

**Comment by:**

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**on the**

**Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment; Notice of proposed rulemaking (NOPR) and public meeting**

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**Agency:** Energy Efficiency and Renewable Energy Office (EERE)

**Parent Agency:** Department of Energy (DOE)

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**Comment:**

*Summary*

Our comment primarily concerns the DOE's use of the social cost of carbon (SCC) in the cost/benefit analysis of the Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment proposed rulemaking. The determination of the SCC is so discordant with the best scientific literature on the equilibrium climate sensitivity and the fertilization effect of carbon dioxide—two critically important parameters for establishing the net externality of carbon dioxide emissions—that, until this situation can be rectified, it should be barred from use in this and all other federal rulemaking.

*Discussion and Analysis*

In the proposed rulemaking, the DOE recognizes that the determination of the SCC is rapidly evolving and dependent on the latest scientific findings. The DOE states that:

DOE is well aware that scientific and economic knowledge about the contribution of CO<sub>2</sub> and other GHG emissions to changes in the future global climate and the potential resulting damages to the world economy continues to evolve rapidly. Thus, any value placed in this NOPR on reducing CO<sub>2</sub> emissions is subject to change. DOE, together with other Federal agencies, will continue to review various methodologies for estimating the monetary value of reductions in CO<sub>2</sub> and other GHG emissions. This ongoing review will consider the comments on this subject that are part of the public record for this NOPR and other rulemakings, as well as other methodological assumptions and issues. However, consistent with DOE's legal obligations, and taking into account the uncertainty involved with this particular issue, DOE has included in this NOPR the most recent values and analyses resulting from the ongoing interagency review process.

In light of the DOE's and other Federal agencies' on-going examination of the SCC, we submit our comments for consideration on this topic. We note, however, that the May 2013 update to the SCC made by the Interagency Working Group (IWG) ignored such a large amount of new science (extant at the time of the update), that the new SCC be considered invalid and discarded. It is better not to include any value for the SCC in federal cost/benefit analyses such as this one, than to include one which is knowingly inaccurate and thus potentially misleading.

#### *Equilibrium Climate Sensitivity*

In May 2013, the Interagency Working Group (IWG) produced an updated SCC value by applying updates to the underlying three Integrated Assessment Models (IAMs) used in its initial 2010 SCC determination, but did not update the equilibrium climate sensitivity (ECS) employed in the IAMs. This was not done, despite there having been, since January 1, 2011, at least 10 new studies and 16 experiments (involving more than 42 researchers) examining the ECS, each lowering the best estimate and tightening the error distribution about that estimate. Instead, the IWG wrote in its 2013 report: "It does not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity)."

The earth's equilibrium climate sensitivity is defined in the Interagency Working Group on Social Cost of Carbon 2010 (hereafter, IWG2010) report as "the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO<sub>2</sub> concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm))" and is recognized as "a key input parameter" for the integrated assessment models used to determine the social cost of carbon.

The IWG2010 report has an entire section (Section III.D) dedicated to describing how an estimate of the equilibrium climate sensitivity and the scientific uncertainties surrounding its actual value are developed and incorporated in the IWG's analysis. The IWG2010, in fact, developed its own probability density function (pdf) for the ECS and used it in each of the three IAMs, superseding the ECS pdfs used by the original IAMs developers. The IWG's intent was to develop an ECS pdf which most closely matched the description of the ECS as given in the

