Spencer when they discussed the topic of equilibrium climate sensitivity. Peabody Ex. 209 at RSL-2, lines 447-475 (Lindzen Direct); Peabody Ex. 212 at RSL-2, pp. 11-12 (Lindzen Rebuttal); Peabody Ex. 223 at RWS-2, pp. 5-6 (Spencer Direct); and Peabody Ex. 225 at RWS-1, pp. 22-23 (Spencer Rebuttal). CEO witness Dr. Abraham accurately observed that, omitted from Drs. Lindzen's and Spencer's

testimony on model climate sensitivity, were a series of peer-reviewed papers that directly refuted those cited by Drs. Lindzen and Spencer. CEO Ex. 102 at 25-26 (Abraham Rebuttal).

Dr. Gurney concluded that Drs. Lindzen's and Spencer's testimony on the topic of equilibrium climate sensitivity were not reliable because an objective, reliable assessment cannot be gleaned from testimony that narrowly cites the witness' own peer-reviewed work without citation to, or discussion of, peer-reviewed papers that directly refute that same work.

Other examples of the Peabody witnesses relying on the narrow citation approach include Dr. Spencer's Rebuttal Testimony. Dr. Spencer testified that current surface temperature measurements have long-term biases due to urbanization, and he offered four references to support his testimony. Agencies Ex. 804 at 7 (Gurney Surrebuttal) (*citing* Peabody Ex. 226 at RWS-2, pp. 21-22 (Spencer Rebuttal). However:

- Dr. Spencer's first reference was from a 1973 book that identified the problem associated with urbanization and other biases in surface temperature measurements. This citation was not relevant, however, to the question of the reliability of current temperature records because, during recent years, extensive effort has gone into corrections for urbanization effects, corrections that have been documented.

- Dr. Spencer's second reference was a paper on temperature records in New Zealand, in which the authors correct for "shelter-contaminated trends" and find a New Zealand warming trend of +0.28 ºC/century versus an uncorrected New Zealand trend of 0.91 ºC/century. New Zealand represents less than 0.2 percent of the land surface of the planet. There are numerous studies that have made adjustments for those stations potentially influenced by urbanization, but these are not cited by Dr. Spencer.

- The third paper Dr. Spencer referenced had no content relating to urbanization and temperature trends.

- The fourth paper identified the impact of urbanization on temperature trends in the urbanized portion of China. There are numerous studies that have

> made adjustments for those stations potentially influenced by urbanization, but these are not cited by Dr. Spencer.

Agencies Ex. 804 at 7-8 (Gurney Surrebuttal).

This very narrow collection of papers demonstrates that there is a scientific concern regarding the influence of urbanization on long-term surface temperature measurements. It is troubling, however, that Dr. Spencer failed to account for, or to disclose the existence of, numerous papers and review efforts that have developed techniques to correct for the effects of urbanization.[69] Most importantly, the results of these urbanization corrections have had little impact on the large-scale warming trends reviewed in the IPCC assessment reports. Dr. Gurney observed that, in contrast, this missed literature and its results were well-presented by Drs. Dessler and Abraham. Agencies Ex. 804 at 8 (Gurney Surrebuttal) (*citing* CEO Ex. 103 at 13-14 (Dessler Rebuttal) *and* CEO Ex. 102 at 23-24 (Abraham Rebuttal)).

2. Misunderstanding of the Science or Cited Literature

A second pattern of argument and reasoning in the testimony of the Peabody witnesses that was misleading, biased or otherwise flawed was a misunderstanding of the science or cited literature. Though less common in proceedings of a serious nature, a misunderstanding of science or cited literature can, and does, occur. Agencies Ex. 804 at 9 (Gurney Surrebuttal).

Examples of this error in the testimony of Peabody witnesses include Dr. Bezdek's citation to a study authored by Strengers *et al*., 2015 in an effort to support his questioning of the consensus on ACC. Dr. Bezdek inaccurately testified, "[t]he most recent study finds that less than half (43 percent) of climate scientists who research the topic and for the most part publish in

[69] This passage from the Spencer Rebuttal is also an example of "straw man argumentation" (the third argument pattern discussed below). In this instance, the relevant question is not whether urbanization effects exist (the community that collects and analyzes long-term surface temperature records are certainly aware of this), but whether they have been adequately accounted for and the impact of those corrections on the analysis.

the peer-reviewed literature agree with the IPCC's main conclusion that CO_2 is the dominant driver of climate change." *Id.* (*citing* Peabody Ex. 233 at RHB-1, p. 7, citation 15 (Bezdek Rebuttal)). Dr. Gurney stated that, in reading through the Strengers *et al*. study, he found no statement or numerical result consistent with Dr. Bezdek's claim. It appeared, instead, that Dr. Bezdek had combined the results of two separate questions, multiplying the percentage results of the two separate questions to arrive at the 43 percent value. Dr. Gurney explained that this is incorrect. The only way to achieve an accurate assessment of the survey response is to ask the complete question to those being surveyed. Combining the results, as Dr. Bezdek did, represents flawed reasoning and violates standard survey protocol. Indeed, the conclusions of the Strengers report, and more importantly, of the subsequently-published peer-reviewed paper based on the survey, which was not cited or otherwise disclosed to the ALJ by Dr. Bezdek[70] came to a conclusion opposite of Dr. Bezdek. To quote the results (presented in the abstract) of the peer-reviewed paper:

> Consistent with other research, we found that, as the level of expertise in climate science grew, so too did the level of agreement on anthropogenic causation. 90% of respondents with more than 10 climate-related peer-reviewed publications (about half of all respondents), explicitly agreed with anthropogenic greenhouse gases (GHGs) being the dominant driver of recent global warming.

Agencies Ex. 804 at 10 (Gurney Surrebuttal).

Another example of a misunderstanding of the science or cited literature by Peabody witnesses include citation number nineteen, in Peabody Ex. 233 at RHB-1, p. 7 (Bezdek Rebuttal), where Dr. Bezdek inaccurately testified that a survey by the American Meteorological Society ("AMS") found that only 25 percent of respondents agreed with the UN IPCC claims that humans are primarily responsible for recent warming. On his review, Dr. Gurney found no

[70] Verheggen *et al*., *Env. Sci. & Tech*., 48, pp. 8963-8971 (2014).

such statement in the AMS survey report. The closest result to this testimony appeared on p. 5 of the cited report:

> Respondents who indicated that global warming is happening were asked their views about its primary causes; a large majority indicated that human activity (59%), or human activity and natural causes in more or less equal amounts (11%), were the primary causes.

Dr. Gurney observed that, again, the report's conclusion was in *direct opposition* to the sworn testimony of Dr. Bezdek. Moreover, like Dr. Bezdek's claim about the Strengers *et al*. survey report, Dr. Bezdek did not disclose the peer-reviewed paper that resulted from this AMS survey. Agencies Ex. 804 at 10 (Gurney Surrebuttal) (*citing* Stenhouse *et al*.)[71].

A further example of selective citation was seen in the testimony of Dr. Happer, which contained references to papers that contain neither Dr. Happer's assertions nor the figures to which Dr. Happer testified. Agencies Ex. 803 at 21-23 (Gurney Rebuttal) (*citing* Peabody Ex. 202 at WH-2, p. 11 (Happer Direct)); Agencies Ex. 804 at 11 (Gurney Surrebuttal).

3. Straw Man Argumentation

The third misleading, biased or otherwise flawed pattern of argument and reasoning used by Peabody witnesses is straw man argumentation. In this type of flawed argumentation, an argument is refuted, but it is not an argument advanced by an opposing witness. This type of argumentation results in the impression of successful refutation, but has no relevance to the proceeding. Agencies Ex. 804 at 11 (Gurney Surrebuttal).

This non-scientific argument was best exemplified by Drs. Bezdek's and Happer's testimony regarding CO_2 fertilization. Peabody Ex. 233 at RHB-1, pp. 13-19 (Bezdek Rebuttal) and Peabody Ex. 204 at WH-1, pp. 2-4, and Peabody Ex. 205 at WH-2, pp. 16-17 (Happer

[71] Stenhouse et al., Meteorologists' Views About Global Warming, A Survey of American Meteorological Society Professional Members, *Bull. Am. Met. Soc.* (2014) 95, pp. 1029-1040. *http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-13-00091.1*

Rebuttal). Dr. Gurney testified that the climate science community has not argued that there is *no* CO_2 fertilization effect or that CO_2 fertilization has a negative impact. The relevant question on this topic is whether the impacts (whether positive or negative) of climate change on vegetation, particularly food crops, have been incorporated into the modeling efforts. The research suggests that the net effect of climate change on food crops is negative and the complete suite of effects have been included, to the extent of scientific knowledge on the subject. Agencies Ex. 804 at 11-12 (Gurney Surrebuttal).

4. Attacking The Messenger

The fourth misleading, biased or otherwise flawed pattern of argument and reasoning used by Peabody witnesses is an argumentation device known as "attacking the messenger." Dr. Gurney explained that this common form of argumentation has been used by those attempting to refute ACC, particularly when responding to content within the IPCC assessments. Agencies Ex. 804 at 12 (Gurney Surrebuttal). Examples of this pattern of argument and reasoning in the testimony of the witnesses of Peabody can be seen in the testimony of Peabody witnesses who mischaracterized the content of the IPCC reports, and used phrases such as "the IPCC claims" or "IPCC models find" and similar phrasing. As was explained in Agencies Ex. 803 at 25-28 (Gurney Rebuttal) however, the IPCC reports did nothing more than review the existing peer-reviewed literature and synthesize the information into an assessment of the scientific knowledge on the topic of climate change. Extensive effort went into how to express the results of the synthesis to best communicate the breadth of results. There is no such thing as "IPCC models." As noted previously, the authors of the IPCC reports are working scientists who volunteer their time to review the science. They often work in teams on particular chapters or report sections. The IPCC Secretariat itself is composed of a very small staff with no modeling or research capability whatsoever. The Secretariat staff serve a predominantly clerical function. The

mischaracterizations by Peabody witnesses, and the use of misleading phrasing, creates the impression that the IPCC is a research entity imposing results with a predisposed agenda rather than a voluntary network of working scientists who engage in a review of all the peer-reviewed literature (including, it is worth noting, that published by self-proclaimed ACC skeptics) and write reports that assess and synthesize that peer-reviewed literature. Agencies Ex. 804 at 12-13 (Gurney Surrebuttal).

L. Criticisms of the IWGs Accounting for Extreme Weather Events and Catastrophic Outcomes in the Federal SCC (Issue 8)

The federal SCC includes in its methodology a valuation of the possibly low-risk but high-cost catastrophic events. It is important that policymakers, including the Commission, take into account the possibly catastrophic outcomes resulting from climate change. Dr. Hanemann stated that justification for this consideration is well expressed by Pindyck (2013a)[72], as follows:

> Why do we need to worry about large temperature increases and their impact? Because even if a large temperature outcome has low probability, if the economic impact of that change is very large, it can push up the SCC considerably. As discussed in Pindyck (2013c)[73], the problem is that the possibility of a catastrophic outcome is an essential driver of the SCC.

Agencies Ex. 801 at 64 (Hanemann Rebuttal).

1. Smith's Criticism of the IWG Federal SCC Fails to Acknowledge the Need to Consider Possibly Catastrophic Outcomes.

Dr. Smith's testimony does not acknowledge the need to consider possibly catastrophic outcomes. Dr. Smith asserted that the analysis of climate impacts should be terminated at 2100 or 2140 because, beyond that time frame, there could be large increases in global temperature

[72] Robert S. Pindyck, "Climate Change Policy: What Do Models Tell Us?" (2013a) *Journal of Economic Literature* 51(3), 860-872.
[73] Robert S. Pindyck, "The Climate Policy Dilemma" (2013c) *Review of Environmental Economics and Policy* 7(2) 219-237.

under some scenarios and simulations. In effect, she argued to exclude potentially catastrophic outcomes from consideration. Agencies Ex. 801 at 64 (Hanemann Rebuttal) (*citing* GRE,MP,OTP,MLIG Ex. 302 at AES-D-2, p. 72 (Smith Direct).

