Xcel Energy®

414 Nicollet Mall
Minneapolis, MN 55401

June 1, 2015

—Via Electronic Filing—

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

RE: DIRECT TESTIMONY – ENVIRONMENTAL COST OF CO_2 EMISSIONS
INVESTIGATION INTO ENVIRONMENTAL AND SOCIOECONOMIC COSTS
MPUC DOCKET NO. E999/CI-14-643
OAH DOCKET NO. 80-2500-31888

Dear Judge Schlatter:

Northern States Power Company, doing business as Xcel Energy, submits the Direct Testimony and Schedules in the above-referenced matter for the following witness:

Nicholas Martin Environmental Cost of CO_2 Emissions

This testimony has been filed in eDockets and thereby served on the parties to this proceeding. Consistent with the First Prehearing Order, we are also providing a printed version via courier to your office.

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

Sincerely,

/s/

JAMES R. DENNISTON
ASSISTANT GENERAL COUNSEL

Enclosures

c: Service Lists

Direct Testimony and Schedules
Nicholas F. Martin

Before the Minnesota Public Utilities Commission
State of Minnesota

In the Matter of the Investigation into Environmental and Socioeconomic Costs
Under Minn. Stat. § 216B.2422, Subd. 3

Docket No. E999/CI-14-643
OAH Docket No. 80-2500-31888
Exhibit___ (NFM-1)

Environmental Cost of CO_2 Emissions

June 1, 2015

Table of Contents

Schedules

I. INTRODUCTION

Q. PLEASE STATE YOUR NAME AND TITLE.

A. My name is Nicholas F. Martin. My title is Environmental Policy Manager for Xcel Energy Services, Inc., which provides services to Northern States Power Company (Xcel Energy, NSPM, or the Company).

Q. PLEASE SUMMARIZE YOUR QUALIFICATIONS.

A. I have 15 years of experience in environmental policy, economics, and science, including climate change and carbon reduction policy, protocols and projects. In my current position, I am the lead carbon policy expert for NSPM, advising the Company on preparing for compliance with the U.S. Environmental Protection Agency's (EPA) proposed Clean Power Plan; Minnesota state policies to reduce greenhouse gas (GHG) emissions; and strategies to reduce carbon emissions through integrated resource planning. Prior to joining Xcel Energy in September 2013, I supervised terrestrial carbon sequestration projects and research for Winrock International, a non-profit organization recognized for its work on GHG reduction globally; and served as Chief Technical Officer developing carbon accounting protocols for the American Carbon Registry. My resume is provided as Exhibit ___ (NFM-1), Schedule 1.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. The purpose of my testimony is to address the following question, posed by the Commission in its October 15, 2014 NOTICE AND ORDER FOR HEARING:

> …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.[1]

My testimony answers this question and proposes a range of carbon dioxide (CO_2) environmental cost values for Commission adoption.

Q. WHAT SHOULD THE CRITERIA BE FOR DEVELOPING THE ENVIRONMENTAL COST OF CO_2?

A. To best fulfill the Commission's directive in this proceeding and responsibilities under Minnesota statute, the methodology to develop the environmental cost of CO_2 must rely on a reasonable and the best available measure, and should be based on a balanced consideration of the following:

- Use of a damage cost approach to valuing environmental costs,[2]
- Reasonably address the inherent uncertainty in estimating climate change damages over almost 300 years,
- Reflect the absence of consensus on discount rate choice,
- Use statistically sound methods,
- Reflect an appropriate level of risk tolerance,
- Minimize subjective judgments,
- Yield a practicable range,[3] and
- Be transparent, replicable, and updatable.

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[1] NOTICE AND ORDER FOR HEARING. *In the Matter of the Investigation into Environmental and Socioeconomic Costs Under Minn. Stat. § 216B.2422, Subd. 3*. Docket Nos. E999/CI-00-1636 and E999/CI-14-643. October 15, 2014, page 8 (Hereafter, "Commission's October 2014 Order").

[2] Commission's October 2014 Order, page 8.

[3] Minn. Stat. § 216B.2422, subd. 3(a) requires the Commission, "to the extent **practicable**, quantify and establish a **range** of environmental costs associated with each method of electricity generation" [emphasis added].

Q. CAN THE FEDERAL SOCIAL COST OF CARBON BE USED FOR DEVELOPING THE ENVIRONMENTAL COST OF CO_2 IN THIS DOCKET?

A. As summarized elsewhere in my testimony, we have serious concerns about using the Federal SCC (SCC) as the basis for the Commission's CO_2 environmental cost values, and do not endorse its use if any single value in the SCC Technical Support Documents (TSD) is proposed for adoption. This would be inappropriate because:

- *The SCC is designed for a purpose* – the cost-benefit analysis of proposed Federal regulations – that is fundamentally different from integrated resource planning and other Commission decisions.
- *The SCC is inherently uncertain and speculative*. Deriving the SCC relies on making assumptions – from now until the year 2300 – about population and GDP growth, the emissions that result from that growth, the temperature change that results from emissions, the damages that result from temperature change, and the appropriate discount rates to apply to those damages. Each of these assumptions is uncertain, and uncertainty builds from one step to the next.
- *There is no single Federal SCC value.* The models used in deriving the SCC predict 450,000 values for any given emissions year, and those values range from negative damages (benefits) to damages of nearly $1,000 per ton of CO_2 emissions. Simply averaging these values is inappropriate, since the average is not an appropriate indication of central tendency for a non-normal probability distribution like the SCC. In fact, adoption of *any* single value would constitute false precision and be inappropriate for resource planning and other Commission decisions.
- *The SCC estimates damages globally to the year 2300*. It is thus much broader than the impacts that CO_2 emissions and climate change may have on

the United States or the State of Minnesota. However, the immediate cost impacts resulting from decisions using the SCC would be borne by utility customers in Minnesota.

Thus, we cannot endorse using the SCC for Commission decisions if any single value is adopted.

However, in the absence of a practicable alternative that meets the Commission's stipulations (including use of a damage costs approach), we believe the *data underlying the SCC* can be used as the basis for developing the Commission's CO_2 environmental cost values, as long as statistical methods are used to derive a range of values rather than a single value, and all values in the range are given equal weight.

In addition to being a requirement in the statute, a range accounts for the inherent uncertainty in estimating future climate change damages, and the lack of consensus on discount rates regarding long-term environmental problems. My testimony presents such a range, and illustrates transparent and replicable methods the Company used to derive this range from the underlying SCC data.

Q. PLEASE SUMMARIZE YOUR TESTIMONY.

A. The question of whether the Federal SCC is reasonable and the best available measure to determine the environmental cost of CO_2 emissions cannot be answered without first noting that there is no single Federal SCC value. Rather, the U.S. Government Interagency Working Group (IWG) that developed the Federal SCC published a large number of different values. The values published in the latest SCC TSD Executive Summary range from $12 to $128/metric ton for emissions in 2020, and Appendix values range from *negative* $29 (that is, net benefits of $29) to positive damage values approaching $1,000/metric ton for that same emissions year.[4] The November 2013 TSD is attached as Exhibit ___ (NFM-1), Schedule 2.

This extremely broad set of values reflects the multiple and currently irreducible uncertainties inherent in predicting global climate damages up to the year 2300 from near-term CO_2 emissions. The methodology to develop the SCC is characterized by significant uncertainty at each step: predicting population and economic growth, predicting the emissions resulting from that growth, predicting the effect of those emissions on temperature change, and predicting the damages that may result from a given change in temperature.

The areas of the greatest uncertainty in the calculation of the SCC include:

- Equilibrium climate sensitivity, or the change in temperature expected to result from doubling atmospheric CO_2 concentrations.
- Damage functions, or the relationship between temperature change and economic damages.
- Adaptation, or the ability of future populations to adapt to climate change and thus decrease damages.
- Modeling of "tipping points," or damages that could result from larger temperature changes.
- The choice of discount rate used to discount future flows of damages

[4] Interagency Working Group on Social Cost of Carbon, United States Government. May 2013, revised November 2013, *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*. (Hereafter, "November 2013 TSD"). See page 3 for executive summary values, and Appendix tables A2 to A4 for the full range of damage predictions for CO_2 emitted in 2020.

(to the year 2300) to their net present value equivalents.

The SCC was developed for use as part of cost-benefit analysis of proposed Federal regulations under Executive Order 12866. The intended purpose of the SCC is to help identify, among the vast array of possible regulations to reduce GHG emissions, those regulations that have positive net benefits. This purpose is inherently different from using the SCC for integrated resource planning and other Commission resource-related decisions.

In the context of regulatory impact analysis, even if the models are imprecise and over- or under-estimate the benefits of reducing CO_2 emissions, as long as benefits exceed costs, it makes sense to develop a regulation. In contrast, if used for Commission decisions, the imprecise SCC would help determine not whether to regulate, but rather how to make individual resource allocation decisions. These decisions – such as whether to operate or retire a power plant, what type of generation capacity to invest in, how to set solar tariffs, how to evaluate Conservation Improvement Program (CIP) benefits – are sometimes binary, difficult to reverse, and often have large and long-term implications for electricity rates, environmental impacts, and reliability.

Therefore considering both the inherent uncertainties, and the Federal SCC's different purpose, the Commission should exercise caution and avoid false precision if using the SCC as the basis for CO_2 environmental cost values. A single value would not reasonably address the uncertainties inherent in predicting climate damages to the year 2300, and would not reflect the absence of consensus on the appropriate discount rate for long-term environmental problems.

While not advancing a legal opinion, I believe adopting a single value would also be contrary to the requirement in Minn. Stat. § 261B.2422, subd. 3(a) "to the extent practicable, [to] quantify and establish a *range* of environmental costs associated with each method of electricity generation."

If the Commission uses the Federal SCC as the basis of its CO_2 environmental cost values, I believe the decision before the Commission is best approached as a probabilistic problem – one of applying statistical methods to identify a practicable range of values that captures, from within the vast population of estimates produced by the SCC models, a reasonable probability of encompassing the value of future climate change damages.

Q. HOW DID THE COMPANY DEVELOP ITS PROPOSED RANGE?

A. We first obtained the raw Federal SCC modeling results, then:

- Aggregated the results across climate models, socioeconomic scenarios, and discount rates, which involved 150,000 data points for each discount rate/emission year combination – a total of 2.25 million data points,
- Analyzed summary statistics,
- Determined an initial range of CO_2 environmental cost values by selecting statistical percentiles representing a significant probability of capturing the value of climate damages as predicted by the SCC models, and
- Equally weighted the SCC values for each of the three discount rates used by the IWG at the low and high ends of our initial range.

Q. WHAT IS THE COMPANY'S PROPOSED CO_2 RANGE?

A. We propose a CO_2 environmental cost range from a low of $12.33 to a high of $41.80 (in 2014 dollars per short ton of CO_2) for emissions in 2020. We provide corresponding low and high values for emissions in each year for which there are SCC data (currently 2010 through 2050). We provide our proposed ranges as Exhibit ___ (NFM-1), Schedule 3 (in 2014 dollars per short ton) and Exhibit ___ (NFM-1), Schedule 4 (in nominal dollars per short ton).

Q. HOW WOULD THE COMPANY'S PROPOSED RANGE BE USED?

A. While my testimony focuses primarily on how to determine appropriate CO_2 environmental cost values, rather than on how those values would be used, I believe some consideration of the appropriate application in integrated resource planning is warranted. The low and high CO_2 environmental cost values I propose are intended as CO_2 externality sensitivities. Since the values underlying our proposed range are derived from symmetrical percentiles and are statistically derived, neither end should be given greater weight than the other. Nor could any midpoint of our range be used without re-introducing the false precision we urge the Commission to avoid.

Q: HOW DOES THE COMPANY'S PROPOSED CO_2 ENVIRONMENTAL COST RANGE COMPARE TO THE REGULATORY COST RANGE CURRENTLY BEING USED IN MINNESOTA?

A: The Commission's April 28, 2014 Order in Docket No. E-999/CI-07-1199 establishes the likely range of costs that future carbon regulation will impose on electricity generation at $9 to $34 per short ton, applied beginning in 2019. The Commission adopted this range for both 2014 and 2015 updates. This regulatory cost is consistent with the Commission's long-standing efforts to assess the risk of potential future carbon regulation. We have long supported the use of this risk planning tool and believe it leads to better decision-making regarding the future of the utility industry.

For near-term emissions, our proposed CO_2 environmental cost range from $12.33 to $41.80 per short ton of CO_2 for emissions in 2020 happens to be close to the regulatory cost range adopted by the Commission in April 2014. Thus, despite our concerns about the SCC, the use of this range is close to current Commission practice, and thus should not disrupt the state's resource planning processes when considering near-term emissions. Further out in time, the values are more divergent. However, unlike the regulatory cost range where the midpoint of the $9-34/ton range is used as a base assumption, in the case of our proposed CO_2 environmental cost range there would be no midpoint or base assumption.

Q. PLEASE EXPLAIN WHY THE COMMISSION SHOULD ADOPT THE COMPANY'S PROPOSAL.

A. In addition to the reasons I described above, the annual ranges we propose are methodologically sound and practicable because they:

- Are based on a damage cost approach, consistent with the Commission's Order,
- Use all Federal SCC modeling results, thus accurately reflecting the degree of uncertainty in predicting emissions, temperature change, and damages out to the year 2300,
- Retain all three discount rates (5 percent, 3 percent, and 2.5 percent) used by the IWG, and are thus neutral on the critical normative

question of discount rate choice,

- Are derived using appropriate statistical methods to capture the underlying uncertainty,
- Require minimal subjective judgment, other than the selection of 25th and 75th percentiles as an appropriate balance of risk tolerance and practicability,
- Produce a practical range that includes the median SCC values at all three discount rates, and
- Require no new modeling, are transparent and replicable, and are easily updated if the Federal SCC values are updated.

Q. HOW HAVE YOU ORGANIZED THE REMAINDER OF YOUR TESTIMONY?

A. My testimony is organized into the following sections:

- *The Federal SCC.* Section II of my testimony describes the definition, purpose, and methodology used to calculate the Federal SCC, and presents the range of values published in the SCC TSDs. The reason for describing the Federal SCC in such detail is not to critique the SCC itself, when used for its intended purpose. Rather, since the Commission is considering using the SCC outside its intended purpose, I believe it is important to understand its merits and flaws, and the sources of uncertainty, in order to understand why we propose a range of CO_2 environmental cost values rather than a single value.
- *The Company's Proposed Approach.* Section III describes how we used the raw Federal SCC model results to develop our proposed CO_2 environmental cost range, and why this approach is more defensible than selecting any single Federal SCC value.

II. THE FEDERAL SCC

A. The Definition, Purpose, and Methodology of the Federal SCC

Q. WHAT IS THE FEDERAL SCC?

A. The Federal SCC is an estimate of monetary damages to society globally, from the year of emission through the year 2300, caused by an additional ton of CO_2 emitted to the earth's atmosphere in a specified year. The SCC TSDs include values for emission years 2010 through 2050; the value for any given emission year represents the net present value of damages from that year through the year 2300.

