ELECTRIC POWER RESEARCH INSTITUTE

June 21, 2021

Dear Director of the Office of Management and Budget, Chair of the Council of Economic Advisors, and Director of the Office of Science and Technology Policy,

Thank you for the opportunity to comment on the "interim" social cost of greenhouse gas (SC-GHG) estimates technical support document (TSD) published by the Interagency Working Group (IWG).[1] As a science organization, the Electric Power Research Institute (EPRI) appreciates that the Biden Administration has taken the initiative to develop science-based SC-GHG estimates and applications by, for instance, reconstituting the IWG and engaging the public through comment opportunities such as this. EPRI has been studying SC-GHG methodologies specifically for over a dozen years and has over forty years of research experience in the science underlying SC-GHG calculations. EPRI's SC-GHG research includes analyzing in detail the models and assumptions that comprise the IWG Framework, as well as detailed assessment of applications using SC-GHG estimates. EPRI's expertise and research led to participation on the National Academy of Science, Engineering, and Medicine (NASEM) Social Cost of Carbon Committee as a committee member, and EPRI's assessment of the IWG Framework (Rose et al, 2017, 2014) was a primary input into the NASEM SCC Committee deliberations, and the resulting studies (NASEM, 2016, 2017) referenced in President Biden's January 2021 executive order as important methodological resources.

EPRI is a nonprofit, scientific research organization with a public benefit mission. EPRI strives to advance knowledge and facilitate informed public discussion and decision-making. EPRI has recognized scientific expertise in the social costs of carbon and other greenhouse gases, climate scenarios, integrated assessment modeling, socioeconomic and energy system transformation, and climate policy evaluation, as well as a long history of research community leadership and participation in the Intergovernmental Panel on Climate Change, National Climate Assessment, and NASEM. See Appendix A for examples of EPRI's SC-GHG related research, including EPRI's 2021 publication identifying needed repairs to the "interim" SC-GHG estimation methodology and current applications to ensure scientific reliability, as well as discussion of key technical challenges that need to be addressed in updating the SC-GHG estimation approach (EPRI, 2021). For easy reference, EPRI (2021) is included as Appendix B.

Based on EPRI's analyses, its NASEM SCC Committee and IPCC expert participation, and other carbon-value-related research and evidence, EPRI recommends the following for scientific reliability, robustness, and public confidence in SC-GHG estimates, applications, and the decisions they inform:

- **Putting science first:** The process to date in developing U.S. Government SC-GHG estimates, going back to the first estimates in 2010, has not instilled confidence, and has contributed to the political instability of SC-GHG estimates that we have observed across administrations. For instance, new SC-GHG estimates have been released in final rules without comment opportunities. Also, known documented methodological weaknesses have not been discussed or addressed; and, despite the importance of the estimates, a formal scientific review of the

[1] USG, 2021. 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, February, https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

reliability and robustness of the SC-GHG methodology and estimates has not been undertaken. To ensure public confidence in estimates and applications, and stability of estimates to facilitate efficient private and public sector planning, methodological and application decisions should be objectively guided by science. Scientific integrity and public confidence should be the overarching principles. Decisions related to process (estimate development, documentation, review, publication), methodology (developing what is needed and not limiting consideration to particular literature), and application (guidance for using SC-GHG estimates) should be guided by these principles to ensure confidence and stability.

- **Developing SC-GHG estimates as scientific metrics, not tools for achieving policy:** SC-GHG estimates are intended to *inform* regulatory policy choices. To do so objectively and effectively, and reliably over the long-run, it is essential that they be regarded and developed as scientific metrics that simply *estimate* potential climate damages. They should not be used to try to make, influence, or achieve policy goals—climate, leadership, equity, justice, or other goals. Focusing on providing reliable information to inform decisions has implications for how the IWG and public approach a variety of SC-GHG methodological decisions (e.g., use of global vs. domestic SC-GHG estimates, treatment of poorly understood potential impacts, selecting a discounting approach, consideration of the distribution of damages), choices of estimates, and application issues.

- **Developing and communicating an SC-GHG update process that will ensure scientific reliability *before use* of estimates from a new methodology, including:**
    - ***Allowing adequate time:*** Granting the IWG sufficient time to collect and assess related scientific inputs, identify and assess methodological options, develop and test a methodology for robustness, adequately document and justify the methodology, undertake an appropriate regulatory scientific review (see below), revise the approach based on scientific review input, have the revised approach reviewed, and finalize and publish estimates.
    - ***Undertaking an appropriate review of the updated SC-GHG methodology and estimates:*** Given the significant financial and social implications of applying SC-GHG estimates, a formal scientific review process appropriate for regulatory methodologies is required. The current IWG Framework used for interim estimates *never* went through a scientific review for regulatory use. Such a review is fundamentally different from an academic journal article review: peer review of a journal article emphasizes intellectual contribution, while scientific review of a methodology for regulatory use emphasizes scientific integrity and robustness. Journal review is focused on advancing knowledge, while regulatory review is focused on public credibility for guiding decisions with significant social and financial implications. The regulatory review process is rightly more critical, thorough, and detailed, requiring the methodology developers to communicate alternatives, defend choices, provide intermediate results related to internal modeling dynamics, and justify the overall approach taken in combining information and tools and developing summary results. See EPRI (2021) (Appendix B) for additional discussion and examples of reviews of regulatory methodologies. Note that, NASEM (2017) recommended a regularized process for reviewing scientific developments and

identifying opportunities for updating the methodology periodically (analogous to what the NASEM SCC Committee was asked to do). That activity is also valuable. However, it is not a substitute for a formal scientific assessment of the reliability and robustness of estimates before they can be finalized and confidently used.

  - ***Developing what is needed and not limiting methodological consideration to what is currently in the literature:*** The IWG should design what is needed to produce estimates fit for purpose, taking into account all the relevant science. Whatever methodology the IWG ultimately proposes, it will still need a formal scientific review before use of its estimates. This is necessary because the proposed methodology will represent having made methodological choices, such as identifying and assessing options, selecting options, choosing input scenarios, parameters, and distributions, combining, selecting, or synthesizing methodologies, combining modules, aggregating results and selecting summary metrics, and evaluating and selecting a discounting approach. Limiting consideration to what is currently in the literature in informing these options, instead of focusing on developing what is needed, is an arbitrary requirement that constrains the IWG to methodologies and results frequently designed for other purposes, other research questions, and academic interest. Note that, previous IWG modeling and estimates of the SC-GHG did not limit consideration to the peer review literature (e.g., documentation for the PAGE model consisted of working papers, which alone falls short of meeting the scientific standard warranted for significant regulatory metrics).

- **Extending the January 2022 deadline for "final" updated SC-GHG estimates at least 6 to 12 months to allow the IWG adequate time to develop scientifically reliable estimates, including proper scientific review, and ensure public confidence in the estimates and applications:** The current timeline is simply too tight for the IWG to do what is needed; and, the stakes are too high not to extend the deadline given that the estimates have the potential to impact billions of dollars of existing and future investments and operations. See previous bullet for specific recommendations regarding the process needed.

- **Immediately revise the "Interim" SC-GHG estimates by revising the framework to remove underlying estimates based on models and assumptions that are not scientifically defensible:** Specifically, the PAGE model and the high and low GHG emissions scenarios are not scientifically defensible. Detailed peer reviewed analysis separately evaluating and comparing individual component (module) behavior for each of the IWG Framework models and assumptions found fundamental technical issues with each model (Rose et al, 2017). The technical issues for the PAGE model, in particular, and the high and low emissions scenarios are especially problematic and do not meet a bare minimum scientific standard for transparency, scientific basis, and plausibility. For instance, PAGE lacks documentation and justification for important modeling elements, as well as required functionality in translating emissions to global average temperature change, while the two emissions scenarios do not pass simple plausibility tests. See EPRI (2021) in Appendix B for further details. As a result, for scientific reliability and public credibility, all the SC-GHG estimates (for carbon dioxide, methane, nitrous oxide, and HFCs) based on the PAGE model and the two scenarios should be removed. Fortunately, removing the problematic SC-GHG estimates and recomputing average values is straightforward and can be readily implemented within days. See EPRI (2021) (Appendix B) for an example of repaired social cost of carbon estimates for a 3% discount rate and emissions in 2020. Note that the problems with the PAGE model also raise additional concerns about (a) the reliability of the "interim" 95th percentile 3% discount rate values, and (b) lower discount rates. Given that PAGE SC-GHG estimates dominate the righthand tail of the combined frequency distribution of estimates (Appendix B Figure 1), PAGE is having a disproportionate effect on the 95th percentile, and PAGE's influence on the mean and 95th percentile increases the lower the discount rate. Finally, given the time required for properly developing scientifically reliable updated "final" estimates as discussed above, revising the "interim" estimates as discussed here would be appropriate.

- **Immediately provide guidance that addresses identified SC-GHG policy application issues:** As discussed in EPRI (2021) (Appendix B), guidance to government agencies at the federal and state level is needed for scientifically reliable SC-GHG application, such as climate benefit and net benefit estimates, as well as standard setting. The guidance should address known SC-GHG application issues (Rose and Bistline, 2016; Bistline and Rose, 2018; EPRI, 2021), such as avoiding pricing GHG emissions more than once across policies, accounting for GHG emissions leakage, ensuring consistency in benefit and cost calculations, and providing guidance on how to use SC-GHG estimates based on different discount rates in applications, including, as recommended by NASEM (2016), appropriately incorporating SC-GHG estimate uncertainty for a given discount rate (versus across discount rates) in analysis and decisions. For example, considering the 5th and 95th percentile estimates for a given discount rate. Note that, considering the 95th percentile estimates alone is not scientifically justified, and should not be based on speculation about potential damages. Furthermore, guidance is needed for SC-GHG application in contexts where broad monetization of costs and benefits is not currently required. As noted in EO12866 and Circular A-4, partial monetization of the estimated implications can lead to misleading results.