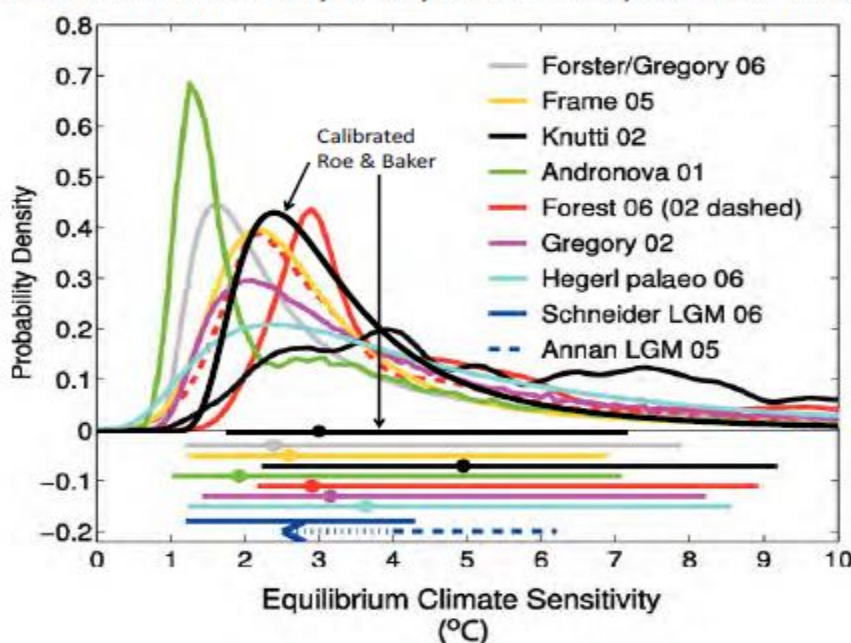
*Fourth Assessment Report* of the United Nation's Intergovernmental panel on Climate Change which was published in 2007.

The functional form adopted by the IWG2010 was a calibrated version of Roe and Baker (2007) distribution. It was described in the IWG2010 report in the following Table and Figure (from the IWG2010 report):

**Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions**

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5 <sup>th</sup> percentile	1.72	1.49	1.37	1.13
10 <sup>th</sup> percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50 <sup>th</sup> percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90 <sup>th</sup> percentile	5.86	5.14	4.93	4.69
95 <sup>th</sup> percentile	7.14	5.97	5.59	5.17