The damages considered are limited to monetary damages, and include damages to human health (mortality and morbidity), agricultural productivity, forests, coastal damages from sea level rise, water resources, energy consumption (space cooling and heating), human migration, extreme weather (for example, hurricanes), ecosystem services, and some catastrophic threshold risks (for example, ice-sheet collapse).

While some of the models used in deriving the SCC estimate damages by region, including for the United States, the TSDs report only global damages. Federal agencies typically have used the SCC in its inverse sense – as the value of damages avoided by reducing CO_2 emissions incrementally – to evaluate the benefits of proposed Federal regulations that would reduce emissions.[5]

[5] S.K. Rose, D. Turner, G. Blanford, J. Bistline, F. de la Chesnaye, and T. Wilson. 2014. *Understanding the Social Cost of Carbon: A Technical Assessment*. EPRI, Palo Alto, CA. Report #3002004657, page 2-2. Hereafter cited simply as "EPRI". Attached as Exhibit ___ (NFM-1), Schedule 5.

Q. WHAT IS THE PURPOSE OF THE FEDERAL SCC?

A. The SCC was developed for a specific and limited purpose. It was designed as a component of cost-benefit analysis of proposed Federal regulations, as part of the regulatory impact analysis required by the White House's Office of Management and Budget (OMB) under Executive Order 12866. According to the SCC reports,

> Under Executive Order 12866, agencies are required, to the extent permitted by law, 'to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.' The purpose of the 'social cost of carbon' (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions.[6]

The OMB has not recommended the SCC for use in applications other than cost-benefit analysis of proposed Federal regulations under Executive Order 12866. The OMB has been requested to address, but has not yet addressed, the appropriateness of the SCC for other applications.[7]

Q. HOW DOES THE INTENDED PURPOSE OF THE FEDERAL SCC DIFFER FROM INTEGRATED RESOURCE PLANNING AND OTHER COMMISSION DECISIONS?

A. 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. In its intended use, the SCC is a tool to help identify – among the vast array of possible regulations to reduce GHG emissions –

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[6] November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, page 2.

[7] OMB first requested public comment on the SCC in November 2013. We, as well as Edison Electric Institute and the Class of '85 Regulatory Response Group, urged OMB to provide guidance on appropriate and inappropriate SCC applications. As of the date of filing of this Direct Testimony, OMB has yet to respond to any comments received. See the Company's Comments at http://www.regulations.gov/#!documentDetail;D=OMB-2013-0007-0123.

those regulations that have positive net benefits.[8]

Determining whether a potential regulation has net benefits does not necessarily require great precision. Even if the models are imprecise and actually over- or under-estimate the benefits of reducing CO_2 emissions, as long as benefits exceed costs, it makes sense to develop a regulation. The net benefits only need to be positive, not precisely quantified. The SCC has not generally been used to decide the approach to regulation, to design the resulting regulation, or to determine its stringency. The criteria for decisions about the design of a particular regulation are dictated by statutory authorities specific to that regulation, not by the SCC.

In contrast, if used in integrated resource planning and other Commission decisions, the imprecise SCC would not help determine whether to regulate, but rather how to make individual resource allocation decisions. These decisions – such as whether to operate or retire a power plant, what type of generation capacity to invest in, how to set solar tariffs, how to evaluate Conservation Improvement Program (CIP) benefits – are sometimes binary, difficult to reverse, and often have large and long-term implications for electricity rates, environmental impacts, and reliability.

For example, if the Commission adopted a single SCC value that in fact overestimates the benefits of reducing emissions, that value could influence the decision to invest in new generating capacity that is not in fact in the public interest; or, in the event the adopted value underestimates the benefits

[8] Greenstone, Michael, Elizabeth Kopits, and Ann Wolverton, 2013. *Developing a Social Cost of Carbon for U.S. Regulatory Analysis: A Methodology and Interpretation*. Review of Environmental Economics and Policy, 7(1). See pages 23-24. The authors worked for the Council of Economic Advisers in 2009-10 and were part of the Interagency Working Group that developed the SCC.

of reducing emissions, influence the decision not to invest in new generating capacity that is in fact in the public interest. In either case, the decision is binary and is driven by a tool that was never intended to be this precise or to be used for resource planning purposes.

Therefore, a degree of caution is necessary if the SCC is used outside its intended purpose. It becomes important to recognize the lack of precision in the SCC modeling and results. This can to a degree be mitigated by adopting a range of values instead of a single point value.

Q. WHO DEVELOPED THE FEDERAL SCC?

A. The SCC was developed in 2009-10 by a multi-agency U.S. governmental working group that included the White House Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, EPA, National Economic Council, Office of Energy and Climate Change, OMB, Office of Science and Technology Policy, and Department of the Treasury. These agencies published the first SCC Technical Support Document (TSD) in February 2010[9] (see attached Exhibit___ (NFM-1, Schedule 6).

A second TSD was published in May 2013, reflecting updates to the underlying climate models, with SCC values generally 60-70 percent higher than the values published in 2010 (see attached Exhibit___ (NFM-1), Schedule 7). Finally, the IWG made additional minor updates and published a third TSD in November 2013 (see Exhibit___ (NFM-1), Schedule 2). Most of

[9] Interagency Working Group on Social Cost of Carbon, United States Government. February 2010. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*. Hereafter cited as "February 2010 TSD."

the SCC development process has been a closed interagency process, without virtually no public input or scientific peer review. The OMB solicited public comment on the SCC for the first time in November 2013, and received over 100 comments to which it has not yet responded.[10]

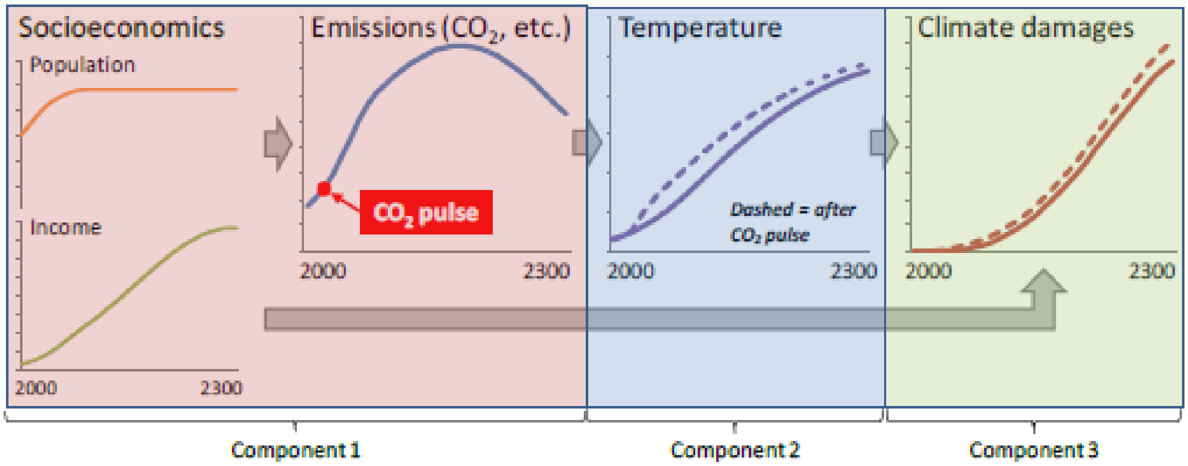
Q. PLEASE DESCRIBE THE METHODOLOGY TO DEVELOP THE FEDERAL SCC.

A. The IWG's methodology for translating an incremental near-term CO_2 emission into an estimate of long-term climate damages involves a "causal chain," depicted in Figure 1 below. Each step in the causal chain is subject to significant uncertainty and each step depends on the prior step, so uncertainty builds across the causal chain.

Because the SCC is an estimate of damages due to an incremental unit of CO_2 emissions – not just total damages from existing atmospheric CO_2 levels – the SCC calculation involves comparing the incremental emission (called the "CO_2 pulse" in Figure 1) to a reference case without that emission. Damages are estimated out to the year 2300 for both the reference case and pulse case, and converted to net present value at various discount rates. The SCC is then the difference in damages, per ton of CO_2 emission, between the two cases.

[10] See http://www.regulations.gov/#!documentDetail;D=OMB-2013-0007-0063.

Figure 1
The Causal Chain Used in SCC Modeling[11]



Q. WHAT IS THE FIRST STEP IN THE SCC METHODOLOGY?

A. The first step in the methodology (referred to in Figure 1 as Component 1) forecasts future emissions based on assumptions about population growth, GDP growth, and the CO_2 intensity of the technologies that fuel GDP growth. These factors are all highly uncertain, so the IWG used five different socioeconomic/emissions scenarios – labeled IMAGE, MERGE Optimistic, MESSAGE, MiniCAM, and 550 ppm average in the TSDs – which they drew from the Stanford Energy Modeling Forum.[12]

Q. WHAT IS THE SECOND STEP IN THE SCC METHODOLOGY?

A. The second step (referred to in Figure 1 as Component 2) is to translate the emissions from step 1 into temperature change. This depends on assumptions about the global carbon cycle, radiative forcing, and equilibrium climate sensitivity (the increase in global average surface temperature resulting from a

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[11] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 3-1.

[12] Clarke, L., J. Edmonds, V. Krey, R. Richels, S. Rose, M. Tavoni, 2009. *International Climate Policy Architectures: Overview of the EMF 22 International Scenarios*. Energy Economics 31 (Supplement 2): S64-S81. See http://www.sciencedirect.com/science/article/pii/S0140988309001960.

doubling of the atmospheric CO_2 concentration relative to pre-industrial levels). This step is conducted using Integrated Assessment Models (IAMs). The five socioeconomic/emissions scenarios from Step 1 function as exogenous inputs to the IAMs.

Q. WHAT ARE THE IAMS USED BY THE IWG?

A. The IWG selected not one but three IAMs: the Dynamic Integrated Climate and Economy (DICE) model developed by Dr. William Nordhaus, the Policy Analysis of the Greenhouse Effect (PAGE) model developed by Chris Hope, and the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model developed by Richard Tol.[13] All three IAMs were developed in the early 1990s and have been updated several times since then. The three IAMs use reduced-form approaches to translate emissions into temperature response and then into net economic damages. However, they are different in many key respects, as I summarize below.

Q. WHAT IS THE THIRD STEP IN THE SCC METHODOLOGY?

A. The third step (referred to in Figure 1 as Component 3) is to translate estimated temperature changes from step 2 into estimated climate damages. This step is also conducted within the IAMs, each of which predicts climate damages, although they model different types of damages and different regions, use different damage functions (that is, the assumed relationship between temperature increase and economic damages), and treat adaptation differently (that is, the ability of future economies to adapt to climate change, thereby decreasing the predicted damages).

[13] See the SCC TSDs, as well as Greenstone, Kopits and Wolverton, 2013.

Q. HOW DID THE IWG USE THE IAMS?

A. Each IAM considers the uncertainty inherent in climate modeling by representing key variables in terms of their probability of occurring, rather than as definite values. This approach is known as Monte Carlo simulation. Models are run repeatedly, each time randomly picking values for uncertain parameters with specified probability distributions. The most important uncertain parameter in this case is equilibrium climate sensitivity, or the change in temperature expected to result from a doubling of atmospheric CO_2 concentrations above pre-industrial levels.

The IWG assumed a probability distribution for equilibrium climate sensitivity, and then ran the IAMs in Monte Carlo mode – 10,000 times for each of the fifteen scenarios (three IAMs * five socioeconomic/emissions scenarios) – with the models making random draws from the distribution for the equilibrium climate sensitivity parameter.[14] As a result, the SCC value for a given emissions year and discount rate results from aggregating 150,000 model results (three IAMs * five socioeconomic/emissions scenarios * 10,000 model runs), and presenting either the simple average (arithmetic mean) or 95^{th} percentile of those 150,000 results. I discuss problems with this approach later in my testimony.

Q. WHAT DISCOUNT RATES DID THE IWG USE?

A. The IWG selected three discount rates to use for discounting future damages and benefits: 2.5 percent, 3 percent and 5 percent. The choice of discount rate

[14] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, pages 12-15. See also Johnson, Laurie T. and Chris Hope, *The Social Cost of Carbon in U.S. Regulatory Impact Analyses: An Introduction and Critique.* J Environ Stud Sci., September 2012; and Metcalf, G. and J. Stock, 2015, *The Role of Integrated Assessment Models in Climate Policy: A User's Guide and Assessment.* Harvard Project on Climate Agreements Discussion Paper, pages 15-68.

is highly controversial and has a greater effect on the SCC than any other single variable. There are arguments in the economics literature for discount rates both lower and higher than those used by the IWG. The IWG acknowledged the absence of consensus on this issue, so it urged agencies to consider the SCC values resulting from all three discount rates when conducting regulatory impact analysis.[15]

Q. HAVE YOU PREPARED A SCHEDULE SHOWING THESE STEPS?

A. Yes. These steps are depicted in the flow chart in Exhibit ___ (NFM-1), Schedule 8.

B. The Federal SCC Modeling Results

Q. WHAT ARE THE PUBLISHED SCC VALUES?

A. The November 2013 TSD presents four SCC values for each emission year in its executive summary, and additional values in an appendix. Three of the executive summary values represent the average across all three IAMs and five socioeconomic/emissions scenarios – that is, the average of 150,000 model outputs for that discount rate and emission year – with the only difference being the choice of discount rate (2.5 percent, 3 percent and 5 percent). The fourth executive summary value represents the 95th percentile, again aggregating across IAMs and socioeconomic scenarios, at a 3 percent discount rate. The four SCC summary values for each emission year are presented in Table 1 below.

[15] November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, page 12.

Table 1
Summary Federal SCC Values from the November 2013 TSD (Shown in 2007 Dollars per Metric Ton of CO_2)[16]

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	32	51	89
2015	12	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

Q. PLEASE EXPLAIN THE ESCALATION OF VALUES OVER TIME.

A. The values in Table 1 are not damages occurring in the year specified; rather, they are the net present value of damages through the year 2300, attributable to an incremental emission in the year specified. The escalation over time is unrelated to inflation, since all values in Table 1 are in $2007; instead, the SCC estimates escalate over time because the IAMs assume a ton of CO_2 emitted in a later year will cause more damage than a ton emitted earlier, since in a later year the climate system is projected to be more stressed due to higher future atmospheric concentrations, and larger societies are projected to have greater climate damage vulnerability.[17]

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[16] November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, page 3. While the SCC TSDs present values in 2007 dollars per metric ton of CO_2, the environmental cost values adopted by the Commission and used in resource planning software would likely be converted to current dollars per short ton of CO_2, since Minnesota utility emissions are generally reported in short tons. However, this is merely a conversion step (adjusting for inflation, and multiplying by 0.907 to convert metric tons to short tons) that can be made after deciding what SCC values to adopt. A short ton is a unit of mass equal to 2000 pounds, while a metric ton equals 2,206 pounds.