- **Not revising the discount rates currently used for the "interim" SC-GHG estimates, and not providing agencies with discretion to do sensitivities with lower discount rates:** There are many technical issues associated with discounting in the context of SC-GHG calculations that warrant time for serious discussion, including considering the type of investment represented, the type of economic values impacted (some not currently converted to consumption equivalents), aligning with discounting of other costs and benefits, consistency across federal decisions, and consistency with economic growth assumptions over time, scenario, and region. For example, emitting or reducing CO_2 is an extremely long-run investment due to 100-plus year atmospheric lifetime of CO_2 and climate system inertia effects; thus, using 10-year Treasury rates as discussed in the TSD and by others (e.g., Carleton and Greenstone, 2021) is impractical. As a point of comparison, Nordhaus (2017) uses dynamic discounting consistent with economic growth over time that considers benefits and costs, types of economic values, and calibration to observed market rates. The result is discount rates that vary over time with an average discount rate of 4.25% per year during the period to 2100. Further, the practicality of applying U.S. rates to global regions with large differences in economic growth rates as well as rates of return also needs to be considered. Note that the NASEM (2017) did not recommend exogenous declining discount rate pathways, but instead, for consistency, using "a path of discount rates based on its particular path of per capita economic growth." Given these many issues needing to be addressed, it would be inappropriate to change the discount rates, or discount rate emphasis, with the "interim" estimates without sufficient technical discussion and scientific review of a proposed discounting approach and application guidance. For the same set of reasons, agencies should not be given discretion to do sensitivities with lower discount rates. Ad hoc discounting decisions by agencies will result in inconsistencies in policy and budgetary decisions across the government. Finally, changing discounting in the near-term, but nothing else, would not instill confidence, since it would be inconsistent, and could appear opportunistic, when there are clearly fundamental fixes to the SC-GHG estimation methodology needed for scientifically reliable estimates. As discussed above, the interim estimate approach is not scientifically reliable as is and would need to be revised first.

- **Addressing known scientific challenges in the process of developing updated SC-GHG estimates:** For scientific reliability and robustness, and public confidence, in a new methodology and estimates, substantive scientific challenges associated with each SC-GHG modeling component need to be addressed, such as the following:

    - *Socioeconomic and emissions projections:* Representing uncertainty not only in emissions, but also society, including uncertainty in the structure of regional economies, sectors, and populations, as well as accounting for the plausibility and likelihood of projections.
    - *Climate change modeling:* Evaluating modeling alternatives that produce significantly different projections and representations of uncertainty.
    - *Climate damage estimation:* Understanding, assessing, and reconciling methodological differences, biases, and large disparities in damage estimates, with fundamental differences in methods affecting the comparability of results (NASEM, 2017) and posing a significant challenge to efforts to utilize the literature to derive robust functional relationships with temperature, sea-level rise, and other climate and non-climate drivers of potential net damage levels and adaptation.
    - *Discounting:* See earlier discussion.
    - *Risk, equity, and environmental justice consideration:* Considering alternatives, but ensuring that policy objectives are not embedded in estimates, there is consistency in treatment of these issues across benefit and cost calculations, and that actual willingness-to-pay is reflected (EPRI, 2021).

    See EPRI (2021) (Appendix B) for additional discussion of these challenges, including examples and references. In addition, EPRI's SC-GHG Scientific Initiative, including educational webcasts and ongoing analyses related to these and other priority challenges, should help facilitate progress on these issues.

Overall, please see EPRI (2021), included as Appendix B to our comments, for technical discussion of the research supporting many of the points in our comments above. Note that, EPRI also provided comments to New York State on their proposed use of the current IWG Framework for valuing GHGs by state agencies (EPRI, 2020). EPRI's comments to New York State highlighted the technical flaws in the current IWG Framework that need to be addressed for scientifically reliable SC-GHG estimates and applications.

In addition to our recommendations above, we provide the following clarifications regarding specific points discussed in the TSD:

- This NASEM (2016) Phase 1 recommendation regarding whether to update the equilibrium climate sensitivity distribution should not be interpreted as validation of the current IWG Framework, but instead recognition that a more significant revision is required. Overall, the NASEM SCC Committee was not tasked with peer reviewing the suitability of the current SC-GHG IWG Framework, nor have the methodology and estimates ever been subjected to a formal scientific review process. More specifically, the IWG explicitly did not ask the NASEM committee to evaluate the suitability of current estimates for regulatory use (e.g., its conceptual appropriateness, and the scientific reliability and robustness of the methodology and estimates). Instead, the NASEM was asked to "examine potential approaches, along with their relative merits and challenges, for a more comprehensive update to the SCC estimates." Thus, the NASEM SCC Committee was asked to review scientific developments and identify opportunities for future updates to the current methodology. In Phase 1 explicitly, the NASEM SCC Committee was simply asked to consider whether the IWG should update one assumption in the IWG Framework—the equilibrium climate sensitivity distribution. The Committee's Phase 1 recommendation on this issue was to not revise only the one assumption because there was more that the IWG needed to re-consider (NASEM, 2016).
- The TSD states that the current "interim" SC-GHG estimates are likely too low. However, the directional bias in the "interim" estimates cannot be assessed until the technical flaws in the current approach are corrected (see above). As we have found and shown, addressing some of the current flaws leads to lower estimates. For example, correcting for the technical issues as we have recommended above to remove scientifically-suspect models and scenarios lowers the summary estimates, suggesting that the current IWG Framework estimates have elements contributing to an upward bias (i.e., current estimates are higher than they should be). See EPRI (2021) for discussion of other factors contributing to biases in the "interim" estimates. While there are omitted types of climate impacts, such as biodiversity, ocean acidification, extreme weather, and arctic access, there are also other omitted or poorly represented factors, such as limited representation of adaptation processes (micro and macroeconomic), how the incremental emission pulses are implemented in calculations, and unspecified damage types, and . Note that potential "big" global risks (e.g., ocean acidification) are unlikely to be affected by a single metric ton of CO_2, or other emissions, which is how an SC-GHG estimate is computed; and, will therefore have little to no impact on estimated values.

In addition, regarding the federal registry notice's questions where public feedback was also sought, we first direct your attention to our recommendations above and the technical publication EPRI (2021). Second, we offer a few additional comments related to each of the notice's questions below:

- ***General advances in science and economics discussed in the TSD*** – As we discussed above, the IWG should develop the methodology needed, and it should be informed by the literature, but not constrained by it. Whatever is developed will need regulatory peer review before estimates are used, which is the most important criteria to satisfy for scientific reliability and public confidence. In addition to the challenges identified above that need to be addressed in developing a new SC-GHG approach, below we highlight a few analyses that provide useful insights relevant to updating individual SC-GHG modeling components. Furthermore, EPRI's SC-

GHG Scientific Initiative will be developing new insights and facilitating technical discussions on these topics that should help the IWG with their efforts.

- *Socioeconomic and emissions projections:* See Rose et al (2017), Rose and Scott (2020, 2018), and EPRI (2021) for evaluation of the IPCC Fourth and Fifth Assessment and IPCC 1.5˚C Special Report global scenarios on their own and relative to the current IWG Framework assumptions, as well as analyses related to global pathway attainability and plausibility.
- *Climate change modeling:* See Rose et al (2017) for comparison of the deterministic and probabilistic performance of the current IWG Framework climate modeling components relative to each other and relative to MAGICC, a prominent reduced complexity climate model. See also IPCC (2018) and Huppmann et al (2018) for comparing MAGICC to the FAIR model in translating emissions to temperature response; and, see the Reduced Complexity Model Intercomparison Project (https://www.rcmip.org/) for additional important insights regarding alternative simplified models, performance, and differences.
- *Climate damages:* See Rose et al (2017) for a decomposition and comparison of deterministic and probabilistic climate damages by IWG Framework model, detailed inventory of the underlying climate impacts literature used, and implied aggregate damage functions by temperature, income, and population drivers.
- *Discounting:* See EPRI (2021) for discussion of the set of issues relevant to discounting in the context of SC-GHG estimation and application.
- *IPCC AR6 report:* The IPCC is currently in the midst of writing the Sixth Assessment Report and it will contain valuable insights on the state of the art in socioeconomic and emissions projections, climate system dynamics, and climate damage estimation. The current Administration and the IWG should explore how it can time their development of updated SC-GHG estimates to take advantage of this unique and valuable scientific resource.

- ***Approaches to implementing the recommendations of the NASEM, including recommendations for prioritizing*** – The IWG should not be prioritizing individual NASEM recommendations. Prioritizing individual NASEM near-term recommendations is inconsistent with the NASEM review and Phase 1 recommendation. The NASEM SCC Committee did not see some near-term recommendations as optional. On the contrary, *all* the near-term recommendations should be implemented. Prioritization would result in a piece-meal and partial update, which is precisely what the NASEM Committee's Phase 1 recommendation not to revise only the equilibrium climate sensitivity distribution assumption was designed to avoid.

- ***Recent advances in science and economics, including approaches to adequately take account of climate risk, environmental justice, and intergenerational equity*** – See recommendations above and EPRI (2021).

- ***How best to reflect the latest scientific and economic understanding of discount rates appropriate for intergenerational analysis when using the interim SC–GHG estimates*** – See recommendations above and EPRI (2021).

- ***Areas of decision-making, budgeting, and procurement by the Federal Government where the SC–GHG estimates should be applied*** – As discussed in Rose and Bistline (2016), the SC-GHG estimates computed by the IWG are appropriate to use in assessment of proposed policies with incremental global emission change implications, but not appropriate with policies with non-incremental emissions effects, including global and national goal setting. An additional issue raised in Rose and Bistline (2016) and EPRI (2021), is the risk of pricing (directly and indirectly) GHG emissions more than once across policies and jurisdictions, which is economically inefficient, increasing the cost of reducing emissions without emissions reduction benefits. We already see GHGs being priced directly or indirectly more than once across federal policies and actions, as well as with and across state policies and actions (e.g., mineral leasing, clean energy standard/clean power plan, CAFE standards, wholesale power pricing, and state GHG caps). Furthermore, with climate policies increasingly being applied to most economic sectors, using the SC-GHG in procurement and budgeting decisions will increase this economic inefficiency given that the value of GHGs will already be internalized into budget activities and goods and services prices. Finally, as noted above, concerns about misleading information from partial monetization should also be taken into account.

