Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide
Interim Estimates under Executive Order 13990

Interagency Working Group on Social Cost of Greenhouse Gases, 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 Health and Human Services
Department of the Interior
Department of Transportation
Department of the Treasury
Environmental Protection Agency
National Climate Advisor
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy

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Preface

The Interagency Working Group (IWG) on the Social Cost of Greenhouse Gases is committed to ensuring that the estimates agencies use when monetizing the value of changes in greenhouse gas emissions resulting from regulations and other relevant agency actions continue to reflect the best available science and methodologies. This Technical Support Document (TSD) presents interim estimates of the social cost of carbon, methane, and nitrous oxide developed under Executive Order 13990. These interim values are the same as those developed by the IWG in 2013 and 2016. The current IWG will take comment on recent developments in the science and economics for use in a more comprehensive update, to be issued by January 2022, which will more fully address the recommendations of the National Academies of Sciences, Engineering, and Medicine as reported in Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide (2017) and other pertinent scientific literature. As a part of that request for comment, the IWG will seek comment on the discussion of advances in science and methodology included in this TSD and how those advances can best be incorporated into the revised final estimates.

Executive Summary

A robust and scientifically founded assessment of the positive and negative impacts that an action can be expected to have on society provides important insights in the policy-making process. The estimates of the social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O) presented here allow agencies to understand the social benefits of reducing emissions of each of these greenhouse gases, or the social costs of increasing such emissions, in the policy making process. Collectively, these values are referenced as the "social cost of greenhouse gases" (SC-GHG) in this document. The SC-GHG is the monetary value of the net harm to society associated with adding a small amount of that GHG to the atmosphere in a given year. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, should reflect the societal value of reducing emissions of the gas in question by one metric ton. The marginal estimate of social costs will differ by the type of greenhouse gas (such as carbon dioxide, methane, and nitrous oxide) and by the year in which the emissions change occurs. The SC-GHGs are the theoretically appropriate values to use in conducting benefit-cost analyses of policies that affect GHG emissions.

Federal agencies began regularly incorporating social cost of carbon (SC-CO_2) estimates in benefit-cost analyses conducted under Executive Order (E.O.) 12866[1] in 2008, following a court ruling in which an agency was ordered to consider the value of reducing CO_2 emissions in a rulemaking process. The U.S. Ninth Circuit Court of Appeals remanded a fuel economy rule to DOT for failing to monetize CO_2 emission reductions, stating that "while the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero."[2] In 2009, an interagency working group (IWG) was established to ensure that agencies were using the best available science and to promote consistency in the values used across agencies. The IWG published SC-CO_2 estimates in 2010 that were developed from an ensemble of three widely cited integrated assessment models (IAMs) that estimate global climate damages using highly aggregated representations of climate processes and the global economy combined into a single modeling framework. The three IAMs were run using a common set of input assumptions in each model for future population, economic, and GHG emissions growth, as well as equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. These estimates were updated in 2013 based on new versions of each IAM. In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) using methodologies that are consistent with the methodology underlying the SC-CO_2 estimates. In January 2017, the National Academies of Sciences, Engineering, and Medicine issued recommendations for an updating process to ensure the estimates continue to reflect the best available science. In March 2017, Executive Order 13783 disbanded the IWG and instructed agencies when monetizing the value of changes

[1] Under E.O. 12866, agencies are required, to the extent permitted by law and where applicable, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." As indicated in the discussion above, many statutes also require agencies to conduct at least some of the same analyses required under E.O. 12866, such as the Energy Policy and Conservation Act which mandates the setting of fuel economy regulations.

[2] *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1200 (9th Cir. 2008).

in greenhouse gas emissions resulting from regulations to follow the Office of Management and Budget's (OMB) Circular A-4.

On January 20, 2021, President Biden issued E.O. 13990 which re-established the IWG and directed it to ensure that SC-GHG estimates used by the U.S. Government (USG) reflect the best available science and the recommendations of the National Academies (2017) and work towards approaches that take account of climate risk, environmental justice, and intergenerational equity. The IWG was tasked with first reviewing the SC-GHG estimates currently used by the USG and publishing interim estimates within 30 days of the E.O. that reflect the full impact of GHG emissions, including taking global damages into account. In this initial review, the IWG finds that the SC-GHG estimates used since E.O. 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG found previously and is restating here that a global perspective is essential for SC-GHG estimates because climate impacts occurring outside U.S. borders can directly and indirectly affect the welfare of U.S. citizens and residents. Thus, U.S. interests are affected by the climate impacts that occur outside U.S. borders. Examples of affected interests include: direct effects on U.S. citizens and assets located abroad, international trade, tourism, and spillover pathways such as economic and political destabilization and global migration. In addition, assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents. Second, the IWG found previously and is restating here that the use of the social rate of return on capital to discount the future benefits of reducing GHG emissions inappropriately underestimates the impacts of climate change for the purposes of estimating the SC-GHG (see Section 3.1). Consistent with the findings of the National Academies (2017) and the economic literature, the IWG continues to conclude that the consumption rate of interest is the theoretically appropriate discount rate in an intergenerational context (IWG 2010, 2013, 2016). The IWG recommends that discount rate uncertainty and relevant aspects of intergenerational ethical considerations be accounted for in selecting future discount rates.

While the IWG works to assess how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates, it is setting interim estimates to be the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The IWG concludes that these interim estimates represent the most appropriate estimate of the SC-GHG until the revised estimates have been developed. This update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

At the same time, consistent with its continuing commitment to a transparent process and a desire to move quickly to update SC-GHG estimates to better reflect the recent science, the IWG will be taking comment on how to incorporate the recommendations of the National Academies (2017) and other recent science , including the advances discussed in this Technical Support Document (TSD), both during the development of the fully updated SC-GHG estimates to be released by January of 2022 and in subsequent updates. The IWG will soon issue a Federal Register notice with a detailed set of requests for public comments on the new information presented in this TSD, as well as other topics and issues the IWG will address as we develop the next set of updates.

This TSD presents the IWG's interim findings and provides interim estimates of the SC-CO_2, SC-CH_4, and SC-N_2O that should be used by agencies until a comprehensive review and update is developed in line with the requirements in E.O. 13990. The TSD maintains the same methodological approach as has been used for global USG SC-GHG estimation to date. The estimates rely on the same models and harmonized inputs and are calculated using a range of discount rates. At this time, the IWG has determined that it is appropriate for agencies to revert to the same set of four values drawn from the SC-GHG distributions based on three discount rates (2.5 percent, 3 percent, and 5 percent) as were used in regulatory analyses between 2010 and 2016 and subject to public comment. However, as described below, based on the IWG's initial review, new data and evidence strongly suggests that the discount rate regarded as appropriate for intergenerational analysis is lower.

Tables ES-1, ES-2, and ES-3 summarize the interim SC-CO_2, SC-CH_4, and SC-N_2O estimates, respectively, for the years 2020 through 2050. These estimates are reported in 2020 dollars but are otherwise identical to those presented in the previous version of the TSD and its Addendum, released in August 2016. For purposes of capturing uncertainty around the SC-GHG estimates in analyses, the IWG emphasized previously and reemphasizes here the importance of considering all four of the SC-GHG values. In particular, this TSD discusses how the understanding of discounting approaches suggests discount rates appropriate for intergenerational analysis in the context of climate change that are lower than 3 percent. Consistent with the guidance in E.O. 13990 for the IWG to ensure that the SC-GHG reflect the interests of future generations, the latest scientific and economic understanding of discount rates discussed in this TSD, and the recommendation from OMB's Circular A-4 to include sensitivity analysis with lower discount rates when a rule has important intergenerational benefits or costs, agencies may consider conducting additional sensitivity analysis using discount rates below 2.5 percent. Furthermore, the IAMs used to produce these interim estimates do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature. For these same impacts, the science underlying their "damage functions" – i.e., the core parts of the IAMs that map global mean temperature changes and other physical impacts of climate change into economic (both market and nonmarket) damages – lags behind the most recent research. Likewise, the assumptions regarding equilibrium climate sensitivity and socioeconomic and emissions scenarios used as inputs to the model runs in this TSD will need to be updated. It is the IWG's judgment that, taken together, these limitations suggest that the range of four interim SC-GHG estimates presented in this TSD likely underestimate societal damages from GHG emissions.

Table ES-1: Social Cost of CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)[3]

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Table ES-2: Social Cost of CH_4, 2020 – 2050 (in 2020 dollars per metric ton of CH_4)

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	670	1500	2000	3900
2025	800	1700	2200	4500
2030	940	2000	2500	5200
2035	1100	2200	2800	6000
2040	1300	2500	3100	6700
2045	1500	2800	3500	7500
2050	1700	3100	3800	8200

[3] The values reported in this TSD are identical to those reported in the 2016 TSD adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). Values are the average across models and socioeconomic emissions scenarios for each of three discount rates (2.5%, 3%, and 5%), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. Values of SC-CO_2 are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

Table ES-3: Social Cost of N_2O, 2020 – 2050 (in 2020 dollars per metric ton of N_2O)

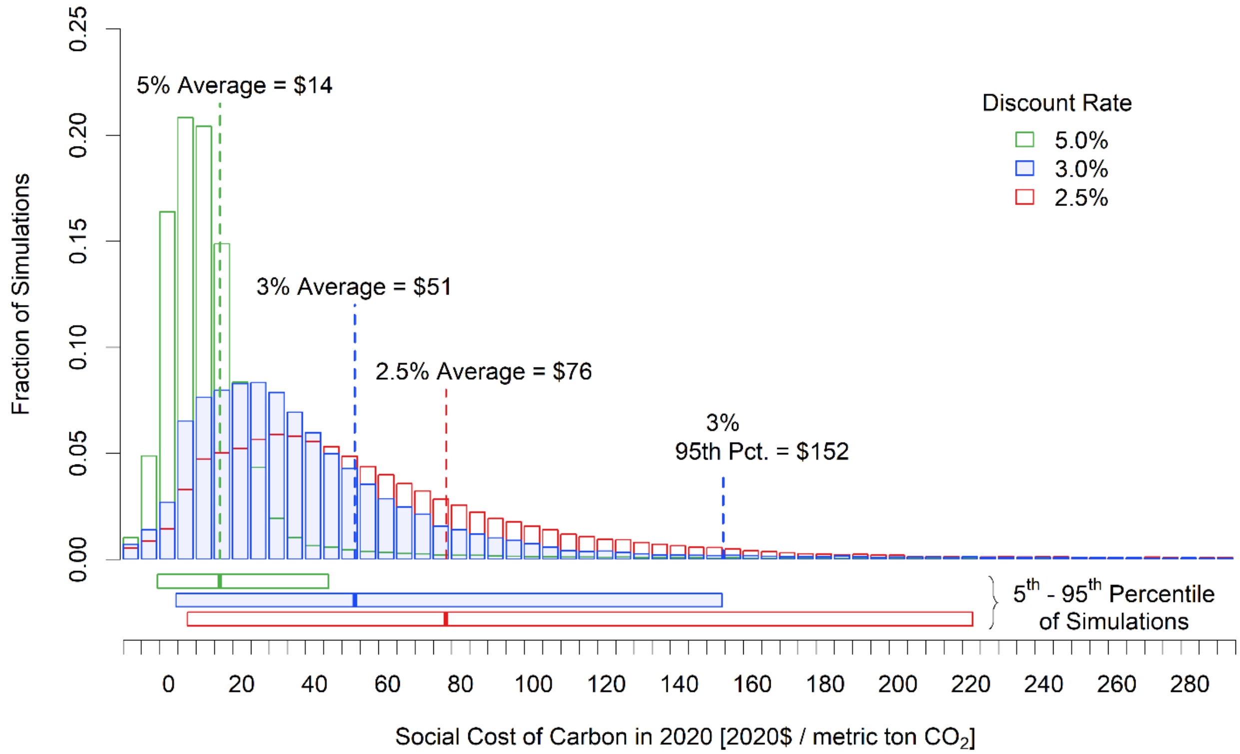
Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	5800	18000	27000	48000
2025	6800	21000	30000	54000
2030	7800	23000	33000	60000
2035	9000	25000	36000	67000
2040	10000	28000	39000	74000
2045	12000	30000	42000	81000
2050	13000	33000	45000	88000

While point estimates are important for providing analysts with a tractable approach for regulatory analysis, they do not fully quantify uncertainty associated with the SC-GHG estimates. Figures ES-1 through ES-3 present the quantified sources of uncertainty in the form of frequency distributions for the SC-GHG estimates for emissions in 2020. The distributions of SC-GHG estimates reflect uncertainty in key model parameters chosen by the IWG such as the equilibrium climate sensitivity, as well as uncertainty in other parameters set by the original model developers. To highlight the difference between the impact of the discount rate and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-GHG estimates for each discount rate. There are other sources of uncertainty that have not yet been quantified and are thus not reflected in these estimates. When an agency determines that it is appropriate to conduct additional quantitative uncertainty analysis, it should follow best practices for probabilistic analysis.[4] The full set of information that underlies the frequency distributions in Figures ES-1 through ES-3 is available on OMB's website[5].

[4] See e.g. OMB's Circular A-4, section on *Treatment of Uncertainty*. Available at: https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf.