**Figure 2: Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)**

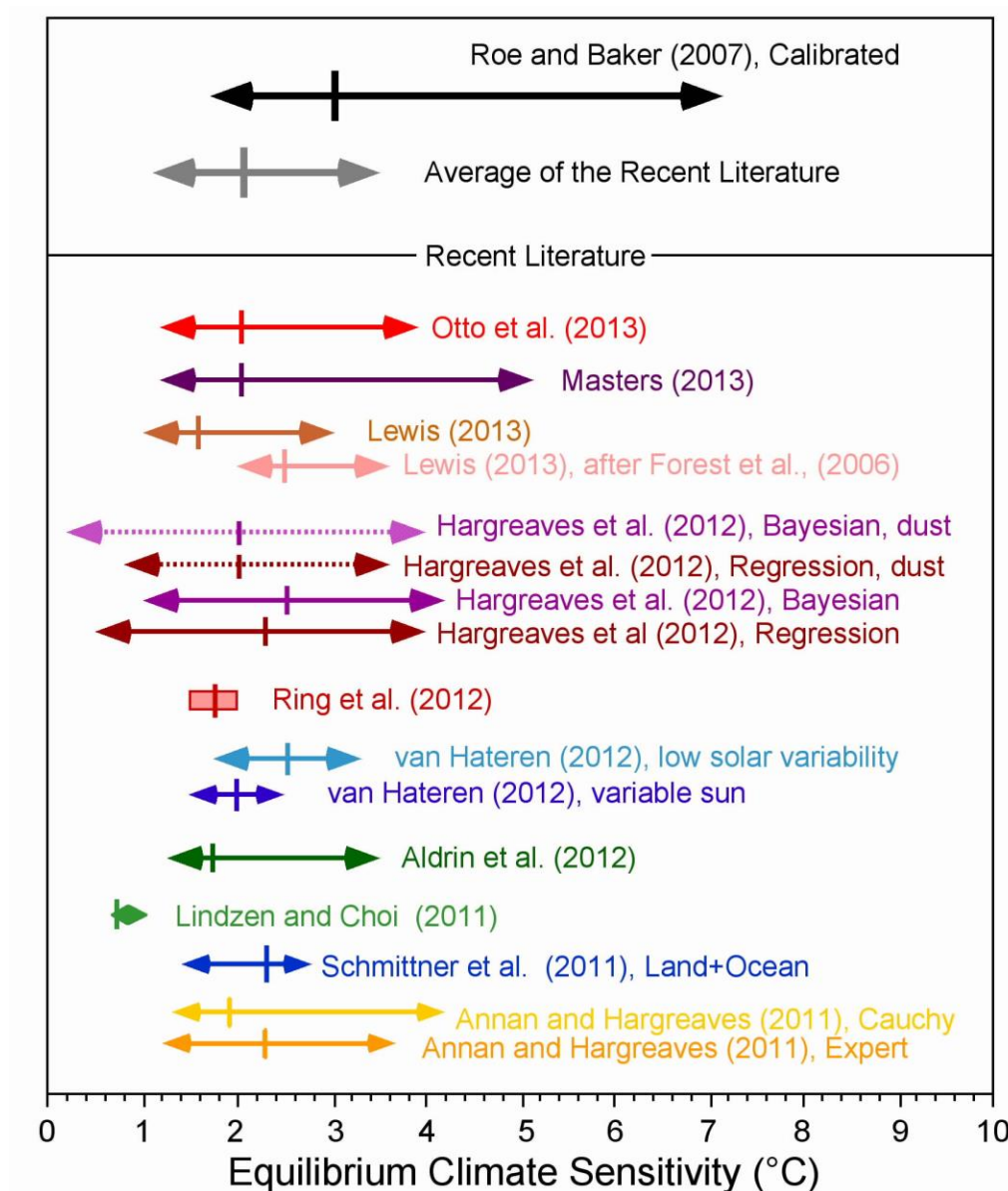


The calibrated Roe and Baker functional form used by the IWG2010 is *no longer scientifically defensible*; neither was it at the time of the publication of the IWG 2013 SCC update.

The figure below vividly illustrates this fact, as it compares the best estimate and 90% confidence range of the earth's ECS as used by the IWG2010/2013 (calibrated Roe and Baker) against the findings in the scientific literature published since January 1, 2011.

Whereas the IWG2010/2013 ECS distribution has a median value of 3.0°C and 5<sup>th</sup> and 95<sup>th</sup> percentile values of 1.72°C and 7.14°C, respectively, the corresponding values averaged from the recent scientific literature are 2.0°C (median), 1.1°C (5<sup>th</sup> percentile), and 3.5°C (95<sup>th</sup> percentile).

These differences will have large and significant impacts on the SCC determination.



CAPTION: The median (indicated by the small vertical line) and 90% confidence range (indicated by the horizontal line with arrowheads) of the climate sensitivity estimate used by the Interagency Working Group on the Social Cost of Carbon Climate is indicated by the top black arrowed line. The average of the similar values from 16 different determinations reported in the recent scientific literature is given by the grey arrowed line (second line from the top). The sensitivity estimates from the 16 individual determinations of the ECS as reported in new research published after January 1, 2011 are indicated by

the colored arrowed lines. The arrows indicate the 5 to 95% confidence bounds for each estimate along with the best estimate (median of each probability density function; or the mean of multiple estimates; colored vertical line). Ring et al. (2012) present four estimates of the climate sensitivity and the red box encompasses those estimates.

The IWG2010 report noted that, concerning the low end of the ECS distribution, its determination reflected a greater degree of certainty that a low ECS value could be excluded than did the IPCC. From the IWG2010 (p. 14):

“Finally, we note the IPCC judgment that the equilibrium climate sensitivity “is very likely larger than 1.5°C.” Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of “very likely” as “greater than 90 percent probability,” it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.”

In other words, the IWG used its judgment that the lower bound of the ECS distribution was higher than the IPCC 2007 assessment indicated. However, the collection of the recent literature on the ECS shows the IWG’s judgment to be in error. As can be seen in the chart above, the large majority of the findings on ECS in the recent literature indicate that the lower bound (i.e., 5<sup>th</sup> percentile) of the ECS distribution is lower than the IPCC 2007 assessment. And, the average value of the 5<sup>th</sup> percentile in the recent literature (1.1°C) is 0.62°C less than that used by the IWG—a sizeable and important difference which will influence the SCC determination.

But even more influential in the SCC determination is the upper bound (i.e., 95<sup>th</sup> percentile) of the ECS probability distribution.

The IWG2010 notes (p.14) that the calibrated Roe and Baker distribution better reflects the IPCC judgment that “values substantially higher than 4.5°C still cannot be excluded.” The IWG2010 further notes that

“Although the IPCC made no quantitative judgment, the 95<sup>th</sup> percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95<sup>th</sup> percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95<sup>th</sup> percentiles of the three other calibrated distributions (5.2-6.0 °C).”