Dr. Hanemann disagreed with Dr. Smith, and he explained why Dr. Smith recommended disregarding the possibility of large degrees of warming. One reason for her recommendation was that she believes that the world's population will not stand by and allow themselves to be exposed to high temperatures. Dr. Hanemann observed that this is akin to arguing to the Nuclear Regulatory Commission that it should disregard the possibility of low-risk but catastrophic accidents because the operator of a nuclear power plant would never allow such accidents to happen. Agencies Ex. 801 at 64 (Hanemann Rebuttal).

Dr. Smith's second reason was that the existing IAM damage functions are not calibrated to large degrees of warming and therefore are unreliable. Professor Pindyck, who is quoted in her testimony, makes a similar point--that the IAM damage functions are not calibrated to large degrees of warming--but he then draws a very different conclusion from it. He states:

> It is difficult to see how our knowledge of the economic impact of rising temperatures is likely to improve in the coming years. More than temperature change itself, economic impact may be in the realm of the "unknowable." If so, it would make little sense to try to use an IAM-based analysis to evaluate a stringent abatement policy. The case for stringent abatement would have to be based on the (small) likelihood of a catastrophic outcome in which climate change is sufficiently extreme to cause a very substantial drop in welfare.

Agencies Ex. 801 at 65 (Hanemann Rebuttal) (*citing* Pindyck (2013a)[74] at 869). Instead of confining the analysis to the time period before catastrophic outcomes occur, Professor Pindyck recommends that we explicitly consider them:

[74] Robert S. Pindyck, "Climate Change Policy: What Do Models Tell Us?" (2013a) *Journal of Economic Literature* 51(3), 860-872.

> First, consider a plausible range of catastrophic outcomes (under, for example, BAU), as measured by percentage declines in the stock of productive capital (thereby reducing future GDP). Next, what are plausible probabilities? Here, "plausible" would mean acceptable to a range of economists and climate scientists. Given these plausible outcomes and probabilities, one can calculate the present value of the benefits from averting those outcomes, or reducing the probabilities of their occurrence

Id. (*citing* Pindyck (2013a)[75] at 870).

Dr. Smith's attempt to exclude catastrophic climatic outcomes from consideration when computing the SCC is absolutely inconsistent with Professor Pindyck's position in his literature. As noted above, Professor Pindyck sees "the possibility of a catastrophic outcome as an essential driver of the SCC." *Id.* at 66.

While the federal SCC accounts more accurately than Smith's proposal for catastrophic events, the existing IAM damage functions nevertheless are likely to be understated because, as outlined in Dr. Hanemann's testimony regarding climate tipping points, they are likely to understate the damage associated with catastrophically large degrees of warming. *Id.* That, in turn, would lead the IWG's estimates to understate the true value of the federal SCC. *Id.*

M. Criticisms of the IWG's Use of the Mean Versus the Median Estimate of the Federal SCC (Issue 20)

As discussed above, the IWG used the mean or average results obtained from the IAMs to calculate the discounted present environmental cost values.

Mr. Martin disagreed with the methodology employed by the IWG to calculate the federal SCC. On the one hand, Mr. Martin correctly pointed out in Xcel Ex. 600 at 26 (Martin Direct) that the mean is a good measure of central tendency for data which are normally distributed, and correctly noted in Xcel Ex. 600 at 26 (Martin Direct) that the SCC values

[75] Robert S. Pindyck, "Climate Change Policy: What Do Models Tell Us?" (2013a) *Journal of Economic Literature* 51(3), 860-872.

developed by the IWG are not normally distributed – they are skewed with a long right tail. Agencies Ex. 801 at 66 (Hanemann Rebuttal). However, Mr. Martin subsequently drew an unsubstantiated conclusion from these observations; he claimed that, with a skewed distribution, the mean is greatly influenced by "outliers." *Id.* (*citing* Xcel Ex. 600 at 27 (Martin Direct)).

Dr. Hanemann explained why "outlier" is the wrong term for what is going on. In statistics, an "outlier" is an observation that is distant from other observations. What we have in the case of the federal SCC, however, is a distribution of observations that includes a number of high-damage, low-probability estimates. In this case, these high-damage estimates cannot be considered "outlier" values of the SCC, rather they are simply values within the distribution of estimates. A non-normal distribution (in this case positively skewed), will intrinsically include data points that are much larger than others in the same population. That is the nature of skewed population, as shown in Figure 9 in Xcel Ex. 600 at 65 (Martin Direct). *Id.* at 67. The much larger damage estimates that Mr. Martin is characterizing as outliers as part of the SCC damage calculation are within the accepted distribution of a population of SCC estimates exhibiting positive skewness[76]. *Id.* at 68.

Dr. Hanemann explained that Mr. Martin proposed to simply eliminate the larger damage values, via his use of the *median* rather than the *mean,* that lie well within the distribution exhibited by the SCC damage estimates. Dr. Hanemann disagreed with this proposal, explaining that exclusion of those data points produces an SCC estimate that is not fully representative of all the possible damage outcomes modeled by the IWG. *Id.* He stated that he disagreed with Mr. Martin's proposal for the same reason as that given by the IWG:

[76] A characterization of data includes skewness. Skewness is a measure of symmetry, or more precisely, the lack of symmetry. A distribution, or data set, is symmetric if it looks the same to the left and right of the center point. NIST Engineering Statistics Handbook, *http://www.itl.nist.gov/div898/handbook/eda/section3/eda35b.htm*

> The choice of the mean or the median as a measure of central tendency depends on the context. In skewed distributions, such as for the SCC estimates, the median will often give a more "typical" outcome, while the mean will give full weight to the tails of the distribution. In some cases, the typical outcome is of most interest. For example, in describing household incomes the median is most often used because the focus is on understanding the income of the typical household, and using the mean might distort this picture by giving undue weight to a small number of very wealthy households. In the climate change context, however, 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). Use of the median to represent the SCC in a regulatory impact analysis would not necessarily lead to the most efficient policy choice that uses resources wisely to mitigate potential climate impacts (e.g., maximize the expected net benefits). In this case, the IWG believes that the mean is the appropriate measure of central tendency.

Agencies Ex. 801 at 69 (Hanemann Rebuttal).

Further, Dr. Hanemann explained, that judgment to use the mean or average rather than the median is a policy judgment. The IWG has clearly made this policy judgment. What is involved is essentially a matter of risk management – regulating GHG emissions so as to avoid the risk of possibly very harmful climatic outcomes in the right tail of the warming and SCC probability distributions. Using the median effectively chops off the tails of the distribution, removing them from consideration. That is contrary to the objective of a risk management policy. *Id.* at 70.

N. Criticism of IWG's Analysis in Reporting the 95-Percentile Value of the SCC Distribution for the 3 Percent Discount Rate. (Issue 21)

Mr. Martin's range of values excluded the 95-percentile of the SCC distribution. Dr. Hanemann disagreed with his decision to exclude the 95-percentile of the SCC distribution from consideration. Agencies Ex. 801 at 69 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 29 (Martin Direct)). Dr. Hanemann stated that there is a case for considering the 95-percentile of the SCC distribution. This is done in other regulatory contexts involving low-risk but potentially

catastrophic outcomes. It is common in this setting to focus attention on events that can occur with as little as a 5 percent probability and to examine the probability density function through at least the 95-percentile (the point where there is a 95 percent probability that a lower value outcome occurs). *Id.* at 70. An analogy is offered by Mr. Nick Robins of the United Nations Environmental Program. Mr. Robins is quoted in a new report on the value at risk from climate change by the Economist Intelligence Unit as follows: "We wouldn't get on a plane if there was a 5% chance of the plane crashing, but we're treating the climate with that same level of risk in a very offhand, complacent way." *Id.* at 71.

Dr. Hanemann explained that the concern with tail risks (that is, risks associated with the low-probability, high-damage events represented in the fat tail of the distribution) is consistent with, and validates, the IWG's analysis in reporting the 95-percentile value of the SCC distribution for the 3 percent discount rate. The Agencies agree and continue to urge that the ALJs recommend use of the federal SCC as adopted by the IWG in 2013.

O. Criticisms of the IWG's Discount Rates (Issue 12)

1. Bezdek and Smith

Dr. Bezdek took issue with the IWG's discount values, and asserted that the discount rates were "arbitrary." Dr. Hanemann discussed why this is not a well-founded concern, explaining that there is a well-developed economic theory of the discount rate. He observed that, technically, when environmental economists speak of using a 5 percent discount rate, say, to compute the SCC, what is actually being referred to is known as the "consumption rate of discount." That, in turn, is derived from something known as the utility rate of discount. Agencies Ex. 801 at 71 (Hanemann Rebuttal).

Dr. Smith also criticized the IWG's use of a 2.5 percent discount rate. She stated that the IWG's use of a 2.5 percent discount rate does not conform to the criterion to base Minnesota's

estimates of environmental cost values on evidentiary foundations. Dr. Hanemann disagreed with Dr. Smith and offered that the federal SCC's consumption rate of discount of 2.5 percent is certainly compatible with calculations based on reasonable economic assumptions. *Id.* at 72.

Dr. Hanemann explained those concepts to show why the IWG's discount rate is neither "arbitrary" nor inappropriate. Agencies Ex. 801 at 71 (Hanemann Rebuttal). The utility rate of discount is the rate at which individuals are willing to trade off an amount of wellbeing – utility - now in exchange for an increase of wellbeing of the same magnitude in the future. This concept can be viewed through the following metaphor: An individual faces future danger. However, taking action now would avert the future harm. Taking action now entails paying a cost, which reduces the money available now to buy other things that could be enjoyed now. Paying the cost and foregoing those items, therefore, would reduce one's immediate wellbeing. On the other hand, the future harm will reduce future wellbeing. The dilemma is whether one should reduce wellbeing today to avoid a reduction in future wellbeing. *Id.* at 72.

Dr. Hanemann explained that in economic theory, the resolution of this choice requires a comparison between changes in one's wellbeing at two points in time – now, and in the future. *Id*. at 72. Two sets of factors influence the comparison: (i) the magnitude of the change in wellbeing, and (ii) how the person feels about future versus present wellbeing. The latter factor is measured by what is called the person's "rate of time preference" or "utility rate of discount" (represented by δ). That rate reflects the extent to which the person is willing to trade wellbeing (utility) at one point in time for wellbeing at another point in time. *Id.* at 72-73.[77] This rate of

[77] If the person values a unit of his future wellbeing as equally important as a unit of present wellbeing, he has a zero rate of time preference ($\delta = 0$). He would apply a zero discount rate to his future wellbeing. If he values a unit of his future wellbeing as less important than a unit of present wellbeing he has a positive rate of time preference ($\delta > 0$). He would apply a positive discount rate to his future wellbeing. The greater the disparity in the value of the future and

time preference is a subjective decision by the decision maker. It measures his willingness to make an investment that entails a cost now but improves his future welfare. In a highly simplified form, this symbolizes the choice being faced with regard to regulating the emission of GHGs. Agencies Ex. 801 at 73 (Hanemann Rebuttal).

Dr. Hanemann also explained the consumption rate of discount, and how it relates to this discussion. The tradeoff in the rate of time preference has been framed in terms of utility or wellbeing – giving up some wellbeing now in exchange for more wellbeing later. The same tradeoff can also be framed in monetary terms: giving up some income or consumption now in exchange for more income or consumption later. That tradeoff depends on how the person values a unit of consumption now versus a unit of consumption later. The factor involved in this trade-off is known as the consumption rate of discount. *Id.* at 74. It is the consumption rate of discount that should be used when calculating the SCC. *Id.*

In 1928, British economist Frank Ramsey first developed the economic growth model on which the DICE model draws. He proved that the consumption rate of discount is the appropriate discount factor to use when an optimizing individual is contemplating the transfer of consumption (income) from one point in time to another. *Id.* at 74. He also demonstrated that the consumption rate of discount depends on two factors: (i) the utility rate of discount, and (ii) the extent to which the person's income (or consumption) will be different in the future compared to today.[78] *Id.*

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present units of wellbeing, the larger the rate of time preference. Finally, if he values a unit of his future wellbeing as more important than a unit of present wellbeing he has a negative rate of time preference ($\delta < 0$). He would apply a negative discount rate to his future wellbeing. In that case, the greater the disparity in the value of the future and present units of wellbeing, the lower the rate of time preference. Agencies Ex. 801 at 75 (Hanemann Rebuttal).

