R.Polasky

https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={570745A1-B82C-47FA-8941-61B4C1DB0982}&documentTitle=20158-113193-02 RESPONSE TO: Haneman (almost entirely agreeing, except IWG note on p.5) REBUTTALS TO: Smith, Gayer, Martin, Mendelsohn, Bezdek SURREBUTTALS BY: Happer, Mendelsohn, Bezdek, Smith, Gayer, Martin

p.8 (to Smith) "It is not valid to say that because uncertainty is large that attempts to deal with it are excessively speculative. It is also not valid to conclude that the proper response to large uncertainty is to just ignore it."

p.16 "Instead, Smith altered the climate change 4 models assuming *zero* emissions of CO2 after 2020. This is a completely absurd projection of the future. Given that the Smith testimony in this hearing is arguing against a modest valuation of the SCC intended to limit future emissions, it is particularly incongruent that the testimony argues that there will be substantially larger emission reductions of CO2 in the future than the IWG projections indicate."

p.24 "The analysis by Tol shows that in SCC studies, ten studies used a discount rate below 3 percent, nine used a discount rate of 3 percent, five used a discount rate of 4 percent, and thirteen used a discount rate of 5 11 percent. "

p.28 "If every state, province, or other political territory only considered the damages of their own CO2 emissions within their own political boundaries then there would be virtually no correcting for externalities."

pp.33-34 Agrees more with Martin, but disagrees with 3 items.

p.51 "Mendelsohn adjusts the DICE damage function by making any temperature increase below 1.5 to 2 degrees beneficial to society, and then there are only damages after warming greater than this."

p.54 "**Bezdek's views on climate change are far outside the mainstream scientific understanding** and ignore the bulk of the available evidence. ... extremely inappropriate to adopt a value of zero for the SCC, as Bezdek recommends." p.55 'Bezdek states that "[i]n reality, the `scientific consensus' is a manufactured myth" (page 28) and that "there is no empirical scientific evidence for significant climate effects of rising CO2 levels" (page 30). Bezdek's testimony also includes a conspiratorial claim that the SCC "[a]re artificial constructs designed by Obama administration to penalize fossil 6 fuels" (page 27)' ... 'Bezdek estimates that between 2012 and 2050 the benefits of higher CO2 concentrations on agricultural yields will be \$10 trillion. This estimate is not reliable....

Unlike laboratory 20 conditions where most factors can be controlled, crop yields in the field are affected by 21 changes in water availability, temperature, other nutrients, pests and pathogens, all factors that cannot be fully controlled by the farmer. Simply providing additional CO2 1 does not account for changes in these other factors, and increases in CO2 concentrations may increase temperatures and the probability of drought such that yields decrease despite the CO2 fertilization effect.

p.56 "conclude that accounting for the **net effect of CO2 concentration increases and climate changes there were small** positive impacts to soybean and rice yields and negative impacts to corn and wheat yields since 1980. These results are in stark contrast to the enormous positive effects of greater CO2 concentrations claimed by Bezdek."

p.57 Quotes Pindyck, showing that despite criticisms of IAMs, he think IWG's number is reasonable start. pp.59-102 - copy of IWG response to comments, July 2015.

On Behalf of

**Clean Energy Organizations** 

PUC Docket No. E-999/CI-14-643 OAH Docket No. 80-2500-31888 Clean Energy Organizations Exhibit \_\_\_\_\_

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1	I.	INTRODUCTION
2	Q.	Please state your name.
3	А.	Dr. Stephen Polasky.
4	Q.	Are you the same Dr. Stephen Polasky who provided direct testimony on behalf of
5		the Clean Energy Organizations in this proceeding?
6	А.	I am.
7	Q.	What is the purpose of your rebuttal testimony?
8	А.	In this rebuttal testimony, I respond to the direct testimony of many of the witnesses for
9		the other parties, including: Dr. Michael Hanemann, witness for the Department of
10		Commerce ("DOC") and the Pollution Control Agency ("MPCA"); Dr. Anne Smith,
11		witness for Great River Energy ("GRE"), Minnesota Power ("MP"), Otter Tail Power
12		("OTP"), and the Minnesota Large Industrial Group ("MLIG"); Dr. Ted Gayer, witness
13		for MLIG; Nicholas Martin, witness for Xcel Energy; and Drs. Robert Mendelsohn and
14		Roger Bezdek, witnesses for Peabody Energy.
15	Q.	Is there anything else you want to address besides responding to these witnesses?
16	А.	Yes.
17	Q.	Please elaborate.
18	А.	I want to make the Judge and parties aware that the Interagency Working Group ("IWG")
19		has recently responded to comments received in response to the Office of Management
20		and Budget ("OMB") notice requesting comments on the technical support document

1		underlying the federal Social Cost of Carbon ("SCC"). A copy of the IWG's July 2015
2		response to comments is attached as Schedule 1.
3		In addition to providing written responses to comments, the IWG also issued a revised
4		technical support document providing a new set of values for the SCC. The values are
5		slightly lower than the values produced in the updated technical support document in
6		2013. For emissions in 2015, the federal SCC per metric ton of $CO_2$ (in 2007 USD) are:
7		• \$56 (2.5% discount rate, average)
8		• \$36 (3.0% discount rate, average)
9		• \$11 (5.0% discount rate, average)
10		• \$105 (3.0% discount rate, 95th percentile)
11	Q.	Why has the IWG changed the value of the SCC?
12	A.	The changes resulted from two minor changes to the models used by the IWG. First, the
13		DICE model had previously been run to the year 2299, instead of the intended end year
14		of 2300. The final year was added to these calculations. Second, past estimates of the
15		SCC were calculated using 2008 U.S. dollars ("USD") in the PAGE model instead of
16		2007 USD. While these corrections are necessary they are not substantive changes and do
17		not alter the process used by the IWG.
18	Q.	Do any of the responses to comments or the changes in the values change your
19		recommendation to the commission?
20	А.	No. I continue to recommend that the Commission adopt the SCC as the appropriate
21		range of externality values for CO <sub>2</sub> emissions

1	Q.	How is the rest of your testimony organized?
2	А.	In the remainder of my testimony, I respond to various witnesses of the other parties. In
3		Section II, I respond to Dr. Michael Hanemann, witness for the DOC and MPCA. In
4		Section III, I respond to Dr. Anne Smith, witness for GRE, MP, OTP, and MLIG as well
5		as Dr. Ted Gayer, witness for MLIG. In Section IV, I respond to Xcel's witness, Nicholas
6		Martin. In Section V, I respond to Drs. Mendelsohn and Bezdek, witnesses for Peabody
7		Energy.
8 9 10	11.	RESPONSE TO DR. MICHAEL HANEMANN, WITNESS FOR THE DEPARTMENT OF COMMERCE AND MINNESOTA POLLUTION CONTROL AGENCY.
11	Q.	Have you read and considered Dr. Hanemann's testimony?
12	А.	Yes.
13	Q.	Do you agree with Dr. Hanemann's testimony, or his conclusions and
14		recommendation?
15	А.	Yes. I agree with Dr. Hanemann's recommendation that the Commission adopt the SCC.
16		I believe his testimony provides a very thorough explanation of the process used by the
17		IWG to develop the SCC, as well as the underlying models and assumptions.
18		There is only one point in his testimony with which I disagree. He appears to suggest that
19		the IWG's SCC is based on annual damages over the period 2010 through 2100
20		(Hanemann Direct, 53). However, my understanding is that the IWG calculated the
21		damages through the year 2300, not 2100.

1	Q.	Are there specific parts of Dr. Hanemann's testimony with which you agree and
2		which you would like to highlight?
3	А.	Yes. Some of the criticisms of the SCC alleged by other witnesses are addressed in Mr.
4		Hanemann's testimony, and I can highlight our agreement on those issues as follows:
5 6 7 8 9		• I agree with Hanemann's claim that "[a] molecule of emitted GHG contributes to damages from climate change experienced everywhere around the globe, regardless of where it is emitted" (Hanemann Direct, 12). This is the reason that I agree with the decision by the IWG to consider the global impacts of emissions of CO <sub>2</sub> . Ignoring the global damages from CO <sub>2</sub> emissions suggests we are not internalizing the full
10		external cost of our actions in Minnesota.
11 12 13 14		• I agree with Hanemann's explanation of market and non-market valuation and its application to the impacts from climate change. Climate change is predicted to cause harm to resources that are not valued in a market. Including damages to these non-market resources is necessary to fully account for the external costs of CO <sub>2</sub> emissions.
15 16 17 18 19		• I agree with Hanemann's definition of the SCC as "the <i>discounted present value</i> of the stream of additional external costs occurring as a consequence of emitting an incremental unit now" (Hanemann Direct, 21). Further, I agree with his definition of SCC as a measure of the marginal external cost, rather than an average external cost, or cost of the first unit of emissions.
20 21 22 23		• I agree with Hanemann's statement that the "empirical evidence and theoretical understanding indicate that, in aggregate, the net effect [of GHGs] is harmful" (Hanemann Direct, 21). Estimates of the SCC are a measure of the net external costs minus the external benefits of an additional unit of CO <sub>2</sub> . The abundance of research
24		indicates that the SCC is a positive value as Hanemann claims.

1		٠	I agree with Hanemann's description of the steps taken to estimate the marginal
2			external cost of an additional unit of $CO_2$ emissions (Hanemann Direct, 22-23). And I
3			agree with his assessment that "[t]he three IAMs used by the IWG are the three main
4			such models in the literature" (Hanemann Direct, 31).
5		•	I agree with Hanemann's characterization of the DICE, FUND and PAGE models. I
6			agree that FUND and PAGE are simulation models while DICE is an optimization
7			model, and I agree with Hanemann's explanation of the differences between a
8			simulation and optimization model. I also agree with Hanemann's assertion that the
9			simplifications used in Integrated Assessment Models ("IAMs") are necessary and
10			appropriate to be used for policy making (Hanemann Direct, 42-44).
11		٠	I agree with Hanemann's explanation of the IWG's approach to standardizing the
12			inputs so the three models had a set of common drivers, his explanation of how DICE
13			was changed from an optimization to a simulation model, and why these changes
14			were reasonable and/or necessary.
15		٠	I agree with Hanemann's assertion that it is not surprising that the three models would
16			use different methodologies to estimate the impact of $CO_2$ emissions on human
17			wellbeing. I believe this is one of the aspects of the IWG process that is most
18			important and provides a level of credibility to the estimates of the SCC that cannot
19			be obtained using any one model's estimate.
20		•	I agree with Hanemann that the three values for the discount rate of 2.5 percent, 3
21			percent and 5 percent were appropriate for the IWG to use. I agree that these values
22			represent an appropriate range across the discount rates most commonly found in the
23			literature on climate change. While the range is appropriate, it is more common to
24			find in the SCC-related literature discount rates below 2.5 percent than above 5
25			percent.
26	Q.	De	o you have any further response to Dr. Hanemann's testimony?

27 **A.** Not at this time.

# III. RESPONSE TO ANNE SMITH, WITNESS OF GREAT RIVER ENERGY, MINNESOTA POWER, OTTER TAIL POWER COMPANY AND THE MINNESOTA LARGE INDUSTRIAL GROUP

#### 4 Q. What is the purpose of this section of your rebuttal testimony?

A. In this section I respond to the direct testimony by Dr. Anne Smith, witness for GRE,
MP, OTP and the MLIG (hereinafter "Smith" or "Smith's testimony"). In her testimony,
Smith lists five areas of concern with the SCC. Smith also produces estimates of the SCC
using different assumptions based on her five concerns. This rebuttal testimony considers
each of the five concerns raised by Smith and states why these concerns are either not

10 valid, or, if they touch on legitimate issues, why the proposed alternatives to the SCC are

11 inappropriate, and therefore why I disagree with her conclusion about the SCC.

### 12 Q. How do you respond to Smith's general concern regarding uncertainty?

A. Before directly responding to each of the five areas of concern it is important to address a
 general issue raised repeatedly throughout Smith's testimony. Smith claims that the SCC

15 contains excessive speculation that is unscientific and therefore the SCC should be

16 disregarded. I believe that the speculation that Smith is referring to is more correctly

17 identified as uncertainty. Damages from climate change, some of which occur well into

18 the future because of the long life of  $CO_2$  and other greenhouse gases ("GHGs") in the

19 atmosphere, are uncertain. Uncertainty in assessing the social cost of carbon cannot be

20 avoided. It is not valid to say that because uncertainty is large that attempts to deal with it

21 are excessively speculative. It is also not valid to conclude that the proper response to

22 large uncertainty is to just ignore it.

1	Decision science and economics have a standard approach for decision-making with
2	uncertainty, which involves assembling the best available evidence and assessing a range
3	of potential outcomes considering both the likelihood (probability) and the net impacts
4	(costs and benefits) of each potential outcome. To estimate the SCC the IWG had to
5	make projections regarding the future economy, quantity of emissions, and degree of
6	warming. The use of multiple models, each of which also incorporates elements of
7	uncertainty and a range of discount factors, clearly shows there is uncertainty about the
8	SCC. The IWG made reasonable attempts to estimate the SCC given this uncertainty.
9	Because we cannot know what the future will be with certainty, this does not mean that
10	we should ignore it. The most appropriate method to employ will account for the range of
11	possible outcomes in the future, and apply the best estimates of how likely those future
12	outcomes may be. In my opinion that is what the IWG has attempted to do. To say that
13	the IWG has used speculative assumptions is an attempt to reframe the appropriate
14	actions of the IWG, which were to estimate the SCC incorporating the uncertainty of
15	future events, as being somehow illegitimate or unscientific.
16	While we cannot know damages from $CO_{2}$ emissions with absolute certainty assuming
10	while we cannot know damages from CO <sub>2</sub> emissions with absolute certainty, assuming
17	that damages are zero simply because they are uncertain is surely the wrong answer and
18	surely would be an illegitimate and unscientific approach.

19 **Q.** 

# Has the IWG addressed the issue of uncertainty?

A. Yes. As I noted above, the OMB issued a public notice requesting comments on the SCC
and the technical support documents underlying the IWG's calculation, and the IWG has

1		recently issued responses to comments received. In its "Response to Comments: Social
2		Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," the IWG
3		squarely addresses the issue of uncertainty. In its response, the IWG acknowledges
4		uncertainty is present in its calculations, but "disagrees that the uncertainty is so great as
5		to undermine use of the SCC estimates in regulatory impact analysis." Further, the IWG
6		states that:
7 8 9 10 11 12 13		While uncertainty must be acknowledged and addressed in regulatory impact analyses, even an uncertain analysis provides useful information to decision makers and the public good regulatory practice requires that agencies use the best available scientific, technical and economic information to derive the best estimates of costs and benefits that they can, and then communicate to the public the limitations and uncertainties fo the analyses. This is what the IWG has attempted to do in developing and discussing the SCC estimates.
14		I agree with the IWG's approach and continue to believe that the SCC is reasonable and
15		the best available measure to determine the environmental cost of CO <sub>2</sub> emissions.
16	Q.	What are the five concerns identified by Dr. Smith in her direct testimony about the
17		SCC?
18	А.	Smith's testimony identifies five concerns with the federal SCC. I list them as follows,
19		quoting from Smith's testimony, pages 15-16:
<ol> <li>20</li> <li>21</li> <li>22</li> <li>23</li> <li>24</li> </ol>		• "First, the IWG's SCC values are calculated assuming that the emitted ton of CO <sub>2</sub> being valued would be the last ton to be added to the global CO <sub>2</sub> emissions inventory, which overstates the marginal damage that Minnesota should consider for environmental cost values from its potential emissions reduction decisions in resource planning."

- "Second, the IWG calculated its SCC values using an analysis horizon through the year 2300, which produces SCC values that contain a degree of speculative content that is inconsistent with what I understand to be Minnesota's criteria for setting its environmental cost values as discussed in the Minnesota Public Utilities Commission's 1997 Order Establishing Environmental Cost Values in Docket No. E-999/CI-93-583 (January 3, 1997)."
- "Third, the Agencies have recommended using only the IWG's SCC value based on a
  3 percent discount rate, which is an unreasonably narrow recommendation. The IWG
  itself also considered a 5 percent discount rate, which is reasonable to include as
  well."
- "Fourth, the IWG's SCC values are based on global damages, not Minnesota damages or U.S. damages. This is inappropriate in the case of an individual state's investment decisions when there are no reciprocal agreements with major emitting nations to also adopt that same SCC."
- "Fifth, the IWG's SCC values have not accounted for the possibility of leakage,
   which is a particular concern for reduction actions that take place within the
   electricity system of a single state that is interconnected to electricity systems in other
   states that are not participating in the same resource planning constraints."
- 19 Q. Regarding her first concern, what has Smith alleged about the marginal damage
- 20

# calculated by the IWG in the SCC?

A. Smith's testimony argues that it is inappropriate to use a marginal damage approach to
 estimating the SCC, and instead advocates for either using the average damage per ton or
 using the damages from the first ton of emissions.

1	Q.	Please explain why Smith's critique of the IWG's marginal damage approach is
2		incorrect.
3	А.	First, Smith's discussion of what is meant by "marginal" damage is unnecessarily
4		confusing and not consistent with the way in which economists discuss marginal damage.
5		Marginal analysis is a fundamental principle agreed upon by economists and is the
6		correct basis on which to analyze to create an efficient or desirable outcome. Pick up any
7		introductory economics textbook and there will be numerous graphs showing that the
8		efficient decision occurs where marginal cost equals marginal benefit, not where average
9		cost equals average benefit, and certainly not where the cost of the first unit is equal to
10		some measure of benefits.
11		Smith's actual argument is with the emission projections from which marginal damage is
12		calculated. She alleges, for example, that if the marginal damage from a scenario in
13		which emissions continue under a business-as-usual projection were calculated, it would
14		be a marginal "last ton" damage. If, however, we constructed a scenario (however
15		unrealistic) in which there are no more emissions after 2020, the marginal damage from
16		this scenario would be what she calls "first ton" (See her report, page 52, testimony, page
17		111).
18		The different definitions of "marginal" Smith supplies only obfuscate her actual point,
19		which is that she believes the IWG used incorrect projections of future emissions.
20		The reason Smith is interested in the projection of future emissions is because the level of
21		emissions in the future affects marginal damages. Marginal damage is not constant but

1	depends on the level of GHGs in the atmosphere both now and in the future, which in
2	turn depends on emissions both now and in the future. If future emissions are higher, then
3	the marginal damage from current emissions in Minnesota will be higher. On the other
4	hand, if there are fewer future emissions, then the marginal damages from current
5	emissions in Minnesota will be lower. This result occurs because marginal damages tend
6	to rise with higher concentrations of GHGs in the atmosphere. The damages from going
7	from 2 to 4 degree increase in temperature are greater than the damages from going from
8	0 to 2 degree increase in temperature.

#### 9 Q. What is Smith's criticism of the IWG's future projection of emissions ?

10 A. Smith argues that the IWG should use emission projections assuming an optimal level of future  $CO_2$  emissions. An optimal emission projection assumes that there is a global 11 climate policy in place that equates the marginal cost of reducing emission with the SCC 12 and determines the quantity of emissions that would result from this policy. As is clear to 13 14 any observer of climate change policy, we do not have such policy in place now, nor is 15 there any guarantee that we will have such policy in the future. Smith's analysis does not 16 actually identify an optimal level of emissions, however, instead she uses an average 17 between a future in which there are no emissions after 2020 and the IWG's projections. 18 The projections used by the IWG, on the other hand, predict the quantity of emissions 19 that are likely to occur in the future given population and economic growth and the actual 20 climate policies that are in place. That being said, future emissions are uncertain and 21 difficult to predict. Future emissions depend on future technology, economic conditions,

1		and policy choices. Most analyses of future emissions use scenarios to make projections
2		under different assumptions about future technology, economic conditions, and policy
3		choices. The IWG follows this approach using five different projections of future
4		emissions that cover a wide range of emissions in the future.
-		
5		To determine the marginal damages of emissions in Minnesota it is more appropriate to
6		use a range of projections of emissions given likely political and economic conditions as
7		opposed to assuming the optimal level of emissions will occur. If in the future a robust
8		global climate policy is adopted that results in far lower CO <sub>2</sub> emissions than originally
9		projected, then new emission projections can be developed and an updated SCC can be
10		calculated by the IWG. For the time being, I believe that the IWG emission projections
11		best reflect the current understanding of the likely potential trajectories of future
12		emissions.
13	Q.	Please explain in more detail the five emission projections used by the IWG.
14	А.	To further understand this issue it is helpful to explore the five projections used by the
15		IWG. Between 2010 and 2100 the five projections indicate that annual global $CO_2$
16		emissions will change by: -59 percent, 46 percent, 88 percent, 153 percent, and 273
17		percent. Consistent with most economic forecasts, most of these projections predict
18		substantial growth in the world economy. Since CO <sub>2</sub> emissions are positively correlated
19		with the level of economic activity, forecasts of economic growth will give rise to
20		predictions of higher future emissions. The table below shows the level of emissions ("Gt
21		CO <sub>2</sub> /year") and the quantity of emissions per unit of economic

	Exhibit

1	output ("Gt $CO_2$ /trillion 2005 USD") from each projection in 2010 and 2100. In four of
2	the projections the quantity of emissions increase, and in one projection they decrease,
3	but in all five projections the quantity of emissions required to produce a dollar of
4	economic output decreases substantially (this is seen comparing the third and fifth
5	columns in the table below, emissions of $CO_2$ per unit of GDP). The projections predict
6	that in the future the economy will be much less $CO_2$ intensive. In other words, the
7	business-as-usual projections incorporate many emission-reduction technologies into the
8	economy even as the total quantity of emissions increases in four projections due to the
9	growing global GDP.

Table 1. Level of emissions and level per unit of economic output 2010 and 2100 by projection.

	2010		2100		
		Gt CO <sub>2</sub> /		Gt CO <sub>2</sub> /	
	Gt CO <sub>2</sub> /	trillion	Gt CO <sub>2</sub> /	trillion	
Projection	year	2005 USD	year	2005 USD	
IMAGE	31.9	0.60	60.1	0.15	
MERGE Optimistic	31.5	0.69	117.9	0.44	
MESSAGE	29.2	0.56	42.7	0.13	
MiniCAM	31.8	0.67	80.5	0.22	
550 ppm average	31.1	0.63	12.8	0.04	

10 Due to the uncertainty regarding the future economy and the quantity of CO<sub>2</sub> emissions, the IWG chose five projections that cover a wide range of possible outcomes, including 11 one scenario where emissions are reduced substantially. The SCC averages the estimates 12 of the marginal damages of emitting an additional ton of CO<sub>2</sub> into each of these five 13 14 possible futures.

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1	Q.	How did Smith alter the models and why is this change inappropriate?
2	А.	If Smith disagrees with the projections used by the IWG, in particular that they predict
3		futures with far more emissions, then Smith should produce estimates of the SCC using
4		different projections of future emissions. Instead, Smith altered the climate change
5		models assuming zero emissions of CO <sub>2</sub> after 2020. This is a completely absurd
6		projection of the future. Given that the Smith testimony in this hearing is arguing against
7		a modest valuation of the SCC intended to limit future emissions, it is particularly
8		incongruent that the testimony argues that there will be substantially larger emission
9		reductions of $CO_2$ in the future than the IWG projections indicate.
10	Q.	What impact does Smith's decision to reduce future emissions to zero after 2020
11		have on the validity of her results?
12	А.	There is no rational or scientific basis for assuming that there will be zero emissions after
13		2020. The assumption significantly lowers the damage costs of current and future
14		emissions in a way that is not justified given what we currently know and can predict
15		about the global economy and GHG emissions. Based on this alone it would not be
16		appropriate for the Commission to rely on Smith's conclusions.
17	Q.	Regarding her second concern, what has Smith alleged about the time horizon used
18		by the IWG?
19	А.	Smith's testimony argues that the time horizon used by the IWG is too long. Instead of
20		estimating the damages of emissions until the year 2300, as done by the IWG, Smith
21		argues that we should only estimate the damages until either the year 2100 or 2140.