Thank you again for the opportunity to provide input into this important activity. For questions related to our comments, or the research and insights discussed, please contact Steven Rose (srose@epri.com) and David Young (dyoung@epri.com).

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Appendix A

EPRI select SC-GHG related scientific resources

- EPRI, 2021. Repairing the Social Cost of Carbon: Immediate Steps for Scientifically Reliable Estimates and Use. #3002020523.
- EPRI, 2020. EPRI Public Comments on New York State Department of Environmental Conservation's Proposal "Establishing a Value of Carbon: Guidelines for Use by State Agencies." EPRI, Palo Alto, CA: 2020. #3002020249.
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Appendix B

EPRI (2021). Repairing the Social Cost of Carbon: Immediate Steps for Scientifically Reliable Estimates and Use. #3002020523.

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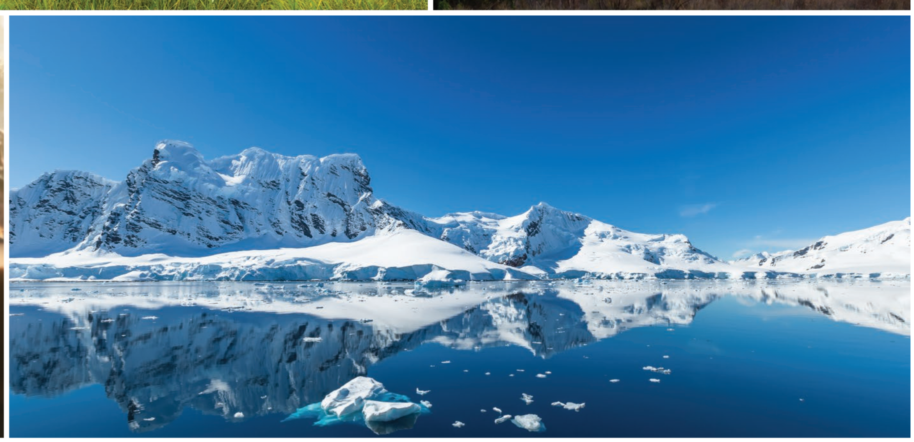
REPAIRING THE SOCIAL COST OF CARBON FRAMEWORK

IMMEDIATE AND ONE YEAR STEPS FOR SCIENTIFICALLY RELIABLE ESTIMATES AND USE



Technical Brief, February 2021

EXECUTIVE SUMMARY

Executive order: President Biden issued an executive order on January 20th, 2021 requesting interim social cost of greenhouse gas (SC-GHG) estimates for carbon dioxide (SCC), methane (SCM), and nitrous oxide (SCN) in 30 days, and final estimates by January 2022, as well as recommendations on appropriate use of these estimates by September 1, 2021. These estimates would be used in all climate and energy related regulations and other federal decisions going forward in assessing proposals, justifying actions, and setting standards.

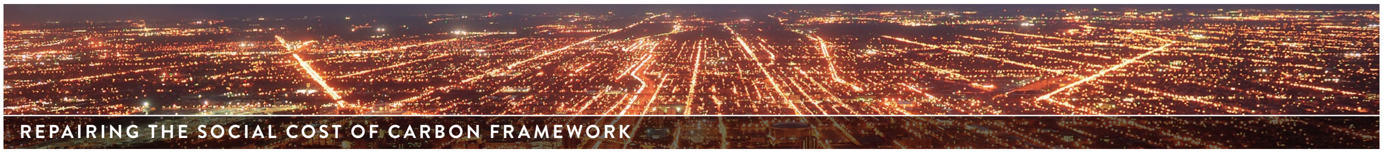
SCC important but complex: The SCC, SCM, and SCN are important metrics but complex to calculate and use. Establishing scientifically reliable and robust estimates, and policy use of SC-GHG estimates, are essential for public confidence; this requires adequate transparency, justification, and review, which takes time, potentially more than a year for developing the *final* estimates President Biden seeks.

U.S. Government SCC modeling framework: The Interagency Working Group SC-GHG modeling framework (IWG Framework) used by the previous two administrations is the obvious candidate for providing the *interim* estimates that will be in place for at least a year. The IWG Framework is complex, using 150,000 scenarios to generate a single SC-GHG estimate from three models each run tens of thousands of times with different assumptions to project global society, climate, sea-level rise, and damages from climate change for 300 years. However, the IWG Framework has not undergone the scientific review needed for significant regulatory methodologies.

Unique EPRI expertise and analyses: The Electric Power Research Institute (EPRI) has been studying SC-GHG methodologies for over a dozen years, including examining in detail the models and assumptions that comprise the IWG Framework. EPRI's research led to participation on the National Academy of Science, Engineering, and Medicine (NASEM) SCC Committee, and EPRI's assessment of the IWG framework was a key input into the NASEM SCC Committee study referenced in President Biden's order as a key methodological resource.

Analyses reveal fundamental technical SCC estimation and use issues: EPRI's detailed analyses deconstructing and assessing the inner workings of the IWG Framework has found that the Framework is not scientifically reliable, or producing robust estimates, due to fundamental technical issues. EPRI has also found significant technical issues in policy applications of SC-GHG estimates to date that impact the scientific reliability of climate benefit and net benefit calculations.

Fixing what is flawed: Based upon these analyses, EPRI concludes that for the Biden Administration to "capture the full costs of greenhouse gas emissions as accurately as possible" they need to consider the following:



FOR INTERIM SC-GHG ESTIMATES:

a. Revise the framework to meet a minimum standard for transparency, scientific basis, and plausibility. If the Biden Administration plans to use the existing IWG Framework to provide *interim* SC-GHG estimates, the IWG Framework needs to be fixed. EPRI recommends excluding those models and assumptions that do not meet a minimum standard for transparency, scientific basis, and plausibility. EPRI finds that this standard can be met by removing all estimates from one of the three models and two of the socioeconomic assumptions. The table below presents the resulting 2020 global SCC estimates from repairing the IWG Framework to meet the scientific standard. Removing SCC, SCM, and SCN estimates that do not satisfy the minimum standard is readily implementable for President Biden's interim estimates.

b. Use discount rates consistent with other federal decisions and the type of value estimated. Use discount rates from 2% to 5% to ensure consistency with other decisions made by federal agencies and the type of climate damages estimated. However, potential inconsistencies with economic growth assumptions over time, scenario, and region should also be considered.

FOR FINAL SC-GHG ESTIMATES:

a. Address key scientific challenges and initiate appropriate scientic review. Based on EPRI's detailed analyses, replacing the current IWG Framework is appropriate for the Biden Administration's *final* SC-GHG estimates; however, the following is needed for scientific reliability and robustness, and public confidence, in the new estimates:

- **i.** Substantive scientific challenges need to be addressed, such as reconciling methodological differences and biases in climate damage estimation,
- **ii.** Given the significant financial and social implications, a formal scientific and public review process for regulatory methodologies is needed, which is far more rigorous than academic journal peer review.

b. Consider alternatives to SC-GHGs. Given the global and multi-century modeling scope, establishing robustness of SC-GHG estimates will be challenging, and the the Administration may need to consider alternatives for meeting the legal requirement to value GHGs in rulemakings.[1]

USE OF SC-GHG ESTIMATES:

a. Ensure reliable climate benefits and net benefits calculations. EPRI recommends providing guidance to agencies that addresses known SC-GHG application issues, such as avoiding pricing GHG emissions more than once, accounting for GHG emissions leakage, and using SC-GHG values based on different discount rates.

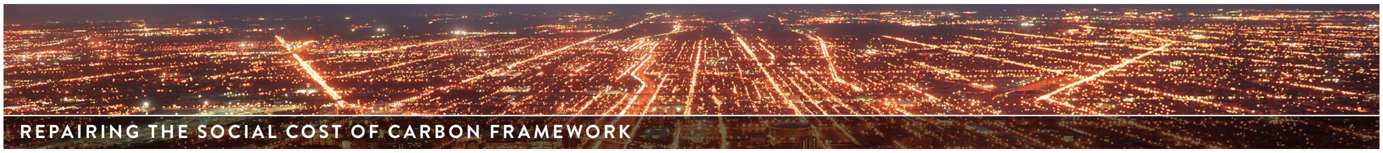
Repaired global SCC estimates for the year 2020 from revising the IWG Framework to satisfy a minimum scientific standard for transparency, scientific basis, and plausibility ($2020)[2]

Discount rate	5th percentile	Average	95th percentile
2.5%	$5	$64	$147
3%	$1	$40	$94
5%	($4)	$10	$27

For questions or comments related to the research and insights discussed, please contact:
Steven Rose (srose@epri.com) and David Young (dyoung@epri.com).

1 U.S. 9th Circuit Court decision (Center for Biological Diversity vs. National Highway Traffic Safety Administration, United States Court of Appeals for the Ninth Circuit, No. 06-71891, November 15, 2007).

2 Derived from IWG Obama Administration SCC data (IWG, 2015, 2016). Converted to 2020 dollars.



TECHNICAL BRIEF

The social costs of carbon dioxide (SCC), methane (SCM), and nitrous oxide (SCN) have significant public and private financial and budgetary implications with many technical intricacies and challenges needing to be communicated to the public and addressed for scientifically reliable estimates and use, and public confidence in the insights they provide and actions they inform.

The SCC is a monetary estimate of the damages from climate change from emitting a metric ton of carbon dioxide (CO_2), and has been used in policy making and evaluation as an estimate of the benefit of reducing a metric ton of CO_2 (Rose and Bistline, 2016). Per unit damage estimates have also been created for emissions of other greenhouse gases (GHGs), including methane and nitrous oxide (e.g., Marten et al, 2015; Waldhoff et al, 2014). SC-GHG estimates are highly sensitive to assumptions, thus there are a broad range of estimates in the literature (see examples in Rose et al., 2014 and Rose, 2012) and scrutinizing models and assumptions is crucial, as is accounting for uncertainties.