[5] Available at https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020[6]



[6] Although the distributions and numbers in Figures ES-1, ES-2, and ES-3 are based on the full set of model results (150,000 estimates for each discount rate and gas), for display purposes the horizontal axis is truncated with 0.02 to 0.68 percent of the estimates falling below the lowest bin displayed and 0.12 to 3.11 percent of the estimates falling above the highest bin displayed, depending on the discount rate and GHG.

Figure ES-2: Frequency Distribution of SC-CH_4 Estimates for 2020

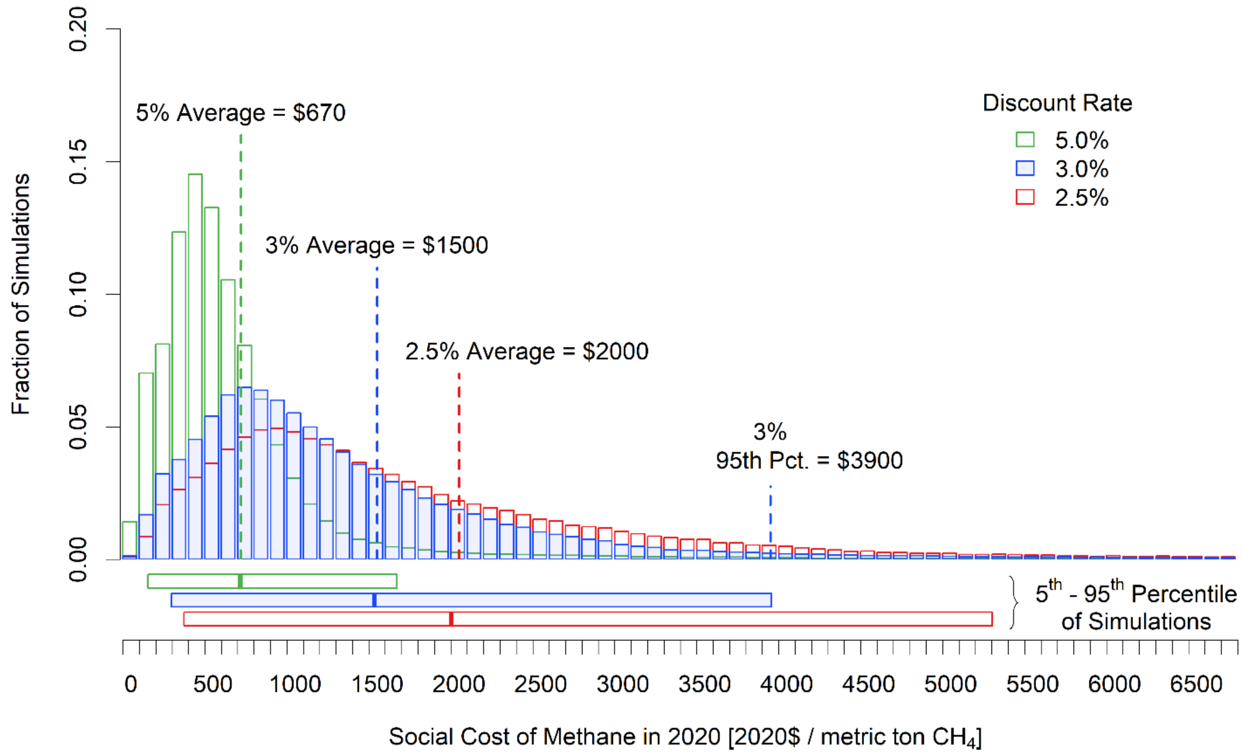
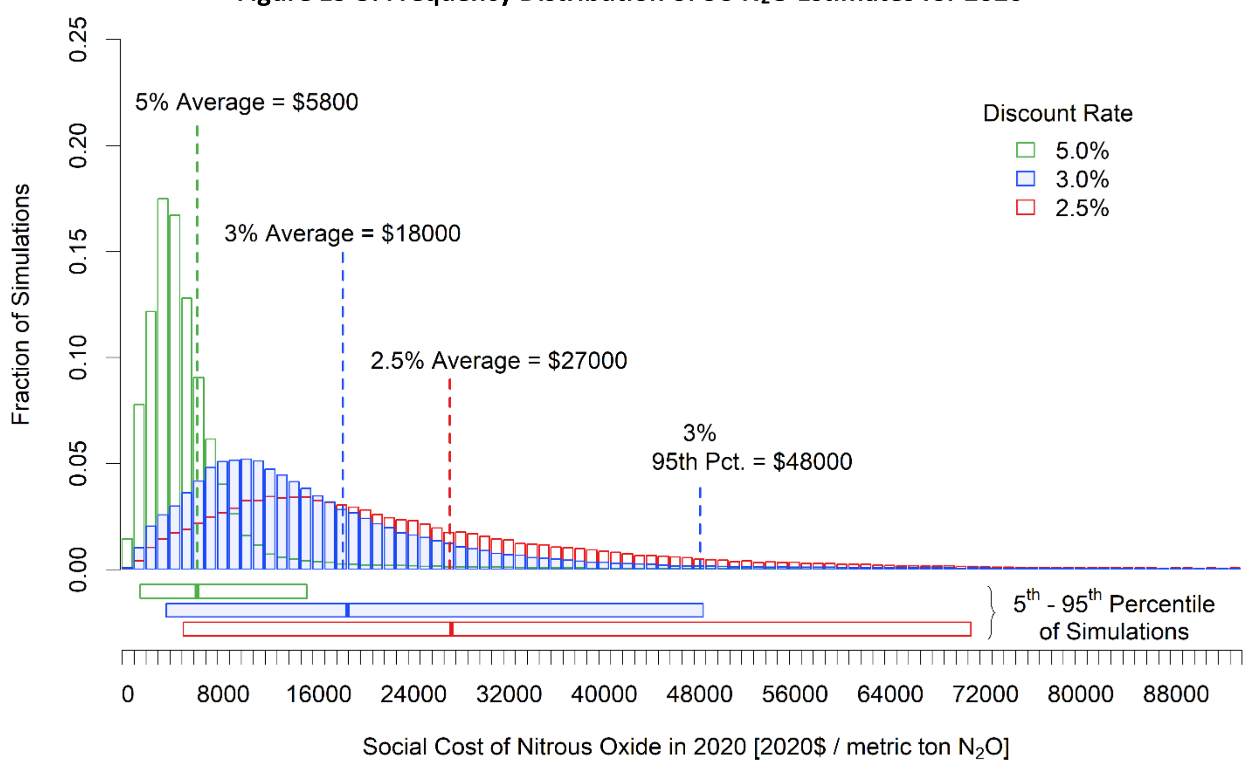


Figure ES-3: Frequency Distribution of SC-N_2O Estimates for 2020



1 Background

The estimates of the social cost of carbon (SC-CO_2), social cost of methane (SC-CH_4), and social cost of nitrous oxide (SC-N_2O) presented here allow agencies to incorporate the social benefits of reducing emissions of each of these greenhouse gases, or the social costs of increasing such emissions, in decision making. Collectively, these values are referenced as the "social cost of greenhouse gases" (SC-GHG) in this document. The SC-GHG is the monetary value of the net harm to society associated with adding a small amount of that GHG to the atmosphere in a given year. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, should reflect the societal value of reducing emissions of the gas in question by one ton. The marginal estimate of social costs will differ by the type of greenhouse gas (such as carbon dioxide, methane, and nitrous oxide) and by the year in which the emissions change occurs. The SC-GHGs are calculated along a baseline path and provide a measure of the marginal benefit of GHG abatement. Thus, they are the theoretically appropriate values to use when conducting benefit-cost analyses of policies that affect GHG emissions.[7]

1.1 Overview of U.S. Government SC-GHG Estimates to Date

Estimates of the social cost of carbon and other greenhouse gases have been published in the academic literature for many years. Meta-reviews of SC-CO_2 estimates were available as early as 2002 (Clarkson and Deyes 2002). Federal agencies began regularly incorporating SC-CO_2 estimates in regulatory impact analyses in 2008, following a court ruling in which an agency was ordered to consider the SC-CO_2 in the rulemaking process. The U.S. Ninth Circuit Court of Appeals remanded a fuel economy rule to the Department of Transportation (DOT) for failing to consider the value of reducing CO_2 emissions, stating that "while the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero."[8]

[7] These estimates of social damages should not be confused with estimates of the costs of attaining a specific emissions or warming limit. Specifically, there is another strand of research that investigates the costs of setting a specific climate target (e.g., capping emissions or temperature increases to a certain level). If total emissions are capped, IAM models can estimate the costs of limiting emissions or temperature increase to that cap. Similarly, other models simulate market trading in a cap and trade system. The price of a permit to emit one ton of carbon provides a measure of the marginal cost of GHG abatement, which can be useful in evaluating policy cost-effectiveness but is not an alternative way to value damages from GHG emissions in benefit-cost analysis. Moreover, a policy that specifies an environmental target implicitly requires a valuation of damages when setting the constraint even though it is not explicitly modeled or estimated. For example, a target set to keep temperature increases below a certain threshold implicitly places value on damages incurred beyond that threshold. For more on how these concepts (e.g., a predetermined target-based approach and a damage (SC-GHG) based approach) can be used when designing climate policy see, for example, Hansel et al. (2020) and Stern and Stiglitz (2021).

[8] *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1200 (9th Cir. 2008).

In 2009, an interagency process was launched, under the leadership of the Office of Management and Budget (OMB) and the Council of Economic Advisers (CEA), that sought to harmonize a range of different SC-CO_2 values being used across multiple Federal agencies. 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 in regulatory impact analyses. This included the establishment of an IWG which represented perspectives and technical expertise from many federal agencies and a commitment to following the peer-reviewed literature. In 2010, the IWG finalized a set of four SC-CO_2 values for use in regulatory analyses and presented them in a TSD that also provided guidance for agencies on using the estimates (IWG 2010). Three of these values were based on the average SC-CO_2 from three widely cited integrated assessment models (IAMs) in the peer-reviewed literature – DICE, PAGE, and FUND[9] – at discount rates of 2.5, 3, and 5 percent. The fourth value was included to represent higher-than-expected economic impacts from climate change further out in the tails of the SC-CO_2 distribution. For this purpose, it used the SC-CO_2 value for the 95th percentile at a 3 percent discount rate.

In May of 2013, the IWG provided an update of the SC-CO_2 estimates to incorporate new versions of the IAMs used in the peer-reviewed literature (IWG 2013). The 2013 update did not revisit other IWG modeling decisions (i.e., the discount rates or harmonized inputs for socioeconomic and emission scenarios and equilibrium climate sensitivity). Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.[10] In August of 2016, the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) that are consistent with the methodology underlying the SC-CO_2 estimates (IWG 2016a, 2016b).

Over the course of developing and updating the USG SC-GHG, through both the IWG and individual agencies, there were extensive opportunities for public input on the estimates and underlying methodologies. There was a public comment process associated with each proposed rulemaking that used the estimates, and OMB initiated a separate comment process on the IWG TSD in 2013. Commenters offered a wide range of perspectives on all aspects of process, methodology, and final estimates and diverse suggestions for improvements. The U.S. Government Accountability Office (GAO) also reviewed the development of the USG SC-CO_2 estimates and concluded that the IWG processes and methods reflected three principles: consensus-based decision making, reliance on existing academic literature and models, and disclosure of limitations and incorporation of new information (U.S. GAO 2014).

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[9] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy was widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

[10] The IWG subsequently provided additional minor technical revisions in November of 2013 and July of 2015, as explained in Appendix B of the 2016 TSD (IWG 2016a).

In 2015, as part of the IWG response to the public comments received in the 2013 solicitation, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the IWG estimates (IWG 2015). Specifically, the IWG asked the National Academies to conduct a multi-discipline, two-phase assessment of the IWG estimates and to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. The National Academies' interim (Phase 1) report (National Academies 2016a) recommended against a near term update of the SC-CO_2 estimates within the existing modeling framework. For future revisions, the National Academies recommended the IWG move efforts towards a broader update of the climate system module consistent with the most recent, best available science and offered recommendations for how to enhance the discussion and presentation of uncertainty in the SC-CO_2 estimates. In addition to publishing estimates of SC-CH_4 and SC-N_2O, the IWG's 2016 TSD revision responded to the National Academies' Phase 1 report recommendations regarding presentation of uncertainty. The revisions included: an expanded presentation of the SC-GHG estimates that highlights a symmetric range of uncertainty around estimates for each discount rate; new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty; detailed explanation of the uncertain parameters in both the FUND and PAGE models; and making the full set of SC-CO_2 estimates easily accessible to the public on OMB's website.