1		Smith claims that it is too speculative to consider what will happen that far into the
2		future. Smith also claims that the damage functions used in the IAMs are only calibrated
3		for the first few degrees of warming, so that it is too speculative to include damages
4		beyond a few degrees warming that is much more likely to occur after 2100.
5	Q.	Do you agree with Smith that it is too speculative to consider possible impacts
6		beyond the next 100 years?
7	А.	No.
8	Q.	Why not?
9	А.	Properly estimating the marginal damages associated with a unit of emission of $CO_2$
10		requires accounting for the impact of that unit as far into the future as it is likely to
11		remain in the atmosphere and cause damages. A unit of $CO_2$ and the associated warming
12		effect persists for many years, with some estimates of residence time in the atmosphere
13		lasting up to two hundred years. It would be inappropriate to arbitrarily exclude any
14		future time period where damages will likely occur. At some point, both because of low
15		probability of remaining in the atmosphere and discounting, future impacts become
16		negligible. The IWG determined that the year 2300 was the appropriate time horizon
17		required to capture all pertinent impacts associated with CO <sub>2</sub> emissions. Of course it is
18		impossible to predict with great accuracy what will happen out to 2300, just as it is
19		impossible to predict with great accuracy what will happen out to 2140, to 2100, or even
20		to 2050.

1	Smith's suggested remedy for future uncertainty is to calculate the SCC using only those
2	damages estimated until the year 2100 or 2140, thereby assuming that all damages
3	beyond this year are zero. Assuming an arbitrary end date is an inappropriate method for
4	dealing with uncertainty. As Smith's testimony shows, truncating the analysis at 2100
5	does reduce the expected value of the SCC. In contrast, extending the analysis beyond
6	2300 would have a negligible impact on the SCC both because there will likely be little
7	CO <sub>2</sub> emitted today still in the atmosphere and even if damages remained, discounting for
8	nearly 200 years would yield very small present values.
9	To see why simply ignoring future uncertainty is the wrong approach, consider how the
10	Congressional Budget Office ("CBO") makes projections regarding the future impact on
11	the federal deficit and debt when determining the budget implications of a proposed bill.
12	These projections often prove to be wrong, but they are based on the best available
13	evidence at the time and include an appropriate time horizon. If, for instance, there was a
14	proposed bill to spend one trillion dollars per year on social security for the next fifty
15	years, we would not instruct the CBO to calculate the budget impacts for the first twenty
16	years, and then assume that there would be zero cost or debt implications from years
17	twenty-one to fifty simply because it would be too speculative to project what will
18	happen beyond twenty years.
19	Smith correctly identifies an area of uncertainty predicting damages from $CO_{2}$ emissions
17	Simili correctly identifies an area of uncertainty, predicting damages from CO <sub>2</sub> emissions
20	for hundreds of years, but the proposed solution, namely to assume there will be no
21	impacts far into the future, has no bearing in reality.

1	Q.	Do you agree with Smith that the damage functions, being only calibrated for the
2		first few degrees of warming, weigh in favor of a shorter time horizon?
3	А.	No.
4	Q.	Why not?
5	А.	Smith argues that in using the longer time horizon "the IWG's SCC values are driven
6		more by the speculative portions of the IAMs' damage functions than by the portions that
7		have at least some evidentiary basis" (Smith Direct, 23). This argument suggests that
8		within the time horizon to the year 2100 (or 2140) we are likely to be on the better-
9		calibrated portion of the IAM damage functions (between 0 and 3 degree Celsius
10		increase), but out to the year 2300 we are more likely to be on the portion of the damage
11		function that is more uncertain (beyond 3 degrees Celsius increase). It is true that the
12		more things change away from present conditions, the more uncertainty there is likely to
13		be. However, uncertainty is not an excuse for assuming that the damages from warming
14		above 3 degrees Celsius are zero.
15		The best evidence we have suggests that the damages beyond 3 degrees of warming will
16		be much greater than damages up to 3 degrees of warming. The IWG and the modelers of
17		the IAMs have made their best judgments regarding the damages from greater than 3
18		degrees of warming, and none of them have concluded that the damages are zero.
19		This issue is demonstrated in the figure below. The black line represents the damage
20		function used in the DICE model, and demonstrates the percentage of GDP lost due to
21		various levels of warming. Smith's argument is represented by the red line, which shows

that for all temperature increases above 3 degrees (the speculative range) we should
 estimate zero damages. This is precisely the range of temperature increases that cause the
 greatest damages according to the DICE model and the temperature increases we as a
 society should be most focused on avoiding.



Figure 1. Comparison between DICE and Smith methods of predicting damages.

5	Smith's argument appears even more inappropriate when considering that many climate
6	scientists and economists believe that the damage functions used in the IAMs
7	underestimate the damages from large temperature increases. For example, Harvard
8	University economist Martin Weitzman suggests that the damage functions in IAMs
9	should reach 50 percent of global GDP from 6 degrees of warming. This is represented
10	by the blue line in the figure by adding a cubic term to the DICE damage function.

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Figure 2. Comparison between DICE, Smith, and Weitzman methods of predicting damages.

1	Smith appears to choose the years 2100 and 2140 based on their use in the prior hearing
2	on this topic in 1997. Simply because these years were chosen as the appropriate time
3	horizon in 1997 does not suggest that the time horizon used by the IWG is inappropriate.
4	Our understanding of climate change science and economics improves through time. The
5	estimates of the SCC should reflect this improved understanding. The IWG used updated
6	IAMs based on the best available current science. I defer to the IWG, a team of experts
7	relying on the best up-to-date scientific understanding, over the recommendation of a
8	single expert, Mr. Ciborowski, from 1997.

1	Q	Has the IWG addressed Smith's concern regarding the time horizon for damages in
2		responses it issued to comments received on the SCC?
3	А.	Yes. This issue is explicitly addressed by the IWG in its July 2015 "Response to
4		Comments: Social Cost of Carbon for Regulatory Impact analysis Under Executive Order
5		12866." In the Response, the IWG notes on page 29, as I have above, that artificially
6		limiting the time horizon would significantly underestimate likely damages: "[B]ecause
7		of the long atmospheric lifetime of CO <sub>2</sub> , using too short a time horizon could miss a
8		significant fraction of damages under certain assumptions about the growth of marginal
9		damages."
10	Q.	Would it be reasonable for the commission to adopt Smith's time horizon rather
11		than the IWG's time horizon?
12	А.	No. Using Smith's shorted time horizon would ignore damages from current emissions
13		that occur far into the future. There is no justification for this approach.
14	Q	Regarding her third concern, what has Smith alleged about the discount rates used
15		by the IWG in the SCC?
16	A.	Smith's testimony argues that the commission should not only adopt the federal SCC
17		using the 3 percent discount rate, but should also consider the higher 5 percent discount
18		rate, but should not include the 2.5 percent discount rate used by the IWG. Smith also
19		states that higher discount rates such as 7 percent would be appropriate for consideration.

#### 1 Q. Do you agree with Smith's recommendation regarding the discount rates?

2 A. I agree that the commission should include a range of discount rates to consider, but I 3 disagree with the specific suggestion of not including the 2.5 percent discount rate. I also 4 disagree with the suggestion of including rates higher than 5 percent. If rates above 5 5 percent were considered as part of an exercise to include a wider set of possible discount rates, then I would also include rates below 2.5 percent. But in any case, I do not believe 6 7 adding higher and lower discount rates than reported in the SCC would be responsive to 8 the question posed by the Commission in this proceeding. That question is whether the 9 SCC is reasonable and the best available environmental cost figure for CO<sub>2</sub> emissions, 10 and I conclude that it is.

11 I believe the range adopted by the IWG is appropriate, including all three values: 2.5 12 percent, 3 percent and 5 percent. I base my recommendation on the discount rates that are 13 commonly used in estimates of the SCC. The 2.5 percent, 3 percent and 5 percent 14 discount rates are within the range of rates that are often used. Rates higher than 5 15 percent are rarely used. However, it is not uncommon to use rates below 2.5 percent. One 16 of the most widely cited economic studies of climate change by Lord Stern on behalf of 17 the U.K. government used a discount rate of 1.4 percent. Christian Gollier and Martin 18 Weitzman in a 2010 paper entitled "How should the distant future be discounted when discount rates are uncertain?" stated that "there exists a rigorous generic argument that 19 20 the future should be discounted at a declining rate that approaches asymptotically its 21 lowest possible value" (p. 351). Given the considerable uncertainty about future 22 economic growth especially under climate change, a strong argument for discount rates

1		lower than 2.5 percent can be made. However, a range from 2.5 percent to 5 percent is
2		clearly in the range of what most prior analysts have considered and the IWG's decision
3		is fully justified and reasonable.
4	0	Have there been studies analyzing the discount rates used by economists working on
-	<b>~</b> •	the SCC2
2		the SCC?
6	А.	Yes.
7	Q.	Please elaborate.
8	А.	A meta-analysis of the SCC by Richard Tol, 2008, summarizes the different discount
9		rates used in SCC estimates through 2006. The analysis by Tol shows that in SCC
10		studies, ten studies used a discount rate below 3 percent, nine used a discount rate of 3
11		percent, five used a discount rate of 4 percent, and thirteen used a discount rate of 5
12		percent. Only two studies considered a discount rate above 5 percent. This number is less
13		than the number of studies that used a discount rate of 1 percent or less (six studies).
14		Given the decisions of the appropriate discount rate used by past researchers for use in
15		estimating the SCC, I find the range of values employed by the IWG appropriate. Given
16		the large number of studies using a discount rate below 3 percent, and using 3 percent
17		and 5 percent, using discount rates of 2.5 percent, 3 percent, and 5 percent as chosen by
18		the IWG is reasonable. Given the relative dearth of studies using discount rates above 5
19		percent, I also find it reasonable that the IWG did not use higher rates.

1	Q.	Has the IWG addressed Smith's concern regarding the discount rate in responses it
2		issued to comments received on the SCC?
3	А.	Yes. This issue is explicitly addressed by the IWG in its July 2015 "Response to
4		Comments: Social Cost of Carbon for Regulatory Impact analysis Under Executive Order
5		12866." In the Response, the IWG explains on page 22, as I have above, that the selected
6		range of discount rates is best supported by the existing literature:
7 8 9 10 11		[A]fter a thorough review of the discounting literature, the IWG chose to use three discount rates to span a plausible range of constant discount rates: 2.5, 3, and 5 percent per year. The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest.
12	Q.	Doesn't the OMB's circular A-4 guidance suggest that agencies use a 7 percent
13		discount rate in addition to 3 percent?
14	А.	It does. But the IWG concluded that the 2.5 percent, 3 percent, and 5 percent discount
15		rates were more appropriate in this particular context and I agree with them. The OMB
16		was one of the parties engaged in the IWG and agreed to its range of discount rates rather
17		than insisting on using 7 percent in addition to 3 percent.
18		Circular A-4, according to its own text, is "designed to assist analysts" and offer guidance
19		but does not define or require a particular approach. The Circular explains two conditions
20		in which it is appropriate to use lower discount rates, both of which apply to the problem
21		of climate change damages because the damages we are discussing are intergenerational.
22		First, there may be ethical considerations that argue for a lower rate. Quoting from
23		OMB's Regulatory Impact Assessment: A Primer:

1 Special considerations arise when comparing benefits and costs across 2 generations. Although most people demonstrate time preference in their own 3 consumption behavior, it may not be appropriate for society to demonstrate a 4 similar preference when deciding between the well-being of current and future 5 generations. Future citizens who are affected by such choices cannot take part in 6 making them, and today's society must act with due consideration of their 7 interests. Many people have argued for a principle of intergenerational neutrality, 8 which would mean that those in the present generation would not treat those in 9 later generations as worthy of less concern. Discounting the welfare of future generations at 7 percent or even 3 percent could create serious ethical problems. 10 11 (p. 11-12)

12 Second, the OMB notes that longer time frames that involve uncertainty about future

13 conditions should have lower discount rates. As noted above, Martin Weitzman and

14 Christian Gollier have shown that given uncertainty about future discount rates "there

15 exists a rigorous generic argument that the future should be discounted at a declining rate

16 that approaches asymptotically its lowest possible value." Given that many economists

17 forecast slower future growth rates than we experienced in the recent past (see for

18 example Robert Gordon, "The Future of Economic Growth: Slowing to a Crawl; in G.S.

19 Morson and M. Schapiro (eds.), *The Fabulous Future? America and the World in 2040*),

20 it is quite plausible to argue for low discount rates and quite implausible to argue for high

21 discount rates.

22 Because these reasons for applying lower, not higher, discount rates apply to the climate

change problem, I agree with the IWG's decision to focus on the 2.5 percent, 3 percent

24 and 5 percent discount rates.

1	Q.	Regarding her fourth concern, what does Smith argue with regard to the
2		geographical scope of damages considered by the IWG?
3	А.	Smith argues that it is inappropriate to account for global or U.Swide damages from
4		Minnesota emissions, and we should only count the damages caused in Minnesota from
5		Minnesota emissions. Because it was not possible to isolate the Minnesota-specific
6		damages in the IWG IAMs, Smith estimated the SCC using damages to the U.S., but not
7		global damages.
Q	0	Do you agree with Smith that SCC demogree should be limited to Minnesote, or
0	Q.	Do you agree with Smith that SCC damages should be minted to Minnesota, or
9		alternatively, the United States?
10	А.	No.
11	Q.	Please explain why not.
12	А.	I believe restricting damages to cover only the portion of damages that accrue within
13		Minnesota or the U.S. fails both from an economic perspective regarding the appropriate
14		policy in response to external costs, and from a legal perspective regarding the clear
15		language of the Minnesota statute. Minnesota Statutes § 216B.2422 requires that "[t]he
16		Commission shall, to the extent practicable, quantify and establish a range of
17		environmental costs associated with each method of electricity generation." There is no
18		disagreement that the emission of $CO_2$ in Minnesota will lead to damages well outside of
19		Minnesota or the U.S. Climate change has global impacts. The statute clearly intends for
20		all environmental costs associated with a method of electricity generation to be included
21		in the resource planning decision.

Exhibit _	
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1		The theory of correcting externalities indicates that the emitting entity, a Minnesota
2		electric power generator, must incorporate the damages caused from the pollution to all
3		parties, into their production decision process. Incorporating only the damages incurred
4		in Minnesota from a ton of CO <sub>2</sub> emitted in Minnesota would ignore the vast majority of
5		the external costs. If every state, province, or other political territory only considered the
6		damages of their own CO <sub>2</sub> emissions within their own political boundaries then there
7		would be virtually no correcting for externalities. By incorporating the <i>full</i> external cost
8		of CO <sub>2</sub> emissions into resource planning decisions in Minnesota, we as a state are both
9		leading and preparing for a future where the price of emitting carbon is no longer free.
10		Other states that fail to adopt these considerations in their decision-making will be
11		unprepared for a future that addresses the concerns of climate change.
12	Q.	Have you also reviewed Dr. Ted Gayer's testimony on this issue?
13	А.	Yes. According to his direct testimony, Gayer believes that only the damages inflicted in
14		Minnesota should be counted in the SCC for Minnesota emissions of CO <sub>2</sub> . Gayer does
15		not deny that emissions of $CO_2$ in Minnesota will cause damages to other states in the
16		U.S. and other countries in the world. Gayer also indicates that to achieve efficiency the
17		polluting entity must internalize the entire external cost of their emissions. Gayer's issue
18		is with the appropriate "economic standing" (emphasis his) regarding "who is to be
19		counted in the calculation of the external costs of pollution, or, equivalently, the external

20 benefits of reducing pollution" (Gayer Direct, 3).

1 Q. What is your response to Gayer's argument?

2 A. Both the economic principles in question and the Minnesota statute are clear. The 3 economic standing should be all parties damaged by the emission of a unit of CO<sub>2</sub>. 4 Minnesota statute § 216B.2422 requires the commission to "quantify and establish a 5 range of environmental costs associated with each method of electricity generation." The 6 environmental costs, or damages, do not follow political boundaries. Calculating the 7 environmental costs in Minnesota associated with a metric ton of CO<sub>2</sub> emission, as Gayer 8 has done in his testimony, is ignoring the full extent of the damages caused by that unit of 9 emission. As set out above, if each polluting entity only accounted for the damages 10 caused within its own political boundaries it would not be possible to correct the 11 externality associated with CO<sub>2</sub> emissions.

Gayer discusses the concept of cost/benefit analysis with regard to economic standing according to who pays for the regulation and who benefits from the regulation. He alleges that "standard benefit-cost practice . . . defin[es] society within the context of legal rights, which means considering the benefits only for residents of the political jurisdiction bearing the costs of the policy under consideration" (Gayer Direct, 4).

I do not agree with Gayer's assertion. Externalities are a market failure. With CO<sub>2</sub>
emissions, we in Minnesota are causing direct harm (even if through a complicated
biophysical process) to people across the planet. By incorporating the damages of our
emissions into our resource planning decisions we are correcting this market failure.
While it is true that people outside of Minnesota will benefit from our emission

1		reductions, I believe that it is more accurate to frame the issue in terms of reducing the
2		damages that we are inflicting on others. Incorporating the SCC into decision-making is
3		not an act of generosity that we are bestowing on the rest of the world; it is an act of
4		taking responsibility for the results of our actions.
5		For the same reason, I reject Gayer's suggestion that accounting for global damages
6		caused by Minnesota emissions would somehow require reconsideration of state poverty
7		policies. Gayer states that considering global costs and benefits "[i]f applied broadly
8		would demand a dramatic shift in all state policies, including state poverty programs"
9		(Gayer Direct, 9). Gayer's comment conflates the justified responsibility of Minnesotans
10		to incorporate the damages that their actions cause to people globally with the
11		responsibility of local jurisdictions to care for their most vulnerable citizens. I do not
12		expect my neighbor to provide me meals, but if my neighbor cuts down a tree and it falls
13		on my house, I do expect him or her to pay for it.
14	Q	Has the IWG addressed Smith's and Gayer's concern regarding the geographical
15		scope of damages in responses it issued to comments received on the SCC?
16	А.	Yes. This issue is explicitly addressed by the IWG in its July 2015 "Response to
17		Comments: Social Cost of Carbon for Regulatory Impact analysis Under Executive Order
18		12866." In the Response, the IWG explained on page 31 that because GHG emissions are
19		a global problem they set up a classic public goods, or tragedy of the commons, scenario:
20		"[I]f all countries acted independently to set policies based only on the domestic costs
21		and benefits of carbon emissions, it would lead to an economically inefficient level of

1		emissions reductions which could be harmful to all countries, including the United States,
2		because each country would be underestimating the full value of its own reductions." The
3		same can be said about Minnesota as a state. Focusing solely on damages to Minnesota
4		would significantly underestimate the value of the state's emission reductions, leading to
5		an inefficient reliance on carbon intensive methods of electricity generation, contrary to
6		the very purpose of the statute at issue here.
7	Q.	Regarding her fifth concern, what has Smith alleged regarding "leakage"?
8	А.	The issue of leakages as a result of an environmental policy can be a legitimate concern.
9		But as Smith describes them, leakages are not a concern regarding the calculation of the
10		marginal damages of a ton of emissions; rather, leakages regard whether there will be
11		emission increases outside of Minnesota as a result of emission reductions in Minnesota.
12		Therefore, the issue of leakage does not affect the externality value the Commission
13		would adopt. Instead, it raises a question about how the PUC should implement policy in
14		response to possible leakages. Leakage therefore does not affect the question of whether
15		the SCC is a reasonable and best available externality value for $CO_2$ .
16	Q.	Has the IWG addressed the issue of leakage?

17A.Yes. The IWG in its response to comments on the SCC explained that leakage "does not18affect the calculation of the SCC itself, which is an estimate of the marginal benefit of a19net one-ton reduction in  $CO_2$  emissions. The SCC estimates are multiplied by estimates20of net GHG emission changes to calculate the value of benefits associated with a policy

1		action in a given year. It is in the estimation of net GHG emissions, and not the SCC, that
2		any leakage should be accounted for."
3		The same reasoning applies here. The amount of GHG emissions is not at issue in this
4		proceeding; rather, the Commission has asked whether the SCC is the appropriate per-ton
5		damage cost to assign to emissions. I conclude that it is.
6	Q.	Do you have a general response to Smith's criticisms of the SCC and her suggested
7		alternative approach?
8	A.	Yes. I note that the five concerns Smith identifies and her recommendation with regard to
9		each have the effect of lowering the value of the SCC. Smith ignores concerns that others
10		have raised that would suggest the possibility that the SCC is too low. Smith's testimony
11		does not try to provide an unbiased account of the potential problems of the SCC, rather,
12		it attempts to highlight only those possible areas a plausible sounding argument could be
13		made that would lower the SCC. For instance, in addressing the speculative nature of the
14		IWG's process, Smith argues that we should not consider damages out to the year 2300,
15		because we will be on the portion of the damage function that we currently know least
16		about. Indeed this is true, but there is a strong argument to be made that the SCC
17		underestimates the damages from large temperature increases many years into the future.
18		In addition, Smith ignores several categories of damages that are left out of the damage
19		functions in the IAMs at this point. Their inclusion would certainly raise the value of the
20		SCC. By seeking only those aspects of the IWG process that could possibly lower the
21		value of the SCC, Smith's testimony does not provide an unbiased review with the goal

- of identifying the best available values to be used in Minnesota resource-planning
   decisions.
- 3 My assessment is that Smith's approach is not credible. In contrast, the IWG made a
- 4 good-faith effort to reasonably address the difficult issues of estimating the SCC. The
- 5 SCC is reasonable and the best available measure of the external costs of  $CO_2$  pollution.

#### 6 IV. RESPONSE TO NICHOLAS MARTIN, WITNESS FOR XCEL ENERGY.

7 Q. What is the purpose of this section of your rebuttal testimony?

A. In this section I respond to the direct testimony by Nicolas Martin, witness for Xcel
Energy (hereinafter "Martin" or "Martin's testimony"). Martin's testimony reviews the
process by the IWG in creating an estimate of the SCC and summarizes his view on the
appropriateness of the SCC for use by the Commission in determining the environmental
cost associated with CO<sub>2</sub> emissions.