The U.S. Government is legally required to value changes in CO_2 and an Interagency Working Group Framework (IWG Framework) was developed that generated estimates of the SCC and other GHGs for this purpose.[3] This framework was used to generate estimates under the Obama and Trump Administrations, but with each treating the outputs differently—the former using the global damage estimates and discount rates of 2.5, 3, and 5% (see, most recently, IWG, 2015, 2016a, and 2016b), and the latter using the U.S. portion of the damage estimates and discount rates of 3 and 7% (e.g., USEPA Proposed Clean Power Plan Repeal, 2017; USEPA Proposed Affordable Clean Energy Rule, 2018).

On January 20, 2021, President Biden issued an executive order requesting interim social cost of greenhouse gas (SC-GHG) estimates for carbon dioxide (SCC), methane (SCM), and nitrous oxide (SCN) in 30 days, and final estimates by January 2022, as well as recommendations on appropriate use of these estimates by September 1, 2021.[4] These estimates would be used in all climate and energy related regulations and other federal decisions going forward in assessing proposals, justifying actions, and setting standards.

The IWG Framework used by the previous two administrations is the obvious candidate for providing the preliminary estimates sought by the Biden Administration that will be in place for at least a year. However, detailed analyses deconstructing and assessing the inner workings of the models and assumptions within the USG Framework have found fundamental technical issues that affect the scientific reliability of the resulting SCC, SCM, and SCN estimates (Rose et al, 2017a, 2014). Furthermore, analyses of policy use of SC-GHG estimates have found fundamental technical issues that affect the scientific reliability of estimated climate benefits and net benefits calculations (Rose and Bistline, 2016; Bistline and Rose, 2018; EPRI, 2020). Scientific reliability and robustness are essential for public confidence. This applies not only to SC-GHG estimates and their use, but also the scientific and public review process.

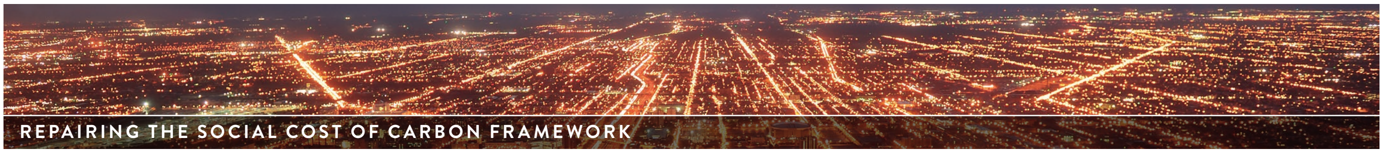
EPRI has done one-of-kind extensive analyses deconstructing and evaluating the individual components on the IWG Framework in recent years, in particular:

- Rose, SK, DB Diaz, GJ Blanford, 2017a. Understanding the Social Cost of Carbon: A Model Diagnostic and Inter-Comparison Study, *Climate Change Economics* 8 (2). doi: 10.1142/S2010007817500099.
- Rose, SK, D Turner, G Blanford, J Bistline, F de la Chesnaye, T Wilson, 2014. Understanding the Social Cost of Carbon: A Technical Assessment. EPRI, Palo Alto, CA. Report #3002004657.

EPRI's research led to participation on the National Academy of Science, Engineering, and Medicine (NASEM) SCC Committee. EPRI's assessment of the IWG Framework was a key input into the NASEM SCC Committee deliberations, published reports, and their recommendations to develop

3 U.S. 9th Circuit Court decision (Center for Biological Diversity vs. National Highway Traffic Safety Administration, United States Court of Appeals for the Ninth Circuit, No. 06-71891, November 15, 2007).

4 Section 5 at this link (Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis).



a new framework (NASEM, 2016, 2017). Rose et al (2017a) extends the analyses of Rose et al (2014), providing detailed tables on the structural elements of each component of the models used by the IWG Framework and experimental results elucidating model behavior within each component for projections to the year 2100 and 2300, including intermediate calculations within components for reference and GHG emissions pulse responses, and deterministic and probabilistic results. Rose et al (2017a) also discusses how the differences in models contribute to the significant differences in results between models and how the detailed insights into the modeling could be used to review the scientific reliability of models and assumptions to filter out indefensible elements.

EPRI researchers have also carried out analyses evaluating application of SC-GHG estimates in policy applications, and discussing SC-GHG modeling decisions that need to be made (Rose and Bistline, 2016; Rose, 2017; Bistline and Rose, 2018; Rose, 2012).

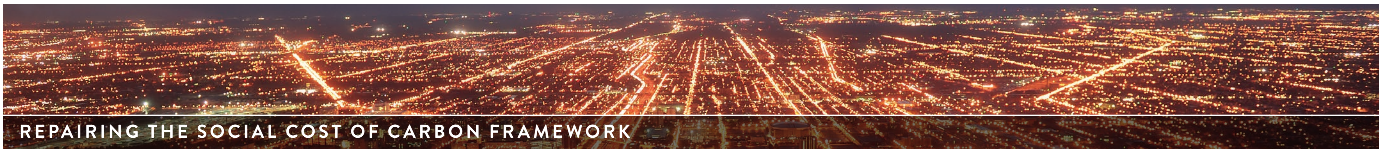
Based on EPRI's analyses, the NASEM deliberations, and other published carbon-value-related research and evidence, EPRI recommends, for scientific reliability and robustness, and for public confidence in results and decisions, the following:

1. Immediately revise the IWG Framework to remove underlying estimates based on models and assumptions that are not scientifically defensible.
2. Immediately provide guidance that addresses identified SC-GHG policy application issues.
3. Allow for sufficient scientific and public discussion for vetting substantive technical challenges for updating the SC-GHG estimation approach, including technical challenges for socioeconomic, climate, and damage component updates, as well as potential changes associated with discounting, environmental justice, and equity.
4. Evaluate and establish the robustness of future SC-GHG estimates to ensure that they are insensitive to reasonable alternative assumptions and components. If robustness cannot be established, consider alternatives for valuing GHGs in rulemakings.
5. For final estimates, plan a formal scientific and public review process appropriate for a regulatory methodology. Such a review is far more demanding than academic journal article peer review.

See subsequent sections for technical discussion of the research supporting these points. Note that, EPRI recently provided comments to New York State on their proposed SCC, SCM, and SCN estimates for valuing GHGs by state agencies (EPRI, 2020).

EPRI is a nonprofit, scientific research and development organization with a public benefit mission. EPRI strives to advance knowledge and facilitate informed public discussion and decision-making. EPRI has recognized scientific expertise in, among other things, the social cost of carbon and other greenhouse gases, climate scenarios, integrated assessment modeling, socioeconomic and energy system transformation, and climate policy evaluation, as well as a long history of research community leadership and participation in the NASEM, Intergovernmental Panel on Climate Change (IPCC), and National Climate Assessment.

EPRI staff have been conducting research specifically related to the SCC for over a dozen years, as well as research related to emissions and climate scenarios, integrated assessment modeling, climate policy modeling, and marginal abatement cost estimation for over four decades. As alluded to above, EPRI has conducted extensive analysis of the IWG's three SCC estimation models (DICE, FUND, and PAGE) and the multi-model IWG Framework used to produce the IWG's official SCC estimates (Rose et al, 2017a; Rose et al, 2014). This research revealed stark differences in how the models represent individual components in SCC calculations. It also found fundamental technical issues with the individual models and the overall framework that affect the scientific reliability and robustness of the results. This research was a key input into the NASEM SCC Committee deliberations and informed the NASEM SCC Committee Phase 1 and 2 studies and their recommendations (NASEM, 2016, 2017). EPRI's research and the NASEM study clearly indicate the need for improving SCC estimation.



Longer-run SCC-related research efforts are on-going at EPRI, as well as organizations like Resources for the Future, the Climate Impacts Lab, and others. However, a reliable and robust new generation of SCC estimates is likely still some time off, with significant methodological challenges remaining, and thorough scientific review needed. Note that, NASEM was not tasked with peer reviewing the IWG methodology nor has the IWG methodology ever been subjected to a formal scientific review process for regulatory use. Peer review of regulatory methodologies and models is a significantly higher bar than peer review of an academic journal article for intellectual merit.

Nonetheless, there continues to be immediate need for SC-GHG estimates for federal applications, as well as within states, now and in the near future. The technical issues identified in the current IWG models and methodology are significant. However, a minimum scientific standard based on the transparency, scientific basis, and plausibility requirements identified by the NASEM SCC Committee (NASEM, 2017) can be applied to improve SCC estimates immediately.

1. CURRENT RESULTS FROM THE IWG FRAMEWORK ARE NOT SCIENTIFICALLY RELIABLE OR ROBUST

An SCC estimate produced from the IWG modeling framework represents a discounted net present value sum of potential future damages from a unit of carbon dioxide emitted to the atmosphere (CO_2). A single estimate is based on an enormous amount of aggregation and averaging—across countries, types of potential climate impacts, 300 years, three different models (DICE, FUND, and PAGE), and 50,000 model runs per model with varying input assumptions. Given the geographic and temporal scope of the IWG Framework (i.e., global socioeconomic, climate, sea level rise, and impact projections through the year 2300), it is inherently complex and there is substantial uncertainty to consider. Understanding how potential societal futures translate into projected emissions, emissions into climate change, and climate change into specific climate damages, is impossible to discern without examining the details of the IWG Framework and the individual models and assumptions to see what, where, and when specific types of damage are projected.

EPRI has unique experience and expertise evaluating the inner workings of the IWG models and the overall framework. EPRI's research was motivated by a desire to understand how to interpret the IWG SCC estimates (e.g., $42/t$CO_2$ for 2020 at a 3% discount rate in 2007 dollars) in terms of actual types of estimated climate change damages and where and when they would occur (Rose et al, 2014; Rose et al, 2017a). Specifically, EPRI re-coded the IWG SCC models and ran diagnostics on the individual components/modules within each model, isolating each component and characterizing, comparing, and evaluating the model structure and behavior of each of the three models at each step of the calculations associated with estimating an SCC value. This analysis provided detailed insights into how each model represented emissions and other elements of radiative forcing; translated emissions into concentrations, radiative forcing, and temperature; translated temperature into regional temperature and sea level rise; and translated these climate change variables into estimated damages over time by type and region. As noted above, this analysis became a key input into the NASEM SCC Committee's studies and the foundation for their recommendations to develop a new modular approach and not to use the current models as is (NASEM, 2016, 2017).