[17] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 2-3.

Q. PLEASE DESCRIBE THE ADDITIONAL SCC VALUES PRESENTED IN THE TSD APPENDICES.

A. The TSD appendices present – for emission year 2020 only – disaggregated results by IAM, socioeconomic/emissions scenario, and discount rate. These results are reproduced below in Table 2. It shows results for each IAM separately and, in addition to the average (labeled "Avg") for each IAM, shows the median (labeled "50^{th}," that is, 50^{th} percentile) and various other percentiles (1^{st}, 5^{th}, 10^{th}, 25^{th}, etc.). Table 2 demonstrates that the range of SCC model predictions is much broader than the aggregated values in the TSD executive summary suggest: from $-29 per ton (that is, net benefits of $29 per ton) to net damages of $991 per ton.

Table 2
Disaggregated Federal SCC Results from the November 2013 TSD (Shown in 2007 Dollars per Metric Ton of CO_2)[18]

Table A2: 2020 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario[12]					PAGE					
IMAGE	6	11	15	27	58	129	139	327	515	991
MERGE	4	6	9	16	34	78	82	196	317	649
MESSAGE	4	8	11	20	42	108	107	278	483	918
MiniCAM Base	5	9	12	22	47	107	113	266	431	872
5th Scenario	2	4	6	11	25	85	68	200	387	955
Scenario					DICE					
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario					FUND					
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table A3: 2020 Global SCC Estimates at 3 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	4	7	10	18	38	91	95	238	385	727
MERGE	2	4	6	11	23	56	58	142	232	481
MESSAGE	3	5	7	13	29	75	74	197	330	641
MiniCAM Base	3	5	8	14	30	73	75	184	300	623
5th Scenario	1	3	4	7	17	58	48	136	264	660
Scenario					DICE					
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario					FUND					
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

18 November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, pages 19-20.

Table A4: 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/metric ton CO_2)

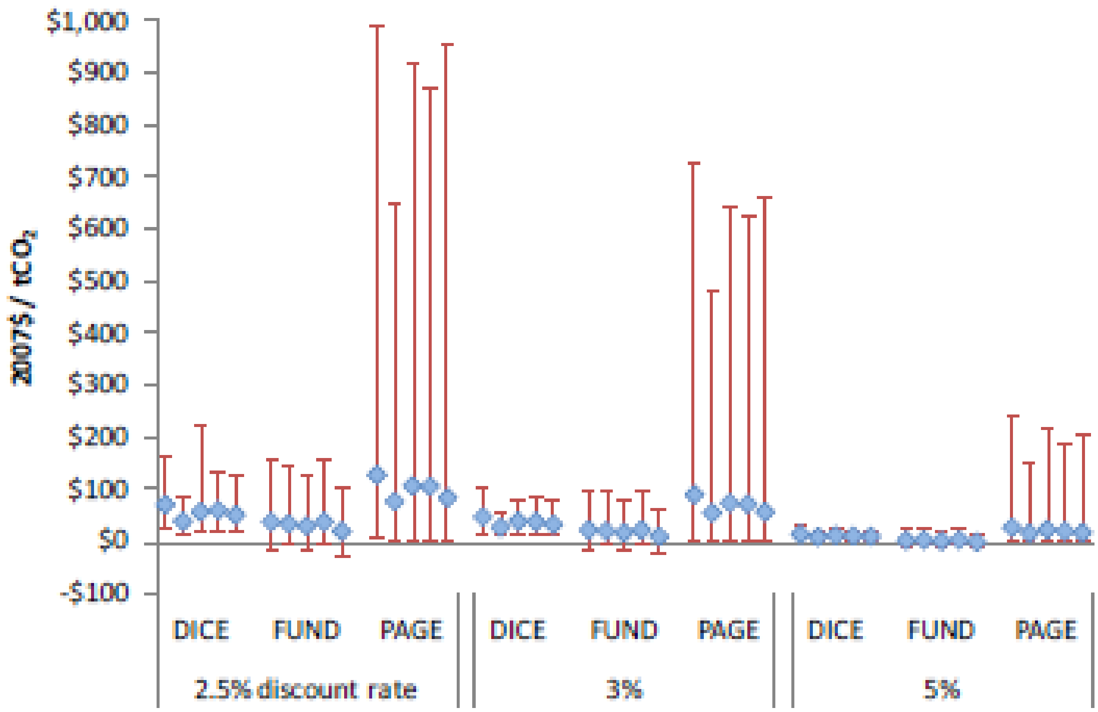
Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	1	2	2	5	10	28	27	71	123	244
MERGE	1	1	2	3	7	17	17	45	75	153
MESSAGE	1	1	2	4	9	24	22	60	106	216
MiniCAM Base	1	1	2	3	8	21	21	54	94	190
5th Scenario	0	1	1	2	5	18	14	41	78	208
Scenario					DICE					
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario					FUND					
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

Q. PLEASE SHOW THE TSD APPENDIX VALUES GRAPHICALLY.

A. Figure 2 below presents graphically the average values (blue diamonds) and 1st to 99th percentile values (red bars) from the TSD appendix tables. Each grouping of five diamonds represents the average values across the five socioeconomic/emissions scenarios for a given IAM and discount rate. Note that the three IAMs differ significantly in damages predicted. FUND generally predicts the lowest net present value damages from CO_2 emitted in 2020, PAGE predicts the highest damages, and DICE is in the middle.

There is a large spread in the results: the damage values range from negative damages (that is, benefits) at the 1st percentile in FUND, to almost $1,000/ton at the 99th percentile and lowest discount rate in PAGE. Even for a given IAM and discount rate, the average SCC values vary considerably by socioeconomic scenario, as shown by the spread within each group of five blue diamonds (which is fairly large despite appearing compressed by the large y-axis scale in Figure 2).

Figure 2
The Mean and 1st to 99th Percentile Federal SCC Values for Emission Year 2020, by Discount Rate, IAM, and Socioeconomic/Emissions Scenario[19]



Q. WHAT DO THE AVERAGE VALUES AND PERCENTILES ABOVE ILLUSTRATE?

A. The 1st and 99th percentile values in Table 2 and Figure 2 confirm that there is too much uncertainty to represent the future value of climate change damages as a single value. For example: PAGE, using the MERGE socioeconomic/ emissions scenario and a 2.5 percent discount rate, predicts an SCC value of $4/ton at the 1st percentile, an average value of $78/ton, and a value of $649/ton at the 99th percentile. This indicates (assuming PAGE credibly predicts damages) that future climate change damages are very likely to be somewhere between $4/ton and $649/ton, but the spread of values is far too wide to have much confidence that the actual value of future climate change damages is close to the average value of $78/ton.

[19] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 2-5.

Q. WHY IS THE AVERAGE VALUE NOT APPROPRIATE?

A. The average values presented in the TSD executive summary are inappropriate for Commission adoption as the environmental cost of CO_2, both because *any* single value raises problems of false precision, and because the average is not the most robust statistic to represent the central tendency of a statistical population that is not normally distributed. Explaining this requires a brief description of normal and non-normal probability distributions.

Q. WHAT IS A NORMAL DISTRIBUTION?

A. For any population of statistical data, a normal distribution (also called a "bell curve") has a symmetric shape. That is, if the distribution is split down the middle, the right side is a mirror image of the left side. Figure 3 provides a generalized depiction of two normal distributions – one (left) in which the values are spread broadly, and one (right) in which they are more tightly clustered around the central value. In the distribution on the right, one can be more confident that the "correct" (most probable) value is close to the central value, since a greater proportion of the values are clustered close to this central value. In the distribution on the left, there is greater spread in the values, thus there is less confidence that the "correct" value is close to the central value.

Figure 3
Generalized Depiction of a Normal Distribution or "Bell Curve."

In a normal distribution, the mean (or average)[20] and the median (or 50th percentile)[21] are the same. When the values in the distribution are ordered from smallest to largest, exactly 50 percent of the values are higher than the mean and median, and exactly 50 percent of the values are lower than the mean and median. Therefore, both the mean and the median are good summary statistics to describe central tendency for a normal distribution.

Q. DO THE FEDERAL SCC MODELING RESULTS HAVE A NORMAL PROBABILITY DISTRIBUTION?

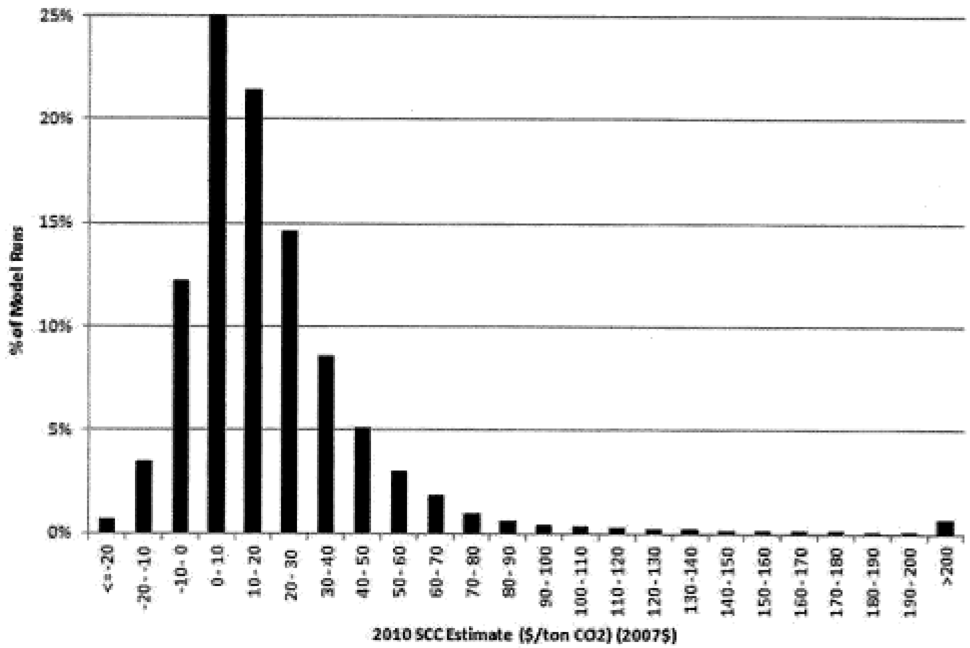
A. No. Figure 4 shows all the SCC values predicted by the IAMs for 2010 emissions, arranged from smallest to largest, on the horizontal axis, with the percent of model results (that is, probability of occurring) arranged on the vertical axis. This distribution is non-normal, with a long right tail of high

[20] According to the *Reference Manual on Scientific Evidence,* the mean (also average) is the expected value of a random variable, derived by adding the numbers and dividing by how many there are. Federal Judicial Center and National Research Council of the National Academies. 2011. *Reference Manual on Scientific Evidence, Third Edition*. Washington, DC: The National Academies Press. See http://www.fjc.gov/public/pdf.nsf/lookup/SciMan3D01.pdf/$file/SciMan3D01.pdf. Hereafter cited as "*Reference Manual on Scientific Evidence*."

[21] According to the *Reference Manual on Scientific Evidence,* the median "is a way to find the center of a batch of numbers. The median is the 50th percentile. Half the numbers are larger, and half are smaller. (To be very precise: at least half the numbers are greater than or equal to the median; at least half the numbers are less than or equal to the median; for small datasets, the median may not be uniquely defined).

damage values. For such a distribution the mean and median will not be the same.

Figure 4
Probability Distribution of SCC Estimates for 3 Percent Discount Rate (2007 Dollars per Metric Ton of CO_2).[22]



Q. WHY IS THE AVERAGE AN INAPPROPRIATE SUMMARY STATISTIC FOR A NON-NORMAL PROBABILITY DISTRIBUTION LIKE THE FEDERAL SCC?

A. The average (mean) is greatly influenced by outliers, that is, values that are much higher or much lower than most of the values. In the case of the Federal SCC – a non-normal probability distribution that is skewed to the right – the mean is significantly higher than the median, since it is pulled up by outliers in the long right tail of damage values that are high but have a relatively low probability of occurring.

This can be confirmed by looking back at Table 2 above: for any given IAM,

[22] Greenstone, Kopits and Wolverton, 2013, page 37.

socioeconomic/emissions scenario, and discount rate, the mean (labeled "Avg" in the tables) is invariably higher, in some cases significantly higher, than the median (labeled "50th" in the tables). The differences are more pronounced at the lower discount rates.

Q. SHOULD THE COMMISSION ADOPT ANY OF THE FIRST THREE TSD EXECUTIVE SUMMARY VALUES?

A. No. The first three values in the TSD executive summary (see Table 1 above) are single point values based on the mean of the aggregated results from all three IAMs and five socioeconomic/emissions scenarios – the result of averaging 150,000 SCC values for a given discount rate and emission year. The Commission should not adopt any of these values as its CO_2 environmental cost value, since – in addition to the problem of false precision if the Commission adopted *any* single value – the mean is greatly influenced by high outliers, making it not an appropriate measure of central tendency for a non-normal probability distribution such as the SCC.

Q. WHAT IS A MORE APPROPRIATE MEASURE OF CENTRAL TENDENCY FOR A NON-NORMAL PROBABILITY DISTRIBUTION?

A. The median is a more robust measure of central tendency for a non-normal probability distribution, because it represents the midpoint – with 50 percent of values below and 50 percent of values above – and is not influenced by outliers.

Q. SHOULD THE COMMISSION THEN ADOPT A SINGLE MEDIAN VALUE?

A. No. Even though the median would be a more appropriate indication of central tendency than the mean, it would still suffer from false precision. In addition, if the Commission adopted, for example, the median SCC value across IAMs at a 3 percent discount rate, the Commission would be selecting a single discount rate – an issue on which the IWG has acknowledged there is no consensus.[23] We do not propose the adoption of any single value, but rather the adoption of a range of values. I describe in Section III of my testimony the range we propose and our methods for arriving at this range.

Q. SHOULD THE COMMISSION ADOPT THE FOURTH EXECUTIVE SUMMARY SCC VALUE, BASED ON THE 95TH PERCENTILE AT 3 PERCENT DISCOUNT RATE?

A. No. The fourth SCC value (see far right column in Table 1 above) was included to "represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution."[24] The IWG presented this value because the three IAMs do not fully model "tipping point" damages or damages under more extreme climate change scenarios (for example, greater temperature increases than the temperature increases for which the models have been calibrated).