13 Q. Are there parts of Martin's testimony with which you agree?

14 A. Yes. I think that Martin's testimony has accurately summarized the process used by the

15 IWG in deriving estimates of the SCC. I think that Martin's testimony is correct in saying

16 that there is uncertainty in estimating damages from  $CO_2$  emissions making this a

- 17 probabilistic rather than a deterministic problem. Damages from climate change, some of
- 18 which occur well into the future because of the long life of  $CO_2$  and other GHGs in the
- 19 atmosphere, are uncertain. The IWG calculated the SCC using three IAMs, five economic
- 20 and emission projections, and 10,000 runs, where each run used a random value for the

1		equilibrium climate sensitivity parameter. This produced 150,000 individual estimates of
2		the SCC for each discount rate (10,000 runs * 3 models * 5 projections). These outputs
3		represent 150,000 different possible outcomes in the future for each discount rate,
4		depending on how we model future climate change, how much population, emissions,
5		and the economy changes in the future, and how much warming will occur from various
6		levels of future emissions. The IWG also used three different discount rates (2.5 percent,
7		3 percent, and 5 percent). By using this probabilistic method, the IWG acknowledges that
8		the outcomes from climate change are uncertain, and attempts to account for many of the
9		possible outcomes. I agree with Martin that the approach used by the IWG and the
10		resulting probability distributions for each discount rate, and use of a range of different
11		discount rates, constitutes a reasonable and best available set of information on which the
12		Commission can proceed with its task of establishing an externality cost for $\text{CO}_2$
13		emissions. Further, I agree with Martin that despite uncertainty the Commission needs to
14		proceed with a practical approach to establishing an externality cost associated with $CO_2$
15		emissions.
16	Q.	Are there any parts of Martin's testimony with which you disagree?
17	А.	Yes. I disagree with Martin's testimony in three areas: (1) Martin's reasons for why
18		adoption of a single value for the SCC would be inappropriate, (2) Martin's preference

- for using median rather than mean, and (3) Martin's method for determining a range of 19 20
  - values for the SCC were the Commission to choose to adopt a range of values.

1	Q.	Why do you disagree with Martin's reasons for why he thinks it is inappropriate to
2		use the federal SCC as an estimate of a single value for the externality cost of $\mathrm{CO}_2$
3		emissions?
4	А.	Let me begin by reviewing Martin reasons for his statement that it is inappropriate to use
5		the SCC as an estimate of a single value for the externality cost of $CO_2$ emissions. On
6		page 3 of his testimony Martin lists four reasons: (1) the SCC is designed for a purpose;
7		(2) the SCC is inherently uncertain and speculative; (3) there is no single Federal SCC
8		value; (4) the SCC estimates damages globally to the year 2300. I address each of these
9		points in turn.
10	Q.	What is your response to Martin's argument that the purpose of the SCC is
11		different from the purpose of Minnesota's Environmental Cost statute?
12	A.	I do not find the argument relevant or persuasive. The impetus for deriving a federal SCC
13		is the requirement to do cost-benefit analysis under Executive Order 12866. Martin
14		asserts that cost-benefit analysis is "fundamentally different from integrated resource
15		planning and other Commission decisions." The SCC is an estimate of the external
16		damages associated with emissions of a ton of CO <sub>2</sub> . Such estimates are applicable to a
17		wide range of applications including cost-benefit analysis as well as the task of the
18		Commission, which is to establish external CO <sub>2</sub> costs that can be used "when evaluating
19		and selecting resource options." Minn. Stat. 216B.2422, subd. 3. It is irrelevant if there
20		are other differences between cost-benefit analysis and the task facing the Commission.
21		In actuality, I see the fundamental logic applied in cost-benefit analysis and integrated
22		resource planning to be quite similar. Both cost-benefit analysis and integrated resource

18	Q.	What is your response to Martin's assertion that there is no single SCC value?
17		uncertainty below in response to witness Anne Smith as well.
16		available data, as has been done by the IWG in deriving the SCC. I address the issue of
15		Commission to proceed than to base its decision on reasonable methods and best
14		to decide on a single estimate for the SCC. I can think of no better way for the
13		make judgments and reach decisions. Ultimately, in a particular case it will be necessary
12		agrees is reasonable and the best available. Uncertainty is not an excuse for failing to
11		out a very reasonable approach for dealing with uncertainty, one that Martin himself
10		climate sensitivity ('ECS') parameter and running a Monte Carlo exercise, the IWG laid
9		and levels of economic activity. By applying a probability distribution to the equilibrium
8		the estimates of the SCC by using several projections of future emissions, populations,
7		uncertainty the IWG has employed appropriate tools to incorporate the uncertainty into
6	А.	As noted above, I agree that the SCC is inherently uncertain. In response to this
5	Q.	What is your response to Martin's argument about uncertainty?
4		establish the external costs of CO <sub>2</sub> emissions.
3		resource planning and is in fact exactly the information needed by the Commission to
2		alternative choices. The SCC is directly relevant for cost-benefit analysis and integrated
1		planning are tools that help inform decision-makers about the relative merits of different

19 A. It is true that the IWG reported a SCC value for each of three discount rates so there is
20 not a single SCC value. Given a discount rate, however, the IWG reported a single
21 number for the SCC. For each discount rate the IWG took the average (mean) of these
1	150,000 outcomes as the basis for the SCC. This produced three estimates of the SCC for
2	the emission of a metric ton of $CO_2$ in the year 2020 (in 2007 USD): \$62 (2.5 percent
3	discount rate), \$42 (3.0 percent discount rate), and \$12 (5.0 percent discount rate). This
4	method is quite standard and reasonable.
5	It would also be reasonable for the Commission to adopt the full range of SCC values,
6	across all three discount rates as well as the 95 <sup>th</sup> percentile value, for purposes of this
7	proceeding. Having a range of values would provide the Commission with more
8	information, allowing for a central value (3.0 percent discount rate) along with sensitivity
9	values that can be used in planning. By adopting this range of values, the Commission
10	would also avoid the perception of "false precision" that is central to Martin's objection.
11	The mean values of SCC under the three discount rates (2.5 percent, 3 percent, and 5
12	percent) are all reasonable numbers to report and generate a spread of values covering
13	much of the range of potential outcomes, with one exception. The high end of the range is
14	not well represented by the mean value. The IWG included the 95th percentile value
15	because it concluded that the federal SCC likely underestimated the true damages of $CO_2$
16	emissions. The IWG explained this in its responses to comments:

1 The IPCC Fourth Assessment Report, which was the most current IPCC 2 assessment available at the time of the IWG's 2009-2010 review, discussed these 3 limitations and concluded that it was "very likely that [SCC] underestimates" 4 climate change damages. Based on the current scientific understanding of climate 5 change and its impacts, and on the limitations of the IAMs in quantifying and 6 monetizing the full array of potential "catastrophic" and non-catastrophic 7 damages, the IWG concluded that the distribution of SCC estimates may be 8 biased downwards. Since then, the peer-reviewed literature has continued to 9 support this conclusion. For example, the IPCC Fifth Assessment report observed 10 that SCC estimates continue to omit various impacts that would likely increase 11 damages. The 95th percentile estimate was included in the recommended range 12 for regulatory impact analysis to address these concerns.

# 13 Q. What response do you have to Martin's point that the SCC estimates damages

14

## globally to the year 2300?

- 15 A. I respond to the criticism of the IWG's decision to consider damages through 2300 in my
- 16 rebuttal to the Smith testimony above at page 15. Since Martin bases his recommendation
- 17 on the IWG, which is based on global estimates to the year 2300, he must also not take
- 18 this objection too seriously.
- 19 In general, having agreed that the IWG methods for establishing the range of potential
- 20 values for the external costs of  $CO_2$  emissions is reasonable and the best available, I do
- 21 not see any valid reason for rejecting adoption of the SCC for use in Minnesota.
- 22 Q. Martin proposed an alternative analysis of the IWG figures that uses the median

# 23 rather than the mean. Do you agree with Martin that the median is a better measure

- 24 than the mean for purposes of establishing the SCC?
- 25 A. No. The mean is a better statistic than the median for purposes of setting the SCC. Both
- 26 the mean and the median can be useful measures. The appropriateness of one over the
- 27 other depends on the context of interest. In the case of trying to estimate expected

- 1 damages as is done in the SCC the mean rather than the median is a better measure to
- 2

use.

## 3 Q. Was this issue raised in comments to the IWG and did the IWG respond?

- 4 A. Yes. The IWG addressed this point directly in their July 2015 response to comments,
- 5 attached as Schedule 1, and I will quote at length:
- 6 The choice of the mean or the median as a measure of central tendency depends 7 on the context. In skewed distributions, such as for the SCC estimates, the median 8 will often give a more "typical" outcome, while the mean will give full weight to 9 the tails of the distribution.
- 10 In some cases, the typical outcome is of most interest. For example, in describing 11 household incomes the median is most often used because the focus is on 12 understanding the income of the typical household and using the mean might 13 distort this picture by giving undue weight to a small number of very wealthy 14 households. In the climate change context, however, sound decision-making 15 requires consideration of not only the typical or most likely outcomes, but also 16 less likely outcomes that could have very large (or small, or even negative) 17 damages (the tails of the distribution). Use of the median to represent the SCC in 18 a regulatory impact analysis would not necessarily lead to the most efficient 19 policy choice that uses resources wisely to mitigate potential climate impacts 20 (e.g., maximize the expected net benefits). In this case, the IWG believes that the 21 mean is the appropriate measure of central tendency.
- 22 Q. Do you agree with the IWG's response?

A. Yes, I agree with the IWG. The mean incorporates information about both the magnitude
of damages and the likelihood of these damages so it contains more relevant information
than does the median. The median ignores the magnitude of damages other than at the
midpoint of the probability distribution. The mean, on the other hand, incorporates the
large (and small) values throughout the distribution. With climate change, high damage
outcomes are the ones we should be most concerned about so that ignoring information
about potential high damages is particularly problematic. The mean, therefore, is a much

better measure than the median for summarizing information about the distribution of
 possible damages under climate change.

3 Q. Can you provide an example of why the mean, in this context, is superior to the
4 median?

5 A. Yes, this point about the superiority of the mean versus the median for purposes of
6 estimated damage calculations can be clearly illustrated with an example.

7 The issues involved in establishing a value for the SCC are similar to the issues involved 8 in the way we price home insurance. They both involve uncertainty about what damages 9 might occur in the future. If we could be certain there would be no damages to our house 10 over the next year, the value of home insurance would be zero. But the value of insurance 11 is greater than zero because there is some, perhaps small, probability that a damage-12 causing event will happen (e.g., severe storm, fire). Suppose there is a 5 percent chance 13 of such an event occurring. That means there is a 95 percent chance that no such event 14 will occur. In other words, 95 times out of 100, the possible future cost of damage to our 15 home is \$0.0. five times out of 100, however, the cost of those damages could be quite 16 large. If we calculate the median of expected damages over the coming year, it is zero. In 17 fact, the range from the 25th to the 75th percentile outcomes would also be zero. This is 18 true regardless of how high the cost is in the five times out of 100 that our home will 19 suffer some damage.

20 The mean, in contrast, gives us a much better understanding of the actual risk to our21 home and the reason for which we would buy insurance. The mean incorporates

1		information about the damages from the 5 percent chance of a damage-causing event, and
2		is a positive value that will vary depending on the amount of damage we might suffer.
3		The mean, rather than the median, is the basis for the price for insurance. This is the exact
4		same concept that should be used when considering the expected damages from climate
5		change, and this is exactly how the IWG calculated the SCC.
6	Q.	Did Martin use the mean in portions of his analysis?
7	<b>A.</b>	Yes. It is interesting to note that when Martin attempts to summarize information across
8		the three different discount rates, he uses the mean rather than the median as the preferred
9		measure. I think this is further indication that the mean rather than the median is the more
10		standard approach and one that is more appropriate for the SCC.
11	Q.	The third area of disagreement you identified was with Martin's method for
12		determining a range of values for the SCC. How do you respond?
12 13	А.	<b>determining a range of values for the SCC. How do you respond?</b> The IWG provided a range of values for SCC by presenting a separate value of the SCC
12 13 14	А.	determining a range of values for the SCC. How do you respond? The IWG provided a range of values for SCC by presenting a separate value of the SCC for each discount rate that they considered (2.5 percent, 3 percent, and 5 percent). The
12 13 14 15	А.	<ul> <li>determining a range of values for the SCC. How do you respond?</li> <li>The IWG provided a range of values for SCC by presenting a separate value of the SCC</li> <li>for each discount rate that they considered (2.5 percent, 3 percent, and 5 percent). The</li> <li>IWG took the mean across 150,000 model runs separately for three different discount</li> </ul>
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12 13 14 15 16 17	А.	determining a range of values for the SCC. How do you respond?The IWG provided a range of values for SCC by presenting a separate value of the SCCfor each discount rate that they considered (2.5 percent, 3 percent, and 5 percent). TheIWG took the mean across 150,000 model runs separately for three different discountrates. Martin advocates a different approach to generating a range of estimates. Martintakes the 25th percentile outcome from each of the three sets of 150,000 runs, and then
12 13 14 15 16 17 18	А.	determining a range of values for the SCC. How do you respond?The IWG provided a range of values for SCC by presenting a separate value of the SCCfor each discount rate that they considered (2.5 percent, 3 percent, and 5 percent). TheIWG took the mean across 150,000 model runs separately for three different discountrates. Martin advocates a different approach to generating a range of estimates. Martintakes the 25th percentile outcome from each of the three sets of 150,000 runs, and thentakes the mean of these three values as the lower end of his range. Then he takes the 75th
12 13 14 15 16 17 18 19	Α.	determining a range of values for the SCC. How do you respond?The IWG provided a range of values for SCC by presenting a separate value of the SCCfor each discount rate that they considered (2.5 percent, 3 percent, and 5 percent). TheIWG took the mean across 150,000 model runs separately for three different discountrates. Martin advocates a different approach to generating a range of estimates. Martintakes the 25th percentile outcome from each of the three sets of 150,000 runs, and thentakes the mean of these three values as the lower end of his range. Then he takes the 75thpercentile outcome from each of the three sets of 150,000 runs, and takes the mean of
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1		both of these choices are inappropriate. I think the IWG method of taking the mean of the
2		distribution for each discount rate and reporting these values across the three discount
3		rates is the appropriate method to summarize the values for the SCC.
4		I agree with Martin that across the 150,000 outcomes from the models for each discount
5		rate there are enormous differences between the lowest and highest values. The mean
6		provides us with a single measure of expected value of damages from this distribution. It
7		is true that no single measure will capture all of the information in the probability
8		distribution. It is also true that no two numbers, such as a high and a low value for range
9		can do so either. In general, having more measures (such as a measure of mean, variance,
10		and skewness) will give more information about the probability distribution, but there is a
11		tradeoff between more information and practicality. In the extreme, we could require the
12		utilities to incorporate all 150,000 outcomes into their resource planning decisions, but
13		that would be ridiculous. The downside of more information is that a range of values
14		provides less guidance for resource planners than does a single value.
15		The particular method used by Martin to create endpoints for the range is arbitrary, and
16		creates a more subjective estimate of the SCC.
17	Q.	Please explain why Martin's selection of the 25 <sup>th</sup> and 75 <sup>th</sup> percentiles is arbitrary
18		and creates a more subjective estimate of the SCC.
19	А.	Martin has chosen the 25th and 75th percentile outcomes as the endpoints of the range to
20		be used to calculate the SCC. There is nothing special about these percentiles and one
21		could just as well choose a range from the 5th to the 95th percentiles. This range would

1	encompass 90 percent of the outcomes produced by the IWG, whereas the Martin's
2	percentiles would only cover 50 percent of the outcomes. In other words, there is a 50
3	percent probability that the actual damages from emitting CO <sub>2</sub> are outside of the range
4	that Martin suggest. The range between 25 percent and 75 percent does not appear to be
5	appropriate and it creates a set of values that are less practical for use in resource
6	planning decisions.

7 The arbitrary end points chosen by Martin can also lead to misleading representations of 8 the SCC. For example, using the outcomes from the IWG process for the 3 percent 9 discount rate, the range between the 25th and 75th percentile outcomes is \$13 to \$44 (in 10 2007 USD for emissions in 2020). The 75th percentile upper value is only slightly higher 11 than the mean value of \$43. In fact, the mean or expected value of damages may well lie 12 outside the range between 25 percent and 75 percent. This result can occur with skewed distributions such as with damages from climate change. The range between the 5th and 13 14 the 95th percentile is \$2 to \$128. The use of a wider range now depicts a very different 15 SCC. Going from the 25th to the 5th percentile only decreases the lower range by \$11, 16 whereas going from the 75th to the 95th percentile increases the upper range by \$84. I 17 believe that the range between the 5th and 95th percentiles provides a better description 18 of the distribution of the SCC than the range between the 25th and 75th percentiles 19 because it better illustrates the degree of uncertainty in the SCC. However, I prefer the 20 mean to a range of values (for a single discount rate) because it incorporates all the values 21 of the distribution and is not arbitrarily chosen. In addition, the mean is more practical for 22 use by the PUC.

Exhibit	

1		Martin's testimony states that they considered using a wider range from the 1st to the
2		99th percentiles, but that the range of values was too wide to be practical, so instead they
3		choose a more narrow set of percentiles. This decision illustrates the arbitrary nature of
4		selecting the endpoints for the range of values. The endpoints should not be selected
5		based on whether the desired result is achieved, rather the endpoints should be chosen
6		based on the best way to describe the distribution of outcomes. It is not the case that the
7		1st and 99th percentiles are not practical for use; rather the distribution of outcomes has a
8		very wide range of values. The IWG could have chosen to incorporate a range of values
9		for the SCC that illustrates this wide range, but it instead selected the mean as a best
10		measure that describes the entire distribution of values. In my opinion that was a
11		reasonable choice because it provides agencies using the SCC, including the
12		Commission, with a central value that represents the wide distribution. What the
13		Commission should avoid is choosing an arbitrarily narrow range.
14	Q.	If you assumed, arguendo, that it were appropriate to use a median or 25 – 75
15		percentile range for calculating the SCC, are there other problems with Martin's
16		analysis?
17	А.	Yes. In Martin's testimony, the 25th and 75th percentile outcomes are calculated
18		separately for each of the three discount rates. This produces three separate ranges, or six
19		values that would have to be considered. Instead of recommending the use of these three
20		ranges, presumably because it would be less practical, Martin decided to take the mean of
21		the three 25th percentile values and the mean of the three 75th percentile values. This
22		decision is clearly inappropriate. There is no reasonable argument that the mean value

1		across the three discount rates is an appropriate measure of the SCC. The discount rate is
2		a parameter value that must be chosen by a modeler or regulator. There are reasonable
3		arguments supporting the use of any of the three discount rates chosen by the IWG. The
4		IWG made the appropriate choice to present the results of the SCC separately for each
5		discount rate, illustrating the difference in the SCC from the use of different discount
6		rates. Averaging the results across the three discount rates has no theoretical basis as we
7		are not considering the entire range of possible discount rates, nor are we applying any
8		probability distribution to the likelihood of any rate being the "true" social discount rate.
9	Q.	What is your overall conclusion with regard to Martin's suggested changes to the
10		SCC?
11	А.	For all of the above reasons I disagree with Martin's recommended values. Instead I
12		recommend the commission adopt the SCC values.
13 14	V.	RESPONSE TO DR. ROBERT MENDELSOHN AND DR. ROGER BEZDEK, WITNESSES FOR PEABODY ENERGY.
15	Q.	What is the purpose of this section of your rebuttal testimony?
16	<b>A.</b>	In this section I respond to the direct testimony of Robert Mendelsohn on behalf of
17		Peabody Energy.
18	Q.	Please describe Mendelsohn's criticisms of the federal SCC.
19	A.	Mendelsohn critiques several aspects of the IWG process in producing the SCC. The
20		critiques can be summarized into four main points:
21		1) The values for the equilibrium climate sensitivity used by the IWG were too high.

1		2) The IWG did not calculate the optimal SCC.
2		3) The PAGE model should not have been included.
3		4) The discount rates used by the IWG were too low.
4	Q.	Do you agree with the first argument regarding the Equilibrium Climate
5		Sensitivity?
6	А.	I am not an expert on climate sensitivity and therefore defer to the testimony of the Clean
7		Energy Organization's other witnesses, Drs. Abraham and Dessler, for specific technical
8		responses to issues raised about climate sensitivity. However, I note that the IWG applied
9		a probability distribution for the ECS that corresponds with the most likely values
10		recommended by the IPCC Fourth Assessment Report ("AR4"). This distribution
11		includes a relatively high probability of some of the lower values that Mendelsohn
12		suggests, while also including a relatively low probability of significantly higher values
13		for the ECS. The advantages of the IWG approach are twofold: first, a distribution of
14		values for the ECS allows for the calculation of the SCC incorporating many possible
15		future effects of CO <sub>2</sub> emissions on global warming, and second, the IWG is committed to
16		updating the SCC when new evidence becomes available. If the preponderance of new
17		research suggests that the ECS parameter should be revised down then future updates to
18		the SCC will be calculated accounting for this new information.

#### 1 Q. Did the IWG address criticisms of the ECS in its response to comments?

- 2 A. Yes. The IWG response to comments addressed this issue on page 12 and the IWG
- 3 committed to updating the ECS used in the models as the scientific understanding
- 4 changes:

5 The IWG is aware that this is an active area of research and remains committed to 6 updating the SCC estimates to incorporate new scientific information and 7 accurately reflect the current state of scientific uncertainty regarding the ECS. 8 While we agree with commenters that the ECS distribution, along with other 9 climate modeling inputs to the SCC calculation, should be updated periodically to 10 reflect the latest scientific consensus, care must be exercised in selecting an 11 appropriate range of estimates for this important parameter. Many studies 12 estimating climate sensitivity have been published, based on a variety of 13 approaches (instrumental record, paleoclimate observations, models, etc.). These 14 individual studies report differing values and provide different information. 15 Picking a single study from the high or low end of the range, or even in the 16 middle, will exclude relevant information. A valid representation of uncertainty 17 regarding climate sensitivity should be obtained from a synthesis exercise such as 18 that done by the IPCC that considers the full range of relevant studies.

- 19 At the time the 2013 SCC update was released, the most authoritative statement 20 about ECS appeared in the IPCC's AR4. Since that time, as several commenters 21 noted, the IPCC issued a Fifth Assessment Report that updated its discussion of 22 the likely range of climate sensitivity compared to AR4. The new assessment 23 reduced the low end of the assessed likely range (high confidence) from 2°C to 24 1.5°C, but retained the high end of the range at 4.5°C. Unlike in AR4, the new 25 assessment refrained from indicating a central estimate of ECS. This assessment 26 is based on a comprehensive review of the scientific literature and reflects 27 improved understanding, the extended temperature record for the atmosphere and 28 oceans, and new estimates of radiative forcing.
- 29 Several of the post-AR4 studies highlighted by some commenters were cited in 30 the AR5 assessment. In particular, both Aldrin et al. (2012) and Otto et al. (2013) 31 were cited in both Chapter 10 and Chapter 12 of the AR5 Working Group I 32 assessment. Eight of the authors of Otto et al. (2013), including the lead author, were authors of Chapter 12 for AR5's Working Group I and one was a lead author 33 34 for the chapter. Hence it is clear that the IPCC considered Otto et al. (2013) in its 35 synthesis of literature on the ECS. More broadly, the AR5 climate sensitivity 36 distribution likely incorporates much of the literature identified by the 37 commenters. The IWG will continue to follow and evaluate the latest science on 38 the equilibrium climate sensitivity and seek external expert advice on the 39 technical merits and challenges of potential approaches prior to updating the ECS

1 2		distribution in future revisions to the SCC estimates, including (but not limited to) using the AR5 climate sensitivity distribution for the next update of the SCC.
3		I find the approach taken by the IWG to be a reasonable approach to uncertainty regarding
4		climate sensitivity.
5	Q.	How do you define the optimal level of CO <sub>2</sub> emissions reductions?
6	А.	The optimal level of emissions reductions minimizes the present value of the sum of the
7		climate damages and the mitigation cost to society. In other words, the optimal emission
8		reduction is where the present value of the marginal damages (damages from an
9		additional ton of carbon) equal the marginal cost of abatement (cost of reducing an
10		additional ton of carbon).
11	Q.	Professor Mendelsohn claims that the IWG should have calculated the SCC
12		assuming an optimal level of emissions reductions. Do you agree?
13	А.	No. If policy existed to make polluters pay for emissions, then a higher SCC should result
14		in lower future emissions as there is a stronger incentive for emitters to reduce emissions.
15		However, we do not currently have such policy and getting to such a policy does not
16		appear likely any time soon. So we are not currently on an optimal path with regard to
17		emissions and there is no guarantee that we will be on an optimal path in the future.
18		Getting to an optimal path would require coordinated global policy, such as a uniform
19		carbon tax across countries or an international trading regime in carbon permits. To
20		assume that these will be in place any time soon and that we will be on an optimal path
21		seems highly unrealistic.

