AESC 2021 Supplemental Study

Update to Social Cost of Carbon Recommendation

Prepared for AESC Supplemental Study Group

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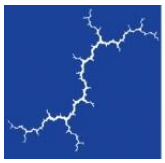

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

In summer 2021, the Massachusetts energy efficiency Program Administrators (MA EE PAs) contracted with Synapse Energy Economics, Inc. (Synapse) to update the recommended social cost of carbon (SCC) to be used in the 2022-2024 Three-Year Energy Efficiency Plan. Synapse most recently recommended a value for the SCC in the *AESC 2021 Study*.[1]

For this update, Synapse worked with a stakeholder group to evaluate the latest information available and compose a recommendation. The stakeholder group, called the AESC Supplemental Study Group, includes the MA EE PAs from Eversource, National Grid, Cape Light Compact, Unitil, Liberty, and Berkshire Gas, along with representatives from Massachusetts state agencies and organizations—including Massachusetts Department of Energy Resources (DOER), Massachusetts Department of Environmental Protection (DEP), the Office of the Massachusetts Attorney General (Mass AGO), and Massachusetts Energy Efficiency Advisory Council (EEAC).

Based on the latest available information, we recommend an SCC equal to $393 per short ton (in 15-year levelized terms, in 2021 dollars).[2] Our justification for recommending this updated SCC is as follows:

- The MA EE PAs will soon file a draft 2022–2024 three-year plan on energy efficiency and demand resources with the Massachusetts Department of Public Utilities (DPU). The MA EE PAs are seeking to ensure that avoided cost values used to calculate benefits for energy efficiency measures are based on the most up-to-date information available. These avoided cost values will be the basis of benefits for measures installed through December 2024, and many of these measures' effects will last for decades.

- The AESC 2021 chapter addressing the SCC was written in February 2021 and first published in March 2021. In it, Synapse recommended a 15-year levelized SCC value of $128 per short ton (in 2021 dollars). In AESC 2021, Synapse noted, "It is possible—even likely—that this value will change as new information becomes available" and that program administrators should continually review this value and potentially update it.[3] Relative to the other avoided cost categories evaluated in the *AESC 2021 Study*, the

[1] The most recent edition of the *AESC 2021 Study*, at the time of this document's writing, was released in May 2021. It is available on the Synapse website at https://www.synapse-energy.com/project/aesc-2021-materials.

[2] In most contexts, the SCC should also be applied to other greenhouse gases (GHGs) (e.g., methane, nitrous oxides, refrigerants), not just carbon dioxide. In these situations, the SCC may be converted to other units (e.g., dollars per short ton of methane, rather than dollars per short ton of CO_2) using a series of calculations that seek to estimate the equivalent impacts of different GHGs. Or the social cost for other GHGs may be calculated independently in the same models used to estimate the SCC. For purposes of simplification, this text makes reference to "SCC" only, although the value recommended in this document may appropriately be converted and applied to other GHG emissions as necessary.

[3] AESC 2021 Study, page 179.

recommended SCC is large and uncertain.[4] As such, it should be reconsidered along with any new information at this time, before the 2022–2024 three-year plan on energy efficiency is filed in October 2021. The AESC 2021 RFP specifically directs the AESC consultant to consider costs of greenhouse gases (GHG) that are "reasonably expected to be enacted," making it clear that the best possible effort should be made to estimate SCC values expected to be analyzed and issued in the very near future, including by the federal government.[5]

- The Federal Interagency Working Group (Federal IWG), the federal organization tasked with issuing guidance on the SCC, plans to issue a "comprehensive update" to the SCC in January 2022. The Federal IWG published a Technical Support Document and request for comments in the *Federal Register* in May 2021. This document elicited over 17,800 comments from the public between May and June 2021, and it greatly expanded the recent literature pertinent to estimating an SCC.[6]

Based on the data available in this recent literature, we recommend that the MA EE PAs use an SCC equal to $393 per short ton.[7] This value is based on the SCC recommendation issued by the Federal IWG, but is evaluated using a 1 percent discount rate, rather than the 3 percent discount rate recommended by the Federal IWG. While it is impossible to know with absolute certainty which sets of SCC values the Federal IWG will recommend in its comprehensive update (or what parameters or inputs will be used to define and determine an expected value for the SCC) a value of $393 per short ton is a reasonable one for the Commonwealth under *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy*.[8]

The following sections describe our rationale for recommending this update and describe how to apply the SCC in benefit-cost analyses.