In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). A description of the National Academies' recommendations for near-term updates are described in Section 1.2 of this document. Shortly thereafter, in March 2017, President Trump issued Executive Order (E.O.) 13783 which called for the rescission and review of several climate-related Presidential and regulatory actions as well as for a review of the SC-GHG estimates used for regulatory impact analysis. E.O. 13783 disbanded the IWG, withdrew the previous TSDs, and directed agencies to ensure SC-GHG estimates used in regulatory analyses are consistent with the guidance contained in OMB's Circular A-4, "including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates" (E.O. 13783, Section 5(c)). Benefit-cost analyses following E.O. 13783 used SC-GHG estimates that attempted to focus on the domestic impacts of climate change as estimated by the models to occur within U.S. borders and were calculated using two discount rates recommended by OMB's Circular A-4, 3 percent and 7 percent.[11] All other methodological decisions and model versions used in SC-GHG calculations remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued E.O. 13990, which re-established the IWG and directed it to ensure that USG SC-GHG estimates reflect the best available science and the recommendations of the National Academies (2017). The IWG was tasked with first reviewing the SC-GHG estimates currently used by the USG and publishing interim estimates within 30 days of the E.O. that reflect the full impact of GHG emissions, including by taking global damages into account. The E.O. instructs the IWG to develop final SC-GHG estimates by January 2022. Section 1.3 describes requirements established by E.O. 13990 in greater detail. In addition, the E.O. instructs the IWG to provide recommendations to the President by

[11] OMB Circular A-4 (2003) indicates that sensitivity analysis using lower discount rates than 3 percent and 7 percent may be appropriate where intergenerational effects are important. See Section 3 for further discussion.

September 2021, regarding areas of decision-making, budgeting, and procurement by the Federal Government where the SC-GHG should be applied. The SC-GHG has been used previously in non-regulatory Federal analysis, such as in federal procurement,[12] grant programs,[13] and National Environmental Policy Act (NEPA) analysis,[14] as well as in state level applications; the latter is discussed further in Section 5.

1.2 Recommendations from the National Academies of Sciences, Engineering, and Medicine

In 2015, the IWG requested that the National Academies of Sciences, Engineering, and Medicine review and recommend potential approaches for improving its SC-CO_2 estimation methodology. In response, the National Academies convened a multidisciplinary committee, the Committee on Assessing Approaches to Updating the Social Cost of Carbon. In addition to evaluating the IWG's overall approach to SC-CO_2 estimation, the committee reviewed its choices of IAMs and damage functions, climate science assumptions, future baseline socioeconomic and emission projections, presentation of uncertainty, and discount rates.

In its final report (National Academies 2017), the National Academies committee recommended that the IWG pursue an integrated modular approach to the key components of SC-CO_2 estimation to allow for independent updating and review and to draw more readily on expertise from the wide range of scientific disciplines relevant to SC-CO_2 estimation. Under this approach, each step in SC-CO_2 estimation is developed as a module—socioeconomic projections, climate science, economic damages, and discounting—that reflects the state of scientific knowledge in the current, peer-reviewed literature. In the longer-term, it recommended that the IWG also fund research on ways to better capture interactions and feedbacks between these components. In addition, the committee noted that, while the IWG harmonized assumptions across the IAMs for socioeconomic and emission projections, climate sensitivity, and discount rates when estimating the SC-CO_2, using a single climate module in the nearer-term (2-3 years) and eventually transitioning to a single IAM framework will enhance transparency, improve consistency with the underlying science, and allow for more explicit representation of uncertainty. It recommended these three criteria also be used to judge the value of other updates to the methodology. In addition, it recommended that the IWG update SC-CO_2 estimates at regular intervals, suggesting a five-year cycle.

Regarding the key components of the SC-CO_2, the committee recommended the following improvements in the nearer-term:

- Socioeconomic and emissions projections: Use accepted statistical methods and elicit expert judgment to project probability distributions of future annual growth rates of per-capita GDP and

[12] For example, SC-CO_2 estimates have been used in Domestic Delivery Services contracts for USG parcel shipping (https://westcoastclimateforum.com/sites/westcoastclimateforum/files/related_documents/FedGSA_DDS3_green_features_fact_sheet.pdf).

[13] For example, in 2016 DOT's Transportation Investment Generating Economic Recovery (TIGER) discretionary grant program required a demonstration that benefits justify costs for proposed projects, and the guidance DOT provides to applicants for how to conduct such an analysis specified that they should use the USG SC-CO_2 estimates (https://www.transportation.gov/sites/dot.gov/files/docs/BCARG2016March.pdf).

[14] See Howard and Schwartz (2019) for examples of the use of SC-CO_2 estimates in NEPA analyses.

population, bearing in mind potential correlation between economic and population projections. Then using expert elicitation, guided by information on historical trends and emissions consistent with different climate outcomes, project emissions for each forcing agent of interest conditional on population and income scenarios. Additional recommendations were offered for improving the socioeconomic module centered on four broad criteria: time horizon, future policies, disaggregation, and feedbacks.

- Climate science: Adopt or develop a simple Earth system model (such as the Finite Amplitude Impulse Response (FaIR) model) to capture relationships between CO_2 emissions, atmospheric CO_2 concentrations, and global mean surface temperature change over time while accounting for non-CO_2 forcing and allowing for the evaluation of uncertainty. It also recommended the IWG adopt or develop a sea level rise component in the climate module that: (1) accounts for uncertainty in the translation of global mean temperature to global mean sea level rise and (2) is consistent with sea level rise projections available in the literature for similar forcing and temperature pathways. It also noted the importance of generating spatially and temporally disaggregated climate information as inputs into damage estimation. It recommended the use of linear pattern scaling (which estimates linear relationships between global mean temperature and local climate variables) to achieve this goal in the near-term.
- Economic damages: Improve and update existing formulations of individual sectoral damage functions when feasible; characterize damage function calibrations quantitatively and transparently; present spatially disaggregated damage projections and discuss how they scale with temperature, income, and population; and recognize any correlations between formulations when multiple damage functions are used.
- Discounting: Account for the relationship between economic growth and discounting; explicitly recognize uncertainty surrounding discount rates over long time horizons using a Ramsey-like approach; select parameters to implement this approach that are consistent with theory and evidence to produce certainty-equivalent discount rates consistent with near-term consumption rates of interest; use three sets of Ramsey parameters to generate a low, central, and high certainty-equivalent near-term discount rate, and three means and ranges of SC-CO_2 estimates; discuss how the SC-CO_2 estimates should be combined with other cost and benefit estimates that may use different discount rates in regulatory analysis.

Additional details on each of these recommendations as well as longer term research needs are provided in the National Academies' final report (National Academies 2017).

1.3 Executive Order 13990

On January 20, 2021, President Biden issued E.O. 13990, "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis." Echoing one of the general principles of E.O. 12866 that an Agency "shall base its decisions on the best reasonably obtainable scientific, technical, economic, and other information", E.O. 13990 states that it is essential for Agencies to account for the benefits of reducing GHG emissions as accurately as possible. It emphasizes that a full global accounting of the costs of GHG emissions "facilitates sound decision-making, recognizes the breadth of climate impacts, and supports the international leadership of the United States on climate issues" (E.O. 13990 2021). Specifically, E.O. 13990 reinstates the IWG as the Interagency Working Group on the Social Cost of Greenhouse Gases, names the Chair of the CEA, Director of OMB, and Director of the Office of Science and Technology Policy (OSTP) as co-chairs of the IWG, and specifies the membership of the IWG to include the following officials, or their designees: the Secretary of the Treasury; the Secretary of the Interior; the Secretary of Agriculture; the Secretary of Commerce; the Secretary of Health and Human Services; the Secretary of Transportation; the Secretary of Energy; the Chair of the Council on Environmental Quality; the Administrator of the Environmental Protection Agency; the Assistant to the President and National Climate Advisor; and the Assistant to the President for Economic Policy and Director of the National Economic Council.

E.O. 13990 tasks the reinstated IWG with the following:

(1) publish an interim update to the SC-GHG (SC-CO_2, SC-CH_4, and SC-N_2O) estimates by February 19, 2021, for agencies to use when monetizing the value of changes in greenhouse gas emissions resulting from regulations and other relevant agency actions until final values are published;

(2) publish a final update to the SC-GHG estimates by no later than January 2022;

(3) provide recommendations, by no later than September 1, 2021, regarding areas of decision-making, budgeting, and procurement by the Federal Government where the SC-GHG estimates should be applied;

(4) provide recommendations, by no later than June 1, 2022, regarding a process for reviewing and, as appropriate, updating the SC-GHG estimates to ensure that these estimates are based on the best available economics and science; and

(5) provide recommendations, to be published with the interim SC-GHG estimates if feasible and by no later than June 1, 2022, to revise methodologies for SC-GHG calculations to the extent that current methodologies do not adequately take account of climate risk, environmental justice, and intergenerational equity.

Finally, the E.O. specifies that in carrying out its activities, the IWG shall consider the recommendations of the National Academies (2017) and other pertinent scientific literature; solicit public comment; engage with the public and stakeholders; seek the advice of ethics experts; and ensure that the SC-GHG estimates reflect the interests of future generations in avoiding threats posed by climate change.

This TSD presents the interim SC-GHG estimates called for in the first of these tasks. It also provides preliminary discussion of how at least one component of SC-GHG estimation, discounting, warrants reconsideration in the more comprehensive update by January 2022 to reflect the advice of the National Academies (2017) and other recent scientific literature.

2 The Importance of Accounting for Global Damages

Benefit-cost analyses of U.S. Federal regulations have traditionally focused on the benefits and costs that accrue to individuals that reside within the country's national boundaries. This is a natural result of the fact that most regulations have a limited impact on individuals residing outside of the United States and do not reflect any other scientific, legal, or other rationale. According to OMB's Circular A-4 (2003), an "analysis should focus on benefits and costs that accrue to citizens and residents of the United States."[15] While Circular A-4 does not elaborate, this guidance towards a focus on U.S. populations in domestic policy analysis is broadly consistent with the fact that the authority to regulate only extends to a nation's own residents who have consented to adhere to the same set of rules and values for collective decision-making (EPA 2010; Kopp et al. 1997; Whittington and MacRae 1986). However, guidance towards a focus on impacts to U.S. citizens and residents is different than recommending that analysis be limited to the impacts that occur within the borders of the U.S. Furthermore, OMB Circular A-4 states that when a regulation is likely to have international effects that "these effects should be reported" though the guidance recommends this be done separately. There are many reasons, as summarized in this TSD, why it is appropriate for agencies to use the global value of damages in making decisions that affect, or may be affected by, GHG emissions. Courts have upheld the use of global damages in estimating the social cost of GHGs, in part in recognition of the diverse ways in which U.S. interests, businesses, and residents may be impacted by climate change beyond U.S. borders.[16]

Unlike many environmental problems where the causes and impacts are distributed more locally, climate change is a true global challenge making GHG emissions a global externality. GHG emissions contribute to damages around the world regardless of where they are emitted. The global nature of GHGs means that U.S. interests, and therefore the benefits to the U.S. population of GHG mitigation, cannot be defined solely by the climate impacts that occur within U.S. borders. Impacts that occur outside U.S. borders as a result of U.S. actions can directly and indirectly affect the welfare of U.S. citizens and residents through a multitude of pathways. Over 9 million U.S. citizens lived abroad as of 2016[17] and U.S. direct investment positions abroad totaled nearly $6 trillion in 2019.[18] Climate impacts occurring outside of U.S. borders will have a direct impact on these U.S. citizens and the investment returns on those assets owned by U.S. citizens and residents. The U.S. economy is also inextricably linked to the rest of the world. The U.S. exports over $2 trillion worth of goods and services a year and imports around $3 trillion.[19] Climate impacts that occur outside U.S. borders can thus impact the welfare of individuals and firms that reside in the United States through their effect on international markets, trade, tourism, and other activities. Furthermore, additional spillovers can occur through pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns (DoD 2014, CCS 2018). As described by the National Academies (2017), to correctly assess the total damages to U.S. citizens and residents, one must account for these spillover effects on the United States.

As an empirical matter, the development of a domestic SC-GHG is greatly complicated by the relatively few region- or country-specific estimates of the SC-CO_2 in the literature. At present, the only quantitative

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[15] OMB's Circular A-4 provides guidance to Federal agencies on the development of regulatory analysis conducted pursuant to Executive Order 12866.

[16] *Zero Zone, Inc. v. Dep't of Energy*, 832 F.3d 654, 678-79 (7th Cir. 2016) (rejecting a petitioner's challenge to DOE's use of a global (rather than domestic) social cost of carbon in setting an efficiency standard under the Energy Policy and Conservation Act, holding that DOE had reasonably identified carbon pollution as "a global externality" and concluding that, because "national energy conservation has global effects, . . . those global effects are an appropriate consideration when looking at a national policy.").

[17] U.S. Department of State's Bureau of Consular Affairs.

[18] BEA Direct Investment by Country and Industry 2019, https://www.bea.gov/data/intl-trade-investment/direct-investment-country-and-industry

[19] BEA National Income and Product Accounts Table 1.1.5.

characterization of domestic damages from GHG emissions, as represented by the domestic SC-GHG, is based on the share of damages arising from climate impacts occurring within U.S. borders as represented in current IAMs. This is both incomplete and an underestimate of the share of total damages that accrue to the citizens and residents of the U.S. because these models do not capture the regional interactions and spillovers discussed above. A 2020 U.S. GAO study observed that "[a]ccording to the National Academies, the integrated assessment models were not premised or calibrated to provide estimates of the social cost of carbon based on domestic damages, and more research would be required to update the models to do so. The National Academies stated it is important to consider what constitutes a domestic impact in the case of a global pollutant that could have international implications that affect the United States" (U.S. GAO 2020).