[78] Dr. Hanemann explained that, if the person expects his income (or consumption) to be the same in the future as today, his consumption rate of discount exactly equals his utility rate of

2. The Range of Discount Rates

Regarding the range of discount rates in the federal SCC, Dr. Hanemann explained that, in Professor Nordhaus' analysis with DICE, *when used in the optimization mode*, the marginal utility factor plays a large role. He assumes a value of 1.5 percent for δ, while the marginal utility factor amounts to 4 percent, yielding a consumption rate of discount totaling 5.5 percent. In contrast, in the Stern Review, Professor Stern assumes a value of 0.1 percent for δ, while the marginal utility factor amounts to 1.3 percent, yielding a consumption rate of discount totaling 1.4 percent.

The consumption rate of discount is what is used for estimating the SCC. These differences in estimates of the consumption rate of discount produce substantial differences in estimates of the SCC. Agencies Ex. 801 at 75 (Hanemann Rebuttal). Dr. Hanemann explained the several assumptions that underlie Ramsey discounting as applied in the IAMs, and why, in his opinion, these are not reasonable assumptions in the context of calculation of the federal SCC. These assumptions include:

- The assumption that climate policy can be viewed through the metaphor of a single, infinitely-lived individual arranging his consumption over the course of his (infinite) lifetime.

- The assumption that the individual has constant preferences and constant expectations regarding what gives him wellbeing throughout the course of his lifetime.

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discount (his δ). If he expects his income to be larger in the future than today, that introduces a correction factor which needs to be added to δ. The correction factor arises because (a) his income will be larger, and (b) as his income rises the marginal utility that he obtains from an additional unit of income decreases. The correction factor that combines (a) and (b) is the marginal utility factor. Conversely, if the person expects his income to be smaller in the future than today, that introduces a correction factor which needs to be subtracted from δ. In this case, the marginal utility factor lowers the consumption rate of discount to a value less than δ. *Id.* at 75.

- The assumption that everything the individual cares about can be boiled down to one item – the amount of money that he has – and all impacts of climate change can be reduced to the equivalent of a change in the money that he has.

Agencies Ex. 801 at 76 (Hanemann Rebuttal). Dr. Hanemann explained that, if any of these assumptions is judged unreasonable, it would change the formula for the consumption rate of discount. In Dr. Hanemann's opinion, these assumptions are not reasonable.

3. Smith's Argument for Higher Discount Rates Based on the Assumption of Optimality

The notion of a single, infinitely lived decision maker determining the world's GHG emissions from now to beyond 2300 is a fiction which provides a mathematically convenient framework for conducting the IAM analysis. But, Dr. Hanemann emphasized, it is a fiction. It does not capture many important elements of the climate problem that we face. In particular, it sweeps aside the ethical issues associated with inter-generational and intra-generational equity. If one took seriously an obligation to preserve the planet for future generations, Ramsey discounting falls away. Agencies Ex. 801 at 77 (Hanemann Rebuttal).

If one were to accept the notion of mankind over the next 300 years being represented through the metaphor of a single, infinitely-lived individual. The notion that human preferences remain unchanged over three centuries, and that what people expect out of life stays unchanged over three centuries, is wildly implausible. *Id.* at 77.

Dr. Hanemann explained that it is this assumption which underlies the argument made by Dr. Smith in that "future generations will be far wealthier and have far higher consumption than is the case in the present." *Id.* (*citing* GRE,MP,OTP,MLIG Ex. 302 at AES-D-2, p. 88 (Smith Direct)). Dr. Smith made the argument in the context of arguing for a high discount rate. The mathematical basis for the argument regarding the increase in future wealth comes directly from the decreasing marginal utility effect, and assumes that future generations will have exactly the

same expectations out of life as we do today – their incomes will be many times higher, in real terms, than our income today but their expectations will be completely unchanged by the passage of time and the rise in their standard of living. *Id.*

If the assumption is *incorrect* – if people's expectations do change over time – that fact undercuts the decreasing marginal utility effect. Depending on how much people's preferences and expectations change, it would reduce or eliminate the decreasing marginal utility effect, thereby lowering the consumption rate of discount. *Id.*

Finally, Dr. Hanemann stated that, if people care separately for both things that money can buy and also for other, non-market things, such as preserving the natural environment, and if they do not see those two types of items as perfect substitutes for one another, this adds an additional, third term, to the Ramsey formula for the consumption rate of discount. If one makes the assumption – which he considered plausible – that people care for unimpaired natural environment but that the unimpaired natural environment is increasingly threatened and declines in scale with economic growth and with climate change, then the mathematical effect is to reduce the value of the consumption rate of discount. *Id.* at 78.

It is for these reasons that Dr. Hanemann regarded Professor Nordhaus' estimate of 4 percent for the marginal utility factor as far too high. *Id.* Dr. Hanemann instead agreed with Professor Pindyck that the choice of the rate of time preference is an ethical judgment.[79] It has

[79] Professor Pindyck opens his discussion of discounting as follows: We can begin by asking what is the "correct" value for the rate of time preference, δ? This parameter is crucial because the effects of climate change occur over very long time horizons (50 to 200) years, so a value of δ above 2 per cent would make it hard to justify even a very moderate abatement policy. Financial data reflecting investor behavior and macroeconomic data reflecting consumer and firm behavior suggest that δ is in the range of 2 to 5 percent. While a rate in this range might reflect the preferences of investors and consumers, should it also reflect intergenerational preferences and thus apply to time horizons greater than fifty years? Some economists (e.g., Stern 2008 and Heal 2009) have argued that on ethical grounds δ should be zero for such

economic implications, but economic theory per se cannot prescribe what numerical value to employ. Setting a value is a policy judgment. For that reason he did not consider Stern's value of δ at 1.4 to be outlandish. *Id.* at 79.

Further, Dr. Hanemann explained that a consumption rate of discount of 2.5 percent is compatible with calculations based on reasonable economic assumptions; he explained that making realistic assumptions about people's preferences over time could plausibly generate values of the marginal utility factor in the range from 1.3 (Stern's value) to 2, and that a pure rate of time preference of, say, $\delta = 0.5$ is ethically highly defensible. Furthermore, a realistic model of people's preferences would admit the possibility that they engage in hyperbolic discounting[80] -- as opposed to geometric discounting[81] – which would further lower the consumption rate of

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horizons, i.e., that it is unethical to discount the welfare of future generations relative to our own welfare. But why is it unethical? Putting aside their personal views, economists have little to say about that question. I would argue that the rate of time preference is a policy parameter, i.e., it reflects the choices of policy makers, who might or might not believe (or care) that their policy decisions reflect the values of voters. As a policy parameter, the rate of time preference might be positive, zero, or even negative. Agencies Ex. 801 at 78-79. (Hanemann Rebuttal).

[80] "Hyperbolic" discounting is the name given to an alternative form of discounting, one in which the rate employed to discount from one period to the next declines as the two periods being considered lie further in the future. Geometric discounting treats the difference between X occurring next year or the year after as the same as that between X occurring 101 years from now versus 102 years from now – in both cases there is a delay of one year. Hyperbolic treats X occurring 101 years from now versus 102 years from now as being different than the comparison of X occurring next year versus two years from now. Hyperbolic discounting focuses on the relative time difference, not the absolute time difference. Waiting 102 years instead of 101 years is a 1 percent delay in the timing of the outcome; waiting two years instead of one year is a 100 percent delay. With hyperbolic discounting, the former delay receives less weight than the latter because it is a delay of only 1 percent.

The value of X when it is delayed for year is discounted less heavily if the delay occurs after 101 years than after one year. With hyperbolic discounting, the distant future is discounted less heavily than with geometric discounting. If hyperbolic discounting were applied when calculating the SCC, as opposed to the geometric discounting used in the IAMs, it would substantially raise the SCC value. *Id.* at 80-81.

[81] Geometric discounting is the technical name given to the conventional type of discounting, the type of discounting employed by the IAMs and the type discussed so far. With geometric

discount. *Id.* at 79. Dr. Hanemann testified that there is now considerable empirical evidence that when people make real choices regarding future outcomes, they generally employ something like hyperbolic discounting rather than geometric discounting to weigh future outcomes. Both the United Kingdom and the French governments have adopted hyperbolic discounting for policy evaluation. *Id.* at 81.

Dr. Smith referred in passing to the notion of a discount rate that declines with the passage of time – in effect, hyperbolic discounting – only to reject it in GRE,MP,OTP,MLIG Ex. 302 at AES-D-2, pp. 82, 88 (Smith Direct). Following an argument given by Farrow and Viscusi (2011), she rejected it on the grounds that it would lead to what is known as time inconsistency.[82]

Dr. Hanemann testified that the possible existence of time inconsistency is not a compelling reason to reject hyperbolic discounting in the context of the calculation of the SCC. He explained that the notion of time inconsistency is based on the assumption of a single decision maker with unchanging tastes and unchanging expectations for life. As he repeatedly explained, that is not an appropriate lens through which to conceptualize the issue of global

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discounting, a constant rate of discount is employed to discount from one period to the next. *Id.* at 78.

[82] The context in which time inconsistency arises is that of a single decision maker making decisions over a span of time. The decision maker recognizes the interdependence between future and present decisions. A decision made now can have consequences for the choices he will face in the future and, therefore, for future decisions. And the future decisions can have consequences for what he should choose today. The individual is rational and makes decisions in a forward-looking manner, recognizing the inter-temporal dependence among his decisions. He determines today not only his present choices but also his future choices based on his expectation today of future circumstances. Time inconsistency arises when, at some future time, he fails to make the choice that he determined now he would make at that time. For example, he makes a particular choice today based on a decision that, 40 years from now, he will choose X over Y. But, when the occasion arrives 40 years from now, at that time he actually chooses Y over X. His future behavior is inconsistent with what today he had planned it to be. This time inconsistency is said to undermine the whole notion of optimality and rational planning. It is known that hyperbolic discounting can lead to this type of time inconsistency. *Id.* at 81-82.

climate policy. And it is therefore not a valid basis for rejecting the use of hyperbolic discounting in an IAM. *Id.* at 82.

Moreover, Dr. Hanemann observed, time inconsistencies occur all the time in the real world. The United States government, under President Obama, makes decisions in 2015 that the United States government under President Bush, looking forward a decade from 2005, had intended to be rejected. That is time inconsistency in government decision making. To reject hyperbolic discounting on the grounds that it could lead the United States government to make time inconsistent choices a century or more from now is, in Dr. Hanemann's opinion, a far from compelling argument. *Id.* at 83.

In his further rejection of Dr. Smith's criticisms, Dr. Hanemann observed that Dr. Smith asserted that an SCC calculated based solely on estimates of the consumption rate of discount is too low. Dr. Hanemann disagreed with this assertion. *Id*. at 83.

Dr. Hanemann explained that, rather than the consumption rate of discount, Dr. Smith argued for using something closer to the market rate of interest ("the opportunity cost of capital") when calculating the SCC. The market rate of interest and the consumption rate of capital are two different concepts. They are different in the same way that the worth of an item to a person is a different concept than the price the person has to pay to acquire the item. *Id.* at 83; Agencies Ex. 800 at 15-17 (Hanemann Direct). The consumption rate of discount measures how much consumption (income) a decision maker would be willing to give up today in exchange for an extra unit of consumption (income) a year from now. The market rate of interest is the price that measures how much it would cost that decision maker in terms of today's consumption (income) in order to acquire an extra unit of consumption (income) a year from now. Dr. Hanemann

explained that what an item is worth to a person is conceptually different than what it costs – the former reflects factors affecting demand, while the latter reflects factors affecting supply.

Dr. Hanemann also observed that there exist circumstances where what an item is worth is equated to its price. That outcome occurs in a competitive market where the intent of the decision maker is to optimize the quantity of the item in question. This condition applies also to equality of the market rate of interest and the consumption rate of discount – the two are equated when the decision maker is making an optimal intertemporal choice[83] in a competitive market. *Id.* at 84.