EPRI's research helped explain why the three models produce dramatically different distributions of estimates (see Figure 1 for an example)—with PAGE (Hope, 2011) responsible for the long right tail in the IWG estimates (e.g., PAGE produces 93% of the 3% discount rate estimates above $110/tCO2), FUND (Anthoff and Tol, 2013) the only model with a distribution that includes some negative values, and DICE (Nordhaus, 2010) contributing to the thickness of the right tail. Through this research, EPRI identified fundamental differences in the way each model computes future global emissions, climate, and damages, responds to different assumptions, and represents uncertainty, as well as how they portrayed future society and its adaptation responses to climate change.

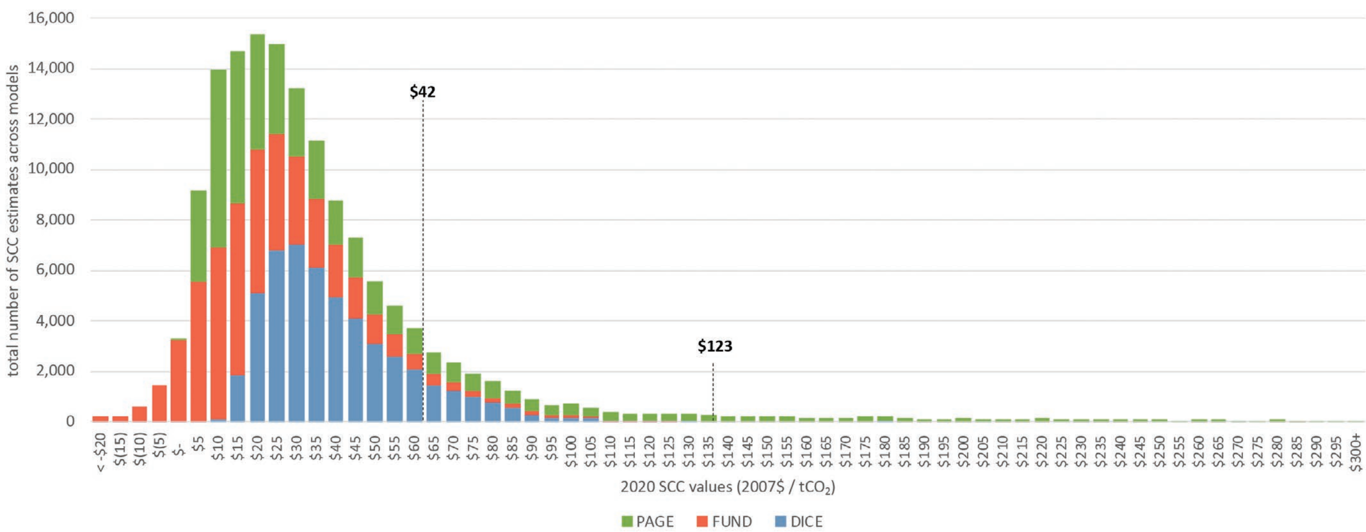


Figure 1: *Histogram of the 150,000 3% discount rate IWG SCC estimates behind the IWG's global average ($42/tCO$_2$) and 95th percentile ($123/tCO$_2$) SCC values for 2020 (Rose et al, 2017a). Each model produced 50,000 estimates. Each model's estimates are differentiated by color in the figure. Estimates shown in 2007 dollars.*

From the detailed component-level analyses, EPRI also identified fundamental technical issues with each model that call into question the scientific reliability and robustness of the current IWG methodology and undermine confidence in the current IWG SCC, SCM, and SCN estimates. See Rose et al, 2017a (both the paper and the supporting supplemental material – link) for details regarding the individual component structures, specifications, and behaviors for each model. The following is a high-level summary of model-specific issues discovered through the sequence of component assessments—socioeconomic, climate, sea-level rise, regional climate, and damages:

- **DICE** – climate feedbacks are not included in temperature modeling, projected non-CO_2 factors in climate projections are exogenous, implementation of the GHG pulse for SC-GHG calculations produces incremental climate change prior to the pulse year and inflates estimates, limited details regarding the quadratic global damage function calibration and justification, adaptation considered implicitly but specification details are lacking, parametric uncertainty limited to one parameter while the other models consider many more, and the climate damage specification is calibrated to the specifications in the other SCC models.[5]
- **FUND** – radiative forcing that drives global temperature change is only partially represented, climate modeling exhibits a long temperature response lag compared to the other models and literature, and the representation of climate benefits and adaptation need more rigorous uncertainty evaluation.
- **PAGE** – non-CO_2 radiative forcing is incomplete and elements exogenous, equilibrium climate sensitivity implementation is missing key functionality, carbon cycle response is relatively slow compared to the other models and literature, implementation of the GHG pulse for SC-GHG calculations produces incremental climate change prior to the pulse year and inflates estimates, regional damage estimates are scaled to damages estimates for the European Union (EU) instead of calculated independently and lack justification, some damage categories are undefined (e.g., "discontinuity" damage), adaptation response is fixed across scenarios, and the climate damage specification is calibrated to the specifications in the other SCC models.

[5] Note that the damage representations in all three models are based on climate impacts literature dating to the mid-1990s and early 2000s. FUND's damage representation is directly based on that literature, while the DICE and PAGE damage representations are indirectly based on that literature because their representations are a function of FUND's representation and older versions of themselves and each other.

Furthermore, the documentation for the individual models varies significantly, with transparency and justification lacking to support individual model structural features, parameter choices, and model component behavior. FUND is the most transparent, and PAGE is the least.

EPRI's research also assessed the IWG's overall multi-model framework—the "IWG Framework." The IWG Framework consists of aggregating 150,000 results from running the DICE, FUND and PAGE models 50,000 times each with prescribed inputs and discounting and deriving average estimates. Using the component-level assessment and evaluation of the models, EPRI's overall assessment identified the following as fundamental scientific issues for the framework that need to be addressed for credibility and confidence in the overall approach and resulting estimates:

- Transparency and justification for IWG Framework choices,
- Justification for the structural and behavioral differences found in the three models,
- Justification of the representation of input and parametric uncertainty (versus alternatives),
- Evaluation of comparability and independence of results across models, and
- Evaluation of the robustness of results (found to be unlikely with the current framework given reasonable alternative assumptions, e.g., for socioeconomic futures, the climate sensitivity parameter, and climate modeling).

EPRI's study concluded with the overarching recommendation to reconsider the multi-model approach and consider developing a new, single model component-by-component, because the multi-model approach creates challenges that are difficult to overcome related to transparency, justification, comparability, and independence. Rose et al (2017a) also concluded with a discussion of how the detailed insights into the IWG Framework could be used to review the scientific reliability of models and assumptions to filter out indefensible elements.

2. NEED TO IMMEDIATELY REVISE SCC, SCM, AND SCN ESTIMATES BY EXCLUDING MODELS AND ASSUMPTIONS THAT ARE NOT DEFENSIBLE

Given continued interest in having and using SCC values and the issues EPRI and others have elucidated with the IWG Framework and individual models, there is a clear need to repair the framework immediately. Replacing the entire approach, as recommended by NASEM, will take time, with significant technical challenges still needing to be addressed (see Section 4 for discussion). In the interim, EPRI suggests applying a minimum scientific standard to identify the more defensible modeling and estimates. The NASEM SCC Committee identified the following requirements for SCC modeling (NASEM, 2017): transparency, scientific basis (justification, consistency with state of knowledge), and characterization of uncertainty. These are essential for evaluating the modeling and establishing scientific reliability and robustness for informing and influencing actual public and private sector decisions.

A minimum scientific standard corresponding to the NASEM requirements would imply the following, which can be applied to each model and the modeling inputs:

- **Transparency** – Is enough documentation provided to describe what is modeled?
- **Scientific basis** – What is the scientific justification provided for modeling choices? Does the modeling have the minimum necessary functionality?
- **Plausibility** – Are the assumptions and modeling reasonable?

Satisfying these criteria allows for model users to understand what was done and why, that the modeling has what is needed for the purpose, and that what is going in and coming out of the model makes sense. This is a very conservative standard—an absolute minimum for defensibility.

Table 1. *Model evaluation according to the minimum scientific standard*

Scientific Criteria	DICE	FUND	PAGE
Transparency	e.g., damages calibration	Most things described	e.g., unspecified discontinuity damages
Minimum scientific justification	e.g., quadratic damages	e.g., probabilistic parameters	e.g., unsubstantiated discontinuity damage, regional damages scaling, & probabilistic parameters
Minimum scientific functionality	e.g., no climate feedback	e.g., partial radiative forcing	e.g., climate modeling missing structural element
Plausibility	Adequate	e.g., some probabilistic outcomes	e.g., some probabilistic outcomes

Green evaluation indicator = adequate; Yellow = meets minimum but could be improved; Red = inadequate.
Text entries are examples of model specific issues listed in the previous section that support the evaluation color.

Table 1 presents the results from applying this minimum scientific standard to the individual models. Red implies that a model does not meet the minimum criteria, while green represents an adequate level, and yellow represents meeting the minimum but there is room for improvement. Text entries are examples of model specific issues listed in the previous section that support the evaluation color. Note that none of the IWG models receive all green indicators, thus there is room for improvement in all. PAGE, however, has red indicators suggesting that it does not meet the minimum criteria for transparency, scientific justification, and scientific functionality. For instance, PAGE includes a damage category referred to as "discontinuity damage" that is undefined in model documentation and code (Hope, 2011). The details of how this type of damage is modeled is not defined, justified, and specified in terms of any specific type of potential global discontinuity and current scientific understanding (e.g., ice sheet collapse, slowing of ocean circulation).