On the other hand, the IAMs do not fully capture adaptation to climate change, which could lead them to over-estimate damages.[25] While acknowledging that these factors could cause the IAMs to over- and under-estimate damages, we note that from a purely statistical perspective, there is no rationale for the IWG to have presented a 95th percentile value without the corresponding 5th percentile value. Adopting this value would be statistically indefensible, and would moreover privilege a single discount rate. We do not propose adoption of any single value (mean, median, 95th, 5th, or any other

[23] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, page 17.
[24] November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, page 2.
[25] Greenstone, Kopits and Wolverton, 2013, page 26.

percentile), but rather proposes the adoption of a range of values.

C. Modeling Uncertainties, Methodological and Procedural Critiques

1. Modeling Uncertainties

Q. WHAT IS THE PURPOSE OF THIS SECTION?

A. This section of my testimony summarizes key uncertainties at each of the steps in the SCC causal chain, drawing primarily on the original February 2010 TSD (Exhibit ___ (NFM-1), Schedule 6), and the Electric Power Research Institute's (EPRI) Technical Assessment of the SCC (Exhibit ___ (NFM-1), Schedule 5).[26] We believe these uncertainties make it crucial for the Commission to adopt a range of CO_2 environmental cost values rather than a single value.

In general, the areas of greatest uncertainty impacting the SCC value are: equilibrium climate sensitivity (the change in temperature expected to result from doubling atmospheric CO_2 concentrations), damage functions (the relationship between temperature change and economic damages), adaptation (the ability of future populations to adapt to climate change and thus decrease damages), modeling of "tipping points" (damages that could result from larger temperature changes), and the choice of discount rate.[27]

[26] The EPRI *Technical Assessment* is attached as a Schedule and cited extensively because it represents, in my view, the most comprehensive and in-depth diagnostic assessment available of the SCC modeling approach. EPRI assesses each of the steps of the causal chain separately – socioeconomics and emissions, temperature response, and climate damages. For each step, EPRI developed and ran diagnostic scenarios isolating that step and running it in DICE, FUND and PAGE separately. This allowed EPRI to see how each IAM treats each step, in isolation from the others. EPRI then assesses the overall IWG experimental design. The assessment reveals significant variation across models in their structure, behavior, and results, and identifies fundamental issues and opportunities for improvements. The *Technical Assessment* is available at http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004699.

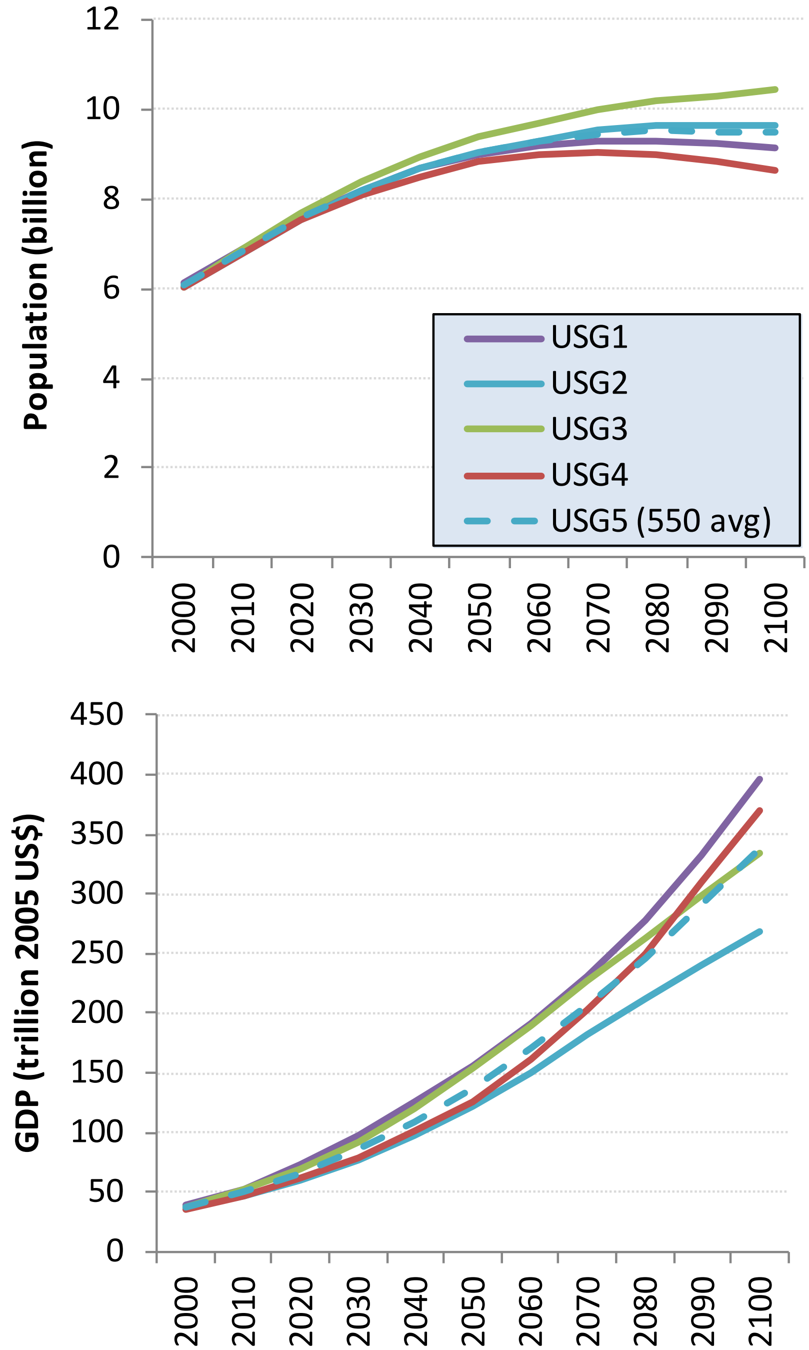
[27] See Metcalf and Stock, 2015; Greenstone, Kopits and Wolverton, 2013; Pindyck, Robert S. 2015. *The Use and Misuse of Models for Climate Policy.* National Bureau of Economic Research. Working Paper 21097;

Q. WHAT UNCERTAINTIES EXIST IN THE CAUSAL CHAIN'S STEP 1, PREDICTING SOCIOECONOMIC CONDITIONS AND EMISSIONS?

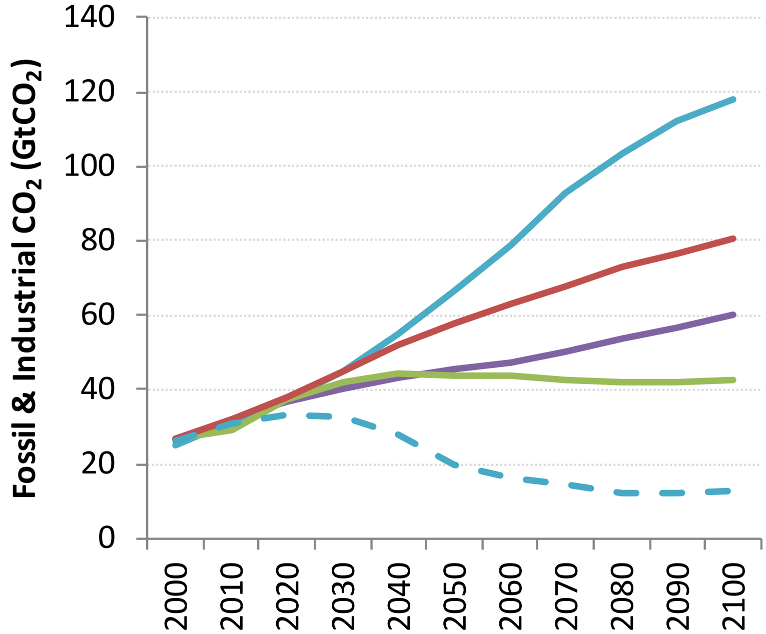
A. First, forecasting population, GDP growth and emissions globally is difficult, and predictions vary widely across the five Stanford Energy Modeling Forum scenarios (IMAGE, MERGE Optimistic, MESSAGE, MiniCAM, and 550 ppm average) used by the IWG. For example, global population in the year 2300 ranges from 8 billion to 11 billion people, and global GDP from about $750 trillion to $2,200 trillion, across the five scenarios. Figure 5 summarizes differences among the five scenarios and shows the variation in expected population, GDP and emissions results.

Pindyck, Robert S. 2013. *Climate Change Policy: What Do the Models Tell Us?* National Bureau of Economic Research, Working Paper 19244.

Figure 5
Variation in Global Population, GDP, and Fossil and Industrial CO_2 Emissions to Year 2300 under IMAGE, MERGE Optimistic, MESSAGE, MINICAM, and 550 ppm Average (Here Labeled as USG1 to USG5 Respectively)[28]



[28] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 4-4. Also predicted by the models, but not shown above, are a broad range in estimates of land use CO_2 emissions and non-CO_2 greenhouse gas impacts.



Second, the five Stanford Energy Modeling Forum scenarios forecast population, GDP growth and CO_2 emissions only out to the year 2100. The IWG used its own, non-peer-reviewed methods to extend these forecasts to the year 2300. For example, the IWG assumed that population growth declines linearly to zero by the year 2200; GDP growth declines linearly to zero by the year 2300; and the decline in the fossil and industrial CO_2 intensity growth rate over the years 2090-2100 is maintained to the year 2300.[29] These are largely arbitrary assumptions, and they drive all subsequent modeling steps (temperature response and damage estimation) after the year 2100.

Third, even if population and GDP growth forecasts are correct, estimating the emissions that will result requires assumptions about (1) the assumed energy intensity of GDP growth and (2) the assumed CO_2 intensity of energy. If we assume the future will be like the past, and other regions of the globe will develop using similar technologies as those that characterized the era of

[29] Greenstone, Kopits and Wolverton, 2013, page 36.

the Industrial Revolution, emissions will be very high. If future growth "leapfrogs" the high energy intensity and CO_2 intensity of the Industrial Revolution, CO_2 emissions for a given unit of population and GDP growth will be lower. The Stanford Energy Modeling Forum scenario assumptions about energy intensity of GDP growth and CO_2 intensity of energy may or may not prove correct.

Fourth, none of the IAMs incorporates what economists call "endogenous technological change." In other words, the IAMs take the Stanford Energy Modeling Forum scenarios as exogenous, front-end inputs and do not account for the possibility that future societies, in response to the impacts of climate change, are likely to develop new technologies with lower CO_2 intensity than was initially assumed. The lack of endogenous modeling of technological change can be put into perspective by recalling that the IAMs are modeling a time period (present to the year 2300) that is significantly longer than the time that has elapsed from the Industrial Revolution to the present, during which technology has changed tremendously.

Fifth, four of the five socioeconomic scenarios (IMAGE, MERGE Optimistic, MESSAGE, and MiniCAM) are "baseline" futures that assume no coordinated global GHG reduction effort or policy, and therefore result in atmospheric CO_2 concentrations ranging from 612 to 889 parts per million (ppm) in the year 2100. In contrast, the "550 ppm average" scenario assumes a global climate agreement to stabilize atmospheric CO_2 concentrations at 550 ppm by the year 2100.[30] The IWG, since it averaged across all IAMs regardless of socioeconomic scenario, essentially treats all five scenarios as equally likely

[30] See February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, pages 15-17; and Greenstone, Kopits and Wolverton, 2013, pages 28-29.

to occur. Four fifths of the model results yielding the SCC value for a given discount rate and emission year (120,000 results) assume no coordinated global GHG reduction effort or policy, while one fifth (30,000 results) assume sufficient global agreement to contain atmospheric CO_2 concentrations at 550 ppm. I cannot prognosticate on the chances of international climate negotiations to reach agreement, but I do believe both of these versions of the future – a global agreement sufficient to achieve 550 ppm, and no global coordination at all – are somewhat unlikely. Yet these socioeconomic/ emissions scenarios drive all subsequent SCC modeling steps.

Because of all the uncertainties summarized above, the five scenarios forecast significantly different CO_2 emissions. Referring back to Figure 5, forecasted fossil and industrial CO_2 emissions in the year 2300 range from about 10 $GtCO_2$ (10 gigatons, or 10 billion metric tons) in the 550 ppm average scenario – less than a third of global emissions today[31] – to an emissions trajectory in MERGE Optimistic that peaks over 140 $GtCO_2$ around the year 2200 and ends at about 100 $GtCO_2$ in the year 2300 (see the bottom chart in Figure 5 above). Thus, there is a greater than tenfold spread in emissions futures forecasted by the five socioeconomic scenarios.

Q. WHAT UNCERTAINTIES EXIST IN THE CAUSAL CHAIN'S STEP 2, PREDICTING TEMPERATURE CHANGE FROM THE EMISSIONS FORECASTED IN STEP 1?

A. Step 2 of the SCC methodology introduces uncertainties on top of those inherited from Step 1. Step 2 is conducted using the three IAMs: DICE, FUND, and PAGE. Translating emissions into higher temperatures depends

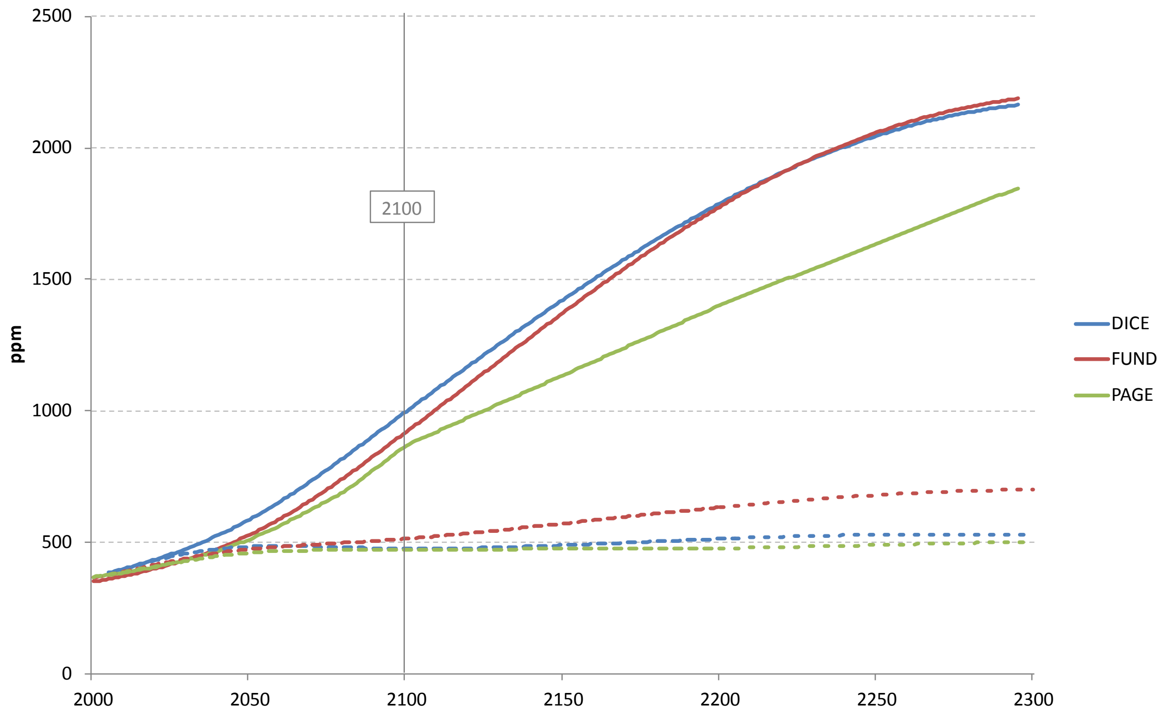
[31] According to the International Energy Agency, global CO_2 emissions in 2014 were 32.3 billion metric tons. See http://www.iea.org/newsroomandevents/news/2015/march/global-energy-related-emissions-of-carbon-dioxide-stalled-in-2014.html.

on several intermediate steps: a) predicting the effect of emissions on atmospheric CO_2 concentrations, b) predicting the effect of increased atmospheric CO_2 concentrations on radiative forcing, and c) predicting the effect of increased radiative forcing on global temperatures.