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[4] For comparative purposes, see ES-Table 1 in AESC 2021, page 5. Avoided cost categories that have relatively large values (e.g., energy capacity, PTF transmission and distribution) either lack more recent information to include in new analysis at this time, or would not be substantially different with the inclusion of new information. (For the most appropriate comparison, a value of 4.07 cents per kWh—representing the SCC value that was recommended in AESC 2021—should be substituted in place of the of 4.74 cents per kWh in the "GHG non-embedded" row.)

[5] *Request for Proposals, Avoided Energy Supply Costs for Use in Energy-Efficiency Program Cost Effectiveness Analyses in New England "AESC 2021 Study."* Issued May 2020.

[6] *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 2021. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostof CarbonMethaneNitrousOxide.pdf?source=email. And Request for Comments: Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates, *Federal Register* Volume 86, Number 87 (Friday, May 7, 2021). Pages 24669-24670.

[7] This updated SCC recommendation is not the only avoided cost component used in the Massachusetts three-year plan that was developed outside the original *AESC 2021 Study* and stakeholder sessions. Other examples of relevant inputs developed outside *AESC 2021 Study* include the electric sector emissions rate (discussed below on page 19), the financial discount rate, avoided costs for water, and distribution avoided costs.

[8] See *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy*, available at https://malegislature.gov/bills/192/S9. For more on this Act, see page 4.

2. BASIS FOR UPDATED SCC RECOMMENDATION

In March 2021 (shortly after AESC 2021 was published) Massachusetts Governor Baker signed *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy* into law.[9] Included in this legislation is an authorization for the Secretary of Energy and Environmental Affairs to set emission limits for future years in different sectors of the economy, a requirement for state agencies to evaluate impacts of proposed projects on environmental justice communities, and a requirement for new codes and standards for energy efficient products.[10] Broadly speaking, this new legislation re-codifies the Commonwealth's commitment to ambitious policies that will blunt the worst impacts of climate change for future generations.

Most relevant to this document is the *Act*'s requirement that the DPU ensure that energy efficiency plans "shall include calculations of the social value of greenhouse gas emissions reductions" when determining cost-effectiveness.[11] For the first time, MA EE PAs are required to consider an SCC and include it in their benefit-cost analyses.[12]

This chapter describes a brief history of SCC calculations and the rationale for the value suggested in the original AESC 2021 document. This chapter also contains detail supporting our updated SCC recommendation, including a discussion of discount rates and other parameters likely to be considered by the Federal IWG in its January 2022 update.

2.1. The social cost of carbon: A brief history

The *AESC 2021 Study* provides an overview of the SCC as it has been considered by federal agencies in the United States.[13] Briefly:

1. In a series of analyses beginning in 2009, the Obama Administration convened an Interagency Working Group to develop a recommended SCC to use in federal agency decision-making. The technical support document published in August 2016

[9] See *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy*, available at https://malegislature.gov/bills/192/S9.

[10] See Governor of Massachusetts March 26, 2021 press release entitled, "Governor Baker Signs Climate Legislation to Reduce Greenhouse Gas Emissions Protect Environmental Justice Communities" at https://www.mass.gov/news/governor-baker-signs-climate-legislation-to-reduce-greenhouse-gas-emissions-protect-environmental-justice-communities and the full text of the legislation (https://malegislature.gov/bills/192/S9) for a more complete description of what it entails.

[11] *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy*, Section 16. Other sections referring to the social value of carbon include Sections 17, 18, 20, 21, 22, 23, 24, 26, and 27.

[12] In this document, we treat the term "social value of carbon" as a synonym for "social cost of carbon." The social value of carbon is rarely used in the literature, while social cost of carbon and "SCC" are much more widespread.