In addition to the discontinuity damage, the PAGE documentation also lacks justification for its regional damage scaling (estimated non-EU damages are simply a scalar function of estimated EU damages), as well as its probabilistic climate and damage component parameter specifications. Regarding minimum functionality, PAGE's climate model component is missing a key structural element identified by climate science (e.g., Urban et al., 2014) that adjusts ocean heat uptake when changing the equilibrium climate sensitivity (ECS) parameter in order to ensure consistency with historical temperature observations. The IWG Framework uses random draws from an ECS distribution for its calculations. Without countervailing adjustments related to ocean heat uptake, PAGE's temperature change responses for a given emissions pathway are significantly more sensitive to alternative ECS values, resulting in higher climate change signals that contribute to its higher SCC estimates (Rose et al., 2017a).

While there is some subjectivity in whether a model receives a green or yellow indicator in Table 1, the red indicator threshold is stark: the model does not have what is needed at a bare minimum to understand, evaluate, and establish a reliable scientific basis for its results. See Rose et al (2017a) paper and supplemental material for more details, discussion, and insights regarding the specific entries of Table 1.

The minimum standard can also be applied to the socioeconomic and emissions input projections used in the IWG Framework, evaluating their plausibility in the near-term and long-run. Importantly, the incremental damage of an additional unit of emissions is dependent on the socioeconomic and emissions pathway assumed. The pathway drives the potential future climate in each model, as well as defines the future society exposed to climate change. The IWG Framework uses five global socioeconomic and emissions projections to the year 2300. Evaluating near-term consistency with historical emissions trends, we find one IWG projection to be implausible in the near-term (USG5

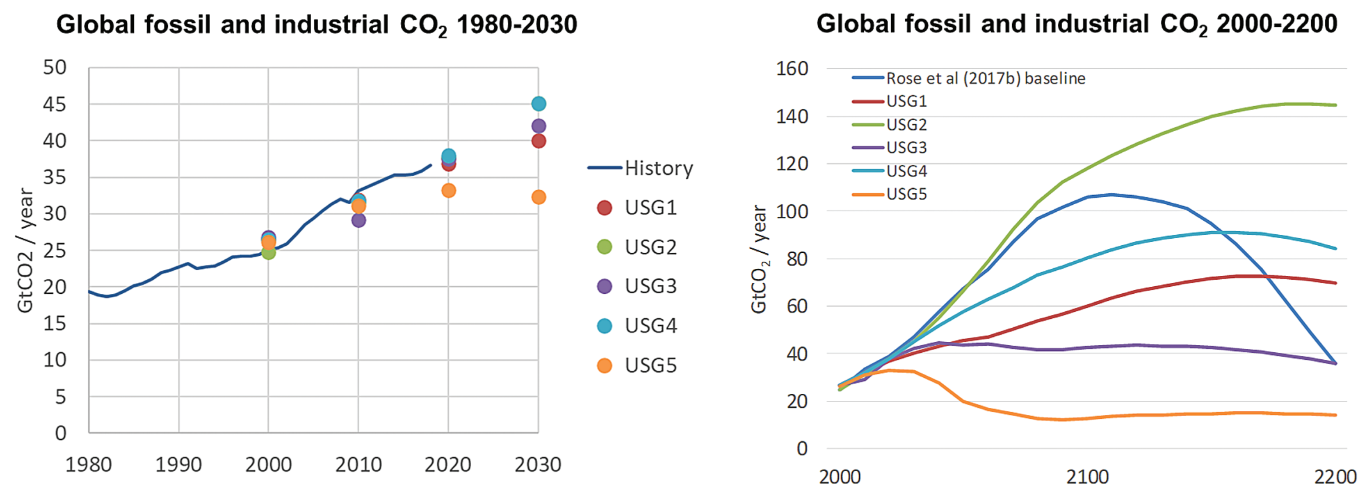


Figure 2: *Near-term and long-run plausibility evaluation of the IWG Framework emissions projections*

in Figure 2 left panel). USG5 is below current emissions and its 2020 peaking is inconsistent with the current upward trend in global emissions. USG5 in 2030 is also below expectations about what country pledges advanced during the Paris Agreement might achieve.

EPRI also evaluated the long-run projections taking into account global fossil resource constraints and regional air pollution policies that are likely if global fossil fuel use continues to grow. Comparing the long-run projections to modeling that considers both issues (Rose et al, 2017b), we conclude that one IWG scenario is implausible in the long-run (USG2 in Figure 2 right panel). The projection from Rose et al (2017b) is a baseline scenario (i.e., no additional climate policy from today) and its emissions pathway is simply shaped by economics and air quality policy, with fossil resource scarcity and regional air pollution constraints leading to a peak and decline in global fossil and industrial CO_2 emissions beyond 2100.

After applying the minimum standard to the models and inputs, we conclude that DICE and FUND and the first, third, and fourth emissions scenario results (USG1, USG3, USG4) satisfy minimum scientific criteria for transparency, scientific basis, and plausibility; while, PAGE and the second and fifth emissions scenarios (USG2, USG5) do not. Based on this assessment, we calculate new SCC estimate distributions, and average and percentile statistics, filtering out the IWG calculations that do not meet the minimum standard. Table 2 summarizes the multi-model estimates based only on the IWG models and assumptions that meet the minimum standard for scientific reliability. For instance, the improved SCC distribution for the year 2020 with a 3% discount rate (and in 2020 dollars) has a mean of \$40/tCO_2 and 5th and 95th percentiles of \$1 and \$94/tCO_2 respectively (versus mean \$53 and 5th and 95th percentiles of \$2 and \$157/tCO_2 respectively from the original IWG Framework distribution).[6]

Through intimate understanding of the IWG Framework, we are able to identify estimates that satisfy the minimum scientific standard and are defensible. The same adjustments should also be made to the IWG Framework's SCC estimates for future years, as well as the SCM and SCN estimates based on the same IWG Framework (Marten et al, 2015; IWG, 2016b).[7] EPRI would be willing to help the Biden Administration with these calculations, and has done many of them already.

6 Estimates converted to 2020 dollars from the IWG's 2007 dollars estimates (IWG, 2015, 2016a) using a consumer price index deflator of 1.27.

7 Note that the IWG social cost of non-CO_2 estimates (IWG, 2016b; Marten et al, 2015) are not fully consistent with the IWG SCC estimates because DICE and PAGE do not model CH_4 and N_2O atmospheric concentrations or radiative forcing (Rose et al, 2017a), and thus substitute climate modeling was required; and, DICE has only a single global region and does not model U.S. damages explicitly. Also, the same SCC distribution improvements EPRI recommends should be made to the domestic SCC estimates used by the Trump Administration, which are based on the IWG Framework. For instance, the repaired distribution for U.S. SCCs for the year 2020 (and in 2020 dollars) with a 3% discount rate has a mean of \$1/tCO_2 and 5th and 95th percentiles of approximately \$0 and \$4/tCO_2 respectively (versus mean \$6 and 5th and 95th percentiles of \$0 and \$27/tCO_2 respectively from the original IWG Framework distribution).

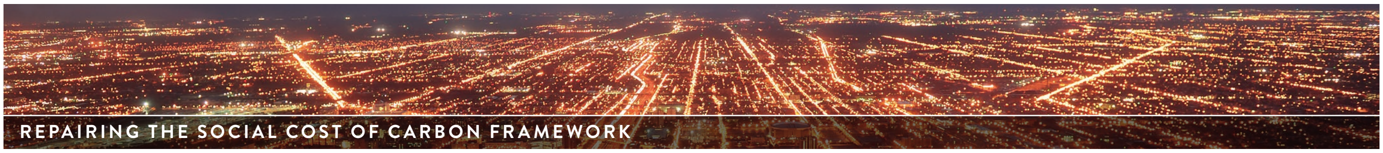


Table 2. *SCC estimates for CO_2 emissions in 2020 from repairing the IWG Framework to be consistent with the minimum scientific standard ($2020). Repaired and orginal estimates shown.*

	Discount rate	5th percentile	Average	95th percentile
Repaired framework SCCs for 2020	**2.5%**	$5	$64	$147
	3%	$1	$40	$94
	5%	($4)	$10	$27
Original IWG Framework SCCs for 2020	**2.5%**	$5	$79	$228
	3%	$2	$53	$157
	5%	($3)	$15	$45

3. USE DISCOUNT RATES OF 2% TO 5%, OR RATES CONSISTENT WITH GROWTH ASSUMPTIONS, IN SC-GHG ESTIMATION

The 300-year time horizon associated with the IWG Framework, and the underlying projections that most of the damages occur many decades into the future (Rose et al, 2014, 2017a), is why the SCC estimates are so sensitive to the choice of discount rate, and why it is important that the discount rate approach be well-grounded in science. The IWG uses 2.5%, 3%, and 5% values, with 3% the "central" value. Recently, some have suggested using rates of 2% or lower (New York State Department of Environmental Conservation, 2020; Carleton and Greenstone, 2021). Based on the evidence discussed below, and the types of applications, EPRI finds justification for a range of 2% to 5%, but not for using values below 2% or for ruling out values above 3%.

The discount rate is important as it reflects the fact that society, in the decisions we observe every day in many contexts, places greater importance on current consumption than future consumption. For consistency with society's revealed preferences, the discount rates used in policy need to reflect the trade-offs between current and future consumption that society has shown they are willing to make. The recent evidence in this regard, including Drupp et al (2018), CEA (2017), and Giglio et al (2015), suggests a lower bound around 2%. Discount rates also need to support consistent decision making across policies and agencies to ensure consistency in budgetary decisions. This is an additional argument for ruling out discount rates not in line with observed decisions. Furthermore, the discount rate is not a policy lever for achieving goals, nor something to adjust to compensate for the state-of-the-art in estimating damages. Instead, the discount rate should be considered independently from the estimation of damages in order to properly reflect the temporal consumption preferences of society.