Dr. Hanemann reiterated that the assumption of optimality is the crux of the analysis when DICE is being run in its native optimization format. In that case, it depicts what would happen to global GHG emissions if they were controlled by a single, infinitely-lived decision maker optimizing his wellbeing over many centuries. Such an individual would choose levels of consumption and investment in each period so as to ensure that the marginal return on investment just equaled the marginal value of consumption or, equivalently, that the market rate of interest just equaled the consumption rate of discount. *Id.*

But, Dr. Hanemann stated, this result is of no practical relevance for climate policy, or for the SCC, in the real world. In the real world, there is no single, infinitely-lived decision maker controlling the trajectories of global consumption, investment and GHG emissions, and those trajectories are not being determined optimally. In the absence of this optimality, there is no presumption that the observed market rate of interest measures the consumption rate of discount. The market rate of interest, therefore, is an incorrect basis for calculating the SCC. *Id.* at 84-85.

[83] "Intertemporal choice" is the study of how people make choices about what and how much to do at various points in time, when choices at one time influence the possibilities available at other points in time. *https://en.wikipedia.org/wiki/Intertemporal_choice*

In concluding his rejection of Dr. Smith's critique of the discount rates selected in the federal SCC, Dr. Hanemann reiterated his opinion that the IWG was not wrong on economic grounds to focus on the SCC results corresponding to a 3 percent consumption rate of discount. *Id*. at 85. The IWG was making a policy judgment when it decided: (a) to use discount rates of 2.5 percent, 3 percent and 5 percent in developing results for the SCC, and (b) to select the 3 percent value of the SCC as the central estimate. Dr. Hanemann accepts the reasonableness of that judgment. *Id.*

4. Smith's Argument for a Higher Seven Percent Discount Rate Based on Federal Guidance

Dr. Smith argued that: "Federal guidance required use of a seven percent rate when a regulation will affect private sector spending because seven percent approximates the opportunity cost of displaced private sector investment." Agencies Ex. 800 at 85 (Hanemann Direct) (*citing* GRE,MP,OTP,MLIG Ex. 300 at 24 (Smith Direct)). This argument was rejected by the IWG. The IWG addressed that argument as follows:

> While most regulatory impact analysis is conducted over a time frame in the range of 20 to 50 years, OMB guidance in Circular A-4 recognizes that special ethical considerations arise when comparing benefits and costs across generations. Although most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations. Future citizens who are affected by such choices cannot take part in making them, and today's society must act with some consideration of their interest. Even in an intergenerational context, however, it would still be correct to discount future costs and benefits generally (though perhaps at a lower rate than for intragenerational analysis), due to the expectation that future generations will be wealthier and thus will value a marginal dollar of benefits or costs less than the current generation. Therefore, it is appropriate to discount future benefits and costs relative to current benefits and costs, even if the welfare of future generations is not being discounted. Estimates of the discount rate appropriate in this case, from the 1990s, ranged from 1 to 3 percent. After reviewing those considerations, Circular A-4 states that if a rule will have important

> intergenerational benefits or costs, agencies should consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.

Agencies Ex. 801 at 85 (Hanemann Direct) (*citing* CEO Ex. 101 at Sched. 1, pp. 21-22) (Polasky Rebuttal) ("Response to Comments, Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," Interagency Working Group (July 2015)).

The IWG examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the net social costs of a marginal change in CO_2 emissions, as the impacts of climate change are measured in consumption-equivalent units in the three IAMs used to estimate the SCC. This is consistent with OMB guidance in Circular A-4, which states that when a regulation is expected to primarily affect private consumption, for instance, via higher prices for goods and services, it is appropriate to use the consumption rate of interest to reflect how private individuals trade-off current and future consumption.

As explained in the IWG 2010 TSD Report, after its review of the discounting literature, the IWG chose to use three discount rates to span a plausible range of constant discount rates: 2.5, 3, and 5 percent per year. *Id*. at 86. The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. The upper value of 5 percent represents the possibility that climate damages are positively correlated with market returns, which would suggest a rate higher than the risk-free rate of 3 percent. *Id.*

Additionally, Dr. Hanemann explained, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods. The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It 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. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to the ethical concerns regarding intergenerational discounting. *Id.* at 87.

In summary, after consideration of the critiques of other witnesses, Dr. Hanemann continued to recommend the range of estimates he recommended in his Direct Testimony. The estimates presented by the IWG corresponding to the alternative discount rates it considered – 2.5 percent, 3 percent and 5 percent.[84] are as follows:

- The range for the 2015 SCC is from $11 (5 percent) to $56 (2.5 percent).
- The range for the 2020 SCC is from $12 (5 percent) to $62 (2.5 percent).

Id.

P. Criticisms of the Federal SCC Regarding Uncertainty (Issue 22)

Numerous areas of uncertainty were addressed by the IWG in development of the Federal SCC.

First, before running the models, the IWG standardized the non-CO_2 radiative forcing and the climate sensitivity parameter used in the models. The IWG made the value of the climate sensitivity a random variable with the same probability distribution for all three models. This was done to acknowledge the scientific uncertainty that exists regarding this parameter which is the key to summarizing the response of the global climate system to increased radiative forcing from accumulation of GHGs in the atmosphere. Agencies Ex. 800 at 46, 52 (Hanemann Direct).

[84] Also, the IWG's estimates of $36 (in 2007 dollars per metric ton of CO_2) for the 2015 SCC and $42 for the 2020 SCC are reasonable, and are the best available "point estimates" if the Commission wished to consider them. Agencies Ex. 801 at 87 (Hanemann Rebuttal).

Second, the economic impact of a climate catastrophe is not modeled separately in DICE or FUND. In PAGE it is represented by a damage function that kicks in with a positive probability when the increase in global average annual temperature exceeds 3°C. The use of a probability distribution for the numerical value of certain parameters in FUND and PAGE was intended to account for scientific uncertainty regarding the value of those parameters. *Id*. at 42, fn. 32.

Other parties raised various topics in which uncertainty was discussed.

A third topic concerns future emissions and the modeling horizon.[85] Mr. Martin considered the IWG's projections of future emissions as a source of uncertainty. Agencies Ex. 801 at 17 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 30 (Martin Direct). Mr. Martin illustrated in Xcel Ex. 600 at 33 (Martin Direct) the wide range of uncertainty in the IWG's projections of future emissions with a panel in his Figure 5, reproduced here as Figures 1A and 1B. Agencies Ex. 801 at 18-19 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 30 (Martin Direct). Dr. Hanemann responded, referring to Mr. Martin's Figure 1A and the IWG's Figure B, with the observation that if one looked only at Figure 1A, presented by Mr. Martin – the IWG projections through 2100 – one might imagine that the projected emissions continue to grow in the two centuries following 2100. In fact, as Figure 1B demonstrates, that is not what the IWG assumed.

[85] Dr. Smith also noted the influence of uncertainty regarding future emissions and the modeling horizon. Dr. Smith attributed some significance to the fact that, whereas the EMF-22 terminated its projections in 2100, the IWG made projections through 2300. She implied that this difference arose because the EMF modelers – unlike the IWG – "know that the uncertainty in any projections they can make expands as those projections go further in time, until at some point the projections are not useful or meaningful." Ex. 801 at 18-19 (Hanemann Rebuttal) (*citing* GRE,MP,OTP,MLIG Ex. 302 at AES-D-2, p. 69 (Smith Direct)). Dr. Hanemann explained that this implication is incorrect. This concern is addressed in this Initial Brief, at above section IV.7.B., entitled, "The IWG's Projection of Future Emissions and Criticisms of the IWG's Modeling Horizon" (Issue 10).

It assumed that emissions level off and then decline. Agencies Ex. 801 at 23 (Hanemann Rebuttal).

Fourth, as to equilibrium climate sensitivity, Mr. Martin, in his Direct Testimony, discussed ECS and cited Professor Pindyck (Pindyck 2015)[86] as to the uncertainty regarding the climate sensitivity, noting that, as Freeman, Wagner and Zeckhauser (2015) have shown, over the past decade uncertainty over climate sensitivity has increased. Agencies Ex. 801 at 31-32 (Hanemann Rebuttal) (*citing* Xcel Ex. 600 at 39 (Martin Direct)) Mr. Martin's critique is not particularly persuasive, however, because Mr. Martin failed point out the implication that Freeman *et al*. drew from this increase in uncertainty, which is the very point of their paper. Dr. Hanemann explained that the economic implication of the increase in the uncertainty regarding climate sensitivity is that it *raises* the SCC in his economic model of climate change. *Id.* at 32-33. Mr. Martin was silent on this fact. Mr. Martin's testimony on this topic is discussed further in this Initial Brief in above section IV.7.I., entitled, "Criticisms of the IWG's Equilibrium Climate Sensitivity" (Issue 5).

[86] Robert S. Pindyck, The Use and Misuse of Models for Climate Policy (2015), *NBER Working Paper 21097,* April 2015.

Figure 1A: IWG'S EMISSION SCENARIOS - PROJECTIONS 1 THROUGH 2100
Xcel Ex. ___ at 33 (Martin Direct)]

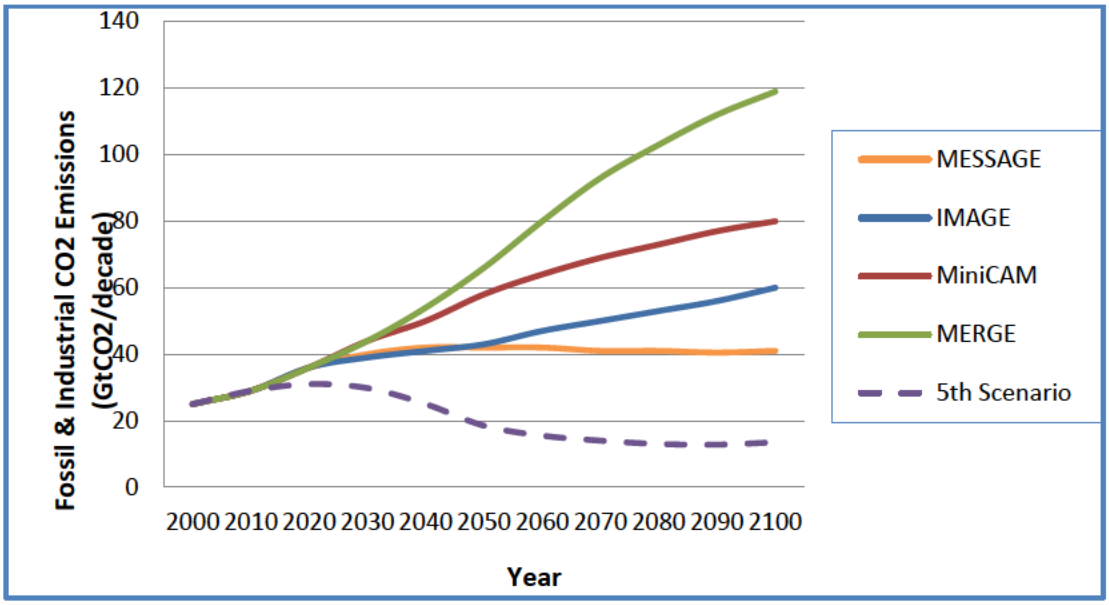
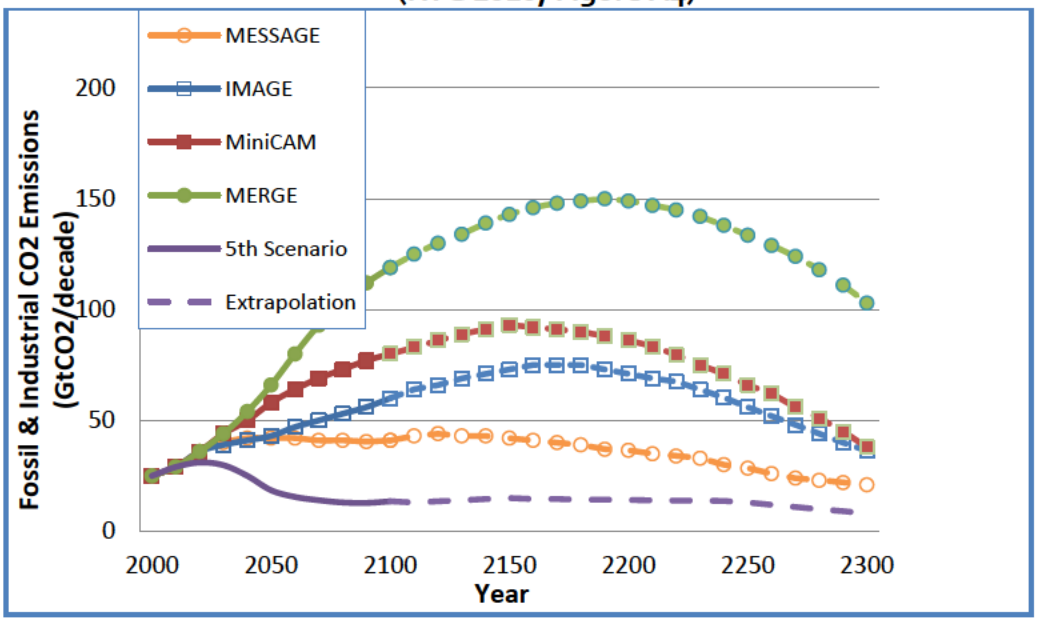