The translation of emissions into higher atmospheric CO_2 concentrations depends on modeling the global carbon cycle, including terrestrial fluxes, ocean uptake, and climate feedbacks. These are exceedingly complex dynamics that DICE, FUND and PAGE all model in different ways. The translation of atmospheric CO_2 concentrations into higher radiative forcing (the change in the earth's heat balance relative to pre-industrial levels) is also modeled differently by DICE, FUND and PAGE. There is a particularly wide range in the IAMs' treatment of radiative forcing from non-CO_2 greenhouse gases.

Figure 6 below illustrates the range in predicted atmospheric CO_2 concentrations (measured in parts per million), radiative forcing (measured in Watts per square meter), and temperature change (measured in degrees Celsius above pre-industrial average temperature) across DICE, FUND and PAGE. The solid lines represent the highest emissions scenario, MERGE Optimistic, and the dotted lines represent the lowest emissions scenario, 550 ppm average.

Figure 6
Change in Atmospheric CO_2 Concentrations (Top Figure, in Parts per Million), Total CO_2 and Non-CO_2 Radiative Forcing (Middle Figure, in Watts/m^2), and Average Global Temperature (Bottom Figure, in Degrees Celsius Above Pre-Industrial) Across the Three IAMs[32]



[32] EPRI, Exhibit ___ (NFM-1), Schedule 5, pages 5-21 to 5-24. (The *solid lines* show IAM predictions for MERGE Optimistic, the highest emission scenario, and the *dashed lines* for the 550 ppm average, the lowest emission scenario.)

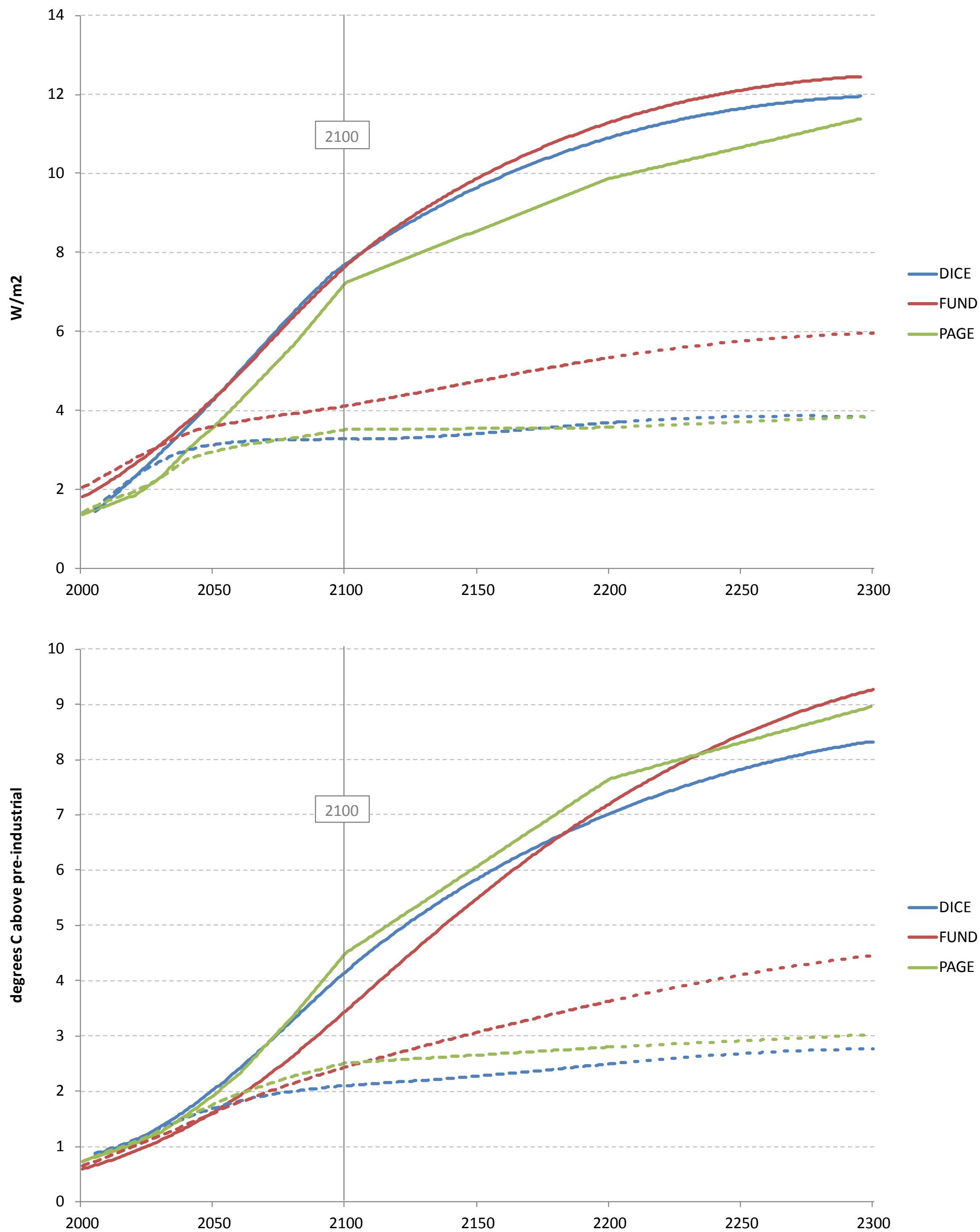


Figure 6 demonstrates two key points. First, the three IAMs produce very different results when they use the same socioeconomic/emissions scenario (the spread within each group of solid or dotted lines). Second, the same IAM produces very different results depending on which socioeconomic/emissions scenario it uses (the gap between solid and dotted lines). The Federal SCC methodology aggregates and averages the SCC results regardless of IAM and socioeconomic/emissions scenario, obscuring their underlying differences and the broad range of results.

Most importantly, there is little agreement on equilibrium climate sensitivity – the temperature change associated with a doubling of atmospheric CO_2 concentrations above pre-industrial levels – and little empirical data on which to base this key parameter of the models. Dr. Robert Pindyck, a vocal critic of the use of IAMs for developing climate policy, has published numerous peer-reviewed articles as well as two Working Papers on this topic for the National Bureau of Economic Research.[33] He notes that:

> We know very little about climate sensitivity, i.e., the temperature increase that would eventually result from a doubling of the atmospheric CO_2 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.[34]

Q. WHAT UNCERTAINTIES EXIST IN THE CAUSAL CHAIN'S STEP 3, PREDICTING DAMAGES FROM THE TEMPERATURE CHANGE FORECASTED IN STEP 2?

A. Step 3 of the SCC methodology introduces uncertainties on top of those inherited from Steps 1 and 2. Step 3, also conducted in the IAMs, calculates damages resulting from a given temperature change. However, the three IAMs differ significantly in how they model the damages. First, the number and type

[33] Pindyck, 2015 and Pindyck, 2013.
[34] Pindyck, 2015, pages 1-2. See also Pindyck, 2013, pages 8-10.

of damages modeled differ. DICE models only two categories of damages, sea-level rise and non-sea level rise, and they are modeled globally without regional differentiation. FUND models 14 types of damages (sea level rise, agriculture, forests, heating, cooling, water resources, tropical storms, extra-tropical storms, biodiversity, cardiovascular respiratory, vector borne diseases, morbidity, diarrhea, migration) in 16 regions. PAGE models 4 types of damages (sea level rise, economic, non-economic, and "discontinuity" (that is, abrupt changes)) in 8 regions.[35]

Second, the IAMs differ in how they model adaptation to climate change. Damages are a function of temperature change in step 2, but are also affected by the socioeconomic assumptions in step 1, since greater income may allow greater resiliency and the ability to adapt to climate change. IWG participants acknowledge that:

> The three models vary widely and how they account for compensatory adjustments, or adaptation, in response to climate change, which will mitigate the negative impacts on well-being… It is possible that the three models fail to account adequately for the various ways in which adaptation could occur. However, the evidence available on this issue is limited. Thus the interagency group retained the modelers' assumptions in this regard.[36]

Third, the IAMs differ in how they predict regional damages. PAGE calculates damages in the European Union, then simply scales damages in other regions based on length of coastline in proportion to the European Union. It shows the majority of near-term global damages in the European Union and United States. FUND, which models damages regionally, shows much more near-term impact in China. DICE does not model damages by region.

[35] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 6-6.
[36] Greenstone, Kopits and Wolverton, 2013, page 26.

Finally, the IAMs differ in the overall magnitude of estimated damages. FUND estimates generally lower damages (and in some cases net benefits) prior to the year 2100, mostly due to enhanced agricultural productivity, reduced heating demand, and an assumed greater ability to adapt to climate change. However, FUND forecasts escalating damages after year 2100. DICE and PAGE estimate higher damages immediately and throughout the modeling timeframe.

EPRI's Technical Assessment found very large differences between the IAMs in predicted damages, even when EPRI isolated this modeling step by setting identical socioeconomic (step 1) and temperature change (step 2) assumptions:

> …using identical climate and socioeconomic futures, we find significant variation in the behavior across models in projected sea level rise (SLR) and overall climate damages. DICE and PAGE produce substantially higher net climate damages (and percent GDP losses) than FUND, and FUND estimates the potential for net benefits from climate change over much of the next half century while the other models estimate net damages for the entire century. For example, we observe the models producing significantly different annual damages for the same temperature increase, differing by as much as a factor of three over the next century.[37]

Figure 7 illustrates the range in expected damages across the IAMs for the highest socioeconomic/emissions scenario (MERGE Optimistic, left hand side, labeled USG2) and lowest scenario (550 ppm, right hand side, labeled USG5). The top chart, focusing on damages to year 2100, shows that DICE and PAGE predict relatively similar overall results, although modeling different damages and regions. FUND initially predicts negative damages, mostly due to enhanced agricultural productivity and reduced heating demand.

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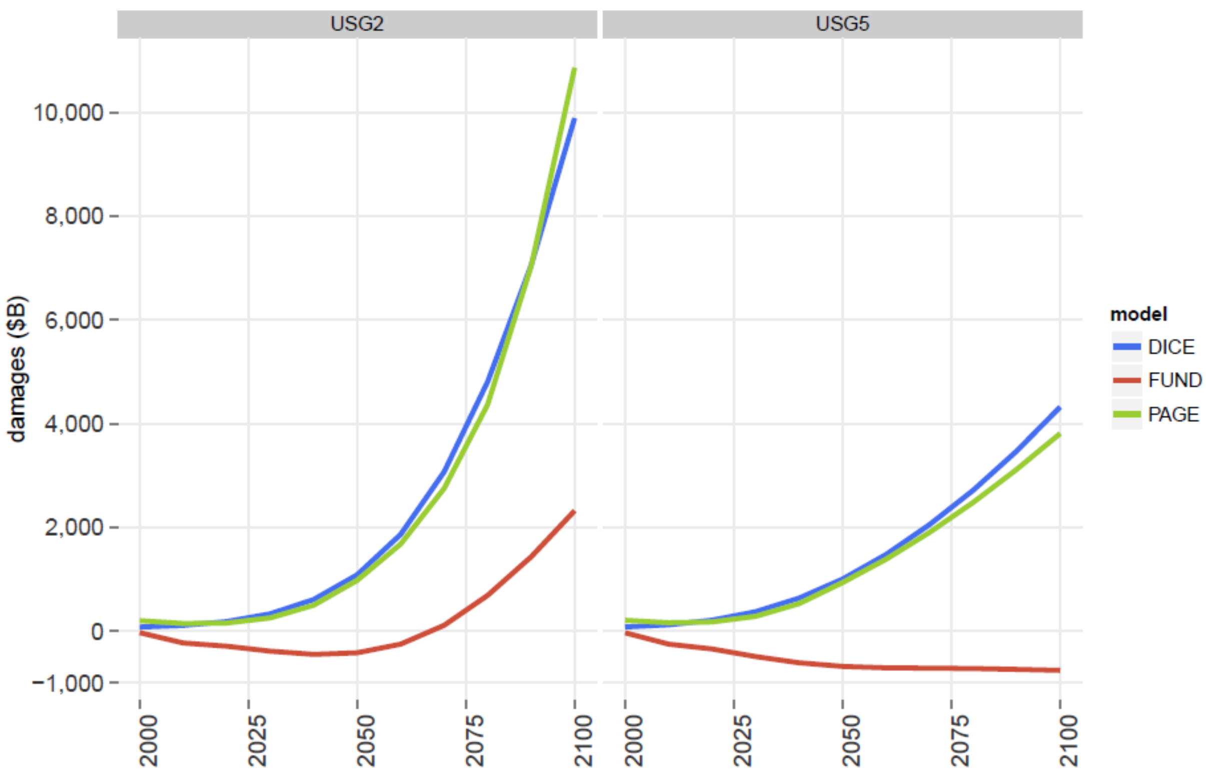
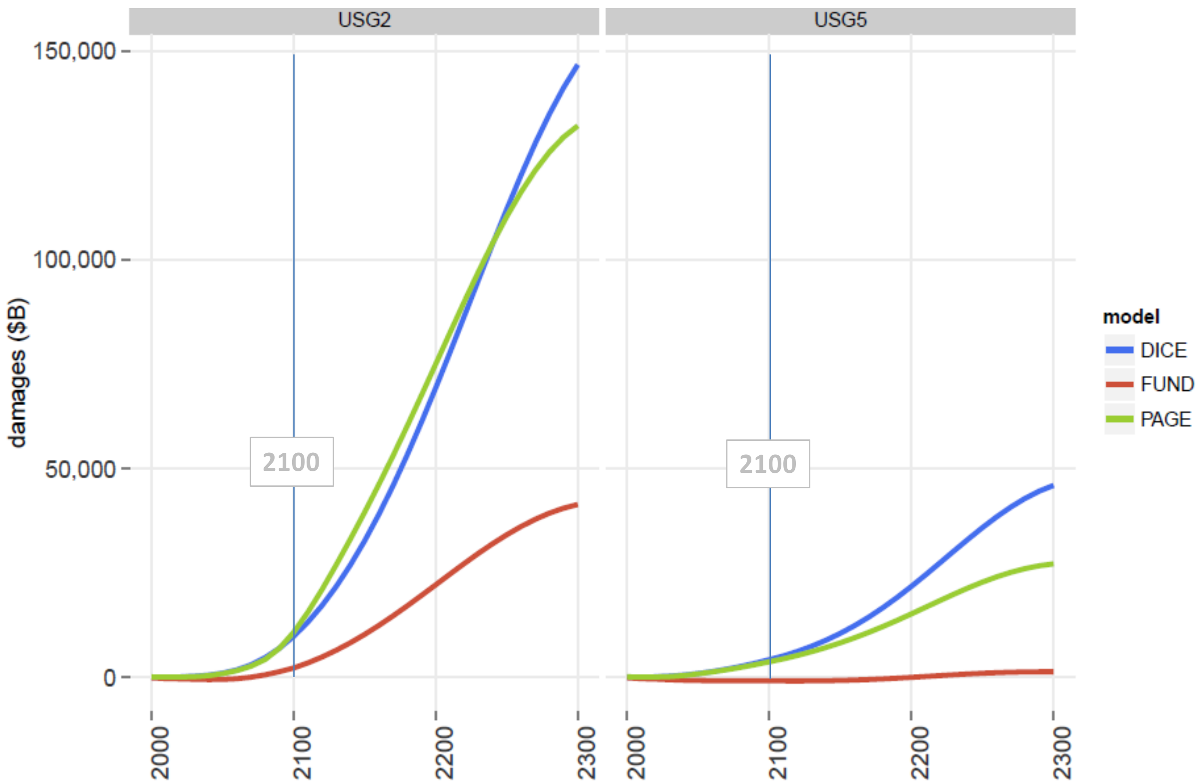
[37] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 6-2.