1	Q.	Does the DICE model used by the IWG seek an optimal SCC?
2	А.	The DICE model was originally created to find the optimal path of emissions reductions
3		by finding the point where the marginal cost of emission reductions is just equal to the
4		marginal damages from CO <sub>2</sub> emissions. But DICE can be run without seeking to find the
5		optimal path. This was done by the IWG to allow the three IAMs used by the IWG to be
6		run with the same emissions across the models.
7	Q.	Would it be more appropriate to use models that optimize the SCC for this
8		proceeding?
9	А.	For the purposes of planning and evaluating the damages from Minnesota emissions the
10		IWG method is preferable to assuming an optimal level of emissions. What we want to
11		know is what is the likely level of future emissions and atmospheric concentrations of
12		GHGs so that we can correctly gauge damages. Instead of assuming that the world will be
13		on an optimal path, the IWG used a range of possible future scenarios for emissions.
14		These scenarios spanned a wide range of potential future emissions trajectories, including
15		a trajectory with large cuts in emissions relative to present emissions levels. I discuss
16		these scenarios in response to witness Smith above at page 12-13. Far from being an
17		incorrect approach as asserted by Mendelsohn, this approach seems like the only
18		reasonable approach to take, given the large uncertainty about future emissions.
19		The optimal SCC is only appropriate if there will actually be optimal emission reductions
20		as a result of this policy adjustment. This will not be the case, considering the scope of
21		the proposed Minnesota policy. As a result of Minnesota adopting a higher value for the

1		SCC will all countries in the world reduce their emissions to the optimal level? No. The
2		SCC examines five possible projections of future emissions of CO <sub>2</sub> . At this point there is
3		no indication that there will be a globally optimal climate policy.
4		If, however, a global policy is adopted, and/or CO <sub>2</sub> emissions are substantially reduced in
5		the coming years, then the IWG can incorporate these into its future emission projections.
6		This would have the effect of lowering the SCC as the world would be more likely to
7		avert future climate catastrophes. Until that time it is appropriate and reasonable to base a
8		Minnesota policy on the IWG projections of emissions.
9	Q.	How to do you respond to Mendelsohn's assertion that the PAGE model should not
10		have been used by the IWG?
10 11	А.	have been used by the IWG? I disagree. The PAGE model along with the FUND and DICE model are the three most
10 11 12	A.	have been used by the IWG? I disagree. The PAGE model along with the FUND and DICE model are the three most prominent economic climate change IAMs. The inclusion of all three models is
10 11 12 13	А.	have been used by the IWG?I disagree. The PAGE model along with the FUND and DICE model are the three mostprominent economic climate change IAMs. The inclusion of all three models isappropriate and preferred to selecting only one or two models. There is uncertainty
10 11 12 13 14	А.	<ul> <li>have been used by the IWG?</li> <li>I disagree. The PAGE model along with the FUND and DICE model are the three most</li> <li>prominent economic climate change IAMs. The inclusion of all three models is</li> <li>appropriate and preferred to selecting only one or two models. There is uncertainty</li> <li>regarding several aspects of climate change. The best method to approach estimating the</li> </ul>
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<ol> <li>10</li> <li>11</li> <li>12</li> <li>13</li> <li>14</li> <li>15</li> <li>16</li> <li>17</li> </ol>	<b>A.</b>	<ul> <li>have been used by the IWG?</li> <li>I disagree. The PAGE model along with the FUND and DICE model are the three most</li> <li>prominent economic climate change IAMs. The inclusion of all three models is</li> <li>appropriate and preferred to selecting only one or two models. There is uncertainty</li> <li>regarding several aspects of climate change. The best method to approach estimating the</li> <li>SCC is incorporating several different methodologies and sets of assumptions. The IWG</li> <li>has done this by running each of these models and evaluating several of the key uncertain</li> <li>parameters with a wide range of values. By including all three models and assigning</li> </ul>
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1	Q.	How do you respond to Mendelsohn's arguments regarding discount rates?
2	<b>A.</b>	My response on this issue is the same as stated above, page 20-24, in response to Smith.
3		The IWG's selection of the three discount rates was appropriate.
4	Q.	Mendelsohn calculated an alternative SCC using DICE. Can you describe the
5		changes to the DICE model he made?
6	А.	Mendelsohn ran the DICE model to calculate the "optimal" SCC and made changes to the
7		damage function, the ECS, and the discount rate. I will describe each of these changes in
8		turn.
9		The damage function in the DICE model assumes that the temperature in 1900 is the
10		optimal temperature, and any increase above this level is harmful. Mendelsohn believes
11		that the optimal temperature is 1.5 to 2 degree Celsius above the 1900 temperature level.
12		Mendelsohn adjusts the DICE damage function by making any temperature increase
13		below 1.5 to 2 degrees beneficial to society, and then there are only damages after
14		warming greater than this. This has two effects on the results. First, for small temperature
15		increases DICE would calculate small damages, whereas Mendelsohn calculates small
16		benefits. Second, much greater temperature increases are required in Mendelsohn's
17		version of the DICE model to generate large damages as compared with the standard
18		DICE model. For instance, at 6 degrees of warming the DICE damage function indicates
19		that damages would be equal to approximately 10 percent of global GDP. The same 6
20		degrees of warming in Mendelsohn's version of the model would only result in
21		approximately 4 percent of global GDP.

1		Rather than use a distribution for the ECS, Mendelsohn has used a value of three.
2		Mendelsohn does a sensitivity analysis using several other lower values for the ECS (1.0,
3		1.5, 2.0, and 2.5), but his recommended range is based on the single value of ECS equal
4		to three. The IWG methodology uses the whole distribution for the ECS parameter and
5		therefore incorporates the uncertainty into the estimates of the SCC.
6		Mendelsohn chooses a discount rate of 5 percent rather than including a range of discount
7		rates (2.5 percent, and 3 percent, along with 5 percent). However, Mendelsohn allows the
8		discount rate to decline over time as a result of slower GDP growth. The discount rate
9		falls to 3.5 percent in 2100 and 2.7 percent in 2200. However, since changes happen well
10		into the future this is not at all equivalent to running the model assuming 2.5 percent or 3
11		percent discount rates. The discount rate used by Mendelsohn is reasonable; however,
12		incorporating a range of reasonable values, as done by the IWG, is more appropriate to
13		account for the uncertainty and disagreement regarding the discount rate.
14		These changes together create an estimated cost value between \$4 and \$6 per ton (it is
15		unclear if this is in metric/short tons, the emission year, the dollar year, so it is difficult to
16		compare to the SCC).
17	Q.	Do you know of other estimates of the SCC based on a similar approach of changing
18		the underlying assumptions of the DICE model?
19	А.	Yes. There are two recent peer-reviewed journal articles that used the DICE model to
20		calculate the SCC. In both articles the authors examine how the possible impact of

- climate change on the growth rate of the economy significantly increases the SCC.
- 2 Quoting from my earlier testimony:

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If climate change reduces the growth rate of GDP then the damages are long-lasting because each successive year GDP is further behind the baseline without climate impacts. Simon Dietz and Nicholas Stern altered the DICE model by incorporating growth effects from climate change, as well as increasing the probability of catastrophic climate outcomes. They ran the DICE model with a discount rate of 4.5 percent (higher than the median 3 percent discount rate used by the IWG) and found that the SCC increased from \$14 per metric ton of  $CO_2$  to as high as \$73 per metric ton of  $CO_2$ . The important conclusion of this article is that changes in how IAMs model the effect on economic growth from climate change and the probability of catastrophic climate change can greatly increase the SCC. The results also highlight that using a high discount rate can still lead to a large estimate of the SCC.

- 14 In another article, Frances Moore and Delavane Diaz alter the DICE model to account for 15 climate change effects on economic growth and find even larger increases in the SCC. 16 They incorporate research that suggests that climate change may accelerate the 17 depreciation of capital from extreme weather events and reduce the productivity of 18 capital because resources have to be directed towards climate mitigation in the future. 19 These factors would lower the growth rate of the economy and greatly reduce the 20 prosperity of future generations. These changes to the DICE model can have an enormous 21 effect on the SCC, increasing the estimate from \$33 to \$220 per metric ton of CO<sub>2</sub>.
- 22 In addition, there is an article from 2009 by Ackerman and Finlayson that made similar
- 23 types of changes to the DICE model as Mendelsohn, but in the opposite direction.
- 24 Ackerman and Finlayson incorporated a lower discount rate, a higher damage function,
- and a higher value of the ECS to calculate the "optimal" SCC. Their changes increased
- 26 the optimal SCC for 1995 emissions of  $CO_2$  from \$6 to \$197 per metric tonne.
- 27 Q. What is your assessment of these four (Mendelsohn, Dietz and Stern, Moore and
- 28 Diaz, and Ackerman and Finlayson) estimations of the SCC using DICE?
- 29 A. All four estimations are based on reasonable applications of the DICE model.
- 30 Mendelsohn's estimates should be viewed as being one possible estimate that comes in
- 31 on the low side of the distribution of possible values of the social cost of carbon. Dietz

1		and Stern, Moore and Diaz, and Ackerman and Finlayson articles all come in on the
2		higher side, and tend to be higher than the mean value of the IWG. All three of these
3		articles have been peer-reviewed, whereas the Mendelsohn estimate is not. These articles
4		highlight the uncertainty surrounding the possible aspects of climate modeling that can
5		greatly influence the estimation of the social cost of carbon.
6		While none of these possibilities should be dismissed, the fact that different applications
7		of the DICE model result in alternative values to the SCC does not mean that the IWG's
8		SCC is wrong or unreasonable. The IWG's process is preferable to using the values from
9		one researcher because it takes into account the wide variability among the different
10		models and different assumptions that go into the models. I believe that the IWG has
11		done a commendable job of incorporating the best available models and information to
12		produce a reasonable estimate of the SCC. As additional research is produced I believe
13		the IWG will incorporate the best available information which is why I recommend the
14		Commission adopt the SCC and use any future updated estimates produced by the IWG.
15	Q.	Do you agree with the opinions and analysis offered in Bezdek's testimony?
16	<b>A.</b>	No. Bezdek's views on climate change are far outside the mainstream scientific
17		understanding and ignore the bulk of the available evidence. The overwhelming majority
18		of economists and climate scientists conclude based on the evidence that the external
19		costs of CO <sub>2</sub> emissions outweigh the external benefits, suggesting that there is a positive
20		SCC. It would be extremely inappropriate to adopt a value of zero for the SCC, as
21		Bezdek recommends.

1	Q.	Can you provide examples of opinions that would be considered "outside the
2		mainstream scientific understanding?"
3	A.	Bezdek states that "[i]n reality, the 'scientific consensus' is a manufactured myth" (page
4		28) and that "there is no empirical scientific evidence for significant climate effects of
5		rising CO <sub>2</sub> levels" (page 30). Bezdek's testimony also includes a conspiratorial claim that
6		the SCC "[a]re artificial constructs designed by Obama administration to penalize fossil
7		fuels" (page 27). Based on his beliefs in the lack of harm from CO <sub>2</sub> emissions Bezdek
8		calculates that the ratio of benefits to costs of CO <sub>2</sub> emissions "range up to more than 200-
9		to-1" (page 28). These statements run counter to the stated positions of the National
10		Academy of Sciences, the American Geophysical Union, the American Meteorological
11		Association, the Intergovernmental Panel on Climate Change, and other prominent
12		scientific organizations.
13	Q.	Are Bezdek's estimates of the benefits of CO <sub>2</sub> emissions for agriculture reliable and
14		consistent with the available literature?
15	А.	Bezdek estimates that between 2012 and 2050 the benefits of higher $CO_2$ concentrations
16		on agricultural yields will be \$10 trillion. This estimate is not reliable. The estimated
17		benefits are derived from an unscientific approach by which the yield effects of higher
18		CO <sub>2</sub> concentrations in laboratory experiments are used to project on-field yield increases.
19		The CO <sub>2</sub> fertilization effect, which the laboratory experiments illustrate, is well known
20		but hardly the only impact of likely to occur from climate change. Unlike laboratory
21		conditions where most factors can be controlled, crop yields in the field are affected by
22		changes in water availability, temperature, other nutrients, pests and pathogens, all

(1)	factors that cannot be fully controlled by the farmer. Simply providing additional $CO_2$
2	does not account for changes in these other factors, and increases in CO <sub>2</sub> concentrations
3	may increase temperatures and the probability of drought such that yields decrease
4	despite the CO <sub>2</sub> fertilization effect. For example, Schlenker and Roberts in a 2009 article
5	find that temperature increases above the optimum growing temperature leads to severe
6	drops in yields for corn and soybeans in the U.S. Crop yields show declines in hot, dry
7	years.
8	In their review of impacts on crop yield in the Fifth Assessment Report, the IPCC
9	concluded that the weight of the evidence using studies from around the world showed
10	that climate change is negatively affecting wheat and corn yields for many regions, and
11	that there has been little impact on soybean and rice yields. Lobell, Schlenker and Costa-
12	Roberts in a 2011 article in <i>Science</i> show that climate changes from 1980 to 2008 had a
13	negative effect on corn and wheat yields, mainly due to increased temperatures. They
14	conclude that accounting for the net effect of CO <sub>2</sub> concentration increases and climate
15	changes there were small positive impacts to soybean and rice yields and negative
16	impacts to corn and wheat yields since 1980. These results are in stark contrast to the
17	enormous positive effects of greater CO <sub>2</sub> concentrations claimed by Bezdek.

# 18 Q. Do the IAMs ignore the benefits of increased CO<sub>2</sub> concentrations on crop yields as 19 Bezdek claims?

A. No. Climate scientists and modelers are well aware of the benefits to plant growth from
 higher CO<sub>2</sub> concentrations. In the IAMs the potential benefits to agricultural from CO<sub>2</sub>

1		emissions are incorporated as are the costs to agriculture, sea-level rise, and other
2		categories. The damage functions indicate that the damages outweigh the benefits.
3	Q.	Do you agree with Bezdek's rejection of the use of IAMs for policy analysis?
4	А.	No. Bezdek's criticisms of IAMs are drawn directly from the opinions of a 2013 article
5		by economist Robert Pindyck in the Journal of Economic Literature. Pindyck is an
6		outspoken critic of IAMs for the analysis of climate change. Despite Pindyck's criticisms
7		of IAMs, he concludes the above article with the following recommendation (page 870):
8 9 10 11 12 13 14 15 16 17 18 19 20		My criticism of IAMs should not be taken to imply that, because we know so little, nothing should be done about climate change right now, and instead we should wait until we learn more. Quite the contrary. One can think of a GHG abatement policy as a form of insurance: society would be paying for a guarantee that a low-probability catastrophe will not occur (or is less likely). As I have argued elsewhere, even though we don't have a good estimate of the SCC, it would make sense to take the Interagency Working Group's \$21 (or updated \$33) number as a rough and politically acceptable starting point and impose a carbon tax (or equivalent policy) of that amount. This would help to establish that there is a social cost of carbon, and that social cost must be internalized in the prices that consumers and firms pay. (Yes, most economists already understand this, but politicians and the public are a different matter.) Later, as we learn more about the true size of the SCC, the carbon tax could be increased or decreased accordingly.
21		Even Pindyck, with his strong opinions regarding the deficiencies of IAMs for analysis of
22		climate change, believes the IWG's federal SCC is reasonable and the best available
23		estimate of the SCC.
24		There exists a wide spectrum of beliefs regarding the impact of CO <sub>2</sub> emissions on the
25		global climate. Bezdek's opinions reflect the extreme end of this spectrum where the
26		external benefits of CO <sub>2</sub> emissions greatly outweigh the external costs. It would be
27		inappropriate for Minnesota to base its resource planning decisions on opinions from

- 1 either end of this spectrum. I believe the IWG federal SCC represents a reasonable
- 2 consensus estimate, consistent with the bulk of the available scientific evidence,
- 3 regarding the likely damages from the emission of CO<sub>2</sub>.

# 4 VI. CONCLUSION

- 5 Q. Does this conclude your rebuttal testimony?
- 6 **A.** Yes.

# Response to Comments: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866

Interagency Working Group on Social Cost of Carbon, United States Government

## With participation by

Council of Economic Advisers Council on Environmental Quality Department of Agriculture Department of Commerce Department of Energy Department of Transportation Environmental Protection Agency National Economic Council Office of Management and Budget Office of Science and Technology Policy Department of the Treasury

July 2015

# Social Cost of Carbon: Response to Comments

**SUMMARY**: On November 26, 2013, the Office of Management and Budget (OMB) published a Federal Register notice requesting comments on the Technical Support Document (TSD) entitled *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*. The Social Cost of Carbon (SCC) is used to estimate the value to society of marginal reductions in carbon dioxide (CO<sub>2</sub>) emissions. This TSD, issued in November, 2013, explained the derivation of the SCC estimates using three integrated assessment models (IAMs) regularly applied in the peer-reviewed scientific literature and provided updated values of the SCC that reflected minor technical corrections to the estimates released in May of that year.

OMB requested that comments be submitted electronically to OMB by January 27, 2014 through *www.regulations.gov*. On that date, OMB issued a subsequent notice extending the comment period until February 26, 2014.

This notice responds to the major comments received and discusses how the Interagency Working Group (IWG) that developed the SCC estimates will approach future updates to the estimates, based on comments received, developments in the academic literature, and advice from external experts.

**SUPPLEMENTARY INFORMATION:** Rigorous evaluation of benefits and costs is a core tenet of the rulemaking process.<sup>1</sup> It is particularly important in the area of climate change. The current estimate of the SCC has been developed over several years, using the best science available, and with input from the public.

In February 2010, after considering public comments on interim values that agencies used in a number of rules, an interagency working group of technical experts, coordinated by OMB and the Council of Economic Advisers (CEA), released updated SCC estimates. The IWG estimated the updated SCC values using the most widely cited climate economic impact models that are capable of estimating the SCC. Those climate impact models, known as IAMs, were developed by outside experts and published in the peer-reviewed literature. The TSD discusses in detail the models, inputs, and assumptions used in generating the SCC estimates, and the basis for their selection (2010 TSD). Recognizing that the models underlying the SCC estimates would evolve and improve over time as scientific and economic understanding increased, the IWG committed in the 2010 TSD to regular updates of these estimates.

In May of 2013, after all three of the underlying models had been updated and used in the peer-reviewed literature, and agencies had received public comments urging them to update their estimates, the IWG released revised SCC values. The May 2013 estimates are similar to those used by other governments, international institutions, and major corporations. Opportunity for public comment on those estimates

<sup>&</sup>lt;sup>1</sup> Executive Order 12866 directs that its regulatory principles, which includes assessing the benefits and costs of intended regulations, should be adhered to by Federal agencies "to the extent permitted by law and where applicable." (<u>http://www.archives.gov/federal-register/executive-orders/pdf/12866.pdf</u>)

was previously provided in a number of proposed rulemakings, and any comments received through the rulemaking process were, or will be, addressed by the agencies in the normal course of finalizing those rules.

A slightly revised TSD with minor technical corrections was issued in November, 2013 (2013 TSD). The 2013 TSD was based on the best scientific information on the impacts of climate change available at that time. Consistent with the IWG's commitment to continued refinement of the SCC estimates to ensure agencies appropriately measure the social damages associated with CO<sub>2</sub> emissions as they evaluate the costs and benefits of rules, on November 26, 2013 OMB requested comments on all aspects of the TSD and its use of IAMs to estimate the SCC. OMB noted that it was particularly interested in comments on the following topics:

- the selection of the three IAMs for use in the analysis and the synthesis of the resulting SCC estimates, as outlined in the 2010 TSD;
- the model inputs used to develop the SCC estimates, including economic growth, emissions trajectories, climate sensitivity, and intergenerational discounting;
- how the distribution of SCC estimates should be represented in regulatory impact analyses; and
- the strengths and limitations of the overall approach.

OMB further clarified that it was not requesting comments on the three peer reviewed IAMs themselves; rather OMB was requesting comments on their use in developing the SCC estimates.

# 1 Introduction

Rigorous evaluation of benefits and costs is a core tenet of the rulemaking process. Since 1981 executive orders have required benefit cost analysis for all significant U.S. Federal regulations, to the extent permitted by law (EOs 12291 and 12866). Estimates of the SCC allow the effects of CO<sub>2</sub> emission changes on society to be counted in benefit cost analysis. Without estimates of the SCC the effect of a change in CO<sub>2</sub> emissions would be considered qualitatively, but could not be quantified in the bottom-line benefit cost estimates. In 2007 the Ninth Circuit Court remanded a fuel economy rule to DOT for failing to monetize the benefits of the CO<sub>2</sub> emissions reductions in its regulatory impact analysis, noting that "the value of carbon emissions reduction is certainly not zero."<sup>2</sup>

In 2009, the Administration launched a process to determine how best to monetize the net effects (comprising both positive and negative effects) of  $CO_2$  emissions and sought to harmonize a range of different SCC estimates across multiple Federal agencies. This process was conducted by an interagency working group made up of Federal agencies likely to issue rules affecting  $CO_2$  emissions and EOP offices that review such rules. The purpose of this process was to ensure that agencies were using the best available information and to promote consistency in the way agencies quantify the benefits of reducing  $CO_2$  emissions, or costs from increasing emissions, in regulatory impact analyses. At the start of the 2009

<sup>&</sup>lt;sup>2</sup> http://cdn.ca9.uscourts.gov/datastore/opinions/2007/11/14/0671891.pdf

effort, the IWG conducted a preliminary assessment of existing peer-reviewed literature to set interim SCC estimates while it worked on a more comprehensive analysis. When agencies began using these interim values in rulemakings, they solicited comments "on all of the scientific, economic, and ethical issues before establishing improved estimates for use in future rulemakings."<sup>3</sup>

In February 2010, after considering public comments on the interim values and conducting additional technical work, the IWG released improved SCC estimates. These improved SCC estimates were developed using the three most widely cited climate economic impact models. Those climate impact models were developed by outside experts and are the most widely used and widely cited models in the economics literature that link physical impacts to economic damages of CO<sub>2</sub> emissions. The National Academies of Science (NAS) identified these three models as "the most widely used impact assessment models" in a 2010 report (NAS, 2010).

With the release of the 2010 SCC estimates the IWG noted that there remained a number of limitations to the analysis and committed to updating the estimates as the science and economic understanding of climate change and its impacts on society improves over time. In particular, a goal was set to revisit the SCC estimates "within two years or at such time as substantially updated models become available." Subsequent to the release of the 2010 TSD, all three of the models used in the development of the SCC estimates were updated by their (academic) developers, in part, to reflect more recent information on the potential impacts of climate change. The three models remain the most widely cited models capable of estimating the SCC.