In other words, the IWG2010 turned towards surveys of the scientific literature to determine its assessment of an appropriate value for the 95<sup>th</sup> percentile of the ECS distribution. Now, more than three years hence, the scientific literature tells a completely different story.

Instead of a 95<sup>th</sup> percentile value of 7.14°C, as used by the IWG2010, a survey of the recent scientific literature suggests a value of 3.5°C—more than 50% lower.

And this is very significant and important difference because the high end of the ECS distribution has a large impact on the SCC determination—a fact frequently commented on by the IWG2010.

For example, from IWG2010 (p.26):

“As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.”

And further (p.30):

*Uncertainty in extrapolation of damages to high temperatures:* The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

And the entirety of Section V [sic] “A Further Discussion of Catastrophic Impacts and Damage Functions” of the IWG 2010 report describes “tipping points” and “damage functions” that are probabilities assigned to different values of global temperature change. Table 6 from the IWG2010 indicated the probabilities of various tipping points.

**Table 6: Probabilities of Various Tipping Points from Expert Elicitation -**

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

The likelihood of occurrence of these low probability, high impact, events (“tipping points”) is *greatly* diminished under the new ECS findings. The average 95<sup>th</sup> percentile value of the new literature survey is only 3.5°C indicating a very low probability of a warming reaching 3-5°C by 2100 as indicated in the 3<sup>rd</sup> column of the above Table and thus a significantly lower probability that such tipping points will be reached. This new information will have a large impact on the final SCC determination using the IWG’s methodology.

The size of this impact has been directly investigated.

In their Comment on the Landmark Legal Foundation Petition for Reconsideration of Final Rule Standards for Standby Mode and Off Mode Microwave Ovens, Dayaratna and Kreutzer (2013) ran the DICE model using the distribution of the ECS as described by Otto et al. (2013)—a paper published in the recent scientific literature which includes 17 authors, 15 of which were lead authors of chapters in the recent Intergovernmental Panel on Climate Change’s *Fifth Assessment Report*. The most likely value of the ECS reported by Otto et al. (2013) was described as “2.0°C, with a 5–95% confidence interval of 1.2–3.9°C.” Using the Otto et al. (2013) ECS distribution in lieu of the distribution employed by the IWG (2013), dropped the SCC by 42 percent, 41 percent, and 35 percent (for the 2.5%, 3.0%, 5.0% discount rates, accordingly). This is a significant decline.

Waldhoff et al. (2011) investigated the sensitivity of the FUND model to changes in the ECS. Waldhoff et al. (2011) found that changing the ECS distribution such that the mean of the distribution was lowered from 3.0°C to 2.0°C had the effect of lowering the SCC by 60 percent (from a 2010 SCC estimate of \$8/ton of CO<sub>2</sub> to \$3/ton in \$1995). While Waldhoff et al. (2011) examined FUNDv3.5, the response of the current version (v3.8) of the FUND model should be similar.

These studies make clear that the strong dependence of the social cost of carbon on the distribution of the estimates of the equilibrium climate sensitivity (including the median, and the upper and lower certainty bounds) requires that the periodic updates to the IWG SCC determination must include an examination of the scientific literature on the topic of the equilibrium climate sensitivity. There is no indication that the IWG undertook such an examination. But what is clear, is that the IWG did not alter its probability distribution of the ECS between its 2010 and 2013 SCC determination, despite a large and growing body of scientific literature that substantially alters and better defines the scientific understanding of the earth’s ECS. It is unacceptable that a supposed “updated” social cost of carbon does not include updates to the science underlying a critical and key aspect of the SCC.

#### *Agricultural Impacts of Carbon Fertilization*

Carbon dioxide is known to have a positive impact on vegetation, with literally thousands of studies in the scientific literature demonstrating that plants (including crops) grow stronger, healthier, and more productive under conditions of increased carbon dioxide concentration. A

recent study (Idso, 2013) reviewed a large collection of such literature as it applies to the world's 45 most important food crops (making up 95% of the world's annual agricultural production). Idso (2013) summarized his findings on the increase in biomass of each crop that results from a 300ppm increase in the concentration of carbon dioxide under which the plants were grown. This table is reproduced below (Table 1), and shows that the typical growth increase exceeds 30% in most crops, including 8 of the world's top 10 food crops (the increase was 24% and 14% in the other two).