The bottom chart extends the timeframe to year 2300, with all three IAMs now predicting positive damages, but still exhibiting a spread in the magnitude of estimated damages under the high socioeconomic/emissions scenario of about $100 trillion.

Figure 7
Estimated Damages to Year 2100 (Top Figure) and Year 2300 (Bottom Figure), Resulting from the Highest (MERGE Optimistic, Here Labeled USG2) and Lowest (550 ppm Average, Here Labeled USG5) Emission Scenarios[38]



[38] EPRI, Exhibit ___ (NFM-1), Schedule 5, pages 6-14 and 6-41.



Q. DOES THE IWG ACKNOWLEDGE UNCERTAINTY IN STEPS 1 TO 3?

A. Yes. The IWG acknowledges that:

> When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009)[39] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.[40]

Q. WHAT UNCERTAINTIES EXIST IN THE CHOICE OF DISCOUNT RATE?

[39] The citation refers to National Research Council, 2009, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press.
[40] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, page 2.

A. Finally, the choice of discount rate – while not a separate modeling step *per se*, but rather the choice of how to weight costs and benefits in the future versus those in the present – has a greater impact on the SCC than any other single variable in the methodology. For the three average values presented in the TSD executive summary, the only difference is discount rate, and it creates a span of values from $12 to $64 per metric ton (in 2007 dollars) for emissions in 2020. Moving from a discount rate of 5 percent to 3 percent more than triples the SCC; moving from 5 percent to 2.5 percent more than quintuples it.[41]

The choice of discount rate raises challenging questions entirely separate from the uncertainties in forecasting emissions, temperature response, and damages. An extensive body of economics and ethics literature has attempted to address the question of appropriate discount rates for long-term environmental problems, but without reaching consensus according to the IWG:

> The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context.[42]

The IWG characterized the choice of discount rate as essentially a choice between a "descriptive" approach that is based on empirical observations of market rates of return on capital, individual preferences for savings vs. consumption, allocation of savings to more or less risky investments, etc.; and a "prescriptive" approach that applies explicit normative judgments to valuing the welfare of present vs. future generations and the marginal utility of income

[41] November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, page 3.
[42] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, page 17.

for individuals at different income levels.[43] In fact, since the SCC is an estimate of damages globally over many generations – predicting varying levels of damage to be experienced by people of varying income levels far into the future – normative judgments are inherent in either approach, whether or not they are made explicit. The IWG reviewed the literature and ultimately chose to present SCC results for three discount rates:

- 3 percent, representing a rate "consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest",
- 5 percent, consistent with market rates of return on capital and the approximate post-tax equivalent of OMB's required (per OMB Circular A-94) discount rate of 7 percent, and
- 2.5 percent, "to incorporate the concern that interest rates are highly uncertain over time," and to "respond to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher."[44]

The IWG recommended that the SCC values at all three discount rates be considered by Federal agencies conducting regulatory impact analysis.[45]

The question of basing discount rates on empirical data about present-day investor and consumer behavior, versus normative judgments regarding how to value the welfare of present and future generations at different income levels, is typified by a debate between climate economists Dr. William Nordhaus and Dr. Nicholas Stern. Nordhaus used market data as the basis

[43] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, pages 17-23.
[44] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, pages 17-23.
[45] November 2013 TSD, Exhibit ___ (NFM-1), Schedule 2, page 12.

for discount rates of 5 percent or higher and derived an SCC of $11 per ton; Stern used normative judgments as the basis for discount rates below 2 percent and derived an SCC over $200 per ton.[46]

Pindyck argues that the discount rate choice alone is sufficient to yield widely differing SCC estimates, and leaves much room for subjective judgment by the modeler:

> With a judicious choice of parameter values (varying the discount rate is probably sufficient), the model will yield an SCC estimate as low as a few dollars per ton, as high as several hundred dollars per ton, or anything in between. Thus a modeler who, for whatever reason, believes that a stringent abatement policy is (or is not) needed, can choose a low (or high) discount rate, or choose other inputs that will yield the desired results… Because reasonable arguments can be made for a low discount rate or for a high rate, the modeler simply has too much flexibility.[47]

A review of the SCC process by the Harvard Project on Climate Agreements maintains that:

> Climate change involves damages that extend many hundreds of years into the future. While there have been advances in our understanding of long term discount rates on the order of a century… it is not clear that an appropriate framework exists for empirically identifying discount rates over the several centuries used to estimate the SCC. One then has two choices: use existing data and – with some assumptions – adapt results to a time span that is an order of magnitude longer than the span over which estimates were made, or an explicitly ethical and normative perspective, along the lines of Stern (2007)… To us, it seems that these basic issues reflect fundamentally different perspectives or philosophies and it is hard to see how debates over discount rates will be resolved soon.[48]

In the context of this uncertainty and lack of consensus regarding discount rate choice, we took essentially a neutral approach, retaining and equally

[46] Pindyck, 2013, pages 4-8.
[47] Pindyck, 2015, page 9.
[48] Metcalf and Stock, 2015, page 14.

weighting the SCC values at all three discount rates used by the IWG. While acknowledging that lower and higher discount rates are also possible, we did not incorporate SCC values at any discount rates other than those used by the IWG, since this would have required new modeling using the IAMs. One of the benefits of our approach, in terms of replicability and updateability, is that it does not require new modeling.

2. *Methodological and Procedural Critiques*

Q. PLEASE DESCRIBE SOME OF THE METHODOLOGICAL CRITIQUES THAT HAVE BEEN MADE OF THE IWG METHODOLOGY.

A. First of all, the IWG could have selected other scenarios to estimate population, GDP growth, and the CO_2 intensity of GDP growth than the five Stanford Energy Modeling Forum scenarios it used. Similarly, it could have chosen other IAMs. Members of the IWG acknowledge that DICE, FUND and PAGE take simplified (that is, reduced-form) approaches to estimate the SCC, and that other IAMs may better reflect the complexity of the science.[49]

Second, key variables in the IAMs suffer from a lack of empirical basis, and the IAMs are highly dependent on assumptions that cannot easily be verified. As noted above, four key areas where the IAMs in particular lack empirical basis are: predicting equilibrium climate sensitivity; creating damage functions to translate temperature change to economic damages; modeling the ability of future populations to adapt to climate change; and modeling possible discontinuous "tipping point" behavior in the climate system that could occur at temperature increases greater than the relatively moderate temperature

[49] Greenstone, Kopits and Wolverton, 2013,page 25.

increases for which the IAMs have been calibrated.[50]

Pindyck argues that the designers of the IAMs, lacking empirical basis on which to base these key model functions, "simply make up arbitrary functional forms and corresponding parameter values."[51] We do not claim authoritative knowledge on these topics, but does urge the Commission not to attribute to the IAMs greater precision than they can claim. The IAM outputs are probabilistic values and our statistical approach to deriving a range treats them as such.

Q. HAS THE IWG'S APPROACH TO THE SCC BEEN SUBJECT TO PEER REVIEW?

A. No. DICE, FUND and PAGE, as well as the socioeconomic/emissions scenarios, have been published in the peer-reviewed literature. However, the IWG methodology itself is distinct from those models and has not been peer reviewed. This methodology includes many decisions and key modeling assumptions made by the IWG, including but not limited to:

- The choice of DICE, FUND and PAGE over other IAMs that provide more specific representations of individual components of the causal chain, but do not represent the full causal chain from emissions to temperature change to economic damages,[52]
- The choice of socioeconomic/emissions assumptions from the Stanford Energy Modeling Forum,
- The assumptions made in order to extend the Stanford socioeconomic/emissions projections from the year 2100 to the year

[50] Greenstone, Kopits and Wolverton, 2013, pages 27 and 40-41; see also Pindyck, 2013 and Pindyck, 2015.
[51] Pindyck, 2015, page 2.
[52] Greenstone, Kopits and Wolverton, 2013, page 25.

2300,

- The assumptions about equilibrium climate sensitivity, a key driver of the results,
- The choice of discount rates, also a key driver,
- The choice to aggregate results across three dissimilar IAMs and five socioeconomic scenarios,
- The choice to present the mean rather than median despite the non-normal distribution of SCC results, and
- The choice to present a 95th percentile value without the corresponding 5th percentile value.

EPRI emphasizes the benefits of peer review in improving the SCC methodology:

> The USG SCC approach is a novel application and, as such, would benefit from external peer review. External review from qualified scientific experts would provide valuable feedback regarding the modeling framework (models, runs, aggregation), uncertainties (standardized, model specific, and specifications), and other elements. The review would lead to improved methods and provide the public with greater confidence in the resulting estimates.[53]

A review of the SCC process by the Harvard Project on Climate Agreements likewise recommends expert review and regular updating as a key improvement to the IWG process.[54] Others have recommended independent review by the National Academy of Sciences.[55]

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[53] EPRI, Exhibit ___ (NFM-1), Schedule 5, page 7-4.
[54] Metcalf and Stock, 2015.
[55] Pizer, William *et al.,* 2014, *Using and Improving the Social Cost of Carbon.* Science, Vol. 346, Issue 6214, pages 1189-90.

Q. DID THE IWG ASK FOR PUBLIC INPUT WHEN IT DEVELOPED THE SCC?

A. No. The IWG developed the SCC in 2009-10, and updated it twice in 2013, with very little public input. The OMB took public comment for the first time on the SCC methodology in November 2013, and the docket indicates that OMB received 108 comments in this solicitation. Many of the comments are critical of the methodology and/or transparency of the SCC development process.[56] There has been no response from OMB, nor any indication how or when OMB plans to respond to these comments.

Some have pointed to the numerous federal rulemakings since 2010 that have used the SCC, as an opportunity for public comment on the SCC. However in any particular rulemaking conducted under specific statutory authority, public comments are expected to focus on the proposed regulation on which comments are sought – not the SCC values and methodology underlying an OMB-required regulatory impact analysis. The November 2013 solicitation was essentially the first and only opportunity for public comment.

III. THE COMPANY'S PROPOSED APPROACH

Q. DOES THE COMPANY ENDORSE THE USE OF FEDERAL SCC?

A. As I have explained above, the Federal SCC was not designed for integrated resource planning or other Commission decisions, and is inherently and irreducibly uncertain. Therefore, we cannot endorse its use if a single SCC value is selected.

However, we also recognize the statutory requirement for a CO_2 externality

[56] See http://www.regulations.gov/#!documentDetail;D=OMB-2013-0007-0063.

value; the need to revisit values set in the 1990s; the Commission's desire for a damage costs approach rather than the cost of regulation approach; and the practical constraints on conducting new climate modeling to develop a more appropriate value than the Federal SCC. While we do not endorse the Federal SCC, we have not been able to identify an alternative starting point that is practicable and meets the Commission's stipulations in its October 15, 2014 NOTICE AND ORDER FOR HEARING.

Some authors have maintained that the IAMs are too deeply flawed to be used at all for estimating the SCC, suggesting instead a process of consulting experts to assign rough probabilities to catastrophic outcomes, to estimate the present value of the benefit of averting those outcomes, and to estimate the emission reductions necessary to avert them.[57]

However, the probability and damages associated with catastrophic outcomes are unknown, and this is not a sufficiently developed proposal to represent a practicable alternative at this time. Others have reviewed the possible alternatives – not using any SCC in regulatory impact analysis until the science is more advanced; basing the SCC on CO_2 prices in existing carbon markets (a cost of regulation approach); the U.S. Government creating and maintaining its own IAM; or simply relying on expert judgment – but ultimately concluded the current IWG process is superior to these alternatives and can be improved.[58]

Considering the Commission's desire to identify the "best available" measure, and stipulation that the CO_2 environmental cost value be based on a damage

[57] Pindyck, 2015, pages 11-13.
[58] Metcalf and Stock, 2015, pages 15-19.

costs approach, we conclude that in the absence of any clearly superior damage cost alternatives, the Federal SCC despite its flaws and uncertainties can be used as the basis for developing CO_2 environmental cost values. However, no single Federal SCC value can be adopted. Instead, the Federal SCC can be used as the starting point for developing values, as long as the Commission adopts a range of values rather than any single value, and the methodology used to arrive at this range is based on a balanced consideration of the criteria I have set forth earlier in my Direct Testimony.

Q. WHY DOES THE COMPANY OPPOSE SELECTING ANY SINGLE POINT VALUE?

A. Given the modeling and other uncertainties involved in estimating climate damages over the next almost 300 years, and the large number of SCC results published in the TSD executive summary and appendix, a single CO_2 value cannot accurately represent future climate damages. Selecting a single CO_2 value – for example, the mean or median across the IAMs at 3 percent discount rate – would raise the problem of false precision, as well as the problem of choosing a single discount rate, an issue of "highly contested and exceedingly difficult questions of science, economics, philosophy, and law" about which there is no consensus, according to the IWG.[59]

Q. SHOULD THE COMMISSION THEN ADOPT A LARGE NUMBER OF DIFFERENT SCC VALUES TO CAPTURE THE UNCERTAINTY?

A. No. Although a large number of SCC values are available in the TSD executive summary and appendix, we believe there would be little practical value in requiring utilities to run dozens of different possible CO_2 environmental cost sensitivities in their resource planning software. Many of

[59] February 2010 TSD, Exhibit ___ (NFM-1), Schedule 6, page 17.

these values – even if they resulted from different IAMs, socioeconomic and emissions assumptions, or discount rates – would be similar in dollar per ton terms and therefore in their planning implications.