Since the publication of the interim estimates in 2009, the IWG's SCC estimates have been used in 34 proposed rulemakings that provided opportunity for public comment. Federal agencies and OMB have continued to review public comments on the SCC estimates that are received through the notice and comment rulemaking process. Public comments received on proposed rulemakings using the 2010 SCC estimates, among other comments, urged the IWG to update the SCC estimates to reflect the newest versions of the models being used in the peer-reviewed scientific literature.<sup>4</sup> In response to these comments and consistent with the 2010 commitment to periodically revise the SCC estimates, in 2013 the IWG released an update to the SCC estimates that maintained the same methodology underpinning the previous estimates, but applied the most current versions of the three IAMs.

That same year, in response to public and stakeholder interest in the SCC estimates, OMB announced it would provide an additional opportunity, in addition to those available in proposed rulemakings, for public comment on the SCC estimates. Over the 90-day comment period<sup>5</sup>, OMB received 140 unique sets of comments and over 39,000 form letter submissions through two letter writing campaigns. The comments covered a wide range of topics including the technical details of the modeling, the aggregation and

<sup>&</sup>lt;sup>3</sup> For example, the proposed rulemaking for Model Year 2012-2016 Light-Duty Vehicle Greenhouse Gas Emissions Standards. <u>http://www.gpo.gov/fdsys/pkg/FR-2009-09-28/pdf/E9-22516.pdf</u>.

<sup>&</sup>lt;sup>4</sup> See Docket ID: EPA-HQ-OAR-2010-0660-10002 (p 4); EPA-HQ-OAR-2010-0660-10888 (p 26); EPA-HQ-OAR-2010-0799-9519 (p 10). Documents are available in www.regulations.gov.

<sup>&</sup>lt;sup>5</sup> OMB originally provided a 60-day comment period but that was subsequently extended, in response to stakeholder requests, for an additional 30 days.

presentation of the results, and the process by which the SCC estimates were derived. The form letters contained a short paragraph supporting the 2013 update. The unique comment letters offered a wide range of perspectives on the process, methodology, and results, including both support and opposition. Commenters also provided constructive recommendations for potential opportunities to improve the SCC estimates in future updates. In this context, the IWG is reconfirming its commitment to periodic review and update of the methodology and estimates to ensure that they continue to reflect the best available science and economics.

The science underlying the assessment and valuation of climate change impacts is constantly evolving. Since the publication of the initial SCC estimates in 2010, the representation of the science and economic consequences of climate change in the three IAMs has improved. The 2013 SCC technical update allowed the SCC estimates to reflect these improvements. However, as explained in the 2013 TSD, this update was limited in scope to those improvements available in more recent versions of the IAMs. As such, there remain additional opportunities for technical improvements to the SCC estimates that should be considered for future updates.

As noted above, commenters provided a wide range of perspectives and technical input on how to further refine the SCC estimates. To help synthesize the technical information and input reflected in the comments, and to add additional rigor to the next update of the SCC, the IWG plans to seek independent expert advice on technical opportunities to improve the SCC estimates, including many of the approaches suggested by commenters and summarized in this document. Specifically, the IWG plans to ask the National Academies of Sciences, Engineering, and Medicine to examine the technical merits and challenges of potential approaches to improving the SCC estimates in future updates. Input from the Academies, informed by public comments and the peer-reviewed literature, will help to ensure that the SCC estimates used by the federal government continue to reflect the best available science and methodologies.

The Academies' review will take some time, during which Federal agencies will have a continued need for estimates of the SCC to use in benefit-cost analysis. After careful evaluation of the full range of comments and associated technical issues detailed below, the IWG continues to recommend the use of the current SCC estimates<sup>6</sup> in regulatory impact analysis until revisions based on the many thoughtful public comments we have received and the independent advice of the Academies can be incorporated into the estimates. We believe the current estimates continue to represent the best scientific information on the impacts of climate change available in a form appropriate for incorporating the damages from incremental  $CO_2$  emissions changes into regulatory analyses.

<sup>&</sup>lt;sup>6</sup> Concurrently with this document, the IWG is releasing a minor technical revision to the estimates, which is explained in a technical addendum below. The current SCC estimates are contained in the *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (Revised July 2015)* which is available at *http://whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.* 

The remainder of this Response to Comments document provides topic specific summaries of the comments received followed by a response. The comments have been categorized into the following topics, which are addressed in turn:

- Choice of Integrated Assessment Models and Damage Functions
- Climate Science
- Socio Economic and Emissions Scenarios
- Discount Rates
- Aggregation of Results and Selection of Final Estimates
- Consideration of Uncertainty
- Use of Global vs. Domestic SCC Estimates
- Other Technical Areas of Comment
- Process by which the SCC Estimates were Developed

These nine major topic sections are further divided into brief summaries of specific comment areas, each followed by a response. Subsequently, there is a brief technical addendum explaining two minor revisions to the TSD.

# 2 Choice of Integrated Assessment Models and Damage Functions

Many commenters addressed the IAMs used to estimate the SCC. Several commenters recommended improvements to the existing IAMs and their damage functions, which monetize the damages associated with the physical impacts of climate change. Finally, a few commenters discussed the value to society of the goods and services whose production is associated with CO<sub>2</sub> emissions.

(1) The IWG's choice of IAMs used to estimate the SCC

A number of commenters were generally supportive of the choice of the three IAMs used in developing the SCC. For example, a letter signed by several commenters noted that these IAMs are "reasonably based on current scientific and economic knowledge" and are "widely cited and accepted in the academic community." One commenter said the models reflect "the best available, peer-reviewed science to tally the benefits and costs of specific regulations with impacts on CO<sub>2</sub> emissions. The IAMs include benefits and costs that have been quantified to date."

Other commenters voiced concern that the economic damages estimated by the IAMs are too uncertain to be useful for policy analysis. Several of these commenters included quotations from Pindyck (2013) and argue that the current IAMs and their damage functions lack sufficient theoretical or empirical foundations. For example, one commenter stated that "... The loss functions in PAGE and FUND, the other two models used by the Interagency Working Group, are more complex but equally arbitrary ... there is no pretense that the equations are based on any theory." Another commenter wrote, "The outputs of the three integrated assessment models (IAMs) are dependent on arbitrary and subjective assumptions used for data inputs."

Some commenters suggested that one or more of the models should be rejected. For example, some cited Dayaratna and Kreutzer (2013) in arguing that the DICE model is "flawed beyond use for policymaking." Others argued that both PAGE and DICE should be omitted because both include "little-to-no CO<sub>2</sub> fertilization benefit" in estimating agricultural damages. Another commenter suggested all three models be rejected because "... DICE and PAGE are too aggregated to represent research on climate impacts in any detail; they offer only their developers' guesses about how to reduce the vast, multi-dimensional array of climate damages to a few summary, monetized impacts", and "FUND ... attempts a higher level of disaggregation, but produces damage results that are too low to be consistent with current climate science."

Finally, a few commenters suggested that other IAMs should be considered for any future SCC updates. Sometimes this was a generic suggestion such as "updates to the SCC should also consider other models that are similarly peer reviewed and based on the state of the art of climate-economic modeling." A model that was mentioned by a few commenters was the World Bank's Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model. One commenter suggested the use of the model, Climate and Regional Economics of Development (CRED).

A few commenters criticized the TSD for failing to adequately explain or justify the choice of models and/or inputs used to run the models. For example, one commenter wrote, "... adequate justification is not currently provided for some aspects of the modeling. ... For example, justification is lacking for ... use of an average 550 ppm scenario, constant discount rates, EMF-22 versus other published scenarios, FUND and PAGE probabilistic modeling, and a variety of 2013 revisions to the individual models ..." Another commenter cited a 1981 D.C. Circuit U.S. Court of Appeals decision that an agency "must provide a complete analytic defense of its model [and] respond to each objection with a reasoned presentation" and must demonstrate "rational connections between factual inputs, modeling assumptions, modeling results and conclusions drawn from those results." A third commenter cited the Administrative Procedure Act (APA), arguing that the "use of the SCC estimates in rulemaking will not meet the requirements of the APA as interpreted by the courts because the IWG and OMB have not provided a rational connection or sufficient justification for the models, data inputs and assumptions used to create the SCC estimates."

# Response

The IWG agrees with those commenters who believe the choice of the three IAMs—DICE, FUND, and PAGE—was the most appropriate for the purpose of estimating the SCC. The IWG made this determination when it began developing the SCC estimates in 2009-2010. DICE, FUND, and PAGE are the most widely used and widely cited models in the economic literature that link physical impacts to economic damages for the purposes of estimating the SCC. As stated in the 2010 TSD:

These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. ... These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. ... Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages.

In addition, the National Academies of Science (NAS) identified these three models as "the most widely used impact assessment models" in a 2010 report (NAS, 2010). Furthermore, in a comprehensive literature review and meta-analysis conducted in 2008, the vast majority of the independent impact estimates that appeared in the peer-reviewed literature were derived from FUND, DICE, or PAGE (Tol, 2008).

While the development of the DICE, FUND and PAGE models necessarily involved assumptions and judgments on the part of the modelers, the damage functions are not simply arbitrary representations of the modelers' opinions about climate damages. Rather they are based on a review by the modelers of the currently available literature on the effects of climate change on society. The conclusions that the modelers draw from the literature, and the bases for these conclusions are documented, and all three models are continually updated as new information becomes available. While we recognize that there are limitations with these models, including some of those discussed in Pindyck (2013), nonetheless IAMs provide valuable information for regulatory impact analysis. In a recent article in the peer-reviewed literature, Weyant (2014) addressed this issue as follows:

While Pindyck's observations about the empirical weaknesses of IAMs or calculations of the SCC are worthy of careful study, the conclusion that IAMs are therefore useless fundamentally misconceives the enterprise. IAMs and the SCC are conceptual frameworks for dealing with highly complex, non-linear, dynamic, and uncertain systems. The human mind is incapable of solving all the equations simultaneously, and modeling allows making "If..., then..." analyses of the impacts of different factors. The models have provided important insights into many aspects of climate-change policy.

The IWG thus believes that it was appropriate to base the SCC estimates on the DICE, FUND and PAGE models. Moving forward, the IWG will continue to follow and evaluate the latest peer reviewed literature applying IAMs. The IWG will seek external expert advice on the technical merits and challenges of using additional models (e.g., CRED, ENVISAGE) to estimate the SCC and/or removing existing models from the ensemble (DICE, FUND, and PAGE) used to estimate the SCC.

Finally, the IWG disagrees with the comment that insufficient justification has been provided for the models, data inputs, and assumptions used to estimate the SCC. The IWG has regularly and repeatedly provided detailed explanations and justifications for the data, assumptions, and models used to estimate the SCC. The 2010 TSD thoroughly detailed each of these aspects, justified their use, and elucidated their limitations. The 2013 TSD provided a detailed explanation of updates and revisions made to the SCC. The additional OMB public comment solicitation provided a further opportunity for the public to comment on the data, assumptions, and models used in developing the SCC estimates; in this Response to Comment the IWG is responding to those comments received. Thus, the IWG has provided clear, transparent analytic defenses of its estimates, explained the rational connections that underlie these estimates, and responded to public comments.

The 2010 TSD provides a complete explanation of the entire modeling exercise, including a description of the chosen integrated assessment models (IAMs) and why they were selected, how the harmonized

modeling decisions were developed, how the sources of the data inputs were selected, and how the model results were aggregated to the final four point estimates that are used in regulatory analysis. For example, Section III A. of the TSD describes, in detail, the structure and connections within the IAMs (DICE, FUND, and PAGE), and the features that make them relevant and appropriate for estimating the SCC. As described in the 2010 TSD, after critical evaluation the IWG concluded that it is reasonable to use these three models from the peer-reviewed literature for the purpose of estimating the SCC. Section III of the 2010 TSD also describes, in detail, other relevant modeling inputs adopted by the IWG, the basis for the specific inputs used, and how these inputs are connected to the modeling and estimates of the SCC. For example, see Section III D. of the 2010 TSD for discussion about the IWG's analysis, development, and application of the distribution for the equilibrium climate sensitivity parameter; Section III E. for discussion about the IWG's analysis, selection, and, application of socioeconomic and emissions scenarios; and Section III F. for discussion about the IWG's literature search, analysis, and selection of discount rates. In addition, in Section V of the 2010 TSD the IWG described potential limitations of the analysis and made clear the resulting implications for the SCC estimates, based on the IWG's critical examination of the models and their underlying assumptions.

#### (2) Recommendations for improving the current IAMs or damage functions

Many commenters suggested improvements to one or more of the models before future SCC updates. Many of these commenters believe that the current SCC estimates underestimate the damages induced by climate change because of incomplete or missing treatment of a number of damage categories. Suggestions for additional damage categories include: ocean acidification, spillover effects from displaced persons, increased variability in weather patterns, wildfires, "catastrophic" damages stemming from exceedance of various "tipping points," loss of species and habitat diversity, cultural impacts, health effects from increased air pollution, and impacts on global security, among others. Commenters also questioned whether the models adequately addressed linkages between the damage categories. One Commenter suggested the use of the aggregate damage function introduced by Weitzman (2010) as an alternative specification relating mean temperature change and GDP loss.

Commenters disagreed about whether the IAMs overestimate or underestimate CO<sub>2</sub> fertilization effects in the agriculture and forestry sectors. For example, one commenter wrote "only one of the three IAMs used by the IWG has any substantial impact from CO<sub>2</sub> fertilization, and the one that does, underestimates the effect by approximately 2-3 times," referencing Idso (2013). However another commenter argued that "the models do not reflect recent research on agricultural changes, which suggests that CO<sub>2</sub> fertilization is overestimated, particularly in the FUND model, and that much, if not all, of the fertilization benefits may be cancelled out by negative impacts on agriculture."

# Response

To date, the IWG has accepted the models as currently constituted, and omitted any damages or beneficial effects that the model developers themselves do not include. The IWG recognizes that none of the three IAMs fully incorporates all climate change impacts, either positive or negative. Some of the effects referenced by commenters (e.g., "catastrophic" effects, disease, and CO<sub>2</sub> fertilization) are explicitly

modeled in the damage functions of one or more of the current models (although the treatment may not be complete), and the model developers continue to update their models as new research becomes available. In fact, the IWG undertook the 2013 revision because of updates to the models, which include new or enhanced representation of certain impacts, such as sea level rise damages. In addition, some of the categories mentioned by commenters are currently speculative or cannot be incorporated into the damage function for lack of appropriate data. Using an ensemble of three different models was intended to, at least partially, address the fact that no single model includes all of the impacts. We recognize that there may be effects that none of the three selected models addresses (e.g., impacts from ocean acidification) or that are likely not fully captured (e.g. catastrophic effects).

The IWG also recognizes that the impacts of climate change on agriculture is an area of active research and that methodological and data challenges persist. As a result there is uncertainty as to the magnitude of these impacts and the role of interactions between changes in the climate and other factors, such as CO<sub>2</sub> fertilization, temperature, precipitation, ozone, pests, etc. Additionally, these effects are likely to vary widely across regions and crops. However, with high confidence the IPCC (2013) stated in its Fifth Assessment Report (AR5) that "[b]ased on many studies covering a wide range of regions and crops, negative impacts of climate change on crop yields have been more common than positive impacts." As noted above, the IWG's approach to date has been to rely on the damage functions included in the three IAMs by their developers.

The IWG agrees that it is important to update the SCC periodically to incorporate improvements in the understanding of greenhouse gas emissions impacts and will continue to follow and evaluate the latest science on impact categories that are omitted or not fully addressed in the IAMs. Also, the IWG will seek external expert advice on the technical merits and challenges of potential approaches to update the damage functions in future revisions to the SCC estimates.

#### (3) Value of goods and services whose production is associated with CO<sub>2</sub> emissions

Some commenters felt that the SCC estimates should include the value to society of the goods and services whose production is associated with CO<sub>2</sub> emissions. Many of these commenters mentioned goods produced using fossil fuels, such as "plastics, chemicals, nitrogen fertilizer, steel, aluminum, synthetic rubber for tires, glass, pharmaceuticals, and paper." One commenter argued for including the benefits to "regions that depend on employment from energy intensive industry, regions dependent on fossil fuels for heating, cooling, food production and other components associated with preserving their standard of living and regions that are in need of low cost fossil fuels to enable the economic development improving their standard of living." Similarly, other commenters focused on the negative consequences of regulating  $CO_2$  emissions, such as the potential effect on energy prices, economic growth, or international competitiveness. One commenter suggested the inclusion of "... the social costs and economic dislocations that could result from carbon reduction policies that would eliminate fuel options such as coal, the social costs associated with higher electricity prices, and the economic and security risks associated with electric reliability problems."

#### Response

Rigorous evaluation of benefits and costs is a core tenet of the rulemaking process. The IWG agrees that these are important issues that may be relevant to assessing the impacts of policies that reduce  $CO_2$  emissions. However, these issues are not relevant to the SCC itself. The SCC is an estimate of the net economic damages resulting from  $CO_2$  emissions, and therefore is used to estimate the benefit of reducing those emissions.

A rule that affects CO<sub>2</sub> emissions may also affect the production or consumption of goods and services, in which case it could create costs and benefits for businesses and households that either produce or use those goods and services. These costs and benefits are important to include in an analysis of the rule's impacts, but are not a result of changes in CO<sub>2</sub> emissions. The SCC is not a measure of social welfare from the consumption of goods and services whose production results in CO<sub>2</sub> emissions, or other positive or negative externalities associated with the production of those goods and services.<sup>7</sup> In other words, the SCC is just one component of a larger analysis that includes consideration of many other potential impacts, including labor market changes, energy security, electricity reliability, and changes in emissions of other pollutants, among others.

# 3 Climate Science

Comments on the climate science components of the modeling fall into three broad areas: the specification of the equilibrium climate sensitivity parameter, the formulation and parameterization of other physical science components in the IAMs, and uncertainty in climate science and climate modeling. In addition, a number of the commenters generally encouraged continued updating of the SCC to maintain the best scientific understanding of the relevant earth system processes as new findings emerge.

# (1) Climate Sensitivity

The equilibrium climate sensitivity (ECS) parameter is a measure of the climate's responsiveness to increased concentrations of greenhouse gases in the atmosphere. Specifically, the ECS is the long-term increase in the annual global-average surface temperature from a sustained doubling of the atmospheric CO<sub>2</sub> concentration relative to pre-industrial levels. Several commenters supported the IWG approach of calibrating the distribution of Roe and Baker (2007) to the IPCC (2007) Fourth Assessment Report (AR4) consensus statement on the ECS. However, many commenters, including many of those that approve of the IWG's basic approach, suggest updating this modeling input. The majority of these commenters suggest incorporating new research published since the 2010 TSD was released. Some commenters noted that in its Fifth Assessment Report the IPCC has revised its discussion of the likely range of climate sensitivity compared to AR4 (IPC 2013). Other commenters pointed to individual papers, such as Otto et al. (2013), which present lower and more constrained probability density functions (pdfs) than either the AR4 or AR5 consensus statements, in support of the commenters' suggestion that the pdf used by the IWG was biased high. Some commenters suggested that certain recent papers (e.g., Loehle, 2014; Otto et

<sup>&</sup>lt;sup>7</sup> Similarly, the SCC does not capture benefits to society from goods and services that reduce CO<sub>2</sub> emissions, or other co-benefits from reducing emissions such as reduced particulate matter pollution. Those benefits are treated elsewhere in a benefit cost analysis.

al., 2013; Aldrin et al., 2012) may be especially informative because they rely on recent historical temperature measurements. A couple of commenters suggested that the mean of the climate sensitivity pdf used by the IWG was too low, because the climate models do not take into account poorly understood climate system feedbacks and tipping points.

#### Response

The IWG is aware that this is an active area of research and remains committed to updating the SCC estimates to incorporate new scientific information and accurately reflect the current state of scientific uncertainty regarding the ECS. While we agree with commenters that the ECS distribution, along with other climate modeling inputs to the SCC calculation, should be updated periodically to reflect the latest scientific consensus, care must be exercised in selecting an appropriate range of estimates for this important parameter. Many studies estimating climate sensitivity have been published, based on a variety of approaches (instrumental record, paleoclimate observations, models, etc.). These individual studies report differing values and provide different information. Picking a single study from the high or low end of the range, or even in the middle, will exclude relevant information. A valid representation of uncertainty regarding climate sensitivity should be obtained from a synthesis exercise such as that done by the IPCC that considers the full range of relevant studies.

At the time the 2013 SCC update was released, the most authoritative statement about ECS appeared in the IPCC's AR4. Since that time, as several commenters noted, the IPCC issued a Fifth Assessment Report that updated its discussion of the likely range of climate sensitivity compared to AR4. The new assessment reduced the low end of the assessed likely range (high confidence) from 2°C to 1.5°C, but retained the high end of the range at 4.5°C. Unlike in AR4, the new assessment refrained from indicating a central estimate of ECS. This assessment is based on a comprehensive review of the scientific literature and reflects improved understanding, the extended temperature record for the atmosphere and oceans, and new estimates of radiative forcing.

Several of the post-AR4 studies highlighted by some commenters were cited in the AR5 assessment. In particular, both Aldrin et al. (2012) and Otto et al. (2013) were cited in both Chapter 10 and Chapter 12 of the AR5 Working Group I assessment. Eight of the authors of Otto et al. (2013), including the lead author, were authors of Chapter 12 for AR5's Working Group I and one was a lead author for the chapter. Hence it is clear that the IPCC considered Otto et al. (2013) in its synthesis of literature on the ECS. More broadly, the AR5 climate sensitivity distribution likely incorporates much of the literature identified by the commenters. The IWG will continue to follow and evaluate the latest science on the equilibrium climate sensitivity and seek external expert advice on the technical merits and challenges of potential approaches prior to updating the ECS distribution in future revisions to the SCC estimates, including (but not limited to) using the AR5 climate sensitivity distribution for the next update of the SCC.

(2) Other Physical Science Components of the Integrated Assessment Models

We define the physical science components of the models to include the modeling of physical impacts, such as changes in mean global temperature or sea level rise. This definition excludes the functions in the models that translate those physical endpoints into economic damages, which is addressed above in the

discussion of damage functions. Some commenters expressed approval of the physical science components of the models but others criticized specific components as being overly simplified or incomplete. For example, some commenters suggested that IAMs under-represent the potential for future damages by concentrating on changes in annual and global mean climate indicators, when changes in variability, or interactions between changes in the mean and natural variability, could be key components in determining future damages. Others noted the need for more explicit representation of the potential for low-probability, high impact "catastrophes," with one commenter calling for better modeling of multiple "tipping points" at the climatic thresholds indicated by the most recent scientific literature. Another commenter suggested that the IAMs assign too high a probability to "catastrophic" and extreme events, such as "ocean circulation shutdown, catastrophic sea level rise, and runaway climate change."

The comments regarding the representation of the carbon cycle were mixed. One commenter suggested that the highly simplified carbon cycles in the IAMs may lead to an underestimation of atmospheric  $CO_2$  concentrations over time because they do not adequately capture the feedback of climate change on the strength of carbon sinks, citing Kopp and Mignone (2012). Other commenters suggested that the ocean uptake of  $CO_2$  has actually been greater than predicted and thus the models may be overestimating atmospheric  $CO_2$  concentrations.