The global nature of GHGs means that damages caused by a ton of emissions in the U.S. are felt globally and that a ton emitted in any other country harms those in the U.S. Therefore, assessing the benefits of U.S. GHG mitigation activities will require consideration of how those actions may affect mitigation activities by other countries since those international actions will provide a benefit to U.S. citizens and residents. A wide range of scientific and economic experts have emphasized the issue of reciprocity as support for considering global damages of GHG emissions (e.g., Kopp and Mignone 2013, Pizer et al. 2014, Howard and Schwartz 2019, Pindyck 2017, Revesz et al. 2017, Carleton and Greenstone 2021). Carleton and Greenstone (2021) discuss examples of how historic use of a global SC-CO_2 may have plausibly contributed to additional international action. Houser and Larson (2021) estimate that under the Paris Agreement, other countries pledged to reduce 6.1 to 6.8 tons for every ton pledged by the U.S. Kotchen (2018) offers a theoretical perspective showing that non-Nash game theoretic behavior can lead countries to optimally chose a social cost of carbon higher than their domestic value to encourage additional reductions from other countries. Using a global estimate of damages in U.S. analyses of regulatory and other actions allows the U.S. to continue to actively encourage other nations, including emerging major economies, to take significant steps to reduce emissions.

The IWG found previously and is restating here that because of the distinctive global nature of climate change that analysis of Federal regulatory and other actions should center on a global measure of SC-GHG. This approach is the same as that taken in regulatory analyses over 2009 through 2016. In the 2015 response to comments, the IWG noted 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 (IWG 2015). Therefore, the IWG continues to recommend the use of global SC-GHG estimates in analysis of Federal regulatory and other actions. The IWG also continues to review developments in the literature, including more robust methodologies for estimating SC-GHG 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.

3 Discounting in Intergenerational Analyses

GHG emissions are stock pollutants, where damages are associated with what has accumulated in the atmosphere over time, and they are long lived such that subsequent damages resulting from emissions today occur over many decades or centuries depending on the specific greenhouse gas under consideration.[20] In calculating the SC-GHG, the stream of future damages to agriculture, human health, and other market and non-market sectors from an additional unit of emissions are estimated in terms of reduced consumption (or consumption equivalents). Then that stream of future damages is discounted to its present value in the year when the additional unit of emissions was released. Given the long time horizon over which the damages are expected to occur, the discount rate has a large influence on the present value of future damages. However, the choice of a discount rate also raises highly contested and exceedingly difficult questions of science, economics, ethics, and law.

In 2010, in light of disagreements in the literature on the appropriate discount rate to use in this context, and uncertainty about how rates may change over time, the IWG elected to use three discount rates to span a plausible range of certainty-equivalent constant consumption discount rates: 2.5, 3, and 5 percent per year. The IWG at that time determined that these three rates reflected reasonable judgments under both descriptive and prescriptive approaches to selecting the discount rate.

The 3 percent value was included as consistent with estimates provided in OMB's Circular A-4 (OMB 2003) guidance for the consumption rate of interest. The IWG found that the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units as is done in the IAMs used to estimate the SC-GHG (National Academies 2017). The upper value of 5 percent was included to represent the possibility that climate-related damages are positively correlated with market returns, which would imply a certainty equivalent value higher than the consumption rate of interest. The low value, 2.5 percent, was included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach. Without giving preference to a particular model, the average of the two rates is 2.5 percent. Additionally, a rate below the consumption rate of interest would also be justified if the return to investments in climate mitigation are negatively correlated with the overall market rate of return. Use of this lower value was also deemed responsive to certain judgments based on the prescriptive or normative approach for selecting a discount rate and to related ethical objections that have been raised about rates of 3 percent or higher. Further details about the process for selecting these rates is presented in the 2010 TSD (IWG 2010). Finally, it is important to note that, while the consumption discount rate is the conceptually correct rate for discounting the SC-GHG, and the three rates originally selected were based on this concept, the latest data as well as recent discussion in the economics literature indicates that the 3 percent discount rate used by the IWG to develop its range of discount rates is likely an overestimate of the appropriate discount rate and warrants reconsideration in future updates of the SC-GHG.

This section discusses three issues related to the selected discount rates: (1) why the social rate of return to capital, estimated to be 7 percent in OMB's Circular A-4, is not appropriate for use in calculating the SC-GHG, (2) new evidence on the consumption rate of interest, which may inform the future updates to the SC-GHG, and (3) analytic consistency across discounting within an analysis.

[20] "GHGs, for example, CO_2, methane, and nitrous oxide, are chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so that their emission has a long-term influence on climate. Because these gases are long lived, they become well mixed throughout the atmosphere" (IPCC 2007).

3.1 Social Rate of Return on Capital and Intergenerational Analyses

When analyzing policies and programs that result in GHG emission reductions, it is important to account for the difference between the social and private rate of return on any capital investment affected by the action. Society is not indifferent between a regulation that displaces consumption versus investment in equal amounts. Market distortions, in large part taxes on capital income, cause private returns on capital investments to be different from the social returns. In well-functioning capital markets, arbitrage opportunities will be dissipated, and the cost of investments will equal the present value of future private returns on those investments. Therefore, an individual forgoing consumption or investment of equal amounts as the result of a regulation will face an equal private burden. However, because the social rate of return on the investment is greater than the private rate of return, the overall social burden will be greater in the case where investment is displaced.

OMB's Circular A-4 points out that "the analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption and to discount them at the rate consumers and savers would normally use in discounting future consumption benefits" (OMB 2003). The damage estimates developed for use in the SC-GHG are estimated in consumption-equivalent terms. An application of OMB Circular A-4's guidance for regulatory analysis would then use the consumption discount rate to calculate the SC-GHG, while also developing a more complete estimate of social cost to account for the difference in private and social rates of return on capital for any investment displaced as a result of the regulation. This more complete estimate of social costs can be developed using either the shadow price of capital approach or by estimating costs in a general equilibrium framework, for example by using a computable general equilibrium model. In both cases, displaced investment would be converted into a flow of consumption equivalents.

In cases where the costs are not adjusted to be in consumption-equivalent terms, OMB's Circular A-4 recommends that analysts provide a range of estimates for net benefits based on two approaches. The first approach is based on using the consumption rate of interest to discount all costs and benefits. This approach is consistent with the case where costs are primarily borne as reduced consumption. The second approach, the social opportunity cost of capital (SOC) approach, focuses on the case where the main effect of a regulation is to displace or alter the use of capital in the private sector (OMB 2003). When interpreting the SOC approach from the point of view of whether to invest in a single government project, it is asking whether the benefits from the project would at least match the returns from investing the same resources in the private sector. Interpreting the approach from the standpoint of a benefit-cost analysis of regulation, the approach focuses on adjusting estimates of benefits downward by discounting at a higher rate to offset additional social costs not reflected in the private value of displaced investment.

Harberger (1972) derived a more general version of the social opportunity cost of capital approach, recognizing that policies will most likely displace a mix of consumption and investment and therefore a blended discount rate would be needed to adjust the benefits to account for the omitted costs. In his partial equilibrium approach, the blended discount rate is a weighted average of the consumption interest rate and social rate of return on capital, where the weights are the share of a policy's costs borne by consumption versus investment. This general result has been extended to the general equilibrium context by Sandmo and Drèze (1971) and Drèze (1974) and can be extended to account for changes in foreign direct investment (CEA 2017). This highlights that using the social rate of return for benefits and costs is at best creating a lower bound on the estimate of net benefits that would only be met in an extreme case where regulatory costs fully displace investment. If the beneficial impacts of the regulation induce private investment whose social returns have not been quantified and fully converted to consumption equivalents, then the net benefits calculated using the social rate of return on capital is not even a lower bound.[21] Li and Pizer (2021) further generalize the SOC framework and demonstrate that temporal pattern of benefits is important and that when benefits occur far in the future discounting using the social rate of return on capital again is not even a lower bound on net benefits.

For regulations whose benefits and costs occur over a relatively short time frame, the range of net benefits computed using the two discounting approaches will be relatively narrow. Therefore, there is less risk in maintaining an uninformed prior over the share of regulatory costs that will displace investment and using the potential bounding cases for net benefits. However, for cases where the costs are borne early in the time horizon and benefits occur for decades or even centuries, such as with GHG mitigation, the two estimates of net benefits will differ significantly. In this case, the risk to society of maintaining an uninformed prior over the share of regulatory costs borne by investment is significantly higher. In turn, the preferred approach is to discount benefits using the consumption rate of interest and strive to provide a more complete measure of costs, accounting for displacement of investment whose social rate of return exceeds the private rate of return, either by using a shadow price of capital approach or a general equilibrium framework, like a computable general equilibrium model.

It is important to note that even if an appropriately specified blended SOC rate could be calculated based on the share of regulatory costs that are expected to displace investment that would not obviate the need to carefully consider issues of uncertainty and ethics when discounting in an intergenerational context, pointing to a lower rate.

For these reasons, the IWG is returning to the approach of calculating the SC-GHG based on the consumption rate of interest, consistent with the findings of the National Academies (2017) [22].

3.2 New Evidence on the Consumption Discount Rate

The three discount rates selected by the IWG in 2010 are centered around the 3 percent estimate of the consumption interest rate published in OMB's Circular A-4 in 2003. That guidance was based on the real rate of return on 10-year Treasury Securities from the prior 30 years (1973 through 2002), which averaged 3.1 percent. Over the past four decades there has been a substantial and persistent decline in real interest rates (see Figure 1). Recent research has found that this decline has been driven by decreases in the equilibrium real interest rate (Bauer and Rudebusch 2020).

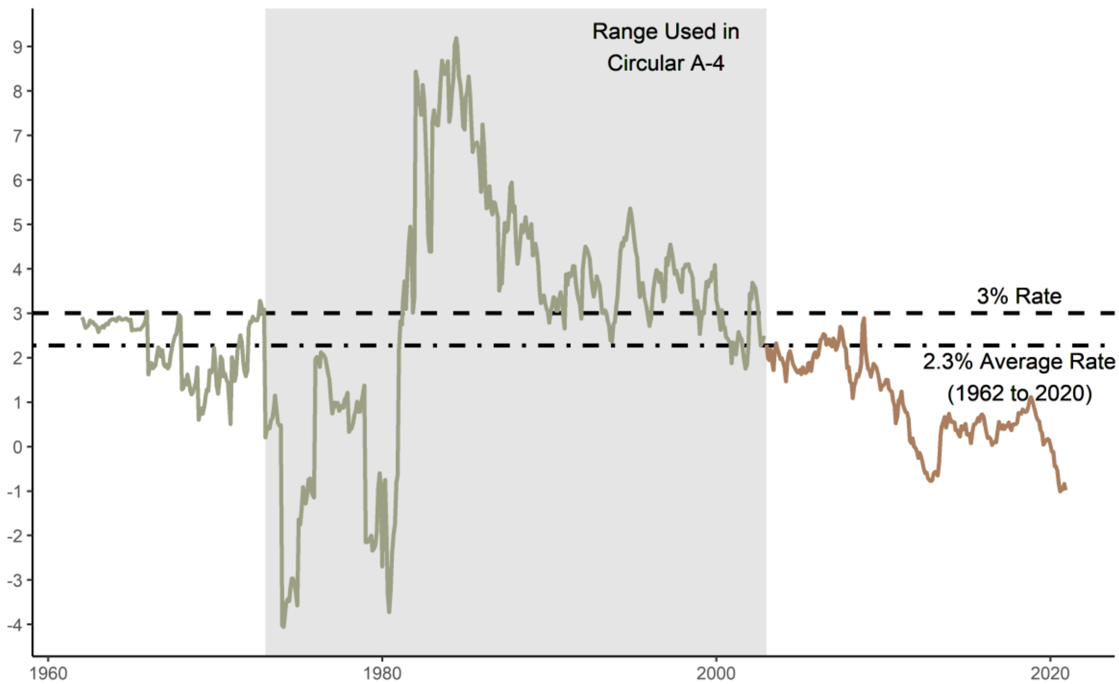
Re-estimating the consumption rate of interest following the same approach applied in Circular A-4, including using data from the most recent 30 years, yields a substantially lower result. The average rate

[21] The SOC approach as outlined in OMB's Circular A-4 is most applicable to cases where the benefits are represented as consumption equivalents and costs may not be. If the benefits of the policy include the inducement of new private investment, discounting both benefits and costs at the social rate of return for capital is no longer appropriate. The results of Bradford (1975) show that in a case where regulatory costs are primarily borne through reduced consumption and the beneficial impacts of the policy may induce private investment the appropriate rate under the SOC approach could be below the consumption interest rate.

[22] NAS (2017) stated "The estimates that result from the SC-IAMs are measured in consumption- equivalent units: thus, a discount rate that reflects how individuals trade off current and future consumption is defensible in this setting" (p. 236-7).

of return on inflation adjusted 10-year Treasury Securities over the last 30 years (1991-2020) is 2.0 percent. These rates are not without historic precedent, such that over the last 60 years the inflation adjusted 10-year Treasury Securities is 2.3 percent. Current real rates of returns below 2 percent are expected to persist. The U.S. Congressional Budget Office (CBO) in its September 2020 Long Term Budget Outlook forecasts real rates of return on 10-Year Treasury Securities to average 1.2 percent over the next 30 years (U.S. CBO 2020). This new information suggests that the consumption rate of interest is notably lower than 3 percent. CEA (2017) examined additional forecasts of 10-Year Treasury Securities and data on futures contracts, reaching the conclusion that the appropriate consumption discount rate should be at most 2 percent.