Q. HOW SHOULD THE COMMISSION USE THE FEDERAL SCC TO DEVELOP A CO_2 ENVIRONMENTAL COST RANGE?

A. We believe the decision before the Commission is best approached as a probabilistic problem – one of applying statistical methods to identify a practicable range of values that captures, from within the vast population of SCC estimates produced by the IAMs, a reasonable probability of encompassing the value of future climate change damages. We have used the underlying Federal SCC data and applied sound statistical methods to identify the low and high ends of a CO_2 environmental cost range that reflects a reasonable probability of including the future climate change damage value. Our range, because it uses statistical percentiles, excludes very low and negative SCC values, as well as very high SCC values, that are represented in the IAM results but have a low probability of occurring.

We emphasize that because our approach relies on the results from the same IAMs the IWG used, it implicitly assumes that the future climate change damage value is included somewhere within the probability distribution of IAM results. The precise value of future damages from climate change is in fact unknowable, since it is subject to multiple and irreducible uncertainties and the IAMs are imperfect. Some of those imperfections would lead the IAMs to underestimate damages, others to overestimate damages.

Q. HOW WOULD THE COMPANY'S PROPOSED CO_2 ENVIRONMENTAL COST RANGE BE USED?

A. Our range is based on applying statistics to identify the low and high ends of a range believed to contain the value of future climate change damages as predicted by the IAMs. Inherent in this approach is that the two ends are interdependent and each has equal weight. Neither end of the range could be discarded without, statistically speaking, eliminating the rationale for the other end. Nor could any midpoint of the range be labeled "central" and used as a base assumption, without reintroducing the false precision we urge the Commission to avoid. Therefore, both the low and high ends would be used as sensitivities to inform resource planning.

Q. WHAT METHODS DID THE COMPANY USE TO DEVELOP ITS PROPOSED CO_2 RANGE?

A. To perform the computations described below, we retained The Brattle Group (Brattle). Brattle is an independent consultancy that provides advisory services for utility regulatory proceedings, including analyses of regulatory economics for energy and environmental matters. Brattle's qualifications, and in particular their expertise in environmental externalities, the Federal SCC, and statistical methods, are provided as Exhibit ___ (NFM-1), Schedule 9.

Our methodology included several steps, which are summarized over the following several questions and depicted in flow chart form in Exhibit ___ (NFM-1), Schedule 8. An Excel spreadsheet containing the results of Brattle's work is provided as Exhibit ___ (NFM-1), Schedule 10.

First, Brattle requested and obtained from the IWG the raw SCC model results from the November 2013 SCC update. The results consist of 2.25 million data points: 3 IAMs * 5 socioeconomic/ emissions scenarios * 10,000 model runs * 3 discount rates * 5 emission years (2010, 2020, 2030, 2040, and 2050). We had intended to provide these raw SCC results as a Schedule, but size constraints make this impractical both electronically and in paper copy.[60] We will provide the raw data to any parties on request, or alternately, parties can request the data from the IWG.

Second, Brattle aggregated the results of the 15 scenarios (3 IAMs * 5 socioeconomic scenarios) for each discount rate/emission year combination. This resulted in 15 distributions, each containing 150,000 data points (10,000 SCC estimates per scenario * 15 scenarios). Brattle repeated this process for each emissions year for which data was provided (2010, 2020, 2030, 2040, and 2050). For each emission year there are therefore 450,000 SCC estimates: 3 IAMs * 5 socioeconomic scenarios * 10,000 runs * 3 discount rates.

Third, Brattle calculated summary statistics for each of the SCC distributions. They used a statistical technique known as bootstrapping,[61] and conducted the analysis using free, open-source statistical software called R.[62] For full replicability, we have provided the coding of R used by Brattle as Exhibit ___ (NFM-1), Schedule 11. However we note that R is not unique; we believe other parties could replicate the calculation of these summary statistics – which are simply percentiles derived from the raw data – using any statistical

[60] The raw SCC data is an Excel spreadsheet with 10,000 rows and 225 columns. It is 12.6 MB zipped, so exceeds the e-filing cap, and as a paper copy would be over 5,000 pages.

[61] Bootstrapping is "a procedure for estimating sampling error by constructing a simulated population on the basis of the sample, then repeatedly drawing samples from the simulated population." Federal Judicial Center and National Research Council of the National Academies. 2011. *Reference Manual on Scientific Evidence, Third Edition*. Washington, DC: The National Academies Press.

[62] See http://www.r-project.org and http://www.revolutionanalytics.com/what-r.

software.

The summary statistics calculated by Brattle for each SCC distribution included the mean, median, and various different percentiles. The percentiles of any data set are derived by arranging the values from smallest to largest; then, for example, the 90^{th} percentile value represents the value for which 90% of the values fall below this value, and 10% fall above this value.[63]

We initially asked Brattle to examine the full range of percentiles from the 1^{st} to 99^{th}. This resulted in an SCC range from $-9/ton (indicating a net benefit of $9/ton from emitting CO_2) to damages of over $600/ton. We considered that this broad of a range did not meet the criterion outlined earlier in my Direct Testimony that we believe are essential to yielding a practicable result. It would have a very high probability (since it represents the 1^{st} and 99^{th} percentiles) of including the future climate change damage value as predicted by the IAMs – but it would include both extremely high values and extremely low values, including negative (that is, net benefit) values.

Also, given the purpose of the range for use in resource planning decisions, such a broad range would not be practical nor provide meaningful information to the Commission. Because the SCC probability distributions include such long tails of damage estimates that have a low probability of occurring, the selection of percentiles to determine a range is a public policy decision that necessarily balances practicability with risk tolerance (the chance that the Commission's adopted range may not capture the future climate change

[63] See definition of "percentile" in Federal Judicial Center and National Research Council of the National Academies. 2011. *Reference Manual on Scientific Evidence, Third Edition*. Washington, DC: The National Academies Press.

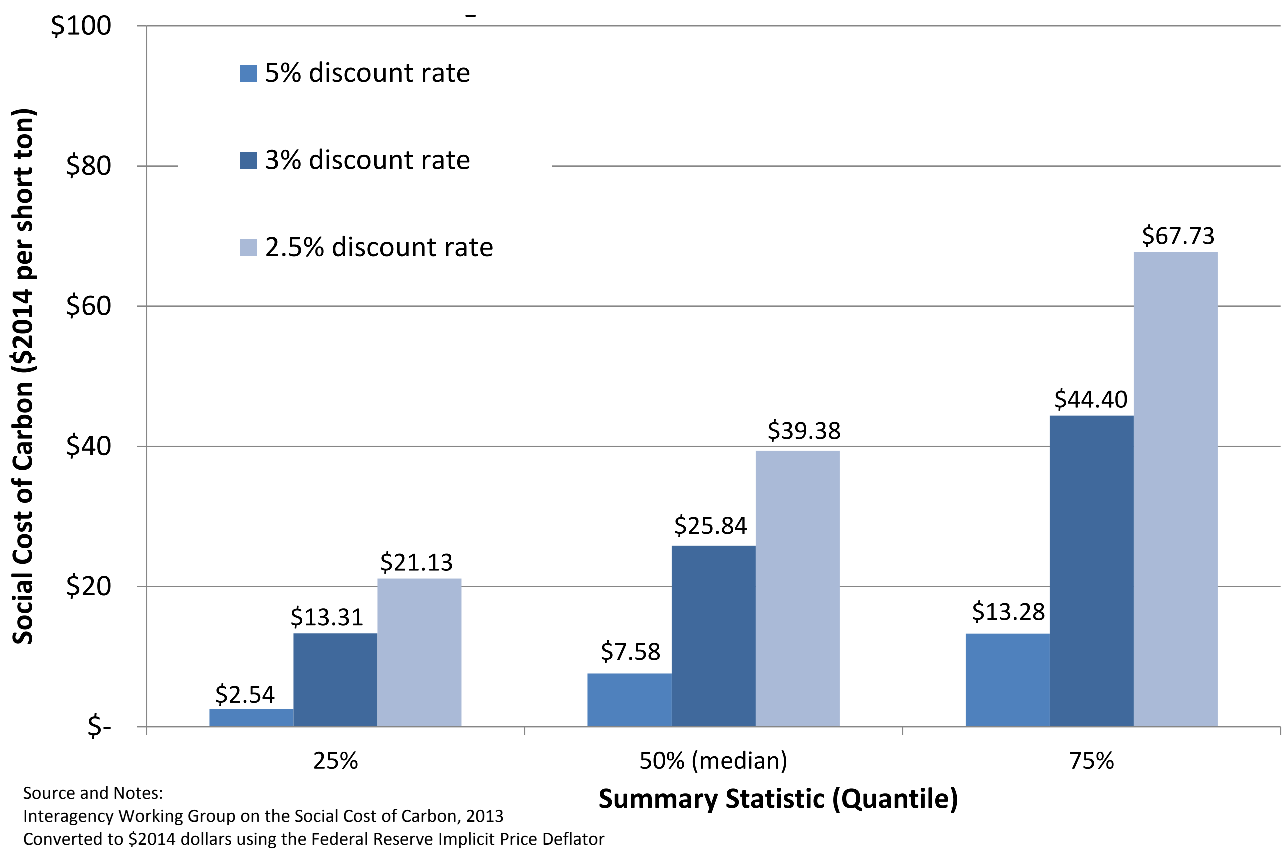
damage value).

Each statistical analysis we include from Brattle was independently audited by an expert within Brattle who was not involved in conducting the work but was able independently to replicate the results.

Q. WHAT PERCENTILES DID THE COMPANY USE TO DEVELOP THE PROPOSED CO_2 RANGE?

A. We decided to focus on the 25th and 75th percentiles for each of the 15 discount rate/emission year distributions, as a way to define a practicable range that still has significant probability of containing the future climate change damage value. We asked Brattle to calculate summary statistics for these percentiles, identifying the SCC values at the 25th, 50th, and 75th percentiles for each of the discount rates used by the IWG. Figure 8 shows these summary statistics for emission year 2020.

Figure 8
SCC Summary Statistics for CO_2 Emissions in 2020. SCC Values in 2014 Dollars per Short Ton



Q. WHAT RANGE OF CO_2 VALUES RESULTED FROM THE 25TH AND 75TH PERCENTILES?

A. As shown in Figure 8, the low end of the resulting range – the 25th percentile at 5% discount rate – was $2.54 (in $2014 per short ton, for emissions in 2020). The high end – the 75th percentile at 2.5% discount rate – was $67.73 (in $2014 per short ton, for emissions in 2020).

Q. DID BRATTLE CALCULATE SIMILAR SUMMARY STATISTICS FOR OTHER EMISSION YEARS?

A. Yes. Brattle calculated the same summary statistics for 2010, 2030, 2040, and

2050. These statistics are shown in Table 3 below, with the high (75th percentile at 2.5% discount rate) and low (25th percentile at 5% discount rate) values shaded.

Table 3
SCC Summary Statistics, by Discount Rate, for the 25th, 50th, and 75th percentiles. In 2014 Dollars per Short Ton.

Summary statistics	Emission year				
	2010	2020	2030	2040	2050
2.5% Discount Rate					
25%	$17.41	$21.13	$24.39	$27.81	$31.24
50% (median)	$32.65	$39.38	$45.56	$52.08	$58.87
75%	$56.04	$67.73	$78.55	$90.03	$102.17
3% Discount Rate					
25%	$9.87	$13.31	$15.76	$18.37	$21.14
50% (median)	$20.23	$25.84	$30.69	$35.89	$41.35
75%	$34.74	$44.40	$52.83	$62.14	$72.06
5% Discount Rate					
25%	$2.07	$2.54	$3.40	$4.46	$5.67
50% (median)	$6.03	$7.58	$9.72	$12.21	$14.93
75%	$10.35	$13.28	$17.10	$21.53	$26.60

Q. HOW DID THE COMPANY APPROACH DISCOUNT RATE SELECTION?

A. Finally, we needed to address the crucial normative question of discount rate choice. Following the proposed criterion outlined earlier in my Direct Testimony, the selection of CO_2 environmental cost values should minimize subjective judgments, we preferred a method that would be neutral on discount rate choice – since this is fundamentally an ethical question on which no consensus exists.

Using the summary statistics prepared by Brattle, as shown in Figure 7 and Table 3, we decided the least subjective method was to equally weight the SCC values for each discount rate at each end of the range. Referring back to

Figure 7, equally weighting the three discount rate values at the 25th percentile ($2.54, $13.31 and $21.13) results in a low bound of $12.33 per short ton for emissions in 2020. Equally weighting the three discount rate values at the 75th percentile ($13.28, $44.40 and $67.73) results in a high bound of $41.80 per short ton for emissions in 2020.

Retaining and equally weighting all three discount rates used by the IWG is neutral on the question of discount rate choice. This, in our view, allows the Commission to avoid entering into lengthy and unresolved (perhaps unresolvable) debates regarding the appropriate discount rate for long-term environmental problems. There are rationales in the environmental economics literature for other discount rates, both higher and lower than those the IWG used. If future updates of the Federal SCC use other discount rates, whether higher or lower, our proposed approach would be able to incorporate the updated discount rates and give them equal weight.

Q. ARE SUBJECTIVE JUDGMENTS MADE IN THE COMPANY'S METHODOLOGY?

A. Earlier in my testimony, I outlined criterion that suggests the selection of the Commission's CO_2 environmental cost values should minimize subjective judgments, reflect an appropriate level of risk tolerance, and yield a practicable result. These three criteria must be balanced against each other. For example, choosing an extremely low risk tolerance (using the 1st and 99th percentiles, for example) would not yield a practicable result because a range of $-9 per ton to $600 per ton would be too wide to provide meaningful information to the Commission in the context of resource planning proceedings.

Therefore, the level of risk tolerance – as represented by the selection of percentiles to determine the range – necessarily must be balanced with practicability. The selection of percentiles to bound the range implies a decision not to consider SCC values that are below the low percentile and above the high percentile. Those values exist in the IAM results, but have a relatively low probability of occurring, compared to the values that are between the percentiles.

We decided to consider the SCC range from the 25th percentile at a 5 percent discount rate to the 75th percentile at a 2.5 percent discount rate, and then equally weight the SCC values for each discount rate at each end of this range. This reflects a balance of risk tolerance and practicability. We could have used other percentiles, in which case the range would include much lower and/or negative SCC values as well as much higher SCC values. Using the 25th and 75th percentiles, symmetrically around the median, excludes lower and negative SCC values, as well as higher values, that are included in the IAM results at low probabilities; but both ends of the distribution are treated symmetrically and there is no bias to exclude only low or only high values.