A few commenters suggested that changes in the temperature response functions across model versions are unsupported by evidence or research.<sup>8</sup> For example, two commenters suggested that a change in the triangular probability distribution of the transient climate response function in PAGE was largely subjective and lacked adequate supporting citations. Another noted that, in the FUND model, the increased rate of temperature change for any given climate sensitivity was inconsistent with recent observations, which the commenter suggests show the rate of warming to be slower than predicted. One commenter suggested that the version of the DICE model used may overestimate sea level rise relative to AR5 projections or estimates projected by the MAGICC climate model because of DICE's reliance on an outdated semi-empirical methodology that uses models of reduced complexity in conjunction with statistical relationships between sea level and climate forcing.<sup>9</sup> Finally, one commenter suggested that the version of set commenter mentions in the IAMs should be replaced by functions from other models. The commenter mentions the more detailed representations such as MAGICC, SNEASY, or BEAM, which would have simultaneous implications for the carbon cycle, sea level rise, and/or temperature response rates.<sup>10</sup>

Response

<sup>&</sup>lt;sup>8</sup> While the ECS determines the long-term magnitude of the climate's response to changes in atmospheric concentrations of GHGs, the IAM's temperature response functions model the near-term dynamics of how the climate responds to increasing atmospheric concentrations.

<sup>&</sup>lt;sup>9</sup> MAGICC is the Model for the Assessment of Greenhouse Gas Induced Climate Change. For more information see Meinshausen et al. (2011).

<sup>&</sup>lt;sup>10</sup> For more information on the SNEASY model see Urban and Keller (2010). For more information on the BEAM model see Glotter et al. (2014).

A key objective of the IWG was to draw from the insights of the three models while respecting the different approaches to linking GHG emissions and monetized damages taken by modelers in the published literature. After conducting an extensive literature review, the interagency group selected three sets of input parameters (climate sensitivity, socioeconomic and emissions trajectories, and discount rates) to use consistently in each model. All other model features were left unchanged, relying on the model developers' best estimates and judgments, as informed by the then-current literature. While the IAMs are periodically updated, the rapid pace of research in the area of climate science means that at any given time there may be new research that has not yet been incorporated into one or more models. Thus, while a given model may not always reflect the most recent research regarding any given climate subsystem, the IWG concluded that, at the time, the IAMs collectively represented the state of the science by bringing all these systems together into a single framework.

A benefit of using an ensemble of three models is that they cover a range of potential outcomes as expressed in the literature. For example the three models used collectively span a range of carbon cycle and climate change responsiveness that reflects the uncertainty in the literature.

With regards to comments on the temperature response function, the past 15 years of observed atmospheric temperatures cannot be compared directly to climate model simulations because (1) observed temperatures were influenced by volcanic eruptions that were not included in simulations because the timing and spatial distribution of eruptions are not known in advance; and (2) the last 15 years of atmospheric temperatures have been strongly influenced by natural climate variability due to oceanic fluctuations, such as the El Niño Southern-Oscillation; models include this variability, but no attempt is made to synchronize the models' timing of this variability with observed variability. In other words, while the models incorporate variability around a trend over time, they cannot predict how that variability affects measured temperatures in a specific year.

Regarding the criticisms by commenters of the sea level rise projections in DICE, the IWG recognizes that sea level rise projections are also an area of ongoing research. One key issue involves projections of melt from the Greenland and West Antarctic ice sheets. The IPCC AR5 report notes there is a possibility of sea level rise "substantially above" their best estimate of a likely range because of uncertainties regarding the response of the Antarctic ice sheet (AR5 Working Group I, Chapter 13). In AR5 the IPCC also discusses semi-empirical methods, stating a low confidence in projections based on such methods, which calibrate a mathematical model against observations rather than projecting individual processes. However, the IPCC did not entirely discount these methods. Further supporting the use of semi-empirical methods, the U.S. National Climate Assessment uses an average of the high end of semi-empirical projections in order to define their "Intermediate-High" Scenario (Parris et al., 2012). Therefore, it is reasonable for one out of three models used by the IWG to include some reliance upon semi-empirical methods.

The IWG is aware that more sophisticated yet still relatively simplified climate models, such as MAGICC, could be used to replace the highly simplified climate science components of the three IAMs. However, given the range of climate models available and the technical issues associated with such a change, replacing the climate modules or other structural features of the IAMs requires additional investigation before it can be applied to SCC estimation. The IWG will continue to follow and evaluate the latest science
on climate modeling and seek external expert advice on the technical merits and challenges of potential approaches to updating this component of the IAMs in future revisions to the SCC estimates.

We agree with the commenters who suggested the IAMs do not fully capture the impacts associated with changes in climate variability and weather extremes. For example, as discussed in the 2010 TSD, the calibrations in FUND and DICE do not account for increases in climate variability that may occur and would affect the agricultural sector. Similarly, we agree that the models' functional forms may not adequately capture potentially discontinuous "tipping point" behavior in Earth systems. In fact, large-scale earth system feedback effects (e.g., Arctic sea ice loss, melting permafrost, large scale forest dieback, changing ocean circulation patterns) are not modeled at all in one IAM, and are imperfectly captured in the others. This limitation of the three IAMs is discussed extensively in the 2010 TSD, and again in the 2013 update. The SCC estimate associated with the 95<sup>th</sup> percentile of the distribution based on the 3 percent discount rate is included in the recommended range partly to address this concern. The IWG will continue to follow and evaluate the latest science on climate variability and potential tipping points, and seek external expert advice on the technical merits and challenges of potential approaches to improve the representation of these components of the modeling in future revisions.

### (3) Uncertainty in Climate Science

A number of commenters discussed limitations in the current state of climate science and climate modeling generally. Some expressed skepticism about the link between anthropogenic CO<sub>2</sub> emissions and climate change. Others suggested that the SCC estimates are unreliable because climate modeling in general is unreliable and too uncertain for use in regulatory analysis. These commenters suggested that the climate models are flawed, have not been properly validated, can disagree with each other, and have biased projections. In many cases these commenters suggested that a recently observed reduction in the rate of surface temperature warming is evidence that the current generation of climate models should not be used to estimate the SCC. One commenter suggested that the SCC estimates don't adequately take into account the potential of a significantly cooler future climate absent GHG emissions, while another suggested that mainstream climate scientists have not appropriately considered the prediction of a grand solar minimum that could lead to a cooling cycle.

Some commenters voiced general criticisms of the IWG approach to the ECS due to the uncertainty about the shape of the climate sensitivity distribution and the sensitivity of the SCC estimates to the specification of the ECS distribution. One commenter suggested that the IPCC has not made progress in reducing uncertainty about climate sensitivity and therefore the IPCC consensus should not be used. Several commenters objected to the IWG use of the Roe and Baker (2007) distribution for the ECS. One of these commenters cited Pindyck (2013), stating that feedback loops within the climate system are largely unknown and therefore the shape of the distribution is unknown. The commenter suggested that Roe and Baker's assumption of a normally distributed climate feedback factor may not be theoretically correct, and suggested the use of alternative distributions. The commenter was particularly concerned that the use of a right-skewed distribution for the ECS would lead to an overestimate of the mean SCC if the ECS distribution would be more appropriately modeled as symmetric, though another commenter suggested that the Roe and Baker approach correctly captured the right-skewed nature of the distribution.

#### Response

Links between  $CO_2$  and temperature are established beyond question by laboratory measurements, physical theory, paleoclimate observations, instrumental observations, and observations of other planets. Climate change and its impacts, such as sea level rise, have been exhaustively documented, and synthesized internationally by the IPCC and domestically by the U.S. National Climate Assessment. Based on the wide acceptance of these conclusions in the scientific community, the IWG believes that: (1) anthropogenic emissions of greenhouse gases are causing atmospheric levels of greenhouse gases in our atmosphere to rise to levels unprecedented in human history; (2) the accumulation of greenhouse gases in our atmosphere is exerting a warming effect on the global climate; (3) there are multiple lines of evidence, including increasing average global surface temperatures, rising ocean temperatures and sea levels, and shrinking ice in glaciers, ice sheets, and the Arctic, all showing that climate change is occurring, and that the rate of climate change in the past few decades has been unusual in the context of the past 1000 years; (4) there is compelling evidence that anthropogenic emissions of greenhouse gases are the primary driver of recent observed increases in average global temperature; (5) atmospheric levels of most greenhouse gases are expected to continue to rise for the foreseeable future; and (6) risks and impacts to public health and welfare are expected to grow as climate change continues, and that climate change over this century is expected to be greater compared to observed climate change over the past century.

While there are inherent uncertainties associated with modeling climate systems over long time spans, the general circulation models (GCMs) upon which estimates of ECS and other climate science research are based have been extensively evaluated. For example, since 1989 the DOE has had a large program (The Program for Climate Model Diagnosis and Intercomparison) dedicated to evaluating these models.

Predictions of future solar activity are highly uncertain. However, even if a new solar minimum of the magnitude of the Maunder minimum (the solar low during the Little Ice Age) were to occur, its cooling tendency would be much less than the warming tendency from human greenhouse gases (e.g., Feulner and Rahmstorf, 2010).

The ECS parameter is a useful parameter for summarizing the strength of the climate system's response to accumulating GHG concentrations in the atmosphere. However, it is influenced by many highly complex and uncertain natural processes, some of which adjust over very long periods of time. Therefore, persistent uncertainty about the ECS is not surprising. Furthermore, persistent uncertainty does not suggest an absence of useful information. However, the IWG does not agree that progress has not been made in reducing this uncertainty. Over the last 30 years the scientific community has elucidated many aspects of the climate system's response to GHGs accumulating in the atmosphere. While the AR5 "likely" range is slightly larger than that of AR4, the assessment presented greater confidence in the tails. AR5 found that climate sensitivity is very unlikely to be greater than 6°C, whereas AR4 stated that the "lack of strong constraints limiting high climate sensitivities prevents the specification of a 95<sup>th</sup> percentile bound." Similarly, while the AR5 and the IPCC's (2001) Third Assessment Report (TAR) bounds look similar, the TAR bounds were presented as a range without estimated probabilities.

In response to the commenter citing Pindyck on climate feedbacks and the shape of the ECS distribution, we agree that potential climate feedbacks and their strength are uncertain. However, the IWG chose a

distribution from the peer-reviewed literature based on its evaluation of the scientific literature and the relationship between this distribution and IPCC range of the ECS. Regarding the skewness of the calibrated ECS distribution, this characteristic is common among the many approaches that have been used to study the ECS distribution and is not unique to the theoretical approach used by Roe and Baker to define the functional form of their distribution. Consistent with the AR4 discussion on limiting the distribution to a range considered possible by experts, such as from 0°C to 10°C, the IWG truncated the distribution at 10°C (Hegerl 2007, p 719).

## 4 Socioeconomic and Emissions Scenarios

Several commenters discussed the socioeconomic-emissions scenarios that are used as inputs for the IAMs. One commenter voiced general support for the IWG's approach, noting that the "use of EMF-22 [scenarios] represents a carefully considered and scientifically defensible decision." Other comments can be grouped into three main categories: the socioeconomic-emissions scenarios should be updated; concerns with the selected scenarios, including potential inconsistencies with other aspects of the modeling; and future updates of the scenarios should include a formal uncertainty analysis.

(1) The socioeconomic-emissions scenarios should be updated

A number of commenters recommended that the scenarios be updated to reflect newer modeling results. Some comments suggested that the SCC should be estimated using the scenarios in the IPCC's Fifth Assessment Report. In some cases the comments specifically suggested use of the representative concentration pathways (RCPs) and the associated shared socioeconomic pathways (SSPs) that were developed to identify a range of future socioeconomic scenarios that could lead to the RCPs. In other cases the commenters did not specify which AR5 scenarios should be used. In addition to the development of the RCP/SSP scenarios, the IPCC supported the AR5 assessment through an open call for qualified scenarios produced since the publication of AR4. The result of the open call was a database of more than 1,200 scenarios from 32 models that represent both "business-as-usual" (BAU) and policy cases, which were used extensively by Working Group III.

#### Response

OMB guidance in Circular A-4 requires benefits and costs to be computed relative to a baseline that represents "the best assessment of the way the world would look absent the proposed action." The IWG determined that BAU socioeconomic scenarios best reflect this approach. While the IWG agrees that, all else equal, the baseline used for the SCC calculation should be updated periodically to reflect the latest projections of BAU scenarios, the RCP/SSP scenarios used in support of AR5 may not be easily adaptable for use in SCC modeling.

To understand why, it is important to note some key differences between the criteria used by the IWG to select socioeconomic-emissions scenarios and what the RCP/SSP scenarios represent and how they were developed. Each scenario in the EMF-22 exercise used by the IWG was clearly identified as reflecting a reference case BAU or a specific CO<sub>2</sub> stabilization scenario. Lacking data on the probabilities of specific

scenarios, the IWG chose four BAU scenarios and one scenario representing stabilization at 550 ppm  $CO_{2}$ e and weighted them equally in its analysis. The IWG acknowledges that this is not a precise characterization of the baseline but believes it is a reasonable approach at present, in light of data limitations.

Some of the AR5 scenarios differ from these scenarios in ways that make them difficult to adapt to the SCC context. An ad-hoc group was formed in anticipation of AR5 to develop new scenarios to support climate impacts, adaptation, and vulnerability research. The initial work focused on the development of RCPs, which represent a wide range of potential radiative forcing pathways over the 21<sup>st</sup> century. The SSPs are a series of human development pathways that could lead to radiative forcing pathways described by the RCPs. The RCPs are not based on a fixed future path of key socioeconomic parameters, which means that multiple SSPs are associated with an RCP. No assessment was made as to the likelihood of any particular RCP being realized, but some of the scenarios clearly would require large-scale global mitigation efforts to be achieved and U.S. involvement in these efforts may be necessary for their success.

In other words, the developers did not assign likelihoods that the various scenarios would achieve the RCPs in the absence of policy interventions, which means that it is not clear which scenarios could reasonably serve as BAU projections. Therefore, using the RCP/SSP scenarios would require the IWG to conduct an assessment of which RCP/SSPs represent BAU scenarios, or of the probability that each scenario occurs in a BAU case. The IWG believes that data are currently lacking to conduct such an assessment.

The IWG will continue to follow and evaluate the latest science on socioeconomic-emissions scenarios and seek external expert advice on the technical merits and challenges of potential approaches to update these scenarios in future revisions to the SCC estimates.

(2) Concerns with the selected scenarios, including potential inconsistencies with other aspects of the modeling

A number of commenters felt the explanation of the selected socio-economic and emissions scenarios was inadequate in both the 2010 and 2013 TSDs and highlighted potential inconsistencies between the GDP, population, emissions, and non-CO<sub>2</sub> radiative forcing trajectories, and in their application to the SCC estimates. For example, one commenter suggested that a better rationale is needed for the choice of the scenarios from the EMF exercise. Other commenters suggested that the scenario assuming immediate and substantial global mitigation efforts is an implausible BAU scenario. Similarly, another commenter suggested that assume future abatement and mitigation efforts may introduce a downward bias when using the SCC as a benchmark for evaluating the very abatement and mitigation efforts that are assumed to be in place in the future. Other commenters suggested that extrapolation of the scenario variables from 2100 to 2300 may not have properly accounted for correlations among the variables; one commenter noted that work is underway to extend the AR5 SSPs out to 2300 along the extended RCPs and that use of such scenarios may improve consistency of the scenarios past 2100. Commenters also noted that treating certain variables as exogenous to the IAMs might introduce inconsistences if other relevant variables or

assumptions differ between the models used to develop the scenarios and the IAMs using them as inputs to estimate the SCC. Other commenters suggested that the average annual global GDP per capita growth rate in the scenarios is too high compared with long term historic growth rates observed in the United States, and that the IWG should have rejected the EMF scenarios because the EMF exercise is not part of a public process and the EMF scenarios are "extreme outliers" relative to recent Energy Information Administration forecasts.

#### Response

The rationale for using the EMF-22 scenarios is explained in the 2010 TSD. In addition to the fact that they were recent, peer-reviewed, and publicly available, they had the key advantage that GDP, population, and emissions trajectories are internally consistent for each model and scenario evaluated. As noted in the 2010 TSD, the scenarios used "span a wide range, from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables)."

Regarding the inclusion of a scenario associated with stabilization of atmospheric concentrations of GHGs at 550 ppm CO<sub>2</sub>-e, the 2010 TSD clearly notes that this is "not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome." As noted above, OMB guidance in Circular A-4 states that the correct baseline for regulatory impact analysis is an agency's best assessment of the state of the world without the regulation, and specifically states that this may include the potential for new domestic and foreign policies that would occur absent the regulation. Including a scenario representative of future mitigation actions is consistent with this guidance, as long as those future policy actions are expected to occur with or without the regulation under examination. As explained in the 2010 TSD, the IWG aimed to select scenarios that span most of the plausible range of outcomes for the socioeconomic variables. Given the level of uncertainty in these trajectories, the IWG felt that it was appropriate to consider a trajectory with significant global mitigation, assuming that this is a distinct possibility even in the absence of U.S. actions. Because there were five scenarios, and each received equal weighting, the stabilization scenario received 20% of the total probability weight.

Regarding potential inconsistencies between scenarios and IAMs, given the nature of estimating the SCC and available data/resources, a full harmonization along all possible dimensions of the three IAMs used to estimate the SCC with the four models used to develop the scenarios was not possible. Therefore, the IWG chose to harmonize the models with respect to the scenario variables to which SCC estimates are most sensitive (GDP, population, and emissions) using common techniques in the literature. The scenarios used were developed by highly respected international modeling groups and published in the peer-reviewed literature. In terms of potential inconsistencies across scenario variables past 2100, an effort was made to account for some basic correlations among scenario variables in the post-2100 extrapolation. For example, extrapolations were based on GDP per capita growth, which implicitly correlates population and GDP growth, rather than GDP levels or growth alone. Similarly, extrapolations were based on CO<sub>2</sub> emissions intensity with respect to GDP, which correlates emissions and GDP growth, rather than CO<sub>2</sub> emissions levels or growth alone.

Consistent with historical observations, it is expected that growth rates of rapidly developing economies will exceed those of already developed economies in the near term. Scenarios with projections of global economic growth that exceed recent trends in developed economies are consistent with this expectation.

The chosen scenarios capture a wide range of potential future states of the world, but were not intended to represent a comprehensive accounting of the full range of uncertainty, and therefore it is possible that future outcomes will fall outside of this range. The IWG acknowledges that the projection of the scenarios beyond 2100 has greater uncertainty than shorter-term projections and will continue to monitor the literature, including the development of extended RCP/SSP scenarios, for ways to improve the estimated trajectories and improve internal consistency.

(3) Future updates should include a formal uncertainty analysis of socio-economic and emissions scenarios.

Multiple commenters noted that the SCC estimates are not based on a detailed accounting of uncertainty over future socioeconomic and emissions conditions, and suggested that in future updates, the estimates should more formally address such uncertainty. It was also suggested that the equal weighting of the five selected scenarios might be inconsistent with their actual probabilities; for example, some commenters felt that given current policies the scenario leading to stabilization of atmospheric GHG concentrations at 550 ppm CO<sub>2</sub>-e by 2100 is unlikely to have the same probability as the four BAU scenarios

### Response

The IWG acknowledges that the SCC estimates do not include a formal, probabilistic assessment of uncertainty. Rather, the IWG attempted to span a reasonable range of uncertainty by including a range of estimates for key input variables, including climate sensitivity, socioeconomic trajectories, and discount rates. As noted in the 2010 TSD, the IWG considered formally assigning probability weights to different socioeconomic scenarios, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways. In this situation, the IWG determined that, because no basis for assigning differential weights was available, the most transparent way to present a range of uncertainty was simply to weight each of the five scenarios equally for the consolidated estimates. The TSD also presented the results for each scenario separately, to show how the SCC estimates varied across the scenarios.

The IWG will continue to follow and evaluate the latest science on incorporating formal uncertainty analysis over socioeconomic-emissions scenarios, and will seek external expert advice on the technical merits and challenges of potential approaches to incorporate scenario uncertainty in future revisions to the SCC estimates.

## 5 Discount Rates

Numerous commenters discussed the discount rates used to estimate the SCC. Their comments can be grouped into three main categories: it would be appropriate to include a 7 percent discount rate in the range used to estimate the SCC; the central SCC estimate should be based on a discount rate lower than

3 percent or on a rate that declines over time; and a Ramsey framework should be used to endogenously determine the discount rates.

(1) It would be appropriate to include a 7 percent discount rate in the range used to estimate the SCC.

Most commenters who made this comment cited OMB's Circular A-4, which identifies 3 percent and 7 percent as appropriate discount rates for regulatory impact analysis conducted pursuant to Executive Order 12866. A few commenters offered more specific rationales for using a higher discount rate. One commenter noted that in the United States market interest rates of around 7 percent per year have typically been associated with per capita GDP growth rates of around 1.5 percent per year, and the socio-economic scenarios used in estimating the SCC assume per capita GDP growth rates at least this high. Another commenter noted that low discount rates place relatively more weight on outcomes further in the future, which are more uncertain than near term outcomes. Several commenters indicated that a 7 percent discount rate is appropriate because it represents a better estimate of the opportunity cost of capital investments that would be displaced under compliance with a potential regulation to mitigate CO<sub>2</sub> emissions.

#### Response

OMB guidance in Circular A-4 recommends that discount rates of 3 percent and 7 percent be used in regulatory impact analysis. The 7 percent rate is an estimate of the average before-tax real rate of return to private capital in the U.S. economy. It is a broad measure that reflects the returns to real estate and small business and corporate capital and is meant to approximate the opportunity cost of capital in the United States. The 3 percent rate is an estimate of the real rate at which consumers discount future consumption flows to their present value, often referred to as the social rate of time preference or the consumption rate of interest. As stated in the 2010 TSD, in a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world, however, risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest.

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

reviewing those considerations, Circular A-4 states that if a rule will have important intergenerational benefits or costs, agencies should consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.

The IWG examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the net social costs of a marginal change in CO<sub>2</sub> emissions, as the impacts of climate change are measured in consumption-equivalent units in the three IAMs used to estimate the SCC. This is consistent with OMB's guidance in Circular A-4, which states that when a regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services--it is appropriate to use the consumption rate of interest to reflect how private individuals trade-off current and future consumption.

As explained in the 2010 TSD, after a thorough review of the discounting literature, the IWG chose to use three discount rates to span a plausible range of constant discount rates: 2.5, 3, and 5 percent per year. The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. The upper value of 5 percent represents the possibility that climate damages are positively correlated with market returns, which would suggest a rate higher than the risk-free rate of 3 percent. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods. The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average rate after adjusting for uncertainty using a mean-reverting and random walk approach as described in Newell and Pizer (2003), starting at a discount rate of 3 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to the ethical concerns discussed above regarding intergenerational discounting.

The IWG recognizes that disagreement remains in the academic literature over the appropriate discount rate to use for regulatory analysis of actions with significant intergenerational impacts, such as CO<sub>2</sub> emissions changes that affect the global climate on long time scales. The IWG will continue to follow and evaluate the latest science on intergenerational discounting and seek external expert advice on issues related to discounting in the context of climate change.

(2) The central SCC estimate should be based on a discount rate lower than 3 percent or a rate that declines over time.

Several commenters noted that uncertainty about future economic growth rates implies that future benefits and costs should be discounted to the present at a rate lower than what would be appropriate in the absence of uncertainty. Some comments also recommended that the pure rate of time preference, one component of the discount rate, be set to zero to ensure that the welfare of all generations is given equal weight in the analysis. One commenter suggested that expected future benefits and costs should be discounted at a rate that is the sum of two components: the risk-free rate of return, which is typically associated with the interest rate on short-term government bonds, and a "risk premium" based on the correlation between the benefits of the policy and the growth rate of the broader economy (including

both market and non-market goods and services). Some commenters indicated that lower discount rates should be used as a sort of hedge against the risk of "climate catastrophes." Other commenters recommended a declining discount rate; they emphasized discount rate uncertainty and cited research by Weitzman (2001), Newell and Pizer (2003), and Arrow et al. (2013) on this topic, noting that these studies show that under persistent uncertainty about the discount rate, and/or economic growth, the maximization of expected net present value implies a discount rate that declines over time.