[13] *AESC 2021 Study*, pages 174-178.

recommended a "central" value of $49 per short ton of CO_2 in 2021 (in 2021 dollars).[14] This central value was calculated using a 3 percent discount rate. The Federal IWG also described other SCC estimates, calculated using higher or lower discount rates, and including (or not including) high-risk extreme events.

2. In 2017, the Trump Administration disbanded the Federal IWG and issued guidance to update the SCC estimate by including only domestic impacts of carbon emissions. The guidance recommended discount rates of 3 to 7 percent. At a discount rate of 7 percent, the Trump Administration found an SCC of $1 per short ton of CO_2 in 2020 (in 2021 dollars).[15]

3. In February 2021, the Biden Administration issued its draft guidance for the SCC, featuring three primary developments: (a) it reverted back to the Obama-era SCC value of $49 per short ton of CO_2 in 2021 (in 2021 dollars), calculated using a 3 percent discount rate, (b) reconvened the Federal IWG, and (c) initiated a process for updating the SCC by January 2022.[16]

More detail on each of the above items is available in the *AESC 2021 Study* on pages 174–178.

While the above history summarizes the official treatment of the SCC by the federal government, this is not the only word on the subject. There is a vast literature written by academics, think tanks, independent consultants, and other parties who have developed their own SCC calculations. Some of these SCC calculations use one of the models used by the Federal IWG, but update key parameters or algorithms.[17] Yet other calculations of the SCC utilize different models or take low-probability but higher-impact costs into account.[18] These studies may also recommend the use of lower discount rates than those analyzed by the Federal IWG.[19] Discount rates have a substantial impact on the SCC value (this impact is discussed in detail beginning on page 12). Depending on the year being described and discount rate used, SCCs in these studies range from roughly $53 to $820 per short ton of CO_2 (in 2021

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[14] Interagency Working Group on Social Cost of Greenhouse Gases. August 2016. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866.* Available at https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc_tsd_final_clean_8_26_16.pdf.

[15] U.S. Government Accountability Office. June 2020. *Identifying a Federal Entity to Address the National Academies' Recommendations Could Strengthen Regulatory Analysis.* Available at https://www.gao.gov/assets/gao-20-254.pdf. See Page 57, Table 10.

[16] Council on Environmental Quality. February 19, 2021. "National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions." *Federalregister.gov.* Available at https://www.federalregister.gov/documents/2021/02/19/2021-03355/national-environmental-policy-act-guidance-on-consideration-of-greenhouse-gas-emissions.

[17] Nordhaus, W.D. 2017. "Revisiting the social cost of carbon." *Proceedings of the National Academy of Sciences,* 114 (7) 1518-1523; DOI: 10.1073/pnas.1609244114. https://doi.org/10.1073/pnas.1609244114 and Hansel, C. M. et al. 2020. "Climate economics support for the UN climate targets." *Nature Climate Change*. http://acdc2007.free.fr/hansel720.pdf.

[18] Van den Bergh, J.X.J.M. and W.J.W. Botzen. 2014. "A lower bound to the social cost of CO_2 emissions," *Nature Climate Change* 4, 253-258.

[19] Stern, N., and J. E. Stiglitz. 2021. "The Social Cost of Carbon, Risk, Distribution, Market Failures: An Alternative Approach." NBER Working Paper Series. http://www.nber.org/papers/w28472.

dollars). There are also published recommendations on the SCC that do not specify values, but instead suggest best practices for performing the calculation.[20]

For example, one source referenced in the *AESC 2021 Study* is "Establishing a Value of Carbon," published by New York State Department of Environmental Conservation (DEC) in December 2020.[21] This document recommends using the values identified by the Biden Administration, but with a different range of discount rates.