**Table 1. Average percentage increase in biomass of each of the world's 45 most important food crops under an increase of 300ppm of carbon dioxide.**

Crop	% Biomass Change	Crop	% Biomass Change
Sugar cane	34.0%	Rye	38.0%
Wheat	34.9%	Plantains	44.8%
Maize	24.1%	Yams	47.0%
Rice, paddy	36.1%	Groundnuts, with shell	47.0%
Potatoes	31.3%	Rapeseed	46.9%
Sugar beet	65.7%	Cucumbers and gherkins	44.8%
Cassava	13.8%	Mangoes, mangosteens, guavas	36.0%
Barley	35.4%	Sunflower seed	36.5%
Vegetables fresh nes	41.1%	Eggplants (aubergines)	41.0%
Sweet potatoes	33.7%	Beans, dry	61.7%
Soybeans	45.5%	Fruit Fresh Nes	72.3%
Tomatoes	35.9%	Carrots and turnips	77.8%
Grapes	68.2%	Other melons (inc.cantaloupes)	4.7%
Sorghum	19.9%	Chillies and peppers, green	41.1%
Bananas	44.8%	Tangerines, mandarins, clem.	29.5%
Watermelons	41.5%	Lettuce and chicory	18.5%
Oranges	54.9%	Pumpkins, squash and gourds	41.5%
Cabbages and other brassicas	39.3%	Pears	44.8%
Apples	44.8%	Olives	35.2%
Coconuts	44.8%	Pineapples	5.0%
Oats	34.8%	Fruit, tropical fresh nes	72.3%
Onions, dry	20.0%	Peas, dry	29.2%
Millet	44.3%		

Idso (2013) found that the increase in the atmospheric concentration of carbon dioxide that took place during the period 1961-2011 was responsible for increasing global agricultural output by 3.2 trillion dollars (in 2004-2006 constant dollars). Projecting the increases forward based on projections of the increase in atmospheric carbon dioxide concentration, Idso (2013) expects carbon dioxide fertilization to increase the value of agricultural output by 9.8 trillion dollars (in 2004-2006 constant dollars) during the 2012-2050 period.

This is a large positive externality, and one that is insufficiently modeled in the IAMs relied upon by the IWG in determining the SCC.

In fact, only one of the three IAMs used by the IWG has any substantial impact from carbon dioxide fertilization, and the one that does, underestimates the effect by approximately 2-3 times.



The FUND model has a component which calculates the impact on agricultural as a result of carbon dioxide emissions, which includes not only the impact on temperature and other climate changes, but also the direct impact of carbon dioxide fertilization. The other two IAMs, DICE and PAGE by and large do not (or only do so extremely minimally; DICE includes the effect to a larger degree than PAGE). Consequently, lacking this large and positive externality, the SCC calculated by the DICE and PAGE models is significantly larger than the SCC determined by the FUND model (for example, see Table A5, in the IWG 2013 report).

But even the positive externality that results from carbon dioxide fertilization as included in the FUND model is too small when compared with the Idso (2013) estimates. FUND (v3.7) uses the following formula to determine the degree of crop production increase resulting from atmospheric carbon dioxide increases (taken from Anthoff and Tol, 2013a):

CO<sub>2</sub> fertilisation has a positive, but saturating effect on agriculture, specified by

$$(A.4) \quad A_{t,r}^f = \gamma_r \ln \frac{CO2_t}{275}$$

where

- $A^f$  denotes damage in agricultural production as a fraction due to the CO<sub>2</sub> fertilisation by time and region;
- $t$  denotes time;
- $r$  denotes region;
- $CO2$  denotes the atmospheric concentration of carbon dioxide (in parts per million by volume);
- 275 ppm is the pre-industrial concentration;
- $\gamma$  is a parameter (see Table A, column 8-9).

Column 8 in the table below (Table 2) shows the CO<sub>2</sub> fertilization parameter ( $\gamma_r$ ) used in FUND for various regions of the world (Anthoff and Tol, 2013b). The average CO<sub>2</sub> fertilization effect across the 16 regions of the world is 11.2%. While this number is neither areally weighted, nor weighted by the specific crops grown, it is clear that 11.2% is much lower than the average fertilization effect compiled by Idso (2013) for the world's top 10 food crops (35%). Further, Idso's fertilization impact is in response to a 300ppm CO<sub>2</sub> increase, while the fertilization parameter in the FUND model is multiplied by  $\ln(CO2_t/275)$  which works out to 0.74 for a 300ppm CO<sub>2</sub> increase. This multiplier further reduces the 16 region average to 8.4% for the CO<sub>2</sub> fertilization effect—some 4 times smaller than the magnitude of the fertilization impact identified by Idso (2013).