#### Response

As noted above, the IWG selected a range of discount rates from 2.5 to 5 percent; a review of the literature and the reasoning that led to the selection of this range are discussed in detail in the 2010 TSD. Several of the issues raised by commenters were explicitly considered and were part of the rationale for the selected range.

The TSD discusses both descriptive and prescriptive approaches to selecting discount rates. A descriptive approach reflects a positive (non-normative) perspective based on observations of people's actual choices (e.g., savings versus consumption and allocation of savings over more and less risky investments). The prescriptive approach adds a normative component and incorporates judgments that decision makers believe should be reflected in the policy choices that the discount rate is intended to inform. For example, some have argued on ethical grounds that in the Ramsey formula—which dissects market rates into three components, the pure rate of time preference ( $\rho$ ), growth rate of per-capita consumption (g), and coefficient of relative risk aversion ( $\eta$ )—the  $\rho$  component should be set to zero so that the welfare of all generations is valued equally. After considering a range of plausible values from the literature for g and  $\eta$ , the IWG concluded that setting a very low  $\rho$  (e.g., 0.1 percent per year) could yield rates in the range of 1.4 to 3.1 percent.

The TSD also discussed uncertainty and its effects on discount rates. The certainty equivalent values of the future benefits of reducing current CO<sub>2</sub> emissions will be lower than the expected value if the benefits and future consumption are positively correlated, assuming people are risk averse on average. This in turn implies that when discounting expected future benefits a discount rate that accounts for uncertainty should exceed a riskless rate. As explained in the TSD, this consideration was part of the logic for setting the upper end of the selected range at 5 percent.

The IWG also considered the issue of "climate catastrophes." To the extent that such outcomes may not be adequately represented in the IAMs, the central tendency estimates from these models may not capture the full range of potential damages from  $CO_2$  emissions. For this reason, in addition to the three mean SCC estimates using discount rates of 2.5, 3 and 5 percent, the IWG recommended including a rate based on the 95<sup>th</sup> percentile damage estimate (with a 3 percent discount rate) for the upper end of the range of plausible SCC estimates.

Finally, with respect to declining discount rates, the IWG agrees that this is an important area of emerging research. However, no widely-accepted declining discount rate schedule has yet been developed. Some key technical issues warrant careful consideration before adopting a declining discount rate schedule, such as determining how to update the discount rate schedule as uncertainty is resolved over time and

ensuring that the use of declining discount rates does not lead to the possibility of time-inconsistent choices. A recent workshop sponsored by the federal government resulted in a paper in *Science* authored by thirteen prominent economists who concluded that a declining discount rate would be appropriate to analyze impacts that occur far into the future (Arrow et al., 2013). However, additional research and analysis is still needed to develop a methodology for implementing a declining discount rate and to understand the implications of applying these theoretical lessons in practice. The IWG will continue to follow and evaluate the latest science on the use of declining discount rates in intergenerational contexts and seek external expert advice on issues related to discounting in the context of climate change.

(3) A Ramsey framework should be used to determine the discount rates.

Some commenters supported use of a Ramsey framework for determining discount rates and noted that the original developers of the IAMs used by the IWG routinely use a Ramsey framework in their own applications of their models. A Ramsey framework, derived from a representative agent who maximizes the sum of discounted utility under specific assumptions, relates the consumption discount rate to the elasticity of the marginal utility of consumption, the growth rate of per capita consumption, and the pure rate of time preference. Some commenters also stated that the socioeconomic scenarios used to calculate the SCC imply growth rates of per capita consumption that change over time, so under the Ramsey framework the discount rates also should change endogenously over time based on the economic growth rates assumed in the underlying socio-economic scenarios.

#### Response

The IWG agrees that a Ramsey framework can be useful in informing the selection of an appropriate range of discount rates for estimating the SCC. As noted above, this was one of the approaches considered by the IWG in the selection of the 2.5, 3, and 5 percent range.

The IWG considered this framework explicitly in exploring the implications of setting the  $\rho$  term (pure rate of time preference) at or near zero to give equal weight to the welfare of all future generations. As explained above, this analysis was part of the basis for selecting the lower end of the range. However, after reviewing several approaches to estimating specific parameters, the IWG noted that there is no consensus in the literature on the appropriate approach for selecting specific values for the components of the Ramsey equation. For this reason, the IWG used this analysis to inform its choice of a range of discount rates, but concluded that the Ramsey equation alone should not determine a specific choice of discount rate.

The IWG agrees that the Ramsey framework could, in theory, support a formulation where discount rates change over time. In a paper summarizing the aforementioned workshop on discounting, thirteen prominent economists indicated that the Ramsey framework "provides a useful framework for thinking about intergenerational discounting" but also pointed out that there is disagreement in the literature about what individual parameters in the Ramsey framework represent ( $\eta$ , in particular), which makes it difficult to select defensible values (Arrow et al., 2012). As noted above, the IWG believes it is premature to use the Ramsey framework as the sole basis for deriving discount rates, either fixed or variable, but did

consider the Ramsey literature in deriving the range of 2.5 to 5 percent for use in estimating the SCC. The IWG will continue to evaluate new research on the Ramsey framework and its applicability to SCC estimation and seek external expert advice on issues related to discounting in the context of climate change.

## 6 Aggregation of Results and Selection of Final Estimates

A number of comments are related to the aggregation of model results and the selection of the final range of SCC estimates. These comments can be grouped into three main categories: concerns with averaging of SCC estimates, the use of means rather than medians as a measure for the central tendency of the SCC estimates, and the use of low and high end estimates in regulatory analyses.

### (1) Concerns with averaging of SCC estimates

Some commenters were concerned that pooling the SCC estimates across scenarios and models ignores variability and uncertainties in the estimates. While one commenter explicitly stated that the IWG synthesized model outputs appropriately, several other commenters expressed concern that pooling the results across models and scenarios masks significant differences between models and inappropriately implies that the "true" value of the SCC falls within the range of estimates calculated by the three models. One commenter argued that pooling the results across models and scenarios that drive the estimates.

#### Response

Both the 2010 TSD and the 2013 TSD update present information about the full distribution of SCC estimates within and across possible combinations of the three models and five socioeconomic-emissions scenarios, for each of three discount rates (45 combinations in total) (see tables A2-A4 in Appendix A of the TSDs). Additional summary statistics for the distributions of the SCC estimates are also provided for each of the three models (see Table A5 in Appendix A). The IWG believes that the information presented in the TSDs is sufficiently disaggregated to reflect the variability of the SCC estimates across models, input assumptions, and discount rates. In addition, the IWG has provided the full set of Monte Carlo modeling results (10,000 model runs for each combination, for a total of 450,000 observations per emissions year) to outside researchers upon request and will continue to do so.

As discussed in the 2010 TSD, using the full distribution of the SCC estimates from the 45 scenarios would be impractical in a regulatory impact analysis. To produce a range of plausible estimates that still reflects the uncertainty about the SCC estimates, the results from the various model and scenario combinations (150,000 observations per emissions year for each of the three discount rates) were pooled to produce three separate probability distributions for the SCC for emissions in a given year, one for each assumed discount rate (2.5, 3 and 5 percent). Three point estimates were then derived from these pooled distributions representing the mean at each discount rate. The IWG considers this approach for presenting the central tendency of the SCC estimates across scenarios. The fourth value, the 95<sup>th</sup> percentile of the pooled

distribution using a 3 percent discount rate, is included to represent higher-than-expected economic impacts from climate change further out in the tail of the SCC distribution - i.e., impacts that may have lower probability of occurring but relatively high damages. For purposes of representing the uncertainties involved, the TSDs emphasized the importance of considering and presenting the full range of these four estimates in regulatory impact analysis.

The IWG agrees that the modeling of uncertainty in our analysis, including the uncertainty explicitly represented in the IAMs, may not capture the full range of uncertainty of the "true" value of the SCC. This concern is common to most quantitative assessments of uncertainty. By definition, the modeling of uncertainty requires a model, and therefore cannot capture the uncertainty associated with model selection. However, the IWG does not agree that pooling results across models implies that the estimates capture the full range of uncertainty, nor did the IWG make such a claim in the TSDs. Rather, the IWG attempted to capture a reasonable range of uncertainty using information available in the peer-reviewed literature and the uncertainty analysis built into the models themselves. Using three models rather than one helps address, but does not eliminate, uncertainty associated with model choice.

(2) Use of means rather than medians as a measure of the central tendency of the SCC estimates

A few commenters suggested that the median of the distribution of SCC estimates rather than the mean, as used by the IWG, would be a more appropriate measure of the central tendency of the SCC estimates. Another commenter suggested using both the mean and the median, along with presenting other distributional information (e.g., variances, low and high end percentile estimates, and other characteristics of distributions).

## Response

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

(3) Use of low and high end estimates in regulatory analyses

Several commenters suggested that both lower and upper end estimates should be part of the final range of estimates used in regulatory analyses. Specifically, they believe the range should include a 5<sup>th</sup> percentile estimate, in addition to the 95<sup>th</sup> percentile estimate from the pooled distribution using the 3 percent

discount rate. In contrast, one commenter suggested that, because the models do not presently account for high-end risks, RIAs should compensate by using only the most conservative estimates reported by the IWG (i.e., the 95<sup>th</sup> percentile estimate using the 3 percent discount rate). Another commenter similarly suggested using only the worst case (highest) estimate out of all the simulation results in place of the mean estimate.

### Response

Along with the four selected SCC estimates for each emissions year, the IWG presented more detailed information about the full distribution of SCC estimates for emissions in the year 2020. Specifically, the 2013 TSD reports information on the full distribution of the SCC estimates for emissions in year 2020 for each model, scenario, and discount rate combination , including the low-end percentiles (i.e., 1<sup>st</sup>, 5<sup>th</sup> and 10<sup>th</sup> percentiles).<sup>11</sup> In addition, as noted above, complete distributions for all emissions years are available upon request. While the IWG did not present a summary 5<sup>th</sup> percentile estimate (i.e., pooling results across the models and scenarios) for use in regulatory impact analysis, for reasons discussed below, the model and scenario specific statistics for 2020 provide a general sense of how the 5<sup>th</sup> percentile relates to the mean. Furthermore, as we note above the IWG has provided the full set of Monte Carlo modeling results to outside researchers upon request and will continue to do so. This information may be used to calculate a full set of 5<sup>th</sup> percentile summary statistics that are comparable to the 95<sup>th</sup> percentile estimates provided in the TSDs.

As the 2010 TSD discusses, the SCC estimates derived from the three integrated assessment models have several significant limitations that could lead to a substantial underestimation of the SCC. These limitations include the incomplete treatment and monetization of non-catastrophic damages, the incomplete treatment of potential "catastrophic" damages, and uncertainty in extrapolation of damages to high temperatures. The IPCC Fourth Assessment Report, which was the most current IPCC assessment available at the time of the IWG's 2009-2010 review, discussed these limitations and concluded that it was "very likely that [SCC] underestimates" climate change damages. Based on the current scientific understanding of climate change and its impacts, and on the limitations of the IAMs in quantifying and monetizing the full array of potential "catastrophic" and non-catastrophic damages, the IWG concluded that the distribution of SCC estimates may be biased downwards. Since then, the peer-reviewed literature has continued to support this conclusion. For example, the IPCC Fifth Assessment report observed that SCC estimates continue to omit various impacts that would likely increase damages. The 95<sup>th</sup> percentile estimate was included in the recommended range for regulatory impact analysis to address these concerns.

In addition, as acknowledged in the 2010 TSD, the SCC estimates derived from the three IAMs did not take into consideration the possibility of risk aversion. That is, individuals may have a higher willingness-to-pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability, lower-impact damages with the same expected cost. The inclusion of the 95<sup>th</sup>

<sup>&</sup>lt;sup>11</sup> The 2010 TSD including information on the full distribution of SCC estimates for the emission year 2010, however the 2013 TSD presented this information for the 2020 emissions year as 2010 was then a historical year.

percentile estimate in the SCC values was also motivated by this concern. In contrast, the IWG is not aware of systematic upward biases in the estimates comparable to the downward biases discussed above. For this reason, while the IWG has been fully transparent regarding the entire range of uncertainty reflected in the probability distributions, we did not include a 5<sup>th</sup> percentile estimate in the selected range for regulatory impact analysis.

Regarding the suggestion that only the high end of the range or worst-case scenario should be used in regulatory cost-benefit analysis, the IWG disagrees. The recommended range represents the central tendency of SCC estimates across three reasonable discount rates, plus a high-end estimate to account for missing damage categories and "catastrophic" outcomes. It is the judgment of the IWG that this approach will best inform decision makers and the public about both the range of "likely" damages and the possibility that actual damages could be much higher.

# 7 Consideration of Uncertainty

The IWG received a number of comments on the analyses and presentation of uncertainty in the TSD, as well as comments regarding the implications of uncertainty for the use of the SCC estimates in regulatory impact analysis.

## (1) Analysis and presentation of uncertainty

Several commenters suggested that the IWG was rigorous in addressing uncertainty by conducting Monte Carlo simulations with the IAMs to estimate distributions of the SCC over probabilistic specifications of the equilibrium climate sensitivity and other uncertain parameters as identified by the model developers. Other commenters suggested that key uncertainties merit further exploration and discussion in the TSD. Several commenters recommended that additional uncertainty analysis be conducted on key aspects of the modeling, such as assumptions regarding the carbon cycle, physical responses to climate change, technological change, adaptation, and post-2100 extrapolations of the socioeconomic-emission scenarios, among others. One commenter called for a separate section in the TSD that identifies key sources of uncertainty, along with a qualitative assessment of the impact those key uncertainties have on the SCC estimates, and to the extent feasible, a quantitative assessment as well. Some commenters suggested that the references in the 2013 TSD to discussions of uncertainty in the 2010 TSD are inadequate and make it difficult for the reader to understand the uncertainty associated with the revised estimates. One commenter questioned whether the IWG reported too many significant digits given the degree of uncertainty about the estimates. Several commenters also suggested that it would be appropriate to shorten the modeling time horizon due to the uncertainty associated with projecting impacts out to 2300. Two commenters suggested a time horizon of 2100 to be consistent with the time horizon considered in IPCC assessment reports. In addition, several commenters requested that additional graphical information be presented, and electronic copies of the results be made publically available.

#### Response

The IWG agrees with the comments that supported the rigor of its uncertainty analysis. Uncertainty is inherent in all regulatory impact analysis. It is especially salient in regards to the SCC estimates because of their broad spatial and temporal dimensions. In addition to conducting Monte Carlo analysis for a subset of key parameters, the IWG included extensive discussion of uncertainty in the TSDs, and the documentation for the individual IAMs themselves contains additional discussion of the assumptions and uncertainties in the models. The 2010 TSD and the updated 2013 TSD provided visual depictions of the distributions of the SCC estimates in addition to detailed statistics including percentiles and higher order moments. In addition to the extensive information provided in the TSDs, the IWG has provided the full range of model results to outside researchers upon request and will continue to do so.

The IWG also agrees that the trajectory of socioeconomic-emission scenarios beyond 2100 is uncertain. However, as the 2010 TSD notes, because of the long atmospheric lifetime of CO<sub>2</sub>, using too short a time horizon could miss a significant fraction of damages under certain assumptions about the growth of marginal damages. Therefore, the IWG ran each model through 2300. The IWG will continue to follow and evaluate the scientific literature on long-term scenario development.

The IWG reported SCC estimates out to one decimal place (i.e., at least two significant digits) in the 2010 TSD and to the nearest dollar in the 2013 TSD (i.e., two or three significant digits, depending on the year and discount rate/statistic). The IWG chose not to use decimal places in the 2013 TSD to avoid the impression of artificial precision but will also explore presentation with a consistent number of significant digits. The IWG welcomes the recommendations to strengthen the characterization of uncertainty and plans to seek external expert advice on the technical merits and challenges of potential approaches to improve the characterization and analysis of uncertainty in future updates.

## (2) Implications of uncertainty for the use of the SCC estimates in regulatory impact analysis

Some commenters suggested the degree of uncertainty in the SCC estimates makes them too speculative for use in regulatory analysis. These commenters argued that SCC is an unknown quantity and cannot be discerned in meteorological or economic data going back a century or more. Some commenters suggested that if non-validated climate parameters, arbitrary damage functions, or below-market discount rates were used, analysts could produce almost any result they desire. Another commenter suggested that the large variance associated with the distributions of the SCC estimates relative to the mean indicates that the estimates are not of sufficient precision to be informative in regulatory analysis. In contrast, other commenters stated that uncertainty in benefits estimates does not mean they should be excluded from regulatory impact analyses. These commenters pointed out that no benefit or cost estimate is certain and both court decisions and executive orders dating back to 1981 have recognized this. To address this, agencies have been directed to use best available estimates and acknowledge uncertainties, which they suggested is appropriately done in the TSDs.

#### Response

All regulatory impact analysis involves uncertainty. The IWG acknowledges uncertainty in the SCC estimates but disagrees that the uncertainty is so great as to undermine use of the SCC estimates in regulatory impact analysis. The uncertainty in the SCC estimates is fully acknowledged and

comprehensively discussed in the TSDs and supporting academic literature. While uncertainty must be acknowledged and addressed in regulatory impact analyses, even an uncertain analysis provides useful information to decision makers and the public. For example, if an analysis shows that benefits of a policy option consistently do (or do not) justify costs even over a broad range of estimates, this may increase confidence in the robustness of this conclusion. Conversely, if choices among parameter estimates within a plausible range significantly affect the conclusions of the analysis, this is an important consideration in deciding how to weigh the analytical results in the decision making process. The presence of uncertainty is thus not a reason to exclude the best available estimates of quantified/monetized benefits, as long as it is appropriately characterized. Rather, good regulatory practice requires that agencies use the best available scientific, technical and economic information to derive the best estimates of costs and benefits that they can, and then communicate to the public the limitations and uncertainties of the analyses. This is what the IWG has attempted to do in developing and discussing the SCC estimates. As noted in the TSDs, the IWG is committed to periodic updates in the estimates to reflect ongoing developments in our understanding of the science and economics of climate change, including the treatment of uncertainty.

## 8 Use of Global vs. Domestic SCC Estimates

Many commenters discussed the scope of the SCC estimates, and the degree to which damages experienced outside U.S. borders should be considered in domestic regulatory analysis. These comments can be grouped into two main categories: those that felt that the focus on global damage estimates is appropriate, and those that felt that domestic damage estimates received inadequate attention. Responses to these comments are provided below. In addition, many commenters stated that domestic SCC estimates must be used in RIAs to ensure consistency with OMB Circular A-4 requirements. This issue is addressed in Section 10 below.

## (1) The focus on global damage estimates is appropriate.

A number of commenters supported the IWG's decision to base the SCC estimates on global damages. Commenters explained that climate change is a global commons problem because carbon pollution does not remain within one country's borders, and that the use of global damages in the SCC is consistent with the economic theory of the commons. One commenter further stated that if damage estimates are limited to only those within each country's borders, any actions based on those estimates would lead to a collective failure to optimally mitigate GHG emissions. Another commenter referred to the importance of this effect by stating that the consideration of global damages in domestic rulemaking can be based on an expectation of reciprocity from other countries. Several commenters stressed the importance of the use of global SCC estimates as a tool in international negotiations. Finally, some commenters offered other reasons for considering damages in regions outside of the United States, including liability, national security concerns, trade-related "spillover effects", and the principle in international environmental law of reducing cross-border harm.

## Response

The IWG agrees that a focus on global SCC estimates in RIAs is appropriate. As discussed in the 2010 TSD, the IWG determined that a global measure of SCC is appropriate in this context because emissions of most greenhouse gases contribute to damages around the world and the world's economies are now highly interconnected. To reflect the global nature of the problem, the SCC incorporates the full damages caused by  $CO_2$  emissions and we expect other governments to consider the global consequences of their greenhouse gas emissions when setting their own domestic policies.

The IWG also agrees that if all countries acted independently to set policies based only on the domestic costs and benefits of carbon emissions, it would lead to an economically inefficient level of emissions reductions which could be harmful to all countries, including the United States, because each country would be underestimating the full value of its own reductions. This is a classic public goods problem because each country's reductions benefit everyone else and no country can be excluded from enjoying the benefits of other countries' reductions, even if it provides no reductions itself. In this situation, the only way to achieve an economically efficient level of emissions reductions is for countries to cooperate in providing mutually beneficial reductions beyond the level that would be justified only by their own domestic benefits. By adopting a global estimate of the SCC, the U.S. government can signal its leadership in this effort. In reference to the public good nature of mitigation and its role in foreign relations, thirteen prominent academics noted that these "are compelling reasons to focus on a global SCC" in a recent article on the SCC (Pizer et al., 2014). In addition, as noted by commenters, there is no bright line between domestic and global damages. Adverse impacts on other countries can have spillover effects on the United States, particularly in the areas of national security, international trade, public health and humanitarian concerns.

## (2) Domestic damage estimates receive inadequate attention.

A number of commenters suggested that the use of global damages creates a mismatch between estimates of costs and benefits in agency RIAs. Use of a global rather than domestic SCC may overstate the net benefits to the United States of reducing emissions, because global benefits are compared to domestic costs. A policy that appears cost-justified from a global perspective may not be from a purely domestic U.S. perspective. Therefore, these commenters suggest that a global SCC is only appropriate when the analysis considers global costs and benefits in the context of a global carbon mitigation program.

Other commenters indicated that the IWG should update and report domestic climate damages separately from global estimates for several reasons, including the public's right to know the domestic benefits of domestic regulatory actions. A few comments stated that the IWG should more clearly articulate that the SCC includes global damages, which they felt was particularly unclear in the 2013 TSD.

Finally, commenters also addressed the provisional range of domestic damages that was presented in the 2010 TSD. Several comments stated that the range discussed in the 2010 TSD for the domestic SCC was too high. Two commenters suggested a range for the domestic share of total global damages of 6 to 8.7 percent based on a paper by Nordhaus (2011). One commenter stated that the methods used to estimate the domestic damages as 7 to 23 percent of global damages is too speculative for quantification of the SCC.

#### Response

As stated in the prior section, GHG emissions in the United States will have impacts abroad, some of which may, in turn, affect the United States. For this reason, a purely domestic measure is likely to understate actual impacts to the United States. Also, as stated above, the IWG believes that accounting for global benefits can encourage reciprocal action by other nations, leading ultimately to international cooperation that increases both global and U.S. net benefits relative to what could be achieved if each nation considered only its own domestic costs and benefits when determining its climate policies.

Further, as explained in the 2010 TSD, from a technical perspective, the development of a domestic SCC was greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature, and impacts beyond our borders have spillover effects on the United States, particularly in the areas of national security, international trade, and public health. As a result, it was only possible to include an "approximate, provisional, and highly speculative" range of 7 to 23 percent for the share of domestic benefits in the 2010 TSD. This range was based on two strands of evidence: direct domestic estimates resulting from the FUND model, and an alternative approach under which the fraction of GDP lost due to climate change is assumed to be similar across countries. We note that the estimated U.S. share of global damages based on the Nordhaus (2011) study cited by several commenters largely falls within the provisional range offered in the 2010 TSD.