At the upper end, the IWG's use of 5% was to account for the possibility that climate damages are positively correlated with interest rates, which was a reasonable approach since the IWG chose to use constant discount rates over time instead of dynamic discounting based on the Ramey equation, which adjusts the discount rate according to the rate of growth in per capita consumption. As a point of comparison, Nordhaus (2017) uses dynamic discounting calibrated to market behavior that results in an average discount rate of 4.25% per year during the period to 2100. In addition, the damages represented in the IWG modeling are not all consumption related, e.g., sea-level-rise and storm surge impacts on infrastructure (Rose et al, 2017a, 2014). This is important because 3% is characterized by OMB, NASEM, and others as the discount rate appropriate for discounting consumption effects, while 7% is characterized as appropriate for discounting investment effects. Furthermore, an issue related to the type of investment is the length of the investment. Emitting (or avoiding) CO_2 is an over 100-year investment because CO_2's atmospheric lifetime is 100 years and climate inertia effects continue beyond that. Thus, when looking for evidence of observed trade-offs citizens are willing to make, we are not interested in short-term investments, such as 10-year U.S. treasuries (e.g., Carleton and Greenstone, 2021), but instead much longer investments such as 30 or more years and considering fluctuations over equally long time horizons. Finally, constant discount rates are inconsistent with economic growth assumptions, and potentially significantly so, which is something that needs to be evaluated and considered.

An alternative to constant discount rates based on observed social trade-offs would be to use dynamic discounting calibrated to market behavior like that done in Nordhaus (2017). This approach ensures consistency and coherency between discounting and projected economic consumption growth assumptions, as well as consistency with near-term observed behavior. The resulting discount rates would vary over time and socioeconomic scenario, as well as potentially by global region. This is the approach recommended by NASEM (2017).

Finally, EPRI notes two issues related to using SCC estimates based on different discount rates. First, is the impression that there are infinite mixing and matching possibilities with discount rates across cost-benefit analysis calculations. Economics constrains the possibilities to the discount rates appropriate to the types of economic values being estimated and the trade-offs society is willing to make. Second, as recommended by NASEM (2016), uncertainty in SC-GHG estimates should be communicated for a given discount rate and incorporated into policy analyses by using SC-GHG ranges for each discount rate, such as shown in Table 2. This issue is discussed more below.

4. FOR PRESIDENT BIDEN'S FINAL REVISED SC-GHG ESTIMATES, THE IWG FRAMEWORK NEEDS TO BE REPLACED, HOWEVER THERE ARE SCIENTIFIC CHALLENGES TO ADDRESS AND AN EXPLICIT SCIENTIFIC REVIEW PROCESS IS NEEDED

There are significant scientific challenges that need to be confronted before a new framework can be put in place. Furthermore, a scientific and public review process appropriate for regulatory methodologies is essential for scientific reliability and public confidence. Note that, it may be difficult to address the scientific challenges and allow for a proper scientific review within a year as suggested in President Biden's Executive Order.

4.a. Challenges and opportunities for replacing the IWG Framework

There are many opportunities for improving SC-GHG estimation from the IWG Framework—for instance, improving inputs, refining elements, and/or replacing components. The list of model-specific issues earlier identifies many of the individual opportunities, and Rose et al (2017a) and NASEM (2017) discuss component and framework opportunities. There is also the option of replacing the IWG Framework entirely in the long-run and implementing the set of NASEM recommendations. All of these opportunities represent substantive changes that will require justification and scientific and public review, well beyond peer reviewed publication, for them to be scientifically reliable for regulatory and agency applications with significant financial and budgetary implications. Note that we have already begun to see some public sector refinements to the IWG calculations, such as the Minnesota Public Utility Commission truncating the IWG calculation time horizon to 2100 for SCC estimates it now uses in utility resource planning, as well as dropping the IWG's 95th percentile 3% SCC estimate.

Long-run research efforts to improve SC-GHG estimation are on-going at EPRI, as well as Resources for the Future, the Climate Impacts Lab, and many others. However, there are substantive methodological challenges that will need to be addressed before we can have a scientifically defensible and publicly credible new generation of estimates. Component specific issues are discussed below, but overarching issues include:

- **Newer doesn't imply better**: details matter and assessment of methods and biases is required.
- **Comparability and aggregation problems**: methodological differences and inconsistencies can undermine comparability, aggregation, and synthesis and calls for reconciliation of differences, as well as more subtle approaches for using the different lines of evidence.
- **Drivers beyond temperature change and sea-level rise**: the impacts of climate change are a function of more than temperature change, with additional climate variables and non-climate variables affecting societal exposure and vulnerability, as well adaptation potential.
- **Characterizing uncertainty**: with SC-GHG estimates highly sensitive to assumptions, accounting for uncertainty is essential for robust estimates; however, defensibly specifying input, parametric, and model uncertainties is challenging.

There are technical challenges for each component associated with estimating SC-GHGs. In addition to discounting (discussed above), there are substantive technical challenges for adequately projecting socioeconomic and emissions futures, including representing uncertainty not only in emissions, but also society, including uncertainty in the structure of regional economies and populations, as well as accounting for the plausibility of projections (e.g., Rose and Scott, 2020), and assigning probabilities to futures. Meanwhile, updating the climate modeling component will require evaluating modeling alternatives that produce significantly different projections and representations of uncertainty (e.g., FAIR versus MAGICC climate model temperature projections in the IPCC's Special Report on 1.5°C; IPCC, 2018; Huppmann et al, 2019).

Additional issues, such as environmental justice, equity, and risk, are also important discussions, where discussing, evaluating, and communicating alternatives will be challenging. Regarding environmental justice and equity, a question is whether the SC-GHG estimates should be increased to give greater weight to damages on poorer populations. "Equity weighting" acknowledges differences in marginal utility, which is appealing; however, it no longer reflects actual willingness-to-pay (Rose, 2012; Goulder, 2007). Furthermore, equity weighting creates an inconsistency problem for regulatory analyses that need to compare benefits and costs in identical monetary units, and equity weighted SC-GHGs also pose a problem for coordinated international mitigation if each country weights from their own perspective.

Developing a new climate damages component will be particularly challenging. Recent literature has offered additional global, national, and sectoral estimates for the potential economic damages of climate impacts based on significantly different methods—structural versus empirical economic modeling (e.g., Burke et al, 2015; Takakura et al, 2019; Roson and Sartori, 2016; Howard and Sterner, 2017; Hsiang et al, 2017; USEPA, 2017). Structural economic modelling and empirical modelling are fundamentally different, which the NASEM SCC Committee identified as an issue affecting the comparability of results (NASEM, 2017). Understanding, assessing, and reconciling differences in methods and biases needs to be a priority. Estimates based on empirical methodologies are categorically higher than structural estimates due, in part, to fundamental differences in the modelling of socioeconomic systems and adaptation. For instance, looking at central estimates, structural modeling approaches such as Takakura et al (2019) and those evaluated by Rose et al (2017a) estimate damages of 0.4 to 2.5% and -0.3% to 1.2% respectively for 2°C of global average warming, compared to empirical modeling estimates by Burke et al (2015) and Pretis et al (2018) of approximately 10 to 35% and 5% to 13% respectively for the same level of warming. There are similar large discrepancies between the methods in regional and sectoral damages estimates (e.g., U.S. estimates from Hsiang et al, 2017, versus USEPA, 2017).

Also, within empirical modelling, results are found to exhibit sizable errors (e.g., the short-run pooled Burke et al, 2015, 90% confidence interval ranges from sizable global gains to sizable losses at approximately -10% to +25% and -50% to +50% of global GDP per year for 2°C and 4°C of global warming respectively), as well as be very sensitive to the statistical model specification. In general, damage estimation critiques and commentaries include, among other things, concerns about empirical methods estimating weather but not climate relationships, out-of-sample extrapolation, and limited consideration of socioeconomic dynamics and responses; concerns about the observational basis of structural modelling; overall concerns about sufficient modelling details, transparency, and justification; critiques and recommendations regarding methods; and questioning the ability to generate robust estimates (Pezzey, 2019; NASEM, 2017; Rose et al., 2014, 2017a; Pindyck, 2017; Diaz and Moore, 2017; van den Bergh & Botzen, 2015).

There are other methodological challenges that also need to be addressed in developing a new damage component: the need for significantly greater transparency and assessment of details and assumptions in newer and older damage methods; calibration of functional representations and data sufficiency for climate and non-climate drivers and non-linearities, especially for levels beyond observations; estimating and representing damage uncertainty;

combining estimates from different sources; aggregating sectoral and regional results that are not additive; evaluating and establishing robustness of estimates including sensitivity to model specification; capturing interactions and spillovers between regions and sectors; estimating welfare implications versus GDP changes; consideration of distributional effects; representing micro and macro adaptation processes (and adaptation costs); and representing nongradual damages.

Critical assessment by the Biden Administration is needed to understand, evaluate, and reconcile the broad ranges and large differences in damage estimates. In addition to taking stock of and assessing the available science, the Biden Administration should consider taking advantage of the IPCC's scientific assessment of the climate damages literature underway in the development of the IPCC's Sixth Assessment Report, which also includes important assessments related to socioeconomic and emissions projections and climate system dynamics. The reports associated with the assessment are expected to be published in 2021 and 2022 (www.ipcc.ch).

Ultimately, the public needs: (1) scientifically reliable estimates that have gone through a detailed methodological scientific review appropriate for regulatory applications with significant financial and budgetary implications (see Section 4b), (2) robust estimates that are insensitive to alternative assumptions because they effectively incorporate relevant uncertainties and demonstrate it, and (3) stable estimates over time that facilitate efficient public and private sector planning. Significantly greater transparency and justification than in the past will be needed. Rose et al (2014 and 2017) are examples of the level of detail needed for proper scientific evaluation and public understanding.