Recommendation in *AESC 2021 Study*

In the *AESC 2021 Study*, Synapse recommended that users rely on the central value recommended by New York DEC in "Establishing a Value of Carbon." This is a value of $128 per short ton (in 15-year levelized terms). This value is calculated using the same methodology as the central value recommended by the Federal IWG, except for the modified discount rate parameter. New York's central value uses a 2 percent discount rate rather than the 3 percent discount rate used in the Federal IWG's central recommendation.[22]

Importantly, we also identified that new information would likely be available shortly after the publishing of the *AESC 2021 Study*. Page 179 of the *AESC 2021 Study* states, "It is possible—even likely—that this value will change as new information becomes available." We recommended that program administrators continually review this value and update it as new information becomes available.[23]

2.2. Likely updates to the Federal IWG's social cost of carbon

In its 2021 Technical Support Document, the Federal IWG identifies four specific areas it plans to update in the upcoming January 2022 update to the SCC. Comments submitted to the *Federal Register* identify several other areas that the Federal IWG may consider in its updates. Generally speaking, we expect these updates to produce a higher SCC value than is currently recommended by the Federal IWG.

The following sections first describe the methodology currently used by the Federal IWG to calculate the SCC. We then describe the updates to the SCC that will likely be considered by the Federal IWG. Next,

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[20] National Academies of Sciences, Engineering, and Medicine. 2017. *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24651.

[21] New York State Department of Environmental Conservation. Revised June 2021. *Establishing a Value of Carbon: Guidelines for Use by State Agencies.* Available at: https://www.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf.

[22] NY DEC also issued SCC values calculated using discount rates of 0 percent, 1 percent, and 3 percent. NY DEC describes the 3 percent value as a maximum discount rate, and states that the 1 percent value "should be considered as the lower bound to ensure that State agencies are properly informed in their decision-making" (NY DEC, page 18). NY DEC further states that, "The 0 percent discount rate is provided to give full consideration of a range of rates as required by the CLCPA, but the Department is not recommending its usage by state agencies" (NY DEC page 18).

[23] *AESC 2021 Study*, page 179, suggests that this update could perhaps be made as part of a mid-term modification process. But there is no reason it could not also be re-evaluated now, given the wealth of new information available related to estimating the SCC.

we discuss the potential direction and magnitude of these impacts in the upcoming comprehensive update to the federal government's SCC estimate. We close with our recommended value for the Commonwealth, based on the information available at this time.

How the social cost of carbon is currently determined by the Federal IWG

This section describes how a dollar-per-ton value for the SCC is mathematically calculated by the Federal IWG. This section is included to provide context on how the potential updates described in the following sections interface with the Federal IWG's methodology, and how these updates inform our updated recommended SCC value for the Commonwealth.

In its current SCC formulation, the Federal IWG relies on three different integrated assessment models (IAMs).[24] IAMs are complex models of the future. They model worldwide population and economic growth; GHG emissions; the global climate; feedback loops related to temperature change, sea level rise, and GHG concentrations; and monetized and non-monetized damages inflicted on society and the earth. Within each IAM, the Federal IWG examines five different scenarios, each of which conceives of a future with different expectations of emissions, GDP growth, and population growth.[25] In each IAM, in each scenario, climate change damages are evaluated through the year 2300. These annual damages are then summed and "discounted back" to a year in the relatively near future.[26] For example, to estimate damages for the year 2020, annual damages in each year between 2020 and 2300 would be added together, with the damages that occur in future years being multiplied by a compounded discount rate. Higher discount rates reduce the costs in the future, meaning that in general, higher discount rates lead to lower social costs of carbon.

For each discount rate being considered by the Federal IWG, the five scenarios are run in each of the three IAMs 10,000 times.[27] Each of these modeling runs is then re-run with a small amount of additional CO_2 emissions existing in each year. Total discounted damages from this second run are compared with the first, then divided by the incremental emission quantity to estimate a dollar-per-ton rate for 2020,

[24] These three IAMs are DICE, PAGE, and FUND.

[25] Greenstone, M. et al. March 2011. *Estimating the social cost of carbon for use in U.S federal rulemakings: A summary and interpretation*. National Bureau of Economic Research. Available at https://www.nber.org/system/files/working_papers/w16913/w16913.pdf. Pages 6-7. We note that four of these scenarios base these assumptions on expectation that emissions will continue along a business-as-usual trajectory, while one scenario represents an emissions pathway with lower emissions.

[26] See page 13 for a more detailed discussion of discount rates.

[27] This step is taken because each of the models includes some number of inputs that are described using probability functions. By running each model and each scenario thousands of times, the Federal IWG is able to understand the range of possible outcomes for an SCC and can discern a typical or average value.