Otherwise, our method makes no subjective judgments because it uses all IAM results, socioeconomic/emissions futures, and discount rates. We do not claim to know that, for example, FUND is more accurate than PAGE, or that one of the socioeconomic/emissions futures is more likely than another. On the most explicitly normative question – discount rate choice – we retain and equally weight the three discount rate values used by the IWG.

Q: WHAT IS THE RESULTING CO_2 RANGE?

A: The resulting CO_2 range is from $12.33 to $41.80 (in 2014 dollars, rounded to the nearest dollar) for a short ton of CO_2 emitted in 2020. We used the same methods to calculate corresponding ranges for each of the other decades for which SCC values were provided by the IWG (2010, 2030, 2040 and 2050). These values are shown in Table 4, and represent the low and high CO_2 environmental cost values we propose for Commission adoption.

Table 4
CO_2 Environmental Cost Values Proposed for Commission Adoption. In 2014 Dollars per Short Ton.[64]

Range proposed for Commission adoption	Emission year				
	2010	2020	2030	2040	2050
Low	$9.78	$12.33	$14.52	$16.88	$19.35
High	$33.71	$41.80	$49.49	$57.90	$66.94

We also provide annual low and high values in 2014 dollars per short ton for emission years 2010 to 2050, calculated by interpolating between the decadal values, as Exhibit ___ (NFM-1), Schedule 3. We also provide annual low and high values in nominal dollars per short ton for emission years 2010 to 2050, as Exhibit ___ (NFM-1), Schedule 4.

Q: WHAT LEVEL OF RISK TOLERANCE CHARACTERIZES THE COMPANY'S PROPOSED RANGE?

A: Our proposed CO_2 environmental cost range is based on underlying statistics (prior to equally weighting discount rates) that span the 25th percentile at a 5 percent discount rate to the 75th percentile at a 2.5 percent discount rate. We asked Brattle to calculate the probability that this range contains the value of future climate change damages as predicted by the IAMs.

[64] Note that in contrast to the SCC TSDs, which present values in constant 2007 dollars per metric ton of CO_2, we have converted to 2014 dollars per short ton of CO_2, since our resource plans and other proceedings generally report emissions in short tons.

Recall that the SCC distribution for a given discount rate/emission year combination contains 150,000 SCC values, thus the SCC distribution for a given emission year when all three discount rates are combined contains 450,000 SCC values. Looking at the combined discount rate distribution for 2020, Brattle calculated that the range from the 25th percentile at a 5 percent discount rate to the 75th percentile at a 2.5 percent discount rate contains approximately 75 percent of the 450,000 data points.[65]

In other words, there is a 3-in-4 chance that our underlying statistics capture the value of future climate change damages as predicted by the IAMs. The SCC values that our method excludes from further consideration – those below the 25th percentile at a 5 percent discount rate and above the 75th percentile at a 2.5 percent discount rate – have only a 1-in-4 chance of representing the value of future climate change damages as predicted by the IAMs.

Our final step, equally weighting the SCC values for each discount rate at each end of the range results in a proposed range from $12.33 to $41.80 (in 2014 dollars per short ton, for CO_2 emitted in 2020). Brattle calculated that the range from $12.33 to $41.80 would correspond to the 36th and 74th percentiles of the combined discount rate distribution of 450,000 data points.

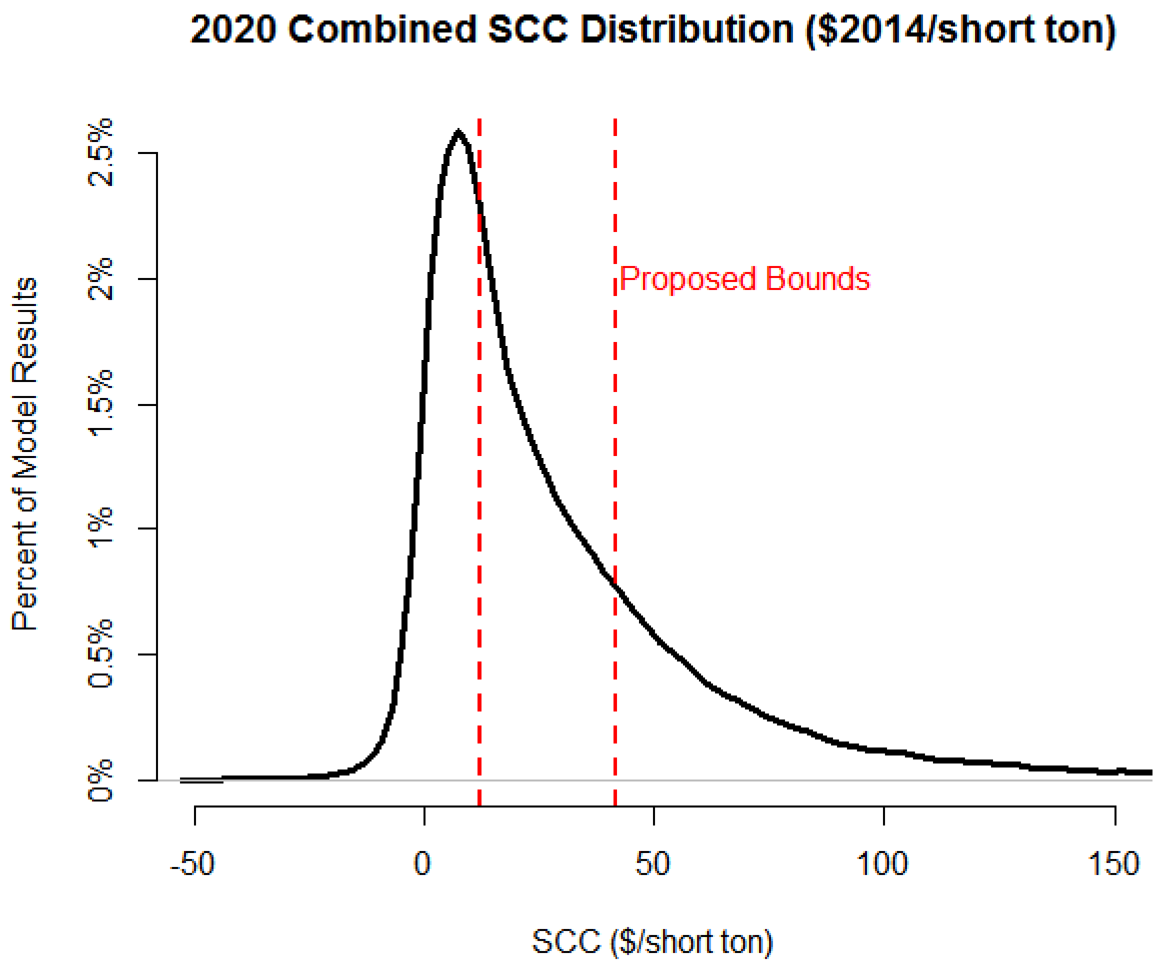
[65] The actual percentage varies slightly by emission year, as follows:

- 2010: 74.82 percent
- 2020: 75.14 percent
- 2030: 74.58 percent
- 2040: 74.00 percent
- 2050: 73.46 percent

This means that for the combined discount rate distribution, 36 percent of the SCC values predicted by the IAMs are below the low end of our proposed range, while 26 percent are above the high end of our proposed range. Thus our proposed range overall excludes more than half the IAM predictions; however, it excludes more SCC values on the low end (36 percent) than on the high end (26 percent). In this sense our proposed range is risk averse. In addition, because $41.80 corresponds to the 74th percentile, 74 percent of all the estimates of future climate change damage are at or below the high end of our proposed range.

This is shown graphically in Figure 9. This figure again illustrates the non-normal, right-skewed shape of the Federal SCC probability distribution. The red dotted lines labeled "Proposed Bounds" are our proposed range of $12.33 to $41.80 (for emissions in 2020). The graph shows that the values excluded on the left side (the SCC predictions lower than the low end of our proposed range) have a greater probability of occurring than the values excluded on the right side (the SCC predictions higher than the high end of our proposed range).

Figure 9
Combined Discount Rate Probability Distribution of SCC Values for Emissions in 2020



Q: WHAT ARE THE ADVANTAGES OF THE COMPANY'S PROPOSED APPROACH?

A: Our approach has several advantages. It fully adheres to the Commission's stipulations in its October 15, 2014 NOTICE AND ORDER FOR HEARING, and also meets all the criteria outlined earlier in my testimony that we believe are essential for the selection of CO_2 environmental cost values. Our proposal:

- *Is based on a damage cost approach*. The Commission's October 15, 2014 NOTICE AND ORDER FOR HEARING stipulates that parties shall use a damage costs approach to valuing environmental costs.[66] A damage-cost approach, as defined in the original externalities proceeding, is an approach that attempts to place an economic value on the net damage to the environment caused by an energy resource.

The Commission contrasted this approach to other possible methods such as willingness-to-pay (estimating the amount that society would be willing to pay for reduced emissions), cost-of-control (using the costs of avoiding or reducing an environmental effect at the source to estimate the value of the externality), mitigation cost (using the costs of eliminating the harm or impact of an externality), and risk of regulation (estimating the future taxes or costs that a utility might incur due to additional regulation).[67]

The ALJ's report indicated a general preference for a damage-cost approach, while acknowledging that a cost-of-control approach could be preferable in instances where "no reasonable estimate of damages is obtainable."[68] The Commission agreed, stating that the cost-of-control method "may be reasonable in certain circumstances… it may be much easier or less expensive to estimate control costs than to estimate actual damages."[69] However, we do not believe these criteria are met in the

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[66] Commission's October 2014 Order, page 8.
[67] *ORDER ESTABLISHING ENVIRONMENTAL COST VALUES*. In the Matter of the Quantification of Environmental Costs Pursuant to Laws of Minnesota 1993, Chapter 356, Section 3. Docket No. E-999/CI-93-583. January 3, 1997, page 14.
[68] *FINDINGS OF FACT, CONCLUSIONS, RECOMMENDATION AND MEMORANDUM*. In the Matter of the Quantification of Environmental Costs Pursuant to Laws of Minnesota 1993, Chapter 356, Section 3. Docket No. E-999/CI-93-583. March 22, 1996, pages 18-20.
[69] *ORDER ESTABLISHING ENVIRONMENTAL COST VALUES*. In the Matter of the Quantification of Environmental Costs Pursuant to Laws of Minnesota 1993, Chapter 356, Section 3. Docket No. E-999/CI-93-583. January 3, 1997, page 14.

present proceeding, since the Federal SCC is available, represents a damage-cost method, and may be used, as I have suggested, as the basis for developing a CO_2 environmental costs range.

- *Reasonably addresses the inherent uncertainty in predicting socioeconomics, emissions, temperature change, and climate damages over 300 years.* Our approach uses results from all three IAMs and five socioeconomic/emissions scenarios used in developing the Federal SCC, not claiming that any IAM is more accurate or any socioeconomic/emissions scenario is more likely than another. By treating these results equally and taking a probabilistic approach, our proposed range reflects the uncertainty and does not attribute to the IAMs and socioeconomic/emissions scenarios greater precision than they in fact claim.
- *Appropriately reflects the absence of consensus on discount rate.* Our approach retains all three discount rates used by the IWG and weights them equally. There are arguments for both higher and lower discount rates than those used by the IWG, but these would require new modeling since they are not published in the SCC reports. In the event the IWG updates the SCC in the future and uses different discount rates, our approach would be able to integrate these rates and weight them equally.
- *Uses statistically sound methods.* Our approach uses appropriate statistics, the median and percentiles, to derive a range from the non-normal probability distribution of Federal SCC values.
- *Reflects an appropriate level of risk tolerance.* The underlying statistics from which we draw our proposed range – the 25th percentile at the 5 percent discount rate to the 75th percentile at the 2.5 percent discount rate – provide approximately 75 percent probability, or a 3-in-4 chance, of

capturing the future climate change damage value (assuming that this value is reflected in the IAM results). When we equally weight the SCC values for each discount rate at each end of our range, we exclude more SCC values on the low end (36 percent) than on the high end (26 percent). We believe this is an appropriate balance of risk tolerance and practicability.

- *Minimizes subjective judgments*. Other than the question of risk tolerance in choosing to base our range on the 25th and 75th percentiles, our approach does not require subjective judgments. It retains all IAM results, socioeconomic/emissions scenarios, and discount rates.
- *Yields a practicable range that envelops other important summary statistics*. Our proposed range of $12.33 to $41.80 per short ton for CO_2 emissions in 2020 contains within it the median SCC values at all three discount rates (see Figure 8). Thus to the extent the median is an appropriate indication of the central tendency of SCC results – more appropriate than the mean, considering the non-normal probability distribution – our proposed range envelops the median. Our proposed range is also narrow enough to yield practicable results.
- *Requires no new modeling*. Our methodology does not involve any new modeling of climate damages, making it practicable and replicable. We only apply well-accepted statistical techniques to the raw SCC data provided by the IWG.
- *Is transparent and replicable*. The methodology we used to develop our range uses transparent techniques that are described in this testimony and accompanying Schedules. These techniques are replicable by other

parties by obtaining the SCC data from the IWG[70] and running summary statistics (whether using the same statistical software or other software) as described in my Direct Testimony.

- *Is updatable*. In the event the IWG publishes future updates to the SCC, and the Commission decides to update its CO_2 environmental cost values accordingly, our proposed range could be updated by obtaining the new SCC results from the IWG and running the same summary statistics. The IWG provided us the raw data within a matter of days from our request.

IV. CONCLUSION

Q. PLEASE SUMMARIZE YOUR TESTIMONY.

A. Our proposal to use the Federal SCC as the basis for the CO_2 environmental cost range we propose in this testimony is practicable because it:

- Uses a damage cost approach to valuing environmental costs,
- Reasonably addresses the inherent uncertainty in estimating climate change damages over almost 300 years,
- Reflects the absence of consensus on discount rate choice,
- Uses statistically sound methods,
- Reflects an appropriate level of risk tolerance,
- Minimizes subjective judgments,
- Yields a practicable range, and
- Is transparent, replicable, and updateable.

[70] Or from the Company; we have not included these raw data as a Schedule due to size constraints, but will provide them on request.

Both ends of our proposed CO_2 environmental cost range (for example, $12.33 and $41.80 per short ton for emissions in 2020) would be used as sensitivities in integrated resource planning. Since the values underlying our range are determined using symmetrical statistical percentiles, neither end of the range, nor the midpoint, could be designated central or used as a base assumption in resource planning. Using a single value would also reintroduce false precision and run against the statutory requirement to "quantify and establish a *range* of environmental costs associated with each method of electricity generation."[71]

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY?

A. Yes.

[71] Minn. Stat. § 216B.2422, subd. 3(a).