Finally, EPRI's IWG Framework modeling assessment findings also inform discussion of whether current estimates are too low and should represent a lower bound based on omitted damages. The only way to assess the direction of the scientific bias in current IWG estimates is to first understand the modeling and correct for technical flaws. Correcting for some of the technical issues as we have recommended above in developing improved estimates (Table 2), suggests that the IWG Framework estimates have some degree of upward bias (i.e., they are too high). In addition, given the stark differences in the types of damages each of the three IWG models includes, and how they are represented (Rose et al, 2014, 2017a), it is impossible to generalize about the bias in the IWG multi-model average SCC estimates. There are potential biases in both directions. There are omitted damages, such as biodiversity, ocean acidification, extreme weather, and arctic access. However, the current modeling also includes questionable elements that are contributing to higher estimates, such as PAGE's "discontinuity" damage and its ECS modeling issue discussed above, DICE's and PAGE's limited adaptation responses and emissions pulse implementation, and PAGE's and FUND's uncertainty specifications (e.g., with some combinations producing damage estimates with 100% GDP losses in some regions). Furthermore, current modeling is also limited in its representation of adaptation processes (micro and macroeconomic) due to the state of the art in the underlying climate impacts literature. Note that potential "big" global risks (e.g., ocean acidification) are unlikely to be affected by a single metric ton of CO_2, which is how an SCC estimate is calculated, and will therefore have little to no impact on SCC estimates.

4.b. Establishing robust SC-GHG estimates is a daunting challenge, so may need to consider alternatives for meeting the legal requirement to value GHGs in rulemakings

If the robustness of SC-GHG estimates cannot ultimately be established, the Administration may need to consider alternatives for meeting the legal requirement to value GHGs in rulemakings.

An alternative to calculating the SCC is to develop marginal abatement cost estimates. The significant SCC modeling challenge of trying to model global physical and economic systems for hundreds of years implies substantial uncertainties and sensitivity of estimates and makes robust estimates elusive. Many authors have highlighted this issue (e.g., Pezzey, 2018; Kaufman et al, 2020; Rose, 2012), with some suggesting that reliable, robust estimates are not possible (e.g., Pezzey, 2019; Pindyck, 2017), and some policy makers who initially embraced the SCC have moved away from it for this reason and others (e.g., the United Kingdom; DECC, 2009).

Marginal abatement cost estimates represent an opportunity for consistency with emissions reduction ambition. Estimates of the marginal costs of reducing emissions over time can be calculated from an assessment of the U.S. economy-wide emissions reduction goal. A marginal cost estimate in a particular year from this analysis represents the cost of the last unit of emissions reduction that year, i.e., the additional cost of the most expensive technology required. These marginal abatement cost estimates are consistent with the overall emissions goal and they could be applied by agencies as a proxy for the benefit of reducing emissions, implying that the marginal benefits of the overall emissions goal are greater than the marginal costs. Key uncertainties affecting marginal abatement costs (e.g., economic growth, available technologies, markets, policy design) would still need to be evaluated and would result in a range of marginal abatement cost estimates that agencies could apply.

4.c. A formal and appropriate scientific and public review process is essential

As noted, the IWG Framework never went through a scientific review for regulatory use. Such a review is fundamentally different from an academic journal article review. Peer review of a journal article emphasizes intellectual contribution, while scientific review of a methodology for regulatory use emphasizes scientific integrity and robustness. Journal review is focused on advancing knowledge, while regulatory review is focused on public credibility for guiding decisions with significant social and financial implications. The stakes are substantially higher for regulatory scientific review and the process is rightly more critical, thorough, detailed, methodical and painstaking than journal review as anyone involved in such a process will attest. Not to mention that the process also needs to be public.[8]

It is important that the U.S. Government take ownership of whatever approach they pursue. The Biden Administration will not be able to simply adopt what is available. They will have to make hard methodological decisions (see the list in Rose, 2012) and defend those choices, communicating alternatives and justifying the approach taken.

A dedicated formal scientific review for regulatory use is essential for the public to have confidence in the SC-GHG estimation methodology, results, and their use. Among other things, this would entail assembling a scientific review panel with the appropriate expertise, and without conflicts of interest (or involvement in the methodology's development), and allowing for public input, and enough time to fully understand and evaluate the methodology. For the integrity of science and public decisions, the process needs to be improved substantially from what was done previously with estimates appearing for the first time within rulemakings, and insufficient discussion, time, and independent expertise applied to the methodology.

5. NEED TO IMPROVE SC-GHG USE AS WELL FOR RELIABLE CLIMATE BENEFITS AND NET BENEFITS CALCULATIONS

While choosing SC-GHG values is the focus of the President's Executive Order, separate, independent issues associated with applying the estimates are also important for the Administration and the public to understand and address. Over the last few years, EPRI has produced studies related to SC-GHG application (Rose and Bistline, 2016; Bistline and Rose, 2018; Rose, 2017; Rose, 2012). This work is also relevant to use of other types of carbon values, like marginal abatement cost estimates. In particular, EPRI's evaluation of federal, state, and other SCC applications identified the following technical issues to avoid in order to develop sound and credible estimates for GHG reduction benefits and net policy benefits (Rose and Bistline, 2016):

- **Valuing/pricing the same CO_2 or other GHG emissions more than once** across policies and jurisdictions.
- **Not accounting for net GHG emissions changes** beyond the segment regulated (or managed) to capture leakage that affects the net climate benefits of a policy.
- **Inconsistencies** across benefit, emissions, and cost calculations being combined in cost-benefit analysis and other policy applications, e.g., inconsistencies in underlying assumptions and representations of uncertainty (for instance, economic growth, energy system, markets) and the types of values estimated and compared (for instance, annualized, annual, net present value).

[8] For examples of the extensive scientific and public process associated with methodology peer review, see the scientific reviews of U.S. EPA's proposed biogenic emissions accounting methodology (Khanna et al, 2012, 2017) and review of individual regulatory models, like that for U.S. EPA's Second Generation Model (link).

- **Not considering uncertainty in carbon value estimates** for a given discount rate and not providing guidance on how to consistently use multiple SCC estimates across policies and agencies.
- **Recognizing that there are different types of SCC estimates** and the relevant type depends on the application (Rose, 2017).

Regarding leakage, Bistline and Rose (2018) evaluated the potential for leakage from applying a regional carbon value in the U.S. and found notable leakage outside the regulated jurisdiction in all cases. Regarding multiple carbon values, there is clearly uncertainty in SCC and marginal abatement cost estimates such that agencies will want to consider this uncertainty to properly evaluate and inform decisions. This does not mean using a range of estimates with varying discount rates, but ranges of estimates for a given discount rate as recommended by the NASEM SCC Committee in their Phase 1 study (NASEM, 2016). Table 2 above provides an example consistent with the NASEM recommendation by including both 5th and 95th percentile estimates for each discount rate.

In addition, across policies and jurisdictions, there is a risk of explicitly or implicitly pricing/valuing CO_2 or other GHGs more than once. Pricing emissions more than once will result in excess cost to society and lead to an inefficient allocation of resources. We already see this happening at and across federal and state levels. For instance, coal mine permitting, public utility commission externalities pricing, and a federal clean energy standard (or Clean Power Plan) would all price the same CO_2. Similarly, the same CO_2 would be priced by a low-carbon technology subsidy, regional emissions cap, and state clean energy or renewables standard, as would wholesale power pricing of CO_2, a state emissions constraint, low-carbon subsidies, and end-use carbon reduction related subsidies.

Figure 3 illustrates how multiple CO_2 pricing is economically inefficient. In Figure 3, CO_2 pricing on top of an emissions cap increases the cost of emissions cap compliance. The marginal cost curve in Figure 3 represents the increasing

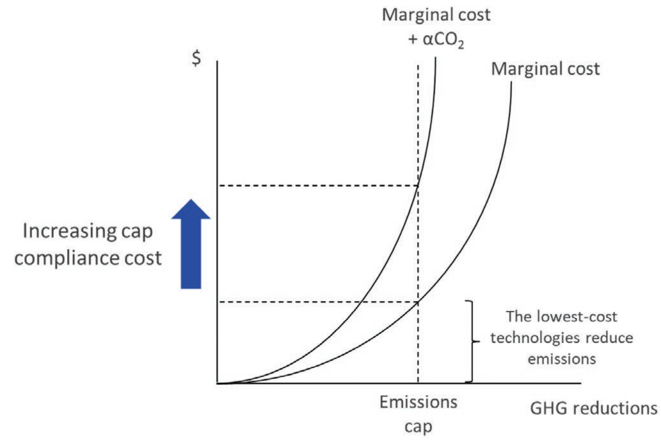
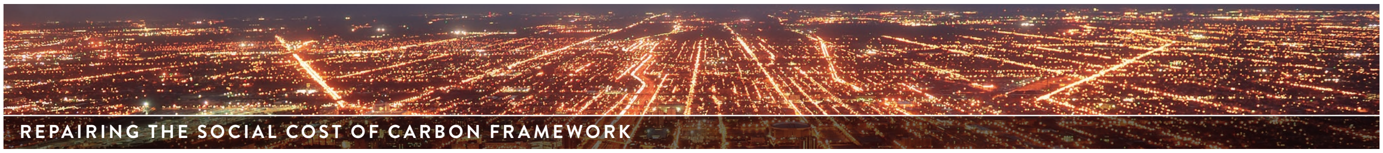


Figure 3. *Illustration of how valuing CO_2 more than once can be economically inefficient (in this example, increasing compliance cost with no emissions reduction benefit)*

cost of reducing emissions, with the lowest cost emissions reduction options deployed to comply with the emissions cap. The cap constrains emissions and creates an implied price on CO_2 that is internalized into decisions. Adding an explicit CO_2 price (αCO_2 with α equal to the carbon value applied to CO_2 emissions, e.g., α = an SCC estimate) only increases the cost of cap compliance without increasing emissions reductions. Some state level proposals for wholesale CO_2 pricing of electricity have recognized this issue and suggested adjusting the carbon value for the GHG emissions allowance price (e.g., $\alpha 1 = \beta SCC$, with β greater than 0, but less than 1). However, the problem persists. While $\alpha 1$ is smaller than the SCC estimate, $\alpha 1$ is still positive and increasing the cost of compliance and creating an inefficient allocation of society's resources. The solution to this problem is recognizing when GHGs are already priced to ensure that a GHG is only valued once.

EPRI recommends that the Biden Administration consider the technical issues discussed above in the use of SC-GHGs, or other carbon values, in policy assessments and provide guidance to agencies; in particular, regarding avoiding pricing GHG emissions more than once, accounting for GHG emissions leakage, and how to use multiple SC-GHG values within and across discount rates.



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