2030, 2040, and 2050.[28] Values for all other years in the study period (e.g., 2021, 2037, 2045) are interpolated from these reported values.

Potential updates to SCC assumptions, other than the discount rate

In its February 2021 Technical Support Document, the Federal IWG identifies four areas it anticipates updating in the forthcoming January 2022 update.[29] According to the Federal IWG: "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."[30] Potential changes could be made to assumptions on climate science, economic damages, and socioeconomic and emission projections. (A fourth area where the Federal IWG has recommended a re-evaluation—discounting—is discussed separately on page 12.) Changes to each of these areas suggest an overall increase in the SCC value that was recommended in the *AESC 2021 Study*, and they are the basis for our updated recommendation for the Commonwealth.

Climate Science

The Federal IWG suggests adopting a simple Earth system model within the IAMs to better capture the relationships between GHG emissions, concentrations, and surface temperature change. It also suggests updating the sea level modeling assumptions used. This update will better address uncertainty in translating global mean temperatures into sea level rise in addition to simply enhancing sea level rise projections with the latest information from the literature.[31] Other commenters note that the IAM's climate modules underestimate the speed of warming likely to occur.[32] Recent climate science research described in the IPCC's August 2021 report "The Physical Science Basis" point to drivers which would likely increase the SCC. These include the impact of warming in cities (where most people live),

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[28] See Resource for the Future's "Social Cost of Carbon 101" website (updated on March 30, 2021 and available at https://www.rff.org/publications/explainers/social-cost-carbon-101/) for a high-level overview of this methodology. For detailed information on the modeling methodology and complete data runs, see the White House's "Regulatory Matters'' website, subsection "Social Cost of Greenhouse Gases" (accessed on September 21, 2021 and available at https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs). We observe that the discount rate discussed for the social cost of carbon is functionally embedded within the values reported by the Federal IWG.

[29] *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 2021. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email, pages 12-13.

[30] *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*, page 4.

[31] For a summary of shortcomings in the IAM's sea level rise assumptions, see *Comments of the Attorneys General of the States Of New York, Colorado, Connecticut, Delaware, Illinois, Maryland, Minnesota, New Jersey, North Carolina, Oregon, Vermont, And Wisconsin, the Commonwealth of Massachusetts, and the California Air Resources Board*. May 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0040.

[32] Carleton, T. and Greenstone, M. June 2021. *Updating the United States Government's Social Cost of Carbon.* Available at https://www.regulations.gov/comment/OMB-2021-0006-0037.

compounding impacts of high-risk events, and precipitation variability.[33] This new research may not be included in the January 2022 update but would likely be considered in subsequent SCC analyses. All else being equal, we would expect these updates to increase estimated damages, and thus increase the recommended SCC.

Economic damages

The Federal IWG suggests updating the IAMs' modeling of the likely economic damages that climate change is likely to inflict. It suggests improving and updating detail on sector-, geographic-, and demographic-specific damages, improving the transparency and characterization of damage functions, and recognizing when the use of multiple damage functions produce correlated damages.[34] In many cases, the data underlying these damage functions is dated (e.g., some rely on sources from the 1990s and early 2000s).[35] More recent literature on this subject is broader in scope and more thorough in detail. One commenter in the *Federal Register* identified "at least 110 empirical studies on climate change's economic impacts published between 2010 and 2016 alone."[36] Another commenter noted that economic damages associated with human mortality and climate change in the current IAMs are far lower than what the latest literature suggests, and that updating one of the IAMs with the latest available research would produce an SCC 7.0 times higher than currently estimated by the Federal IWG.[37]

Other commenters noted that the Federal IWG's current modeling practices exclude the cost of adaptation: "as climate change unfolds, individuals, governments, and firms will make innumerable decisions and investments in response to the gradually changing environment."[38] These adaptation measures could include infrastructure like sea walls or mass migration of populations away from coasts. One researcher at University of California Davis found that accounting for adaptation impacts in one of the IAMs used by the Federal IWG would increase the SCC by a multiple of 6.1.[39] Some commenters

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[33] International Panel on Climate Change. August 7, 2021. *AR6 Climate Change 2021: The Physical Science Basis*. IPCC Sixth Assessment Report. Materials available at https://www.ipcc.ch/report/ar6/wg1/.