Figure 1B: IWG'S EMISSION SCENARIOS - PROJECTIONS THROUGH 2300
(IWG 2010, Figure A4)



Agencies Ex. 801 at 19 (Hanemann Rebuttal). Dr. Hanemann observed that if one looked only at Figure 1A, presented by Mr. Martin – the IWG projections through 2100 – one might imagine that the projected emissions just continue to grow in the two centuries following 2100. Agencies

Ex. 801 at 23 (Hanemann Rebuttal). In fact, as Figure 1B demonstrates, that is not what the IWG assumed. It assumed that emissions level off and then decline. *Id*.

Fifth, regarding Dr. Smith's criticism of the IAM damage functions, Dr. Hanemann responded and observed that Dr. Smith failed to acknowledge the IWG's observation that its SCC estimate does not fully account for the possibility of climate tipping points that would create uncertainty and not only raise the SCC estimate, but also overturn the conventional pattern in which the SCC starts out low and rises over time: with tipping point uncertainty, the SCC would start out high. Agencies Ex. 801 at 59-60 (Hanemann Rebuttal). This topic is more fully addressed in this Initial Brief in above section IV.7.E., entitled, "Criticisms of the IAM Damage Functions" (Issue 9).

A sixth topic involving uncertainty concerns discount rates. In response to Dr. Smith's criticism of the IWG's selection of the discount rates, Dr. Hanemann explained the uncertainty for which the IWG accounted, explaining that "the low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time." "It 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." Moreover, "a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return." *Id.* at 87. This topic is more fully addressed in this Initial Brief, in above section IV.7.O., entitled, "Criticisms of the IWG's Discount Rates" (Issue 12).

Seventh, another area of uncertainty is hyperbolic discounting. Dr. Hanemann explained in his in response to Dr. Mendelsohn that "[o]ne recent development involves hyperbolic discounting," which is discussed in Agencies Ex. 801 at 79-83 (Hanemann Rebuttal). Hyperbolic discounting occurs when the rate used to discount from one period to the next

declines as the two periods being considered lie farther out in the future. There is empirical evidence that people often see things this way when making real decisions. Given the long span of time involved in the computation of the SCC, any form of hyperbolic discounting would significantly reduce the value of the discount rate. Another consideration is uncertainty and risk aversion. Many uncertainties can arise in the context of long-run decision making on climate mitigation and damage reduction. There is some uncertainty about long-run growth – one doesn't know just how rich future generations will be. There is some uncertainty about how fast the planet will warm, and how damaging this will be. Such uncertainties can be a cause for risk aversion -- a concept explained in Agencies Ex. 801 at 60-62 (Hanemann Rebuttal). If an allowance is made for risk aversion, it has been shown that the effect is to lower the effective discount rate. Agencies Ex. 802 at 24-25 (Hanemann Surrebuttal).

Eighth, regarding Mr. Martin's argument with regard to Dr. Hanemann's Rebuttal Testimony, referring to the 95-percentile value of the SCC "which captures some uncertainty regarding 'tipping point' damages, but not the counterbalancing uncertainty regarding adaptation and technological change." Dr. Hanemann agreed to a limited degree. He agreed that some degree of adaptation and endogenous technological change will occur in the future. The degree to which they will occur is unknown. Since it is unknown, he was not sure how it could be incorporated in IAMs. He observed that, while some adaptation and technological change will occur, it would be wrong to assume that they will occur instantaneously and will be costless and 100 percent effective. In other words, even with adaptation and technological change, costs will still be incurred due to the impacts of climate change. Moreover, while the uncertainty regarding adaptation and technological change offsets to some degree the uncertainty regarding catastrophic damages from climate change, Dr. Hanemann strongly doubted that the former

uncertainty fully "counterbalances" the latter uncertainty. Agencies Ex. 802 at 34 (Hanemann Surrebuttal).

Ninth, Mr. Martin asserted that Xcel's "data trimming" approach to setting SCC values recognized uncertainty and applied well-accepted statistical methods to manage that uncertainty by excluding both low and high outlier values that have a low probability of occurring. Agencies Ex. 802 at 38 (Hanemann Surrebuttal) (*citing* Xcel Ex. 601 at 3 (Martin Rebuttal). Dr. Hanemann denied that Xcel's approach constituted well-accepted statistical methods; he explained that data trimming is applied when the extreme values of the data are regarded as outliers, which is how Mr. Martin mischaracterized them in his Direct Testimony. The values at issue here are not outliers but part of a distribution of SCC values that is skewed with a long right tail. *Id.* at 38-40.

Tenth, regarding the range of SCC values proposed by Dr. Smith in her Direct Testimony, (for 2020, that range was from $1.62 to $5.14 per net metric ton.) Mr. Martin stated: "In the event that the Commission retains a focus on global damages, a range this low and narrow would not capture much of the inherent uncertainty, and would not, in my view, reflect an appropriate level of risk tolerance." Dr. Hanemann agreed with his rejection of those values. *Id.* at 41.

Eleventh, Dr. Hanemann agreed with Mr. Martin's testimony: "I do believe the low, tight SCC ranges recommended by Dr. Mendelsohn … do not adequately capture the inherent uncertainty in predicting climate damages, and imply an inappropriately high level of risk tolerance." and "I do not believe that climate damages are likely to be lower than predicted by the SCC, but I do agree that the range of SCC values recommended by Professor Mendelsohn implies an inappropriately high tolerance of risk." *Id.* at 42.

Q. The Relevance of Leakage for Applying an SCC (Issue 23)

The Commission is required "to the extent practicable, [to] quantify and establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422, subd. 3. The statute makes no exception that would justify the Commission not setting environmental costs when those costs are imposed by electrical generators on particular jurisdictions inside or outside the footprint of Minnesota.

The term "leakage," as discussed by Dr. Smith, and in the context of regulation to limit GHG emissions from electricity generation, refers to the phenomenon that some of the emission reductions resulting from a regulation in one jurisdiction may be offset by increased emissions in other jurisdictions not controlled by the regulator. For example, electric utilities in a regulated jurisdiction switch from high- to low-carbon fuels; but the high-carbon fuel not burned to generate electricity in the regulated jurisdiction ends up being burned by some other utility to generate electricity for consumption in another jurisdiction. Thus, Dr. Smith's argument goes, emissions "leak" from the regulated jurisdiction to the unregulated jurisdiction. Agencies Ex. 801 at 29 (Hanemann Rebuttal).

Dr. Smith asserted that leakage should be taken into account by the Commission when applying the estimate of SCC, arguing:

> If a Minnesota entity reduces its emissions by 100 tons but another entity elsewhere reacts by increasing its emissions by 75 tons (a phenomenon called 'leakage'), the actual change in global emissions is only 25 tons. In this case, the total environmental value of Minnesota's action would only be equal to the environmental value of the net reduction of 25 tons. That is, whatever value one might estimate for a SCC on a $/ton basis, that $/ton should only be multiplied by the net change in global tons, which may be lower than the number of tons that would be reduced directly as a result of a change in a Minnesota resource plan.

Id. (*citing* GRE,MP,OTP,MLIG Ex. 302 at AES-D-2, p. 100 (Smith Direct)).

To be clear, what Dr. Smith asserted was that, if the leakage factor is 75 percent and a regulated entity in Minnesota emits 100 tons of GHGs, the Commission should apply its SCC value to only 25 tons of GHG emissions because the other 75 tons will leak away and will be emitted elsewhere in the United States.

Dr. Hanemann and the Agencies disagree that leakage should be considered when applying an SCC value.[87] Dr. Hanemann explained that the Commission regulates only utilities in Minnesota and does not regulate utilities in other states or other countries. The level of GHG emissions in other states is not the responsibility of the Commission. Further, the Commission has no responsibility for the aggregate level of emissions in the U.S. *Id.*

Consequently, what other states do -- or fail to do -- to control emissions is outside the jurisdiction of the Minnesota Commission. While the Commission is free to consider the actions of other jurisdictions in its decisions regarding the application of externality values, there is no reason to modify its assessment of externality cost ranges based on what may or may not happen in other jurisdictions. The marginal damages resulting from an incremental ton of emissions is not affected by application decisions.

R. Criticisms of The IWG's Assumptions Regarding Mitigation of and Adaptation to Higher Atmospheric Carbon Concentrations.

"Mitigation" refers to activities that cause a reduction of atmospheric carbon concentrations. "Adaptation" refers to practices that enable people to accommodate, or adapt to, increased GHG impacts. The three IAMs used by the IWG were developed in the 1990s for the purposes of determining the benefits and costs of GHG mitigation and measuring the social cost

[87] It is important to note that this proceeding concerns the establishment of a range of externality values for certain pollutants emitted from electricity generation. The issues related to externality value application are many and complex, and have not been fully developed or vetted because they are outside the scope of this proceeding.

of carbon.[88] Agencies Ex. 800 at 31 (Hanemann Direct). Dr. Mendelsohn, Mr. Martin, and Dr. Smith each raised topics involving mitigation or adaptation to which Dr. Hanemann responded.

Dr. Mendelsohn incorrectly stated that Dr. Hanemann appeared "to be unaware that the IWG is measuring the SCC assuming that the rest of the world will never do any mitigation." Agencies Ex. 802 at 6 (Hanemann Surrebuttal) (*citing* Peabody Ex. 218 at ROM-1, p. 3 (Mendelsohn Rebuttal). Dr. Hanemann rebutted this statement, indicating that 1) he was well aware of the IWG's assumption with regard to mitigation, and 2) Dr. Mendelsohn's statement misrepresents what the IWG actually did assume. As shown in Dr. Hanemann's Figure 1B on page 19 of his Rebuttal Testimony (reproduced in this Initial Brief in section 7.B, entitled "The IWG's Projection of Future Emissions and Criticisms of the IWG's Modeling Horizon," the IWG's emission scenarios all assume that GHG emissions are reduced eventually), and one of the five emissions scenarios assumes that emissions are reduced sufficiently to ensure that the atmospheric concentration of CO_2 is stabilized at 550 ppm by the end of this century. Thus, it is incorrect to assert that the IWG assumed the rest of the world will never do any mitigation (i.e., never reduce GHG emissions). *Id*. at 6-7.