Figure 1: Monthly 10-Year Treasury Security Rates, Inflation-Adjusted[23]



Several surveys have been conducted in recent years to elicit experts' views on the appropriate discount rates to use in an intergenerational context (e.g., Drupp et al. 2018; Howard and Sylvan 2020). For example, Drupp et al. (2018) offers confirming evidence that the economics profession generally agrees that the appropriate social discount rate is below 3 percent as reflected in the recent trends in data. They surveyed over 200 experts and found a "surprising degree of consensus among experts, with more than three-quarters finding the median risk-free social discount rate of 2 percent acceptable" (Drupp et al. 2018).[24]

[23] Monthly 10-Year Treasury Security returns, adjusted for inflation. Real interest rates prior to 2003 (green line) are calculated by subtracting the annual rate of inflation as measured by the CPI-U from the nominal rate of return on 10-Year constant maturity Treasury Securities. Interest rates from 2003 onwards (brown line) are based on the 10-Year Treasury Inflation-Protected Securities.

[24] For a detailed explanation of discounting concepts and terminology see EPA's *Guidelines for Preparing Economic Analysis* (2010). https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses

It is important to note that the new information pointing to a lower consumption rate of interest, lower than 3 percent, does not obviate the need to carefully consider issues of uncertainty and ethics when discounting in an intergenerational context.[25] If 2 percent was used as the consumption interest rate and adjusted for uncertainty using the results of Newell and Pizer (2003) as was done in the 2010 TSD, the process would yield a discount rate lower than 2 percent. Therefore, a consideration of discount rates below 3 percent, including 2 percent and lower, are warranted when discounting intergenerational impacts.

This is consistent with the 2003 recommendation in OMB's Circular A-4 that noted "[a]lthough 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" and found that certainty equivalent discount rates as low as 1 percent could be appropriate for intergenerational problems (OMB 2003). Similarly, if implementing a declining discount rate schedule to account for uncertainty (see next section), an updated consumption rate of interest, based on additional data presented above, may be a starting point for an update.

In light of the evidence and discussion on discount rates presented in this TSD and elsewhere, the recommendation from OMB's Circular A-4 to include further sensitivity analysis with lower discount rates when a rule has important intergenerational benefits or costs, and the direction to the IWG in E.O. 13990 to ensure that the SC-GHG reflect the interest of future generations, the IWG finds it appropriate as an interim recommendation that agencies may consider conducting additional sensitivity analysis using discount rates below 2.5%.

3.3 Analytic Consistency and Declining Discount Rates

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time, as may be observed in Figure 1. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2005) confirmed empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. This is because lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2005; Gollier 2009; Summers and Zeckhauser 2008; Gollier and Weitzman 2010; Arrow et al. 2013; Cropper et al. 2014; and Arrow et al. 2014).

The proper way to specify a declining discount rate schedule remains an active area of research. One approach is to develop a stochastic model of interest rates that is empirically estimated and used to calculate the certainty equivalent declining discount rate schedule (e.g., Newell and Pizer 2003; Groom et al. 2007). An alternative approach is to use the Ramsey equation based on a forecast of consumption growth rates that accounts for uncertainty (e.g., Cropper et al. 2014; Arrow et al. 2013). If the shocks to consumption growth are positively correlated over time then the result of the Ramsey equation will be a certainty-equivalent discount rate schedule that declines over time (Goiller 2014). Others have argued for a less structural approach to specify a declining discount rate schedule (e.g., Weitzman 2001, the United

[25] For a more detailed explanation of ethical and uncertainty considerations around discounting see National Academies (2017) and the 2010 TSD (IWG 2010).

Kingdom's "Green Book" for regulatory analysis (HM Treasury 2020), the declining discount schedule in France (Lebègue 2005) and varying the discount rate based on the time period in Germany (Schwermer 2012, U.S. GAO 2020)). This approach uses a higher discount rate initially, like the current estimate of the consumption interest rate, but applies a graduated scale of lower discount rates further out in time.[26]

Instead of explicitly specifying a declining discount rate schedule, the IWG in 2010 elected to use a constant but lower discount rate to capture the directional effect of the literature on discounting under uncertainty. Specifically, the IWG considered two declining discount rate schedules based on the mean-reverting and random walk models from Newell and Pizer (2003) starting at a discount rate of 3 percent. The 2.5 percent discount rate selected by the IWG in 2010 reflected the midpoint between the average certainty equivalent discount rates of both models. The approach of using a lower, but constant, discount rate to capture the effect of uncertainty has led to inconsistency in regulatory analyses, where impacts occurring in a given year are discounted at different rates depending on whether they are related to climate change (Arrow et al. 2014). The National Academies (2017) and EPA's Science Advisory Board (2021) have recommended that the U.S. Government establish an explicit declining discount rate schedule that is applied to all regulatory impacts in an analysis to capture the effect of uncertainty on long-term discount rates, while also maintaining consistency across impact categories in the analysis. The IWG will consider the literature on declining discount rates and the recommendations of the National Academies (2017) and EPA's Science Advisory Board (2021) as it develops future updates to the SC-GHG. In the interim, the IWG is returning to the use of the 2.5, 3, and 5 percent discount rates in calculating the SC-GHG but recommends that agencies describe potential limitations in their analyses to ensure transparency. As noted above, agencies may also consider discount rates below 2.5 percent as part of a sensitivity analysis.

4 Interim Estimates of SC-CO_2, SC-CH_4, SC-N_2O

The interim SC-GHG estimates presented in this TSD rely on the same models and harmonized inputs for the socioeconomic emissions scenarios and equilibrium climate sensitivity distribution used for USG SC-GHG estimates since 2013. Specifically, the SC-GHG estimates rely on an ensemble of three IAMs: Dynamic Integrated Climate and Economy (DICE) 2010 (Nordhaus 2010); Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) 3.8 (Anthoff and Tol 2013a, 2013b); and Policy Analysis of the Greenhouse Gas Effect (PAGE) 2009 (Hope 2013). IAMs are useful because they combine climate processes, economic growth, and feedback between the climate and the global economy into a single modeling framework. They gain this advantage at the expense of a more detailed representation of underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches and have been widely used in the economic and scientific literature since the 1990s. They are periodically updated by the model developers, but as discussed further in Section 5, the versions of the three models used in the 2013 and 2016 TSDs do not reflect the tremendous increase in the scientific and economic understanding of climate-related damages that has occurred in the past decade. The three IAMs

[26] For instance, the United Kingdom applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

were run using a common set of assumptions in each model for future population, economic, and GHG emissions growth, as well as equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. The socioeconomic and emission projections included five reference scenarios based on the Stanford Energy Modeling Forum EMF-22 modeling exercise (Clarke, et al. 2009; Fawcett, et al. 2009). The models were run using a probability distribution for ECS, calibrated to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report findings using the Roe and Baker (2007) distribution. Details on these versions of the IAMs and the harmonized inputs are presented in the 2016 TSD and Addendum and 2010 TSD. (IWG 2010, 2016a, 2016b). The 2016 Addendum also describes the methodology used to calculate the SC-CH_4 and SC-N_2O estimates in greater detail.[27] Finally, for the reasons set forth in Section 3 above, the interim estimates were based on three constant discount rates of 2.5, 3, and 5 percent.

The combination of three models and five scenarios produced 15 separate frequency distributions of SC-GHG estimates for each discount rate in a given year, with each distribution consisting of 10,000 estimates based on draws from the standardized ECS distribution (as well as distributions of parameters treated as uncertain in two of the models (FUND and PAGE)). For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then selected a set of four values for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5%, 3%, and 5%), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change, conditional on the 3% estimate of the discount rate. For this purpose, the SC-GHG value for the 95th percentile at a 3 percent discount rate was presented.[28] For the purposes of capturing the uncertainties involved in analyses, the IWG emphasized previously and emphasizes in this TSD the importance and value of including all four SC-GHG values. In particular, values based on lower discount rates are consistent with the latest scientific and economic understanding of discounting approaches relevant for intergenerational analysis (described in Section 3).

Tables 1-3 show the four selected values for SC-CO_2, SC-CH_4, and SC-N_2O, respectively, in five-year increments from 2020 to 2050. These estimates are reported in 2020 dollars but are otherwise identical to those presented in the previous version of the TSD and its Addendum, released in August 2016.[29] The

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[27] The IWG calculated the SC-CH_4 and SC-N_2O estimates following the approach used in Marten et al. (2015). In order to develop SC-CH_4 and SC-N_2O estimates consistent with the methodology underlying the SC-CO_2 estimates, Marten et al. (2015) needed to augment the IWG modeling framework in two respects: (1) augment the climate model of two of the IAMs to explicitly consider the path of additional radiative forcing from a CH_4 or N_2O perturbation, and (2) add more specificity to the assumptions regarding post-2100 baseline CH_4 and N_2O emissions. See IWG (2016b) for more discussion of these two modeling modifications and the peer review and public comment processes accompanying their development.

[28] A detailed set of percentiles by model and scenario combination and additional summary statistics for the 2020 values is available in the 2016 TSD and Addendum (IWG 2016a, 2016b).

[29] The values in Tables 1-3 are the same as those reported in the 2016 TSD and Addendum adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in U.S. Bureau of Economic Analysis (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). Values of SC-CO_2 presented in this TSD are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs.

full set of annual SC-GHG values between 2020 and 2050, calculated using linear interpolation between the numbers shown in Tables 1-3, is reported in the Appendix and the full set of model results are available on the OMB website.[30] The SC-GHG estimates increase over time within the models – i.e., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2025 – because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP.

Table 1: Social Cost of CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)[31]

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Table 2: Social Cost of CH_4, 2020 – 2050 (in 2020 dollars per metric ton of CH_4)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	670	1500	2000	3900
2025	800	1700	2200	4500
2030	940	2000	2500	5200
2035	1100	2200	2800	6000
2040	1300	2500	3100	6700
2045	1500	2800	3500	7500
2050	1700	3100	3800	8200

[30] https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs

[31] The values reported in this TSD are identical to those reported in the 2016 TSD adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). The IWG combined the distributions across models and socioeconomic emissions scenarios for each of three discount rates (2.5%, 3%, and 5%), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. Values of SC-CO_2 are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs.

Table 3: Social Cost of N_2O, 2020 – 2050 (in 2020 dollars per metric ton of N_2O)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	5800	18000	27000	48000
2025	6800	21000	30000	54000
2030	7800	23000	33000	60000
2035	9000	25000	36000	67000
2040	10000	28000	39000	74000
2045	12000	30000	42000	81000
2050	13000	33000	45000	88000

Multiplying the SC-GHG in year *t* by the change in emissions in year *t* yields the monetized value of future emission changes from a year *t* perspective. This value must then be discounted to the present before being included in an analysis. For this purpose, the monetized value of future emission changes should be discounted at the same rate used to calculate the initial SC-GHG to ensure internal consistency—i.e., future damages from climate change using the SC-GHG at 2.5 percent should be discounted to the base year of the analysis using the same 2.5 percent rate.

As noted above, to correctly assess the total climate damages to U.S. citizens and residents, an analysis must account for both the impacts that occur within U.S. borders and spillover effects from climate action elsewhere. For the reasons discussed in Section 2 above, estimates focusing on the climate impacts occurring within U.S. borders are an underestimate of the benefits of GHG mitigation accruing to U.S. citizens and residents and, therefore, are not equivalent to a domestic estimate of the SC-GHG. (Section 2 also discusses why analyses should center their attention on a global measure of the SC-GHG). Additionally, models differ in their treatment of regional damages[32] with one of the model developers recently noting that regional damages are "both incomplete and poorly understood" (Nordhaus 2017). The IWG further notes that the domestic focused SC-GHG estimates used under E.O. 13783[33] did not

[32] Both the PAGE and FUND model contain a U.S. region and so the damages for this region are reported directly for those models. The DICE 2010 model does not explicitly include a separate U.S. region in the model. For the domestic focused SC-GHG estimates used under E.O. 13783, the DICE model damages occurring within U.S. borders were approximated as 10 percent of the global estimate from the DICE model runs, based on the results from a regionalized version of the model (RICE 2010) reported in Table 2 of Nordhaus (2017). Although the regional shares reported in Nordhaus (2017) are specific to SC-CO_2, they were also used in approximating the share of marginal damages from CH_4 and N_2O emissions occurring within U.S. borders. Direct transfer of the U.S. share from the SC-CO_2 likely understate the U.S. share of the IWG global SC-CH_4 estimates based on DICE due to the combination of three factors: a) regional damage estimates are known to be highly correlated with output shares (Nordhaus 2017, 2014), b) the U.S. share of global output decreases over time in all five EMF-22 based socioeconomic scenarios used for the model runs, and c) the bulk of the temperature anomaly (and hence, resulting damages) from a perturbation in emissions in a given year will be experienced earlier for CH_4 than CO_2 due to the shorter lifetime of CH_4 relative to CO_2.