In conclusion, the IWG believes that the only way to achieve an efficient allocation of resources for emissions reduction on a global basis is for all countries to base their policies on global estimates of damages and will therefore continue to recommend the use of global SCC estimates in regulatory impact analyses. The IWG will also continue to review developments in the literature, including more robust methodologies for estimating SCC values based on purely domestic damages, and explore ways to better inform the public of the full range of carbon impacts, both global and domestic.

## 9 Other Comments

Other comments include those related to "leakage" and valuation of changes in non-CO2 GHG emissions.

(1) CO<sub>2</sub> emissions "leakage"

Several commenters suggested that the methods used to estimate climate damages should account for "leakage" of emissions in the quantification of the SCC. Specifically, commenters suggested that in cases where a new regulation increases domestic operating costs and causes industrial activity to shift to jurisdictions with less stringent regulations, net GHG emissions could fall less than predicted, or even increase. In these cases, the actual emissions reduction would be lower than indicated in a simple analysis. Commenters suggested that this effect be addressed either by the provision of additional guidance to agencies conducting RIAs, or in the estimated SCC value itself by adjusting estimated climate damages to account for it.

## Response

The IWG agrees that this is an important issue for analysts to consider in determining the net  $CO_2$  reductions to be valued in an RIA. However, this does not affect the calculation of the SCC itself, which is an estimate of the marginal benefit of a net one-ton reduction in  $CO_2$  emissions. The SCC estimates are multiplied by estimates of net GHG emissions changes to calculate the value of benefits associated with a policy action in a given year. It is in the estimation of net GHG emissions, and not the SCC, that any leakage should be accounted for.

### (2) Valuation of changes in non-CO<sub>2</sub> GHG emissions

Several commenters recommended that estimates be developed for valuing changes in the emissions of other greenhouse gases, such as methane, HFCs, and black carbon, as soon as possible. One commenter specified that the direct modeling approach for estimating the social cost of methane is preferable, but even an approximation approach (e.g., based on the use of the global warming potential (GWP) gas comparison metric) has merit and would be better than no estimate. The commenter asserted that the failure to set a social cost of methane estimate has the effect of eliminating any benefit of methane reductions from regulatory consideration and such a failure is arbitrary and capricious. Another commenter advocated for the use of both 100 and 20-year GWPs for converting non-CO<sub>2</sub> GHG emission changes into CO<sub>2</sub> equivalents before applying the SCC estimates.

#### Response

The IWG recognizes the importance of quantifying and monetizing the benefits of regulations to the extent feasible, and discussing qualitatively any benefits that cannot be quantified. The IWG does not agree that benefits that are not monetized are eliminated from regulatory consideration. On the contrary, most RIAs include discussion of non-quantified benefits and these may be an important factor in decision-making, depending on their projected significance. However, as noted by the commenters, the IWG has not established a methodology for valuing the social cost of other GHGs. In the absence of such estimates, a few recent rulemakings have included sensitivity analyses in which the GWP gas comparison metrics are used to convert non-CO<sub>2</sub> emissions reductions to CO<sub>2</sub> equivalents, which are then valued using the SCC estimates. For example, the 2012 New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry and the 2017-2025 Light-duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards used this approach in sensitivity analyses.

Although more directly modeled estimates of the climate change benefits of reducing some GHGs (e.g., methane) have been presented in the scientific literature, the methodology behind these estimates differs from the methodology behind the USG SCC estimates. Assessing the strengths and limitations of alternate approaches for estimating economic damages from other GHGs has so far been outside the scope of the IWG's assessment of economic damages from CO<sub>2</sub> emissions, though the 2010 TSD identified this as an area we hope to address in future updates. We also note that a recently published paper (Marten et al., 2014) develops estimates of the social cost of CH<sub>4</sub> and N<sub>2</sub>O using a methodology that is intended to be consistent with the IWG estimates of the SCC. The IWG will continue to follow and evaluate the literature on the social cost of non-CO<sub>2</sub> GHGs and the feasibility of developing non-CO<sub>2</sub> social cost estimates.

# **10** Process Related Comments

Many commenters either voiced support for or criticized particular aspects of the interagency process used to develop the SCC estimates. Process issues raised included legal/statutory authority for issuing the estimates, consistency with applicable OMB guidance documents, transparency, opportunity for public comment, and appropriate use of the estimates.

## (1) Legal/statutory authority for issuing the SCC estimates

One group of commenters asserted that the legal basis for using the SCC is clear and well-established. These commenters highlighted the 2007 Ninth Circuit decision that concluded that a National Highways and Transportation Safety Administration rule was arbitrary and capricious for not including a monetized estimate of the SCC. The Court noted that "...while the record shows that there is a range of values, the value of carbon emissions reductions is certainly not zero."

Other commenters argued that OMB's adoption of the SCC estimates is arbitrary, capricious, and contrary to law because OMB requires all Federal agencies to use its SCC estimates without identifying any legal basis or authority for doing so. These commenters argued that because OMB's "promulgation" of the SCC values falls within the APA's broad definition of a rule, OMB must comply with the procedural and substantive requirements laid out in the APA for rulemaking. These commenters further stated that the TSDs do not show a "rational connection between the facts found and the choices made," and that even if the three IAM models themselves were entirely sound, the non-public inputs into those models would render the SCC estimates arbitrary and capricious.

## Response

As a preliminary matter, the IWG notes that although the development of the SCC estimates was cochaired by OMB and CEA, the estimates and supporting TSDs were not issued by OMB, but rather through a consensus based process involving the entire working group.

The IWG agrees with commenters who believe that it has legal authority to develop these estimates, and was cognizant of the Ninth Circuit decision referenced by these commenters when it decided to do so. The IWG does not agree that issuance of the SCC estimates constitutes an APA rule making. The APA definition of a rule is "an agency statement of general or particular applicability and future effect designed to implement, interpret, or prescribe law or policy." The SCC estimates are not designed to implement, interpret, or prescribe law or policy. Rather they are intended to provide guidance to agencies on a science-based methodology for estimating the benefits of  $CO_2$  reductions in regulatory impact analysis.

OMB has long-established authority to oversee the regulatory review process, including preparation of regulatory impact analyses. OMB's authority in this area is contained in Executive Orders 12866 and 13563, among others, and has been acknowledged by Congress in a series of statutes, including the Small Business Regulatory Enforcement and Fairness Act, the Congressional Review Act, the Information Quality Act, and the Regulatory Right to Know Act. It is fully consistent with this authority for OMB to offer guidance to agencies on best practices for conducting regulatory impact analysis, as it did, for example, in

issuing Circular A-4. In the present case, OMB determined that it was appropriate to exercise this authority through a consensus-based process involving a broad range of agencies that may issue rules affecting CO<sub>2</sub> emissions.

The TSDs explain in detail the factual and policy basis for all of the various methodological choices involved in developing the SCC estimates. The IAMs are documented in the scientific literature. In addition, the IWG has assisted interested members of the public in obtaining additional information on the workings of the models. It has also provided full technical details of its own use of the models, including output of model runs, to interested parties upon request. However, because the SCC estimates are not a rule, as a legal matter they are not subject to the arbitrary and capricious standard of the APA.

(2) Consistency with OMB guidance documents, including the Information Quality Act guidelines, Peer Review Bulletin, and Circular A-4

Some commenters stated that the process used to develop the SCC estimates did not adhere to the OMB Information Quality Act (IQA) guidelines. The IQA requires federal agencies to take steps to maximize the quality, objectivity, and integrity of the information they disseminate, and to provide a mode of redress to correct flawed or incomplete information. These commenters stated that the SCC estimates are clearly "influential information" under the Guidelines and as such, must be reproducible and transparent with respect to: (1) the source of the utilized data; (2) the various assumptions employed; (3) the analytic methods applied; and (4) the statistical assumptions employed. Some commenters also stated that OMB's response to an IQA petition from a group of trade associations was inadequate and did not provide any information that was not already in the TSDs.

Several commenters focused on peer review in particular. These commenters stated that while peer review of the models themselves is important, it is not sufficient because the model inputs and subsequent manipulation of results (e.g., equal averaging) were not peer reviewed. They believe that the IWG must subject the SCC estimates and methodology to peer review to give the public greater confidence in the results. Some also stated that the IWG should consider model-specific peer review as well. This would consist of a review of each model's theoretical underpinnings and methodologies, as well as their appropriateness to specific applications. These commenters indicated that while specific applications may have been peer reviewed when published in the scientific literature, the models themselves were not.

Additionally, some commenters focused on the degree to which the SCC estimates are consistent with the OMB Circular A-4 guidelines for conducting regulatory impact analysis. These commenters stressed that the selected discount rates do not comply with Circular A-4 and should be selected through an open process including peer review. They noted that while Circular A-4 allows a sensitivity analysis with lower discount rates when a rule will have "important intergenerational benefits or costs," it still requires use of 3 percent and 7 percent. They also indicated that the estimates are not consistent with Circular A-4 guidelines regarding the use of domestic rather than global estimates of regulatory benefits.

Response

The IWG does not agree that the TSDs are inconsistent with the IQ Guidelines. To ensure that the IWG's methodology is transparent, the TSDs are comprehensive and technically rigorous in explaining the sources of data, the assumptions employed, the analytic methods applied, and the statistical assumptions employed. To ensure that the results are reproducible, IWG members have provided technical assistance and modeling results to external stakeholders upon request. Regarding the IQA petition, OMB responded to all of the points raised by petitioners. The fact that OMB's response used some language from the TSDs reflects OMB's judgment that these issues were already addressed in the TSDs themselves.

With regard to peer review, the IWG notes that the assumptions and models employed in generating the SCC estimates are all drawn from the peer-reviewed academic literature. To further strengthen the robustness of the SCC estimate, the IWG plans to seek external expert advice on technical opportunities to improve the SCC estimates in future updates, including many of the approaches suggested by commenters and peer-reviewed literature, and summarized in this document.

Circular A-4 is a living document, which may be updated as appropriate to reflect new developments and unforeseen issues. OMB was fully involved in the development of the SCC estimates as a working group co-chair and supports the working group's recommendations regarding the discount rate and the focus on global damages. The departure from the standard discount rate recommendations in Circular A-4 is explained in detail in the TSDs and in Section 5 of this document. Briefly, the use of 7 percent is not considered appropriate for intergenerational discounting. There is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself. The emphasis on global rather than domestic damages is also explained in detail in the TSDs. Beyond the fact that good methodologies for estimating domestic damages do not currently exist, basing decisions on only the domestic damages from carbon emissions will lead to an inefficient allocation of resources to reducing them, especially if all countries adopt a similarly short-sighted approach. An efficient outcome can only be achieved if all countries consider the full costs and benefits of their actions; the United States continues to be a leader in working to establish such a regime internationally.

## (3) Transparency

Several commenters asserted that the process of selecting the models and input assumptions, including much of the basic information underlying these decisions, has been insulated from public scrutiny. Commenters expressed concern that the IWG has not revealed the identity or qualifications of its participants, the role of government contractors, or the details of its internal processes, including the frequency of meetings and the nature of its deliberations. These commenters further suggested that the TSDs discuss only a few selected inputs to the models, which, though important, are not the only important inputs. They believe greater transparency is also needed regarding the models themselves and the key differences among them.

Some commenters also suggested that the discussion in the TSD of the 2013 revisions is insufficient for understanding and interpreting the changes in the SCC estimates. Additional justification for many of the revisions would be helpful (e.g., space heating expenditure reductions, transient temperature responses, constant indirect methane radiative forcing effect, saturation, regional scaling factors, probability of a

discontinuity, adaptation, CO<sub>2</sub> absorption, regional climate modeling). Commenters suggested that discussion of uncertainty regarding the revisions would also be helpful. At a minimum, commenters suggested it would be reasonable to explain differences across models for similar components (e.g., sea level rise, transient temperature response, saturation, and adaptation), noting as a source of confusion that the TSDs have references to previous model versions, websites, and working papers, and suggested that a clear citation for each of the revisions in each model would be useful.

Other commenters explicitly noted ways in which they disagreed with the comments above. They indicated that the 2010 TSD sets out in detail the IWG's decision-making process with respect to how it assessed and employed the models, and that the 2013 TSD discusses how the three IAMs used in the analysis were updated in the publically-available academic literature over the three-year interim period by the independent researchers who developed them, and clarifies that the increase in the SCC estimate from 2010 to 2013 resulted solely from updates to the three underlying IAMs.

#### Response

The IWG believes that its process was inclusive, transparent, and appropriately considered public input. The TSDs fully document the methodology used to develop the estimates and the considerations that led the IWG to adopt this methodology. While the details of the IWG's internal processes were not discussed in the TSDs, this is common for most government (and non-government) documents. Such details were not considered germane to the public's understanding of the SCC estimates and the methodology used to produce them, but a general overview is provided here.

In developing the 2010 estimates, the IWG met frequently in the year preceding the release of the February 2010 TSD. For the 2013 update, only a few meetings were needed because the group decided to make no changes beyond incorporating the most recent versions of the IAMs. The IWG, in particular professional economic staff with modeling expertise, oversaw the primary modeling and calculations for both the 2010 and 2013 SCC estimates using the most recent versions of the three IAMs available at the time. To develop the 2010 estimates, the staff members ran two of the three models and contracted with the developer of the third model to perform those runs. The contractor did not participate in any of the interagency meetings but rather received instructions for how to conduct the model runs (e.g., specification of the three sets of input assumptions as determined by the working group). The staff members ran all three models to develop the 2013 estimates. Decision making for both the 2010 and 2013 processes was by consensus of IWG members. The details of internal discussions are deliberative, but the discussions were generally technical in nature and the issues discussed and conclusions reached are well documented in the TSDs. Regarding the transparency of the underlying models themselves, the IWG notes that they are well documented in the academic literature.

The Government Accountability Office (GAO) recently completed a review of the process used to develop the SCC estimates. GAO concluded that according to IWG participants, all major issues discussed were documented in the TSDs, which is consistent with Federal standards for internal control, and the processes and methods used were based on the principles of (1) consensus-based decision-making, (2) reliance on existing academic literature and modeling, and (3) disclosure of limitations and incorporation of new information through consideration of public comments and revision of the estimates as updated research became available.<sup>12</sup>

IWG members have also assisted individual requestors in obtaining more detailed information about the modeling. For example, one requestor noted publically that IWG "modelers have been very open, collegial, and helpful."<sup>13</sup>

Regarding the explanation in the TSD for the 2013 revisions, no changes were made to the input assumptions developed by the IWG between the 2010 and 2013 estimates. The only changes were those made by the model developers themselves to the underlying models, which are documented in the academic literature. To assist the public in understanding these changes, the 2013 TSD provides a brief summary of the most important ones, as well as references to the relevant literature where more detailed information can be found. As with the 2010 TSD, the IWG did not attempt to evaluate the modeling choices made by the modelers. Rather, by selecting the three "most widely used impact assessment models" (NAS, 2010), the IWG intended to reflect a reasonable range of modeling choices and approaches that collectively reflect the current literature on the estimation of damages from CO<sub>2</sub> emissions. As explained in the 2010 TSD:

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socio-economic and emissions trajectories, and discount rates...All other model features were left unchanged, relying on the model developers' best estimates and judgments...The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates.

Accordingly, the IWG did not attempt to explain in detail how the damage functions in the models were constructed or their strengths and weaknesses, either for the earlier model versions used in the 2010 estimates or for the updated versions used for the 2013 estimates. Rather, stakeholders who are interested in these details are encouraged to consult the model documentation and the related academic literature referenced in the TSDs, as well as the model developers themselves. The IWG accepts the point that clearer citations to specific model versions and revisions would be helpful and will attempt to address this in the next update of the TSD.

## (4) Opportunities for public comment

While some commenters acknowledged that the public has had multiple opportunities to comment on the SCC estimates and TSDs, others felt that the opportunities for public comment have been insufficient. A few of these commenters indicated that the public has not been provided sufficient information and

<sup>&</sup>lt;sup>12</sup> http://www.gao.gov/products/GAO-14-663

<sup>&</sup>lt;sup>13</sup> http://dailysignal.com/2013/11/06/white-house-reopens-the-scc/

asked that additional supplemental and supporting documents be made available to the public for comment, including all of the data, models, assumptions, and analyses relied on to arrive at the SCC estimates. They suggested that OMB's responses to FOIA requests implied that there are thousands of pages of supporting documents that have not been released to the public.

Some commenters stated that the continued development of SCC estimates should have strong oversight in both the Executive branch and Congress, that there should be continued opportunities for the public to comment, and that the analysis should be conducted in an open fashion.

### Response

The IWG agrees with those commenters who believe the public has had ample opportunities to comment on the SCC estimates and methodology. Opportunity for public comment on all aspects of the SCC estimates was provided on the interim estimates selected by the IWG and in the numerous proposed rules issued by Federal agencies between February 2010 and May 2013 that made use of the estimates. As a general practice, agencies request comments on all aspects of the regulatory impact analysis, thereby providing ample opportunity for the public to comment on SCC estimates used in these analyses. These comments helped inform the IWG's development of the 2013 revised estimates. In addition, OMB provided a stand-alone comment period on the 2013 estimates. This document summarizes the comments received and provides the IWG's response.

Regarding the adequacy of the information provided to the public as a basis for comment, the TSDs provide a complete record of the methodology and assumptions used to develop the SCC estimates, including references to the academic literature. Independent analysts have sought and received information from the IWG allowing them to implement the IWG approach and modify it further if they choose. Additional documentation is available in the academic literature on the IAMs themselves.

With regards to several FOIA requests received by OMB and other IWG members, the only documents withheld were deliberative documents that are protected under applicable FOIA exemptions. Most of these documents were either intermediate drafts of TSD language or e-mails exchanged among IWG participants discussing various aspects of the methodology and results. Such documents are not typically provided in the record of agency actions and are not necessary for informed public comment.

The IWG is committed to providing additional opportunities for public comment when future updates of the SCC are released and agrees that analysis should continue to be conducted in an open fashion.

## (5) Use of the SCC Estimates in Regulatory Impact Analysis

In addition to expressing views about how the SCC estimates were derived, many commenters discussed the *application* of the estimates. Some commenters explicitly endorsed the use of the SCC in rulemaking analyses, highlighting that accounting for the economic harms caused by climate change is a critical component of sound benefit-cost analyses of regulations that directly or indirectly affect greenhouse gas emissions. These commenters stated that without an SCC estimate, regulators would by default be using a value of zero for the benefits of reducing carbon pollution, implying that carbon pollution has no costs.

They urged the IWG to continuously update the SCC, as new economic and scientific consensus emerges, in line with the stated intentions of the IWG.

Other commenters disagreed with continued use of SCC estimates based on both process and substance concerns. On the process side, some commenters asserted that the limitations of the process used to generate the estimates (see earlier comments in this section) render them unsuitable for use in regulatory impact analysis and requested that the IWG withdraw the TSDs until these process flaws have been corrected. Issues specifically highlighted in this area were lack of peer review and inadequate opportunity for public comment. Other commenters stated that the SCC estimates are too uncertain for decision making, and several requested that the IWG provide more explicit guidance on when and when not to use them. For example, several commenters said the TSD should explicitly note that the SCC estimates are only for use in benefit-cost analysis of Federal regulations and are not a "price" on carbon or a proxy for the anticipated cost of complying with CO<sub>2</sub> regulations; in addition they should not be used in NEPA environmental impact statements or state level decision making. One commenter stated that the SCC is more suitable for use in international discussions for now.

### Response

The IWG agrees with those commenters who believe that use of the SCC estimates is an important component of regulatory impact analyses of rules that affect CO<sub>2</sub> emissions. However, it is not true that benefits that cannot be quantified or monetized are assigned zero weight in regulatory impact analysis. Although the monetized benefit estimates may not reflect unquantified benefits, the qualitative analysis provides important information about these benefits that must be given full consideration in regulatory decision-making. OMB guidance directs agencies to quantify benefits and costs of regulations to the extent feasible using the best available science and analytic techniques, but also to take non-quantified benefits into consideration when determining if the benefits of a regulatory action justify its costs. The SCC estimates and supporting TSDs are intended to assist agencies in adopting a consistent approach, based on the best available science and economics, for monetizing this important category of benefits. The IWG also agrees that the estimates should be updated periodically based on advances in the scientific and economic literature and has committed to do so.

Previous sections have addressed the perceived process flaws that have led some commenters to suggest that the estimates not be used until a future update that corrects these perceived flaws is completed. As noted, the IWG has accepted the suggestion of increased opportunity for public comment and plans to seek external expert advice as it considers futures updates, but does not feel that it is appropriate to withdraw the current estimates in the meantime as they represent the best available science in a form that is currently usable for monetized benefits estimates.

Regarding uncertainty, the IWG notes that most if not all benefits estimates in regulatory analyses are uncertain. This does not negate the value of the estimates. It does underscore the importance of a full and transparent discussion of uncertainty, and the TSDs have provided this (see, for example, *Section V: Limitations of the Analysis*, in the 2010 TSD, and *Section IV: Other Model Limitations and Research Gaps*, in the 2013 TSD). The TSDs are explicit that the estimates were developed for use in regulatory impact

analysis. The 2010 TSD states that the SCC estimates were developed for use in "cost-benefit analyses of regulatory actions that have small, or 'marginal,' impacts on cumulative global emissions." The IWG has not addressed the use of the SCC estimates outside the regulatory context, such as in NEPA analysis,<sup>14</sup> state level decision making, and "pricing" carbon in the marketplace. In addition, the 2010 TSD states, "For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here." While the concept of an SCC is appropriate for international discussions, the IWG recognizes that any use of such estimates beyond the domestic regulatory context will require further discussion with our international partners; that said, our current work in this area can certainly help to inform such discussions.

# **11** Technical Addendum

As previously noted, the IWG continues to receive feedback from stakeholders through public comments on proposed Agency rulemakings that use the SCC in supporting analyses, the additional OMB comment period on the SCC, and regular interactions with stakeholders and research analysts implementing the methodology used by the IWG to compute the estimates. As a result of our engagement in this continuous review process, we recently discovered two areas where minor technical corrections are appropriate. First, the DICE model had been run up to 2300 rather than through 2300, as was intended, thereby leaving out the marginal damages in the last year of the time horizon. Second, due to an indexing error, the results from the PAGE model were in 2008 U.S. dollars rather than 2007 U.S. dollars, as was intended. A revised TSD with the corrected estimates (all models run through 2300 and all estimates in 2007 U.S. dollars) has been posted on OMB's website. On average the revised SCC estimates are one dollar less than the mean SCC estimates reported in the November 2013 TSD. The difference between the 95<sup>th</sup> percentile estimates with a 3% discount rate is slightly larger, as those estimates are heavily influenced by results from the PAGE model. The revised (July 2015) TSD includes an addition to the technical appendix (Appendix B) explaining these revisions.

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<sup>&</sup>lt;sup>14</sup> On December, 18 2014, the Council on Environmental Quality released draft NEPA guidance on GHG Emissions and Climate Change Impacts (<u>https://www.whitehouse.gov/administration/eop/ceq/initiatives/nepa/ghg-guidance</u>). The draft guidance states: "When an agency determines it appropriate to monetize costs and benefits, then, although developed specifically for regulatory impact analyses, the Federal social cost of carbon, which multiple Federal agencies have developed and used to assess the costs and benefits of alternatives in rulemakings, offers a harmonized, interagency metric that can provide decision makers and the public with some context for meaningful NEPA review. When using the Federal social cost of carbon, the agency should disclose the fact that these estimates vary over time, are associated with different discount rates and risks, and are intended to be updated as scientific and economic understanding improves." The comment period for the draft guidance closed on March 25, 2015. CEQ is currently considering the comments received as it develops final guidance.

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