Dr. Hanemann also rebutted Dr. Mendelsohn's further assertion, that Dr. Hanemann appeared not to have realized that "the IWG values assume that not only is Minnesota the first place to undergo mitigation, but it is the only place to ever do mitigation" and is "not troubled that the cost of global mitigation is borne by Minnesota alone in this analysis." Dr. Hanemann explained that Dr. Mendelsohn's statement misrepresents what the IWG assumed. The IWG's value of the SCC assumes neither that Minnesota is the first place to undergo mitigation nor that

[88] DICE in its optimization form, was designed to allocate each period's output to consumption, investment and mitigation so as to maximize the total discounted present value of the representative individual's wellbeing (utility) over the span of time considered. Agencies Ex. 800 at 38 (Hanemann Direct).

it is the only place ever to do mitigation. The IWG's estimate was developed, after all, to value mitigation by federal agencies and mitigation resulting from federal regulations. The IWG's SCC estimate measures the value of the damage from an incremental unit of CO_2 emissions added to the emission profiles shown in Figure 1B of Dr. Hanemann's Rebuttal Testimony, or the benefit from a unit of emissions subtracted from those emission profiles, regardless of where in the world the addition (or subtraction) of emissions occurs. Agencies Ex. 802 at 7 (Hanemann Surrebuttal).

Finally, responding to Dr. Mendelsohn's claims that climate change will benefit Minnesota, Dr. Hanemann identified likely impacts of climate change in Minnesota and the limited role for adaptation to address those impacts. He explained that, while he is aware of no published scientifically-based opinions on likely impacts of climate change to Minnesota, the recent US National Climate Assessment characterized the likely impacts of climate change in the Midwest region, including Minnesota, as follows:[89]

1. The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.

2. Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.

3. The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average.

4. Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.

[89] Melillo, Jerry M., Terese Richmond and Gary W. Yohe (eds.) 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*, p. 419.

5. Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.

6. And finally, in one area of impacts, agriculture, adaptation will have a limited effect: In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.

Agencies Ex. 802 at 8-9 (Hanemann Surrebuttal).

Dr. Hanemann also observed that nothing in the testimony of Dr. Mendelsohn showed that he personally studied the impacts of climate change in Minnesota or the mitigation of, or adaptation to, climate change in Minnesota, and did not appear, therefore, to be in a position to offer the assessment he gave. Dr. Mendelsohn's statements about Minnesota were speculative at best. Agencies Ex. 802 at 8 (Hanemann Surrebuttal).

Mr. Martin also provided testimony about adaptation to climate change, to which Dr. Hanemann responded. Mr. Martin made statements regarding Dr. Polasky's testimony and Dr. Hanemann's testimony on this point. Mr. Martin stated:

> Professor Polasky discusses why the IAMs' omission of some damages and incomplete modeling of possible catastrophic damages could lead them to underestimate the value of the SCC, but he does not mention a significant counterbalancing omission that the IAMs incompletely model adaptation to climate change and do not incorporate any endogenous technological change at all.

Mr. Martin made a similar remark regarding Dr. Hanemann's testimony and the 95-percentile value of the SCC, which, Mr. Martin said:

> …captures some uncertainty regarding 'tipping point' damages, but not the counterbalancing uncertainty regarding adaptation and technological change.

Agencies Ex. 802 at 34 (Hanemann Surrebuttal) (*citing* Xcel Ex. 601 at 22, 24 (Martin Rebuttal).

In response to these statements, Dr. Hanemann explained that some degree of adaptation and endogenous technological change will occur in the future, but the degree to which they will occur is unknown, so it is not evident that these processes can be incorporated in IAMs. And, while some adaptation and technological change will occur, it will not occur instantaneously and be costless and 100 percent effective. In other words, even with adaptation and technological change, costs will still be incurred due to the impacts of climate change. Moreover, while the uncertainty regarding adaptation and technological change offsets to some degree the uncertainty regarding catastrophic damages from climate change, Dr. Hanemann strongly doubted that it fully "counterbalances" the latter uncertainty. *Id*.

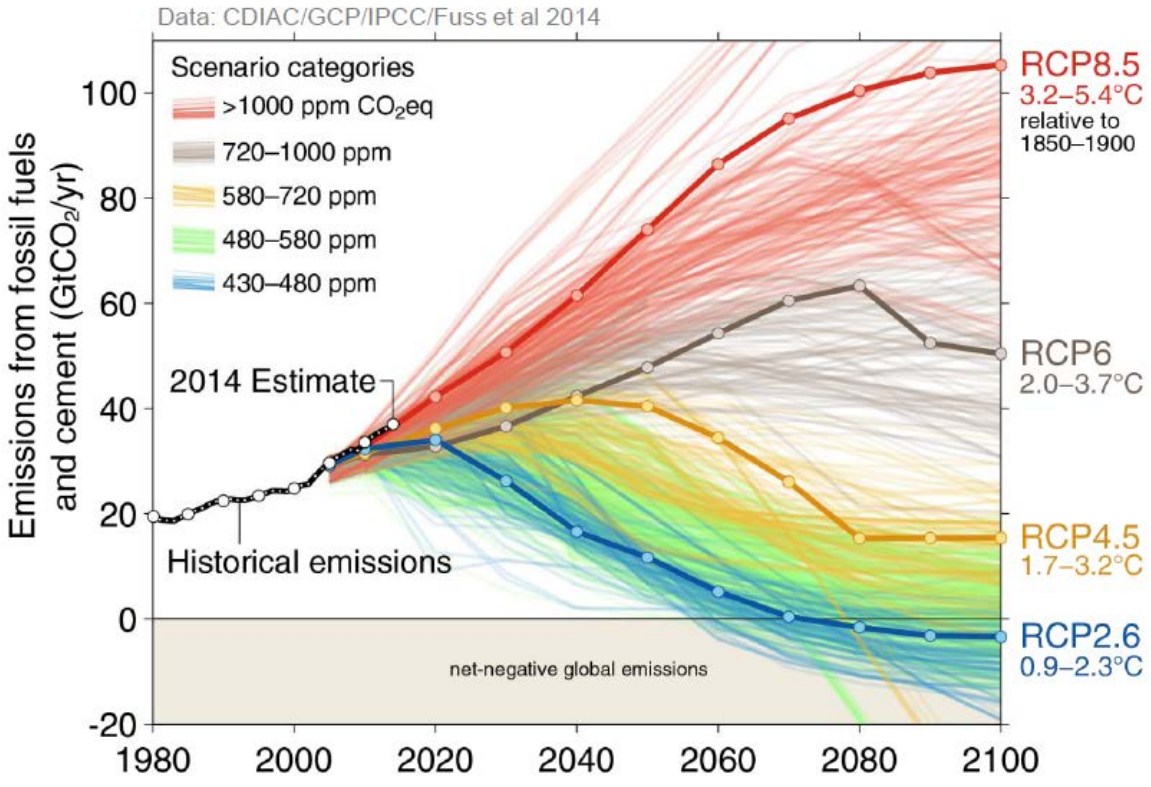
Mr. Martin similarly argued that it is counterintuitive, and contrary to current evidence, to assume that future societies will take no action to scale up GHG mitigation and adaptation, despite experiencing severe climate damages. Mr. Martin claimed that there is "tremendous technical innovation occurring today to reduce the CO_2 intensity of energy, as well as governmental efforts at the state, federal and global scale to mitigate CO_2 emissions and adapt to climate change." *Id*. at 35 (*citing* Xcel Ex. 601at 48 (Martin Rebuttal)).

Dr. Hanemann agreed that there is considerable technical innovation underway to reduce the CO_2 intensity of energy, and significant governmental efforts to promote mitigation, such as the Clean Power Plan in the United States, but observed that in the United States, there is also significant political opposition to these governmental efforts, and the outcome is as yet unclear. Agencies Ex. 802 at 35 (Hanemann Surrebuttal).

The thrust of Mr. Martin's remarks is that the IWG's estimate of the SCC may be too high because it has not adequately accounted for future actions to reduce CO_2 emissions or

otherwise mitigate the climate change impacts of atmospheric carbon. Dr. Hanemann disagreed, explaining that it is premature to draw that conclusion, as it is not factually supportable. The fact is that global emissions have risen significantly over the past fifteen years. As shown in Figure 1 in the Hanemann Surrebuttal (reproduced below) global emissions are currently on track to follow the highest of the four GHG concentration scenarios adopted by the IPCC for its 5th Assessment Report. The United States might move to lower emission and concentration scenarios later in this century, but Mr. Martin's confidence in that outcome is, at present, premature. *Id.*

Hanemann Surrebuttal (p. 36) Figure 1-Observed Emissions and Emissions Scenarios



The black line in Hanemann Surrebuttal Figure 1 shows historical emissions from 1980 through 2014. The faint lines in the diagram are projections of emissions under various scenarios. Each

faint line is a particular scenario that traces the link from economic activity to changes in climate but not the link from changes in climate to impacts and external costs. The majority of the scenarios (about 95 percent) were generated as part of nine model inter-comparison exercises, one of which was the EMF-22 exercise. Agencies Ex. 802 at 35-36 (Hanemann Surrebuttal). The scenarios fall into two groups: those in which emissions were unconstrained ("baseline" scenarios) and scenarios in which emissions were constrained to meet some target level, typically in 2100 – as was the case with the EMF-22 exercise.[90] These heavy lines are colored to indicate the range of 2100 CO_2–equivalent concentrations to which it most closely corresponds. The red scenarios generally correspond to baseline emission scenarios. Hanemann Surrebuttal Figure 1 shows that, as of 2014, the actual trajectory of global emissions corresponds most closely to the highest representative concentration pathway ("RCP") scenario, which is similar to a baseline (unconstrained) trajectory. Agencies Ex. 802 at 37 (Hanemann Surrebuttal).

In conclusion, this present actual trajectory should be taken into account in the ALJs' recommendation and Commission decision, and, as time passes, and more becomes known about the likely trend of emissions during the coming decades, that information can, and should, be used to update future estimates of the SCC. Agencies Ex. 800 at 26 (Hanemann Direct); Agencies Ex. 802 at 37 (Hanemann Surrebuttal).

[90] The scenarios were also classified in a second manner. All the scenarios were run through a single climate model to determine, in a comparable manner, the CO_2-equivalent atmospheric concentration in 2100 associated with the scenario. The scenarios were classified into five groups corresponding to five ranges of CO_2–equivalent values. The five colors, from blue to red, represent this classification. The four heavy colored lines show the four scenarios of anthropogenic forcings ("representative concentration pathways" or RCPs) used by Working Group 1 when running climate models to simulate future climate outcomes. The emissions scenarios were assembled by Working Group III for the 5th Assessment Report. The database contains over 1000 scenarios that met the criteria set for acceptability. The emissions scenarios start in 2010. *Id*. at 37.

Mr. Martin characterized the IWG's future projections of climate impacts negatively, stating:

> [A]ttempting to model climate damages and societal response out to the year 2300 is equivalent to scientists in the early 1700s attempting to model our society today. It is similarly difficult for us to imagine what technologies may be available in the year 2300, and how societies may innovate to reduce CO_2 emissions in response to climate change.

Xcel Ex. 601 at 25 (Martin Rebuttal.

Dr. Hanemann disagreed with Mr. Martin's characterization of what is involved in future projections of climate impacts. The atmospheric concentration of CO_2 is estimated to have been about 280 ppm prior to 1800, the start of the industrial revolution. It rose to about 290 ppm in 1900. In May 2015, the NOAA announced that the monthly global average concentration of CO_2 in the atmosphere exceeded 400 ppm. The last time the Earth had this much CO_2 in the atmosphere was several million years ago,[91] before *Homo sapiens* existed on the planet. The likely climate outcomes are unprecedented in human history. Agencies Ex. 802 at 38 (Hanemann Surrebuttal).

Another topic raised by Mr. Martin that undercuts his suggestion that adaptation and/or mitigation were undervalued by the IWG is his advocacy for the use of the median rather than the mean value of the distribution. Dr. Hanemann disagreed with that recommendation, pointing out that use of the median rather than a mean would fail to incentivize rational economic responses to implement mitigation, as result that runs counter to Mr. Martin's critique of the IWG. Agencies Ex. 801 at 69 (Hanemann Rebuttal).