[33] For emissions occurring in 2020, the average estimates of marginal damages occurring within the U.S. borders for CO_2, CH_4, and N_2O emissions across all model runs that were used in 2017-2020 regulatory analyses were \$7/mtCO_2,

benefit from a consensus-based IWG process, were not documented in a dedicated TSD, subjected to a SC-GHG specific notice and comment period, or considered by National Academies in their 2017 review. The IWG will request public comments on the new information presented in this TSD, as well as other topics and issues the IWG will address as we develop the next set of updates (see Section 6).

4.1 Treatment of Uncertainty

Uncertainty about the value of the SC-GHGs is in part inherent, as with any analysis that looks into the future, but it is also driven by current data gaps associated with the complex physical, economic, and behavioral processes that link GHG emissions to human health and well-being. Some sources of uncertainty pertain to aspects of the natural world, such as quantifying the physical effects of greenhouse gas emissions on Earth systems. Other sources of uncertainty are associated with current and future human behavior and well-being, such as population and economic growth, GHG emissions, the translation of Earth system changes to economic damages, and the potential extent and costs of adaptation. It is important to note that even in the presence of uncertainty, scientific and economic analysis can provide valuable information to the public and decision makers. Such uncertainty should, however, be acknowledged, communicated as clearly as possible, and taken into account in the analysis whenever possible.

The 2016 TSD and the 2017 National Academies report provide detailed discussions of the ways in which the modeling underlying the development of the SC-GHG estimates addressed quantified sources of uncertainty.

In developing the SC-CO_2 estimates, the IWG considered various sources of uncertainty through a combination of a multi-model ensemble, probabilistic analysis, and scenario analysis. For example, the three IAMs used collectively span a wide range of Earth system and economic outcomes to help reflect the uncertainty in the literature and in the underlying dynamics being modeled. The use of an ensemble of three different models is also intended to, at least partially, address the fact that no single model includes all of the quantified economic damages. It also helps to reflect structural uncertainty across the models, which is uncertainty in the underlying relationships between GHG emissions, Earth systems, and economic damages that are included in the models. Bearing in mind the different limitations of each model (discussed in the 2010 TSD) and lacking an objective basis upon which to differentially weight the models, the three IAMs were given equal weight in the analysis.

The IWG used Monte Carlo techniques to run the IAMs a large number of times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions. In all three models the equilibrium climate sensitivity is treated probabilistically based on the probability distribution described in the 2010 TSD. The equilibrium climate sensitivity is a key parameter in this

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\$190/mtCH_4, and \$2,300/mtN_2O (in 2020 dollars), respectively, using a 3 percent discount rate, and \$1/mtCO_2, \$59/mtCH_4, and \$380/mtN_2O (in 2020 dollars) using a 7 percent discount rate. These values increased over time; for 2050 emissions, the average estimates of marginal damages occurring within the U.S. borders are \$11/mtCO_2, \$380/mtCH_4, and \$4,000/mtN_2O (in 2020 dollars) using a 3% discount rate and \$3/mtCO_2, \$160/mtCH_4, and \$1,000/mtN_2O (in 2020 dollars) using a 7% discount rate. Using the same approach with a 2.5 percent discount rate, the average estimates of marginal damages occurring within the U.S. borders of CO_2, CH_4, and N_2O for emissions in 2020 are \$10/mtCO_2, \$240/mtCH_4, and \$3,300/mtN_2O (in 2020 dollars), respectively; for 2050 emissions, these values increase to \$15/mtCO_2, \$450/mtCH_4, and \$5,300/mtN_2O (in 2020 dollars).

analysis because it helps define the strength of the climate response to increasing GHG concentrations in the atmosphere. In addition, the FUND and PAGE models define many of their parameters with probability distributions instead of point estimates. For these two models, the model developers' default probability distributions are maintained for all parameters other than those superseded by the IWG's harmonized inputs (i.e., equilibrium climate sensitivity, socioeconomic and emissions scenarios, and discount rates). More information on the uncertain parameters in PAGE and FUND is presented in Appendix C of the 2016 TSD (IWG 2016a).

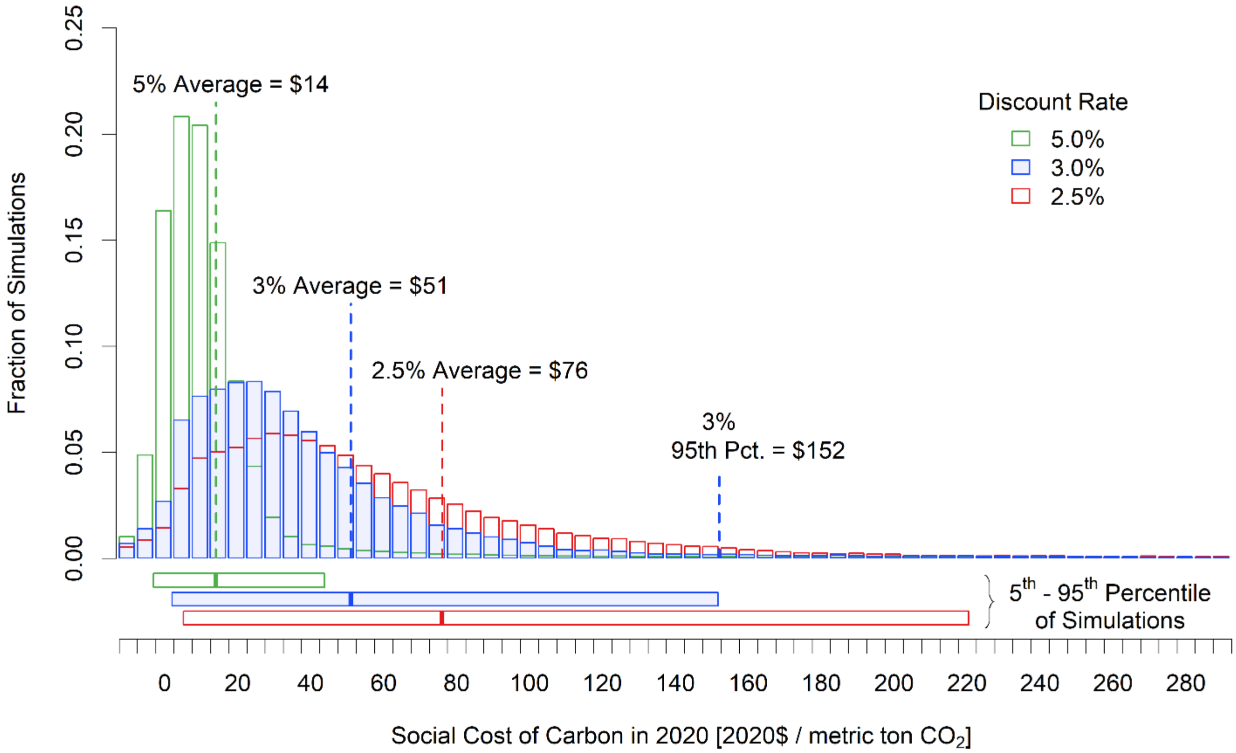
Finally, based on the review of the literature, the IWG chose discount rates that reflect reasonable judgements under both prescriptive and descriptive approaches to intergenerational discounting. As discussed in the 2010 TSD, in light of disagreement in the literature on the appropriate discount rate to use in this context and uncertainty about how rates may change over time, the IWG selected three certainty-equivalent constant discount rates to span a plausible range: 2.5, 3, and 5 percent per year. However, unlike the approach taken for consolidating results across models and socioeconomic and emissions scenarios, the SC-GHG estimates are not pooled across different discount rates because the range of discount rates reflects both uncertainty and, at least in part, different policy or value judgements.

The outcome of accounting for various sources of uncertainty using the approaches described above is a frequency distribution of the SC-CO_2 estimates for emissions occurring in a given year for each of the three discount rates. These frequency distributions reflect the uncertainty around the input parameters for which probability distributions were defined, as well as from the multi-model ensemble and socioeconomic and emissions scenarios where probabilities were implied by the equal weighting assumption. It is important to note that the probability distribution for the SC-GHG calculated using the modeling approach outlined above does not fully characterize uncertainty about the SC-GHG due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations. To name just one example of many known GHG-induced damages omitted in the three IAMs, none of the models include damages associated with ocean acidification, and, therefore, naturally the models do not reflect uncertainty as to the potential severity of those damages.

Figures Figure ***2*** through Figure ***4*** present the frequency distribution of the interim SC-CO_2, SC-CH_4, and SC-N_2O estimates, respectively, for emissions in 2020 and for each discount rate. Each distribution represents 150,000 estimates based on 10,000 simulations for each combination of the three models and five socioeconomic and emissions scenarios. In general, the distributions are skewed to the right and have long right tails, which tend to be longer for lower discount rates. To highlight the difference between the impact of the discount rate on the SC-GHG and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-GHG estimates conditioned on each discount rate. The full set of SC-GHG results through 2050 is available on OMB's website.

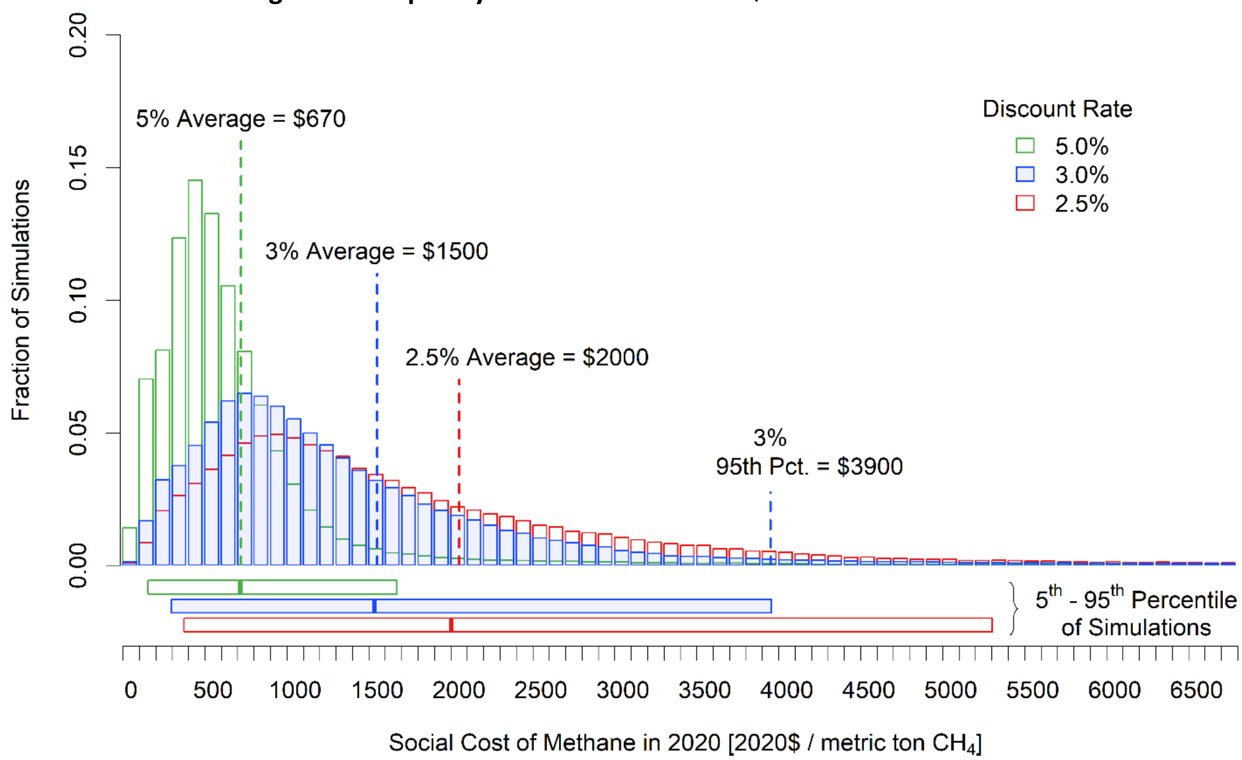
As illustrated by the frequency distributions in Figures Figure ***2*** through Figure ***4*** , the assumed discount rate plays a critical role in the ultimate estimate of the SC-GHG. As explained in Section 3, this is because GHG emissions today continue to impact society far out into the future, so with a higher discount rate, costs that accrue to future generations are weighted less, resulting in a lower estimate. As discussed in Section 3.1, new data and evidence strongly suggest that the consumption interest rate is likely to be less than 3, near 2 percent or lower.

Figure 2: Frequency Distribution of SC-CO_2 Estimates for 2020[34]



[34] Although the distributions and numbers in Figure 2 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.81 percent of the estimates falling below the lowest bin displayed and 3.56 percent of the estimates falling above the highest bin displayed.