[34] The Federal IWG also recommends counting global damages, rather than only domestic damages. The Trump-era approach to counting domestic-only damages was widely criticized in both the scientific literature and popular press and was ultimately rejected in favor of global counting in the February 2021 Biden-era recommendation. See *AESC 2021 Study*, pages 175-176 for more detail of this topic.

[35] *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide*. The National Academies of Sciences. (2017). Available at https://www.nap.edu/read/24651/. Chapter 4

[36] Carleton, T. and Greenstone, M. June 2021. *Updating the United States Government's Social Cost of Carbon.* Available at https://www.regulations.gov/comment/OMB-2021-0006-0037. Page 14.

[37] Bressler, R.D. June 2021. *The Mortality Cost of Carbon*. Columbia University. Available at https://www.regulations.gov/comment/OMB-2021-0006-0031.

[38] Carleton, T. and Greenstone, M. June 2021. *Updating the United States Government's Social Cost of Carbon.* Available at https://www.regulations.gov/comment/OMB-2021-0006-0037. Page 18.

[39] Moore, F.C. Comments to the *Federal Register*. June 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0020.

noted that the current IAMs do not adequately account for the impact of climate change on agriculture. The same researcher at University of California Davis calculated the impact of updating these agriculture assumptions in one of the three IAMs considered by the Federal IWG and found this would increase the SCC by a multiple of 1.7 to 2.3.[40] Still other literature makes specific arguments in favor of more equitably monetizing damages on human life, rather than relying on other modeling practices which vary the value of human life globally according to local incomes.[41] All else being equal, we would expect these updates to increase estimated damages, and as a result, increase the recommended SCC by at least a factor of 1.7 to 7.0.

Socioeconomic and emissions projections

The Federal IWG suggests that inputs related to population, GDP, and emissions in the five default scenarios be updated. The Federal IWG recommends several different methods for doing this update, including using accepted statistical methods and elicited expert judgement. These modifications are likely to result in a more granular approach to modeling different areas of the globe and different sectors of the economy (or groups of people) within each area. These modifications may also incorporate new feedback loops that more comprehensively consider the impact of changes in climate and damages on population, GDP, and emissions.[42] It is difficult to say whether these changes will cause worldwide damages to be greater or lower, all else being equal, but these changes are likely to enhance the models' resolution. They may increase estimated damages in some parts of the modeled world but decrease estimated damages in other parts. As a result, we cannot say definitively what directional impact this would have on the recommended SCC.

Other areas of potential changes

These are not the only areas that the Federal IWG may revisit in its anticipated January 2022 update. In comments submitted to the *Federal Register*, and elsewhere in the literature, organizations and individuals have suggested updates to the following parameters:

- Better accounting of low-probability, high-impact events: The IAMs used in modeling the SCC account for some variables using probability functions. These functions describe how likely certain events are to occur (for instance, the chance of there being *X* meters of sea level rise rather than a mainstream estimate *Y*, or the cost of such sea level rise on the economy being *A* rather than *B*). Because each modeling run and each scenario is run 10,000 times, there are some modeling run results with far higher social costs of carbon than the Federal IWG's central estimate would indicate. Some authors have

[40] Moore, F. C. Comments to the *Federal Register*. June 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0020.

[41] Friends of the Earth U.S. and Applied Economics Clinic. June 2021. *Comments on 2021 Guidance Towards Updating the U.S. Social Cost of Greenhouse Gases*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0039.