Dr. Hanemann disagreed for the same reason as that given by the IWG, namely, that the choice of the mean or the median as a measure of central tendency depends on the context. He

[91] National Research Council, *Understanding Earth's Deep Past*, National Academies Press, Washington, D.C., 2011 Figure 2.2.

explained that in skewed distributions, such as for the SCC estimates, the median will often give a more "typical" outcome, while the mean will give full weight to the tails of the distribution. 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). Use of the median to represent the SCC in a regulatory impact analysis would not necessarily lead to the most efficient policy choice that uses resources wisely to mitigate potential climate impacts (e.g., maximize the expected net benefits). In this case, the IWG concluded that the mean is the appropriate measure of central tendency. Agencies Ex. 801 at 69 (Hanemann Rebuttal) (*citing* CEO Ex. 101 at Sched. 1, p. 26) (Polasky Rebuttal) ("Response to Comments, Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," Interagency Working Group (July 2015)).

Dr. Hanemann summarized three points that the IWG provided in its choice of the mean rather than the median. First, the choice of a measure of central tendency with which to represent a probability distribution depends on the decision context and the purpose for which the measure of central tendency will be used. It depends on the criteria by which the decisions are being made. Second, that judgment is a policy judgment. The IWG has clearly made this policy judgment. Third, what is involved is essentially a matter of risk management – regulating GHG emissions so as to avoid the risk of possibly very harmful climatic outcomes in the right tail of the warming and SCC probability distributions. Using the median effectively chops off the tails of the distribution, i.e. ignores the risk of very harmful climatic outcomes. It removes them from consideration, including from consideration of efficient mitigation policy. That is contrary to the objective of a risk management policy. Agencies Ex. 801 at 69-70 (Hanemann Rebuttal).

Dr. Hanemann criticized Dr. Smith's testimony regarding the damage function because she failed to acknowledge the IWG's long-standing observation that its SCC estimate fails to account for the possibility of "climate tipping points" which would raise the SCC estimate and significantly affect mitigation policies. Agencies Ex. 801 at 58 (Hanemann Rebuttal). This topic is addressed more fully in this Initial Brief in above section IV.7.E.d, entitled "The IWG Acknowledges that the SCC Estimate Fails to Account for Climate Tipping Points." Briefly, however, Dr. Hanemann explained "tipping points" and the fact that, once the tipping point danger is resolved, the pace of mitigation may fall back (unless another uncertain threshold for a tipping point lies ahead). *Id.* at 59-60. Dr. Hanemann criticized Dr. Smith for her failure to acknowledge the effect of tipping points. *Id*. at 60.

CONCLUSION

The Agencies respectfully request a Recommendation from the Administrative Law Judges and an Order from the Commission, determining that the 2013 estimate of the federal Social Cost of Carbon developed by the federal government's Interagency Working Group is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422. Such a finding is consistent with the Commission's requirement that the parties to this proceeding evaluate the environmental cost of CO_2 using a damage cost approach, and that the Agencies' consultants use reduced-form modeling to estimate damage costs.[92] It satisfies the Commission's obligation, with respect to CO_2 "to the extent practicable, [to] quantify and establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422, subd. 3.

[92] MPUC Dockets. E-999/CI-00-1636 and E-999/CI-14-643, Notice and Order for Hearing at 5 and 8 (October 15, 2014).

The Agencies request that the Commission issue an Order consistent with the principles, analyses and recommendations addressed in the Agencies' testimony and this Initial Brief.

Dated: November 24, 2015

Respectfully submitted,

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Attorneys for Minnesota Department of Commerce
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ATTACHMENT A TO AGENCIES' INITIAL POST HEARING BRIEF

COMPLETE PROCEDURAL HISTORY OF DOCKET 14-643

On February 10, 2014, the Minnesota Public Utilities Commission ("Commission" or "MPUC") issued an Order in Docket No. E-999/CI-00-1636 reopening its investigation into environmental costs of different methods of generating electricity under Minn. Stat. § 216B.2422, subd. 3. The Commission determined that the investigation would be best resolved in the context of a contested case proceeding conducted by the Office of Administrative Hearings ("OAH"), and sought input on the scope of the investigation, whether to retain an expert, and the possible role of an expert, from a stakeholder group led by Minnesota Department of Commerce, Division of Energy Resources ("DOC-DER") and the Minnesota Pollution Control Agency ("MPCA").[93]

On June 10, 2014, DOC-DER and MPCA filed a report noting a lack of agreement among participants to previous stakeholder meetings or in subsequent comments. The report included the agencies' recommendations concerning the scope and process of the investigation, and the retention of an expert.[94] The contentious issue was that the Commission should adopt the federal social cost of carbon without further proceedings.[95] On June 16, 2014, the Commission requested comments on the report and recommendations.

From June 25, 2014, through August 20, 2014, the Commission received comments from the following entities:[96]

- Fresh Energy, Sierra Club, Izaak Walton League of America – Midwest Office, Will Steger Foundation, Center for Energy and the Environment,

[93] Notice and Order for Hearing at 1 and 4, MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643 (October 15, 2014).
[94] *Id.* at 3-4.
[95] *Id.* at 4.
[96] *Id.* at 1-2.

and the Minnesota Center for Environmental Advocacy ("the Clean Energy Organizations" or "CEO");

- Great River Energy, Minnesota Power, and Otter Tail Power Company (filing jointly);
- The Lignite Energy Council
- Peabody Energy Corporation ("Peabody");
- The Minnesota Chamber of Commerce ("the Chamber");
- The Minnesota Large Industrial Group
- The State of North Dakota
- Xcel Energy ("Xcel")

On October 15, 2014, the Commission issued its Notice and Order for Hearing in which it set forth the scope of the investigation, as follows:[97]

> The Commission will investigate the appropriate cost values for $PM_{2.5}$, SO_2, NO_x, and CO_2. The Commission will not further investigate at this time the environmental costs of other greenhouse gasses such as methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Because CO_2 represents 99% of greenhouse gas emissions, an accurate environmental cost value for CO_2 will account for almost all greenhouse gas costs. This will result in a more manageable proceeding and allow the parties to focus their resources.
>
> It would be premature at this stage to adopt the federal SCC values for CO_2 as the Agencies recommend. The Commission still believes that a contested case proceeding is necessary to fully consider the Agencies' proposed CO_2 cost values. The Commission will therefore not act at this time on the Agencies' proposal to adopt the federal SCC values immediately. But, in light of the record so far, the Commission will ask the Administrative Law Judge to determine whether the Federal Social Cost of Carbon is reasonable and the best available measure to determine the environmental cost of CO_2 and, if not, what measure is better supported by the evidence.
>
> The Commission will require parties in the contested case proceeding to evaluate the costs using a damage cost approach, as opposed to (for example), market-based or cost-of-control values. When last faced with the question of the

[97] Notice And Order For Hearing, *id.*, at 4-5.

> preferred approach to estimate environmental cost values, the Commission stated that, as between estimates based on damage or based on cost-of-control, the damage-cost approach is superior because it appropriately focuses on actual damages from uncontrolled emissions.
>
> Nothing in this proceeding justifies reaching a different conclusion now. Where a damage cost can be reasonably estimated, it represents a superior method of valuing an emission's environmental cost. The Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it.

The Commission also authorized DOC-DER, on a discretionary basis, to work with the Office of Management and Budget to retain a consultant under Minn. Stat. § 216B.62, subd. 8 and, if a consultant was retained, the Commission required that the consultant use reduced-form modeling to estimate damage costs. The Commission also referred the matter to OAH for a contested case proceeding, Administrative Law Judge ("ALJ") LauraSue Schlatter assigned.[98]

Also in its October 15, 2014, Notice and Order for Hearing the Commission identified the issues for parties to "thoroughly address," as follows:[99]

- Whether the Federal Social Cost of Carbon is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422 and, if not, what measure is better supported by the evidence.

- The appropriate values for $PM_{2.5}$, SO_2, and NO_x under Minn. Stat. § 216B.2422, subd. 3.

The Commission referred the above two issues to the OAH for separate contested case proceedings. The Initial Brief of DOC DER and MPCA (jointly, "the Agencies") filed on November 24, 2015 addresses only the first issue, of Carbon Dioxide ($CO_{2)}$.

On December 9, 2014, following a prehearing conference on November 14, 2014, the ALJ issued the First Prehearing Order that:

[98] Notice and Order for Hearing, *id.* at 5 and 8.
[99] Notice and Order for Hearing, *id.* at 5 and 8.

1. Identified the following entities as parties: Clean Energy Organizations; DOC-DER; Peabody; Otter Tail Power; Great River Energy; Minnesota Power; Lignite Energy Council; the Chamber; Minnesota Large Industrial Group; and Northern States Power d/b/a/ Xcel Energy;

2. Established process to develop a public notice plan;

3. Allowed parties to submit memoranda on the question of the burden of proof as it applies to the Federal Social Cost of Carbon, alternative means of measuring the cost of CO_2, SO_2, NO_x, and $PM_{2.5}$; and

4. Adopted the following schedule:

Document or Event	Due Date
Public Notice Plan	January 30, 2015
Memoranda Regarding Burdens of Proof	February 4, 2015
Comments on Public Notice Plan	February 17, 2015
Responsive Memoranda Regarding Burdens of Proof	February 18, 2015
Second Prehearing Conference	March 3, 2015
Intervention Deadline	April 1, 2015
Public Notice Implementation	May 1, 2015

Document or Event	Due Date CO_2	Due Date SO_2, NO_2, and $PM_{2.5}$
Direct Testimony	June 1, 2015	TBD *(August 1, 2015)*
Public Hearing(s), if any (not bifurcated)	TBD *(August, 2015)*	TBD *(August 2015)*
Rebuttal Testimony	TBD *(September 1, 2015)*	TBD *(October 15, 2015)*
Surrebuttal Testimony	TBD *(October 1, 2015)*	TBD *(November 15, 2015)*
Deadline for Public Testimony	TBD *(October 1, 2015)*	TBD *(October 1, 2015)*
Status Conference	TBD *(October 5, 2015)*	TBD *(January 4, 2016)*
Evidentiary Hearing	TBD *(October 12-16, 2015)*	TBD *(approx. January 6-15, 2016)*
Issues Matrix	TBD *(November 12, 2015)*	TBD *(February 1, 2016)*
Initial Briefs	TBD *(November 24, 2015)*	TBD *(February 16, 2016)*

Reply Briefs, Proposed Findings of Fact and Comments, if any, on Issues Matrix	TBD *(December 15, 2015)*	TBD *(March 1, 2016)*
ALJ Report (May or may not be bifurcated)	TBD *(April 15, 2016, if bifurcated; or May 16, 2016 if not bifurcated)*	TBD *(May 16, 2016)*

On March 5, 2015, the ALJ issued a Protective Order.

On March 11, 2015, the ALJ filed a Recommendation for Public Hearings and Public Notice Plan that summarized for the Commission her consultation with the parties and Commission staff, consistent with the Commission's Notice and Order for Hearing, that stated her recommendation that the public should be offered the opportunity to provide input in writing as well as through public hearings, and that stated her request that the Commission agree to implement and bear the cost of the public notice pan and the public hearings in this matter.

On March 20, 2015, the ALJ granted MPCA's petition to intervene as a party.

On March 27, 2015, based on parties' legal memoranda and comments, the ALJ issued an Order Regarding Burdens of Proof that provides, as follows:

> 1. A party or parties proposing that the Commission adopt a new environmental cost value for CO_2, including the Federal Social Cost of Carbon, bears the burden of showing, by a preponderance of the evidence, that the value being proposed is reasonable and the best available measure of the environmental cost of CO_2.
>
> 2. A party or parties proposing that the Commission adopt a new environmental cost value for one or more of the criteria pollutants – SO_2, NOx, and/or $PM_{2.5}$ – bears the burden of showing, by a preponderance of the evidence, that the cost value being proposed is reasonable, practicable, and the best available measure of the criteria pollutant's cost.
>
> 3. A party or parties proposing that the Commission retain any environmental cost value as currently assigned by the Commission bears the burden of showing, by a preponderance of the evidence, that the current value is reasonable and the best available measure to determine the applicable environmental cost.
>
> 4. An environmental cost value currently being applied by the Commission is presumed to be practicable, as required by Minn. Stat. § 216B.2422, subd. 3. A party challenging an existing cost value on the grounds that it is not practicable

bears the burden of demonstrating impracticability by a preponderance of the evidence.