Figure 3: Frequency Distribution of SC-CH_4 Estimates for 2020[35]



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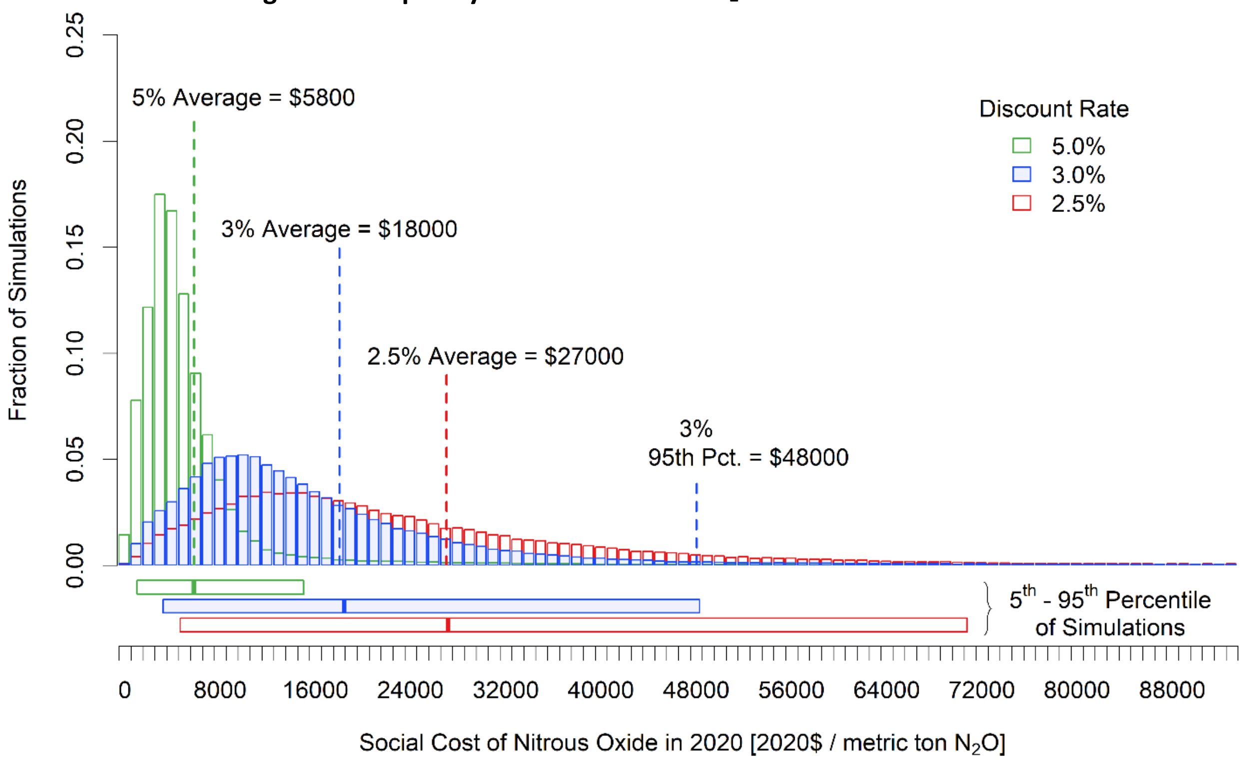
[35] Although the distributions and numbers in Figure 3 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.12 percent of the estimates falling below the lowest bin displayed and 2.84 percent of the estimates falling above the highest bin displayed.

Figure 4: Frequency Distribution of SC-N_2O Estimates for 2020[36]



While the figures above reflect the uncertainties that are explicitly considered in a quantitative manner, there are other areas of uncertainty that are not quantitatively reflected in the interim SC-GHG estimates. The scientific and economics literature has further explored known sources of uncertainty related to estimates of the SC-GHG. For example, published studies explore the sensitivity of IAMs and the resulting SC-GHG estimates to different assumptions embedded in the models (see, e.g., Hope 2013, Anthoff and Tol 2013a, and Nordhaus 2014). However, there remain additional sources of uncertainty that have not been fully characterized and explored due to data limitations and lack of consensus in the scientific or economic literature about how to represent them. Additional research is needed to expand the quantification of various sources of uncertainty in estimates of the SC-GHG (e.g., developing explicit probability distributions for more inputs pertaining to climate impacts and their valuation).

4.2 Other Modeling Limitations

The interim SC-GHG estimates presented in this TSD have a number of limitations, as would be expected for any modeling exercise that covers such a broad scope of scientific and economic issues across the complex global landscape. These include the incomplete treatment of catastrophic and non-catastrophic impacts in the IAMs, their incomplete treatment of adaptation and technological change, the incomplete way in which inter-regional and intersectoral linkages are modeled, uncertainty in the extrapolation of

[36] Although the distributions and numbers in Figure 4 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 percent of the estimates falling below the lowest bin displayed and 2.85 percent of the estimates falling above the highest bin displayed.

damages to high temperatures, and inadequate representation of the relationship between the discount rate and uncertainty in economic growth over long time horizons.

There are newer versions available of each of the IAMs used to calculate the interim SC-GHG estimates in this TSD that offer improvements in some of these areas beyond the version of the models used for the interim estimates. For example, the latest version of the PAGE model, PAGE-ICE (Yumashev et al. 2019, Yumashev 2020), extends PAGE09 (Hope 2013) with representation of two nonlinear Arctic feedbacks (permafrost carbon feedback and surface albedo feedback) on the global climate system and economy, among other changes. The newest version of the DICE model, DICE2016-R3 (Nordhaus 2017), includes numerous updates, including changes to the carbon cycle (to better simulate the long-run behavior of larger models with full ocean chemistry) and updated methods for estimating economic activity.[37] At comparable discount rates, DICE2016-R3 would result in SC-CO_2 estimates roughly twice that of the interim estimates presented in this TSD. For example, using a 3% constant discount rate and other IWG modeling assumptions, DICE2016-R3 yields an average SC-CO_2 of $104 (2018 international dollars) for 2020 emissions (Nordhaus 2019a). However, even DICE2016 and PAGE-ICE do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature and the science underlying their damage functions lags behind the most recent research. Likewise, the socioeconomic and emissions scenarios used as inputs to the models in this TSD do not reflect new information from the last decade of scenario generation or the full range of projections.

The modeling limitations discussed above do not all work in the same direction in terms of their influence on the SC-GHG estimates. However, it is the IWG's judgment that, taken together, the limitations suggest that the interim SC-GHG estimates presented in this TSD likely underestimate the damages from GHG emissions. In particular, the IPCC's Fourth Assessment Report (IPCC 2007), which was the most current IPCC assessment available at the time when the IWG decision over the ECS input was made, concluded that SC-CO_2 estimates "very likely…underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC's Fifth Assessment report (IPCC 2014) and other recent scientific assessments (e.g., IPCC 2018, 2019a, 2019b; U.S. Global Change Research Program (USGCRP) 2016, 2018; and National Academies 2016b, 2019). These assessments confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. For example, sea level rise projections from the IPCC's Fourth Assessment report ranged from 18 to 59 centimeters by the 2090s relative to 1980-1999, while excluding any dynamic changes in ice sheets due to the limited understanding of those processes at the time (IPCC 2007). A decade later, the Fourth National Climate Assessment projected a substantially larger sea level rise of 30 to 130 centimeters by the end of the century relative to 2000, while not ruling out even more extreme outcomes (USGCRP 2018). Section 5 briefly previews some of the recent advances in the

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[37] Relative to the previous version of DICE, DICE2013, the DICE2016 updates to the carbon cycle and the methods for estimating economic activity had the greatest impact on the SC-CO_2. Based on Archer et al. (2009), DICE2016's three-box carbon cycle model aims to better simulate the long-run behavior of larger models with full ocean chemistry. In measuring economic activity, one of the important changes in DICE2016 was to move from market exchange rates to measures adjusted for purchasing power parity when comparing monetary values across countries. See Nordhaus (2017, 2019a) for more discussion of these and other updates included in DICE2016-R3. Nordhaus has also recently explored side extensions of DICE2016. For example, DICE-GIS extends DICE2016 to include representation of sea level rise from melting of the Greenland Ice Sheet (Nordhaus 2019b, Pizer 2019).

scientific and economic literature that the IWG is actively following and that could provide guidance on, or methodologies for, addressing some of the limitations with the interim SC-GHG estimates.

5 Scientific and Economic Advances

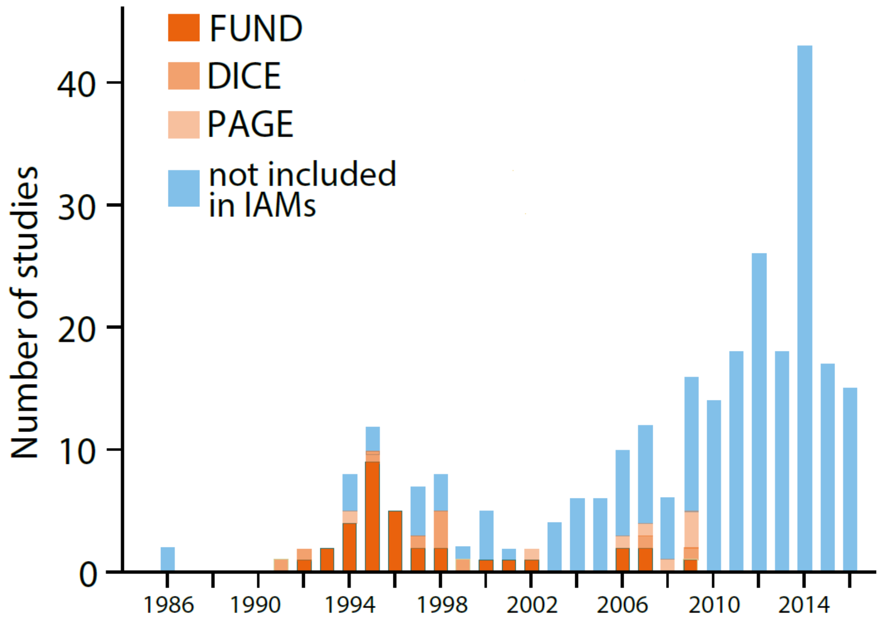
The research community has made considerable progress in developing new data and methods that will provide a path forward for bringing the USG SC-GHG estimates closer to the current frontier of climate science and economics and could address many of the National Academies' (2017) recommendations. This research since 2010/2013 has advanced knowledge regarding each key component in the process of estimating the SC-GHG. This TSD does not intend to provide a detailed review of all these advancements, but this section does highlight some of the key research and new information that the IWG will be reviewing as it works to improve the SC-GHG estimates. As part of the process for updating the SC-GHG estimates by January 2022, the IWG will survey the scientific literature, including the economic literature, to identify advances to address the National Academies (2017) recommendations.

Climate system representation. There have been advancements in climate science since the publication of the IPCC's Fourth Assessment Synthesis report (IPCC 2007), which was the basis for the IWG decision on what equilibrium climate sensitivity (ECS) input to use in the IAM model runs. The conclusions of recent scientific assessments, e.g., from the IPCC (2014, 2018, 2019a, 2019b), the USGCRP (2016, 2018), and the National Academies (2016b, 2019), confirm and strengthen the science, updating projections of future climate change and documenting and attributing ongoing changes. In addition, there are reduced complexity climate models that could offer meaningful improvement over current representation of climate dynamics in existing IAMs (Nicholls et al. 2020). For example, the National Academies (2017) stated that the FAIR model (Smith et al., 2018) satisfies all of the criteria set by National Academies (2017) recommendations related to the representation of climate system dynamics, generates projections of future warming consistent with more complex, state of the art models, can be used to accurately characterize current best understanding of uncertainty, and can be easily implemented and transparently documented. Reduced complexity sea level rise models are also being developed that can provide projections for damage functions that require sea level estimates, including the contributions of thermal expansion and glacial and ice sheet melting based on recent scientific research (e.g., Wong et al. 2017).

***Damage functions*.** At the core of IAMs are "damage functions" that map global mean temperature changes and other physical impacts of climate change into economic (both market[38] and nonmarket[39]) damages. Relative to how much progress has been made in modeling and improving our understanding of climate system dynamics and the physical impacts resulting from temperature change, efforts involved in, and the public resources targeted at, understanding how these physical changes translate into economic impacts have been significantly smaller (Auffhammer 2018). Even so, as illustrated in Figure 5, in the time since the versions of the IAMs used in this TSD were published, there has been an explosion of research on climate impacts and damages.

[38] Examples of market damages include changes in net agricultural productivity, energy use, and property damage from increased flood risk.
[39] Examples of nonmarket damages include services that natural ecosystems provide to society.

Figure 5. New Research on Climate Impacts[40]



Source: Greenstone (2016).

Several efforts are underway to draw on recent literature for improving damage functions and to generate new damage estimates. In particular, the Climate Impact Lab is undertaking an effort to quantify and monetize damages at a fine spatial scale, relying on rigorous empirical methods to develop plausibly causal estimates for several sectors, including health (Carleton et al. 2020), energy (Rode et al. 2021), labor productivity (Rode et al. 2020), agriculture, conflict, and sea level rise.[41] Other research efforts have sought to update the damage function for one sector in an existing IAM based on an updated review of the empirical literature on climate impacts pertaining to that sector (e.g., Moore et al. (2017) for agriculture damages in the FUND model). Damage functions specific to impacts within the U.S. have also been developed and improved for a number of sectors, such as impacts on coastal property, mortality due to extreme temperatures, transportation infrastructure, electricity supply and demand, water quality, recreation, and allergies (Neumann et al. 2020) and impacts of climate change on air quality and human health (Fann et al. 2021). There is also an emerging literature focused on incorporating interactions among

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[40] In many cases, the three IAMs used different studies for calibration. This is particularly true of FUND, which used studies relating to different subsectors of the model, whereas DICE and PAGE did not have as detailed a sectoral breakdown. That means that summing across these different models is likely valid in all but a few isolated cases. The blue bars include studies uncovered from a comprehensive literature review in the economics literature (and a few others in public health or relevant disciplines) by the Climate Impact Lab (CIL) through early 2016. Each of the studies counted in blue was determined by CIL to have employed a research design that allowed for the causal interpretation of results (Greenstone 2016).