**Table 2. Impact of climate change on agriculture in FUND model.**

	Rate of change (% Ag. Prod/ 0.04°C)		$\delta_r^l$		$\delta_r^q$		CO <sub>2</sub> fertilisation (% Ag. Prod)	
USA	-0.021	(0.176)	0.026	(0.021)	-0.012	(0.018)	8.90	(14.84)
CAN	-0.029	(0.073)	0.092	(0.080)	-0.016	(0.009)	4.02	(6.50)
WEU	-0.039	(0.138)	0.022	(0.002)	-0.014	(0.013)	15.41	(11.83)
JPK	-0.033	(0.432)	0.046	(0.022)	-0.024	(0.030)	23.19	(36.60)
ANZ	-0.015	(0.142)	0.040	(0.071)	-0.016	(0.037)	10.48	(8.50)
EEU	-0.027	(0.062)	0.048	(0.097)	-0.018	(0.048)	9.52	(5.14)
FSU	-0.018	(0.066)	0.042	(0.075)	-0.016	(0.039)	6.71	(5.48)
MDE	-0.022	(0.032)	0.042	(0.071)	-0.017	(0.037)	9.43	(2.66)
CAM	-0.034	(0.061)	0.064	(0.043)	-0.030	(0.043)	16.41	(5.38)
SAM	-0.009	(0.060)	0.003	(0.005)	-0.004	(0.003)	5.96	(5.04)
SAS	-0.014	(0.021)	0.025	(0.024)	-0.011	(0.018)	5.80	(1.64)
SEA	-0.009	(0.482)	0.014	(0.004)	-0.010	(0.008)	8.45	(41.81)
CHI	-0.013	(0.075)	0.043	(0.076)	-0.017	(0.040)	19.21	(6.13)
NAF	-0.016	(0.023)	0.033	(0.043)	-0.014	(0.027)	7.27	(1.90)
SSA	-0.011	(0.026)	0.024	(0.034)	-0.010	(0.020)	5.05	(2.20)
SIS	-0.050	(0.103)	0.043	(0.077)	-0.017	(0.040)	23.77	(8.64)

Standard deviations are given in brackets.

Although approximately 4 times too small, the impact of the fertilization effect on the SCC calculation in the FUND model is large.

According to Waldhoff et al. (2011), if the CO<sub>2</sub> fertilization effect is turned off in the FUND model (v3.5) the SCC increases by 75% from \$8/tonCO<sub>2</sub> to \$14/tonCO<sub>2</sub> (in 1995 dollars). In another study, Ackerman and Munitz (2012) find the effective increase in the FUND model to be even larger, with CO<sub>2</sub> fertilization producing a positive externality of nearly \$15/tonCO<sub>2</sub> (in 2007 dollars).

Clearly, had the Idso (2013) estimate of the CO<sub>2</sub> fertilization impact been used instead of the one used in FUND the resulting positive externality would have been much larger, and the resulting net SCC been much lower.

This is just for one of the three IAMs used by the IWG. Had the more comprehensive CO<sub>2</sub> fertilization impacts identified by Idso (2013) been incorporated in all the IAMs, the three-model average SCC used by the IAM would be been greatly lowered, and likely even become negative in some IAM/discount rate combinations.

## Conclusion

The social cost of carbon used by the DOE in its proposed Energy Conservation Standards for Commercial Refrigeration Equipment is unsupported by the scientific literature and unsuitable for rulemaking. Not only should it not serve as basis of the cost/benefits analysis in this proposed rulemaking, but its use must be reconsidered in all proposed rulemaking.

Although the full impact of including better estimates of the equilibrium climate sensitivity as well as the carbon dioxide fertilization effect is beyond the scope of this Comment, it should not be beyond the scope of the IWG. Until the IWG takes it upon itself to address these substantial exclusions, the use of the SCC in federal cost/benefit analysis such as the Energy Conservation Standards for Commercial Refrigeration Equipment should be suspended.

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