5. A party or parties, opposing a proposed environmental cost value must demonstrate, at a minimum, that the evidence offered in support of the proposed values is insufficient to amount to a preponderance of the evidence. This requirement does not apply to a party challenging an existing cost value based on its alleged impracticability, as described in paragraph 4, above.

6. Any proponent of an environmental cost value, including existing environmental cost values, shall file direct testimony in support of its proposal according to the schedule set forth in the Second Prehearing Order in this matter.

7. A party advocating for retention of an existing cost value may not refer by reference to evidence or testimony from the Commission's CI-93-583 docket or related dockets, but must introduce any evidence on which it intends to rely in this docket, whether the evidence is drawn from an older docket or is new evidence.

8. A party may propose an environmental cost value not proposed in direct testimony in the party's rebuttal testimony only if the new cost value is offered in response to a cost value proposed in direct testimony.

9. The order in which the parties will conduct direct and cross-examination at the evidentiary hearings will be determined at later dates after rebuttal testimony has been filed, but at least two weeks before either evidentiary hearing.

10. The Administrative Law Judge incorporates the following portions of the Commission's Notice and Order for Hearing into this Order:

> a. the parties will use a damage cost approach; and [Footnote omitted]
> b. any DOC consultant must use reduced-form modeling. [Footnote omitted]

On April 16, 2015, the ALJ issued her Third Prehearing Order that encouraged parties to jointly file pre-filed testimony, briefs or other pleadings, and to share responsibilities for cross-examination of witnesses to the extent appropriate and consistent with their positions and interests in the docket, and ordered parties to be prepared to discuss their plans for sharing cross-examination at the prehearing status conferences on September 17 and December 18, 2015. Absent a specific demonstration of relevance, the ALJ determined that testimony as to the

efficacy of renewable energy or renewable energy policy is presumed to be irrelevant to the proceedings and will be excluded.

On April 16, 2015, the ALJ granted the petitions to intervene as parties of Doctors for a Healthy Environment ("DHE"), the Clean Energy Business Coalition ("CEBC") and Interstate Power and Light ("IPL").

On May 27, 2015, following its April 23, 2015, meeting, the Commission issued its Order Requiring Public Hearing, as recommended by the ALJ.

May 29, 2015, the Commission provided the ALJ with its proposed date, time and place for a public hearing, as well as its proposed Notice Plan.

On June 1, 2015, parties filed Direct Testimony regarding CO_2.

On June 2, 2015, the Commission issued its Notice of Public Hearing and Comment Period.

On August 4, 2015, the ALJ issued her Fourth Prehearing Order that identified the evidentiary hearing date for the CO_2 matter as September 24-30, 2015, and scheduled a prehearing conference to take place on August 14, 2015, for the primary purpose of discussing parties' plans for cross-examination, waiver of witness appearances and requests for dates or times certain regarding witness trial appearances.

On August 14, 2015, the ALJ held a prehearing conference.

On August 5, 2015, parties filed Direct Testimony regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

On August 12, 2015, parties filed Rebuttal Testimony regarding CO_2.

On August 28, 2015, the ALJ issued her Fifth Prehearing Order setting forth the following changes to the CO_2 schedule:

Document or Event	New date	[Original Date]
Final CO_2 Prehearing Conference	September 21, 2015 [time omitted]	[September 17, 2015]
Objections to any prefiled direct or rebuttal testimony or witness	September 3, 2015	[September 11, 2015]
Responses to objections to prefiled direct or rebuttal testimony or witness	September 11, 2015	
Objections to any surrebuttal testimony or witness	Unchanged	September 17, 2015
Response to surrebuttal objections	September 18, 2015	

On September 3, 2015, in the CO_2 matter, DOC-DER and MPCA filed a Notice of Motion and Motion to Strike direct and rebuttal testimony of witnesses Drs. Happer, Lindzen, Bezdek and Tol.

On September 3, 2015, in the CO_2 matter, Peabody filed a Motion to Exclude the Rebuttal Testimony of Shawn Rumery and Christopher Kunkle, and a Motion to Exclude the Direct and Rebuttal Testimony of Dr. Hanemann, Dr. Polasky in their entirety, and the statistical opinions of Mr. Martin.

On September 3, 2015, in the CO_2 matter, the Minnesota Large Industrial Group filed a Motion to Strike testimony of Dr. Hanemann, Dr. Polasky, and certain testimony of Mr. Martin.

On September 10, 2015, parties filed Surrebuttal Testimony regarding CO_2.

On September 11, 2015, certain parties filed responses to motions to strike or exclude testimony.

On September 15, 2015, Peabody filed a Motion to Exclude the Surrebuttal testimony of Dr. Peter Reich in its entirety, and certain testimony of Drs. John Abraham, Andrew Dessler, and Kevin Gurney.

On September 15, 2015, the Minnesota Large Industrial Group filed a Motion to Strike the Surrebuttal Testimony of Dr. Peter Reich.

On September 15, 2015, as to certain motions regarding direct and rebuttal testimony, the ALJ issued an Order on Motions By Peabody Energy Corporation, the Minnesota Department of Commerce, and the Pollution Control Agency to Exclude and Strike Testimony which:

- Denied the Agencies' motions to strike direct and rebuttal testimony, with a limited exception;

- Granted the Agencies' motion to strike certain rebuttal testimony of Mr. Happer; and

- Denied Peabody's motion to exclude the testimony of Mr. Rumery and Mr. Kunkle;

On September 15, 2015, as to certain other motions regarding direct and rebuttal testimony, the ALJ issued an Order On Motions By Minnesota Large Industrial Group and Peabody Energy Corporation to Exclude and Strike Testimony which:

- Denied motions of the Minnesota Large Industrial Group and Peabody to exclude the testimony of Drs. Hanemann and Polasky; and

- Denied motions of the Minnesota Large Industrial Group and Peabody to exclude certain parts of Mr. Martin's testimony.

On September 18, 2015, the Agencies filed their Response to Peabody Motion to Exclude Expert Witness Surrebuttal Testimony.

On September 18, 2015, the Clean Energy Organizations filed their Response to Minnesota Large Industrial Group's Motion to Strike Surrebuttal Testimony of Dr. Peter Reich, and Peabody Energy's Motion to Exclude Dr. Peter Reich and Certain Testimony of Drs. Abraham and Dessler.

On September 21, 2015, as to motions regarding surrebuttal testimony, the ALJ issued an Order On Motions by Minnesota Large Industrial Group and Peabody Energy Corporation to Exclude and Strike Testimony which:

- Denied both parties' motions to exclude the testimony of Dr. Reich with limited exception;
- Denied Peabody's motion to exclude certain testimony of Dr. Abraham; and
- Denied Peabody's motion to exclude certain testimony of Dr. Dressler.

On September 21, 2015, the Agencies filed a Motion to Amend Protective Order in order to accommodate discovery by the Agencies and to identify the MPCA as one of the government agencies that will possess protected data in this matter.

On September 23, 2015, granting the Agencies' motion to amend, the ALJ issued an Amended Protective Order.

On September 24 – 30, 2015, the evidentiary hearing in the CO_2 matter took place in the Commission's large hearing room.

On October 14, 2015, regarding the CO_2 matter and the criteria pollutants $PM_{2.5}$, SO_2, and NO_x, the ALJ issued her Sixth Prehearing Order that set forth the following schedule:

Document or Event	**Due Date CO_2**	**Due Date SO_2, NO_2, and $PM_{2.5}$**
Rebuttal Testimony		October 30, 2015
Status Conference		November 2, 2015, 9:30 a.m.
Objections to any prefiled direct or rebuttal testimony or witness		November 6, 2015
CO_2 Issues Matrix	November 12, 2015	
Responses to objections to direct or rebuttal testimony or witness		November 18, 2015

CO_2 Initial Briefs	November 24, 2015	
Surrebuttal Testimony		December 4, 2015
CO_2 Reply Briefs, Proposed Findings, Comments on Issues Matrix	December 15, 2015	
Status Conference – in person		December 18, 2015, 9:30 a.m.
Objections to any prefiled surrebuttal testimony or witness		December 18, 2015
Evidentiary Hearings (may be adjusted if status conferences indicate less time is needed		January 6-8, and 11-15, 2016 - 9 a.m.
Issues Matrix		February 16, 2016
Initial Briefs		March 1, 2016
Reply Briefs, Proposed Findings, Comments on Issues Matrix		April 15, 2016
ALJ Report	April 15, 2016	June 15, 2016

On November 24, 2015, parties filed Initial Briefs in the CO_2 matter.

STATE OF MINNESOTA

OFFICE OF THE ATTORNEY GENERAL

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November 24, 2015

The Honorable LauraSue Schlatter
The Honorable Jeffrey Oxley
Administrative Law Judges
Office of Administrative Hearings
600 North Robert Street
P.O. Box 64620
St. Paul, MN 55164-0620

RE: In the Matter of the Further Investigation in to Environmental and Socioeconomic Costs Under Minnesota Statute 216B.2422, Subdivision 3
PUC Docket No. E-999/CI-14-643;
OAH Docket No. 80-2500-31888

Dear Judges Schlatter and Oxley:

Enclosed please find Initial Post Hearing Brief of the Minnesota Department of Commerce, Division of Energy Resources, and the Minnesota Pollution Control Agency.

Respectfully submitted,

s/ **Linda S. Jensen**
Linda S. Jensen

Attorney for the Minnesota Department of Commerce and Minnesota Pollution Control Agency

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Enclosure
cc: Service List

AFFIDAVIT OF SERVICE

RE: In the Matter of the Further Investigation in to Environmental and Socioeconomic Costs Under Minnesota Statute 216B.2422, Subdivision 3 (2014)
PUC Docket No. E-999/CI-14-643;
OAH Docket No. 80-2500-31888

STATE OF MINNESOTA)
) ss.
COUNTY OF RAMSEY)

I, Annabel Foster Renner, hereby state that on the November 24, 2015, I filed by electronic eDockets the attached **Initial Post Hearing Brief of the Minnesota Department of Commerce, Division of Energy Resources, and the Minnesota Pollution Control Agency** .and eServed or sent by US Mail, as noted, to all parties on the attached service list.

See attached service list for PUC Docket No. E-999/CI-14-643;
OAH Docket No. 80-2500-31888

/s/ **Annabel Foster Renner**
ANNABEL FOSTER RENNER

Subscribed and sworn to before me on
this 6th day of November, 2015.

/s/ **LaTrice Woods**
Notary Public – Minnesota
My Commission Expires January 31, 2020.

Electronic Service Member(s)

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Brown	Hugh	brown.hugh@dorsey.com	Dorsey & Whitney LLP	Electronic Service	No
Cronin	Carl	carl.cronin@xcelenergy.com	Xcel Energy	Electronic Service	Yes
Currie	Leigh	lcurrie@mncenter.org	Minnesota Center for Environmental Advocacy	Electronic Service	No
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Denniston	James	james.r.denniston@xcelenergy.com	Xcel Energy Services, Inc.	Electronic Service	Yes
Dexter	Jessica	jdexter@elpc.org	Environmental Law & Policy Center	Electronic Service	No
Draxten	Brian	bhdraxten@otpco.com	Otter Tail Power Company	Electronic Service	No
Duncan	Tristan	tlduncan@shb.com	Shook Hardy & Bacon, L.L.P.	Electronic Service	No
Eknes	Bret	bret.eknes@state.mn.us	Public Utilities Commission	Electronic Service	Yes
Erickson	Jim	jim.g.erickson@xcelenergy.com	Xcel Energy	Electronic Service	Yes
Gerber	Benjamin	bgerber@mnchamber.com	Minnesota Chamber of Commerce	Electronic Service	No
Gerhardson	Bruce	bgerhardson@otpco.com	Otter Tail Power Company	Electronic Service	No
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Johnson Phillips	Sarah	sjphillips@stoel.com	Stoel Rives LLP	Electronic Service	No
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Klein	Brad	bklein@elpc.org	Environmental Law & Policy Center	Electronic Service	No
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Moratzka	Andrew	apmoratzka@stoel.com	Stoel Rives LLP	Electronic Service	No
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