[41] The Climate Impact Lab is a multidisciplinary collaboration of climate scientists, economists, computational experts, researchers, analysts, and students working to build empirically derived, local-level estimates of climate change damages and an empirically based SC-CO_2. More information on the Climate Impact Lab can be found at: http://www.impactlab.org/.

regions and impacts. For example, biodiversity loss (e.g., animal pollinators) as a result of climate-driven ecosystem stress could amplify impacts of climate change on agriculture. See National Academies (2017) for more discussion of recent research addressing these and other types of interactions.

Related to the development of damage functions, damages from climate change are uncertain and hence pose additional risks. Reductions in GHG emissions reduce not only expected damages, but also reduce the uncertainty and risks of catastrophic events. Evaluating the damages using the mean outcome does not account for the benefits of reducing uncertainty. Some researchers have raised the need to include this consideration in the SC-GHG (e.g., Carleton and Greenstone 2021) consistent with the observation that individuals are regularly willing to pay for insurance against bad outcomes.

Furthermore, E.O. 13990 instructs the IWG to consider how best to reflect environmental justice and intergenerational equity concerns in assessing climate damages. In the context of climate policy, equity considerations are discussed by economists, ethicists, and others in several ways: distributional effects within a specific country, effects across countries, and intergenerational equity impacts. Economists, ethicists, and others have proposed potential ways to incorporate equity into the SC-GHG. For example, IAM developers have introduced the use of equity weights potentially incorporate these concerns (e.g., Hope 2008; Anthoff and Emmerling 2019).

Socioeconomic and Emissions Projections. The socioeconomic and emissions projections underlying current USG SC-GHG estimates were developed around 2007. Since that time, there have been efforts to develop updated baseline scenarios. Several researchers have started using deterministic scenarios available as part of the IPCC's Fifth Assessment Report Working Group 3 database and the Shared Socioeconomic Pathways (SSPs) linked with the Representative Concentration Pathway (RCP) emissions scenarios (Riahi et al. 2017 and Moss et al. 2010) as benchmark scenarios. Resources for the Future (RFF) has engaged in a research effort to implement each of the National Academies' (2017) recommendations, in collaboration with research partners.[42] One part of this effort is focused on developing probability distributions for future paths of population, GDP, and emissions via using econometrics and expert elicitation techniques. For example, economic growth projections are being built off the results of a formal expert elicitation of leading growth economists together with recent research by Muller, Stock and Watson (2020), who have refined a foundational statistical methodology for generating long-run projections of economic growth at the country level. RFF plans to make these probabilistic scenarios easily usable on Mimi.jl, an open-source modular computing platform used for creating, running, and performing analyses on IAMs.[43]

Discounting. Another area of active research relates to discounting, including the best available evidence on the consumption rate of interest and the application of discount rates to regulations in which some costs and benefits accrue intra-generationally while others accrue inter-generationally. As described in Section 3.2, new empirical evidence suggests that consumption interest rates are now below the previous estimate of 3 percent presented in OMB's Circular A-4. This empirical evidence is also consistent with long-term forecasts by the Congressional Budget Office, suggesting these lower rates will persist (U.S. CBO

[42] For more information on RFF's Social Cost of Carbon Initiative, see: https://www.rff.org/topics/scc/.

[43] Mimi.jl was developed by a team of researchers at UC Berkeley led by David Anthoff in response to a core recommendation from the National Academies (2017) to create an integrated modular approach to draw more readily on expertise from the wide range of scientific disciplines relevant to SC-CO_2 estimation. Mimi.jl provides an interface for defining components and building models in a modularized, transparent way (mimiframework.org).

2020). Future updates to the SC-GHGs estimates will need to reflect the best available evidence from the time series of risk-free rate data and expectations of these rates into the future.

As described in Section 3.3 uncertainty in the discount rate over time yields a declining certainty-equivalent discount rate schedule and can have a dramatic effect on the size of the SC-GHG. While this is not a new theoretical result, new literature has proposed methods for how to incorporate discount rate uncertainty (e.g., Arrow et al., 2013; Cropper et al., 2014) and other nations have implemented declining discount rate schedules for policy analysis (e.g., United Kingdom, France, and Germany). Recent recommendations by the National Academies (2017) and EPA's Science Advisory Board (2021) have encouraged the development and use of a declining certainty-equivalent discount rate schedule as theoretically appropriate and as a method of introducing consistency into analyses that have both near-term and long-term impacts.

In light of new science and evidence, including many of those highlighted in the paragraphs above, other jurisdictions are already considering or have implemented some of the scientific and economic advances discussed above. For example, some states that use SC-GHG estimates in policy analysis have recently updated their approach to discounting based on the increasing evidence that a 3% discount rate is too high for intergenerational analysis. In December 2020, New York issued guidance recommending state agencies use SC-GHG estimates based the same IWG modeling and input decisions as presented in this TSD but with lower discount rates: 2 percent in central scenarios (\$125/mtCO_2 for 2020 emissions (2020 dollars), along with sensitivity analysis at 1 percent and 3 percent (New York Department of Environmental Conservation 2020). Similarly, in Washington state an April 2019 law required utilities to use estimates based on the IWG methodology with a 2.5% discount rate when developing "lowest-cost analyses" for its integrated resource planning and clean energy plans.[44]

Canada is also in the process of updating the SC-GHG estimates used in their regulatory analyses. While the update is underway, they are continuing to use the estimates they adopted in 2016 (which are an adaptation of the IWG global SC-GHG estimates presented in this TSD) as well as a side analysis based on more recent estimates from the academic literature. Based on their review of the literature and latest climatological and economic evidence, they present their current estimates as a "likely underestimate [of] climate-related damages to society" and the side analysis as a way "to illustrate a range of plausible values if the Department were to update its [social cost of carbon] estimate based on new versions of the models currently used."[45] Specifically, the side analysis includes SC-CO_2 estimates based on DICE2016 and PAGE-ICE (\$135 and \$440/mtCO_2 for 2020 emissions (2019 Canadian dollars)).[46]

The IWG will consider the new science and evidence as it works towards a more comprehensive update, including the new research and information described in this section.

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[44] Wash. Sen. Bill. 5116 (signed by Gov. Inslee on May 7, 2019). More information on Washington and other states' use of SC-GHG estimates is compiled by the Institute for Policy Integrity at NYU School of Law (see http://www.costofcarbon.org/states) and discussed in U.S. GAO (2020).

[45] Proposed Clean Fuel Regulations (published for public comment on 12/20/20) http://www.gazette.gc.ca/rp-pr/p1/2020/2020-12-19/pdf/g1-15451.pdf.

[46] Proposed Clean Fuel Regulations (published for public comment on 12/20/20) http://www.gazette.gc.ca/rp-pr/p1/2020/2020-12-19/pdf/g1-15451.pdf.

6 Path Forward

E.O. 13990 reaffirms that "[a]n accurate social cost is essential for agencies to accurately determine the social benefits of reducing greenhouse gas emissions when conducting cost-benefit analyses of regulatory and other actions" (E.O. 13990 2021). The E.O. instructs the IWG to publish interim SC-CO_2, SC-CH_4, and SC-N_2O estimates (collectively, SC-GHG estimates) within 30 days and to publish a set of final estimates by no later than January 2022.[47] In doing so, the E.O. instructs the IWG to consider the recommendations of the National Academies of Science, Engineering, and Medicine as reported in Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide (2017) and other pertinent scientific literature; solicit public comment; engage with the public and stakeholders; seek the advice of ethics experts; and ensure that the SC-GHG estimates reflect the interests of future generations in avoiding threats posed by climate change.

In developing the SC-GHG estimates in 2010, 2013, and 2016 the IWG used consensus-based decision making, relied on peer-reviewed literature and models, and took steps to disclose limitations and incorporate new information by considering public comments and revising the estimates as updated research became available (U.S. GAO 2014). Going forward the IWG commits to maintaining a consensus driven process for making evidence-based decisions that are guided by the best available science and input from the public, stakeholders, and peer reviewers.

While the IWG assesses the current state of the science in each component of the SC-GHG modeling exercise, the IWG is beginning by asking for public comment on how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates. The IWG will soon issue a Federal Register notice with a detailed set of requests for public comments on the new information presented in this TSD, as well as other topics and issues the IWG will address as we develop the next set of updates. Among other things, the IWG will ask for public comment on how to incorporate the best available science in the updated SC-GHG estimates, due to be published by January 2022, and how to incorporate the recommendations of the National Academies (2017).

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[47] The Executive Order also requests that the IWG assess the application of the SC-GHG to inform government decision making beyond regulations, in addition to recommending a robust long-term structure for ensuring the SC-GHGs continue to reflect the best available science and economic and that long-term research needs are met.

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Appendix – Annual SC-CO_2, SC-CH_4, and SC-N_2O Values, 2020-2050

The values in Tables A-1 through A-3 are the same as those reported in the 2016 TSD and Addendum adjusted for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in U.S. Bureau of Economic Analysis (BEA) NIPA Table 1.1.9: 113.626 (2020)/ 92.486 (2007) = 1.228575 (U.S. BEA 2021). Values of SC-CO_2 presented in this TSD are rounded to the nearest dollar; SC-CH_4 and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available on OMB's website for use in regulatory and other analyses: https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs.

Table A-1: Annual SC-CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2021	15	52	78	155
2022	15	53	79	159
2023	16	54	80	162
2024	16	55	82	166
2025	17	56	83	169
2026	17	57	84	173
2027	18	59	86	176
2028	18	60	87	180
2029	19	61	88	183
2030	19	62	89	187
2031	20	63	91	191
2032	21	64	92	194
2033	21	65	94	198
2034	22	66	95	202
2035	22	67	96	206
2036	23	69	98	210
2037	23	70	99	213
2038	24	71	100	217
2039	25	72	102	221
2040	25	73	103	225
2041	26	74	104	228
2042	26	75	106	232
2043	27	77	107	235
2044	28	78	108	239
2045	28	79	110	242
2046	29	80	111	246
2047	30	81	112	249
2048	30	82	114	253
2049	31	84	115	256
2050	32	85	116	260

Table A-2: Annual SC-CH_4, 2020 – 2050 (in 2020 dollars per metric ton of CH_4)

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	670	1500	2000	3900
2021	690	1500	2000	4000
2022	720	1600	2100	4200
2023	750	1600	2100	4300
2024	770	1700	2200	4400
2025	800	1700	2200	4500
2026	830	1800	2300	4700
2027	860	1800	2300	4800
2028	880	1900	2400	4900
2029	910	1900	2500	5100
2030	940	2000	2500	5200
2031	970	2000	2600	5300
2032	1000	2100	2600	5500
2033	1000	2100	2700	5700
2034	1100	2200	2800	5800
2035	1100	2200	2800	6000
2036	1100	2300	2900	6100
2037	1200	2300	3000	6300
2038	1200	2400	3000	6400
2039	1200	2500	3100	6600
2040	1300	2500	3100	6700
2041	1300	2600	3200	6900
2042	1400	2600	3300	7000
2043	1400	2700	3300	7200
2044	1400	2700	3400	7300
2045	1500	2800	3500	7500
2046	1500	2800	3500	7600
2047	1500	2900	3600	7700
2048	1600	3000	3700	7900
2049	1600	3000	3700	8000
2050	1700	3100	3800	8200

Table A-3: Annual SC-N_2O, 2020 – 2050 (in 2020 dollars per metric ton of N_2O)

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	5800	18000	27000	48000
2021	6000	19000	28000	49000
2022	6200	19000	28000	51000
2023	6400	20000	29000	52000
2024	6600	20000	29000	53000
2025	6800	21000	30000	54000
2026	7000	21000	30000	56000
2027	7200	21000	31000	57000
2028	7400	22000	32000	58000
2029	7600	22000	32000	59000
2030	7800	23000	33000	60000
2031	8000	23000	33000	62000
2032	8300	24000	34000	63000
2033	8500	24000	35000	64000
2034	8800	25000	35000	66000
2035	9000	25000	36000	67000
2036	9300	26000	36000	68000
2037	9500	26000	37000	70000
2038	9800	27000	38000	71000
2039	10000	27000	38000	73000
2040	10000	28000	39000	74000
2041	11000	28000	39000	75000
2042	11000	29000	40000	77000
2043	11000	29000	41000	78000
2044	11000	30000	41000	80000
2045	12000	30000	42000	81000
2046	12000	31000	43000	82000
2047	12000	31000	43000	84000
2048	13000	32000	44000	85000
2049	13000	32000	45000	87000
2050	13000	33000	45000	88000