[42] The National Academies of Sciences. 2017. *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide,* Chapter 3. Available at https://www.nap.edu/read/24651/.

argued that because of the potentially cataclysmic results of mitigating climate change, these "extreme tail" events should be given greater weight in the more general conception of the costs of climate change.[43] In the Federal IWG's Obama-era recommendation, it reported a High Impact (95th percentile) case, indicating that the SCC value for 2020 could be three times higher than described by the central case alone.[44] If these low-risk, high-impact events were taken into account—as suggested by some commenters—then we would expect the recommended SCC to increase.[45]

- Reducing or updating the IAMs used: Some commenters suggest updating the IAMs to newer versions of the same model, or combining the existing IAMs with other models that have a noted specialty.[46] One example is integration of the FAIR model into the existing IAMs (the FAIR model is regarded as being better at rendering the relationship between warming and emissions than the three IAMs).[47] One study of this type of integration, issued by the Canadian government in December 2020, observes that updating two of the three IAMs produces SCC values roughly three to six times larger than those currently recommended by the Federal IWG.[48] Some commenters have instead recommended the use of a single IAM to maximize transparency and stakeholder engagement.[49] As discussed above, to the degree that these updated models would render projections of the economy, society, emissions, climate, and

[43] In *Worst-Case Economics* (Anthem Press, 2017), Frank Ackerman composed an analogy with fire insurance. Many homeowners are happy to pay a regular cost for fire insurance. Such an event is so potentially catastrophic (many people have only one home, after all) that fire insurance is a cost worth bearing notwithstanding the actual risk of a devastating fire.

[44] Interagency Working Group on Social Cost of Greenhouse Gases. August 2016. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866.* Available at https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc_tsd_final_clean_8_26_16.pdf.

[45] Commenters suggesting this include: *Comments on 2021 Guidance Towards Updating the U.S. Social Cost of Greenhouse Gases*. Friends of the Earth U.S. and Applied Economics Clinic. June 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0039.; Howard, P. *Omitted Damages: What's Missing from the Social Cost of Carbon.* March 2014. Institute for Policy Integrity, New York University School of Law. Available at https://www.regulations.gov/comment/OMB-2021-0006-0074; and Carleton, T. and Greenstone, M. *Updating the United States Government's Social Cost of Carbon.* June 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0037.

[46] Rennert, K. J. June 2021. *RFF's Implementation of Near-Term Recommendations of the National Academies of Sciences, Engineering, and Medicine to Improve the Estimation of Social Costs of Greenhouse Gases*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0059.

[47] Carleton, T. and Greenstone, M. June 2021. *Updating the United States Government's Social Cost of Carbon.* Available at https://www.regulations.gov/comment/OMB-2021-0006-0037 and Faulwasser, T. et al. 2018. *Towards a FAIR-DICE IAM: Combining DICE and FAIR Models*. IFAC-PapersOnLine. Volume 51, Issue 5, Pages 126-131. https://doi.org/10.1016/j.ifacol.2018.06.222.

[48] Canada Gazette, Part I. Vol. 154, No. 51. December 19, 2020. Pages 154-155 and 205-206. Available at https://canadagazette.gc.ca/rp-pr/p1/2020/2020-12-19/pdf/g1-15451.pdf. We observe that both the Canadian and Mexican federal governments have SCC methodologies that are aligned with the United States. See *The Economic Benefits of a 50 Percent Target for Clean Energy generation by 2025.* June 2016. White House Blog. Available at https://obamawhitehouse.archives.gov/blog/2016/06/29/economic-benefits-50-percent-target-clean-energy-generation-2025.

[49] Friends of the Earth U.S. and Applied Economics Clinic. June 2021. *Comments on 2021 Guidance Towards Updating the U.S. Social Cost of Greenhouse Gases*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0039.

damages with the most up-to-date information, we would generally expect an increase in the recommended SCC.

- Clear process for updating the SCC over time: Numerous commenters highlighted a need for a routine process for updating the SCC.[50] This change in the Federal IWG's broader process is unlikely to yield an increase or decrease in the SCC recommended in the February 2022 update.

Summary of expected impacts

Overall, we observe that the updates specifically identified as under consideration by the Federal IWG, as well as the other updates that the Federal IWG is likely to consider, support an increase in the value of the SCC above the Federal IWG's current recommendation. It is challenging to estimate precisely just how much of an increase these changes could cause. First, most of the studies that have published changes to the SCC resulting from changes to inputs have focused on updating the quantification of economic damages, rather than changes to climate science assumptions or some other assumptions category. Second, most of the preliminary analyses of these changes have been performed with just one of the IAM models, not all three. These models differ in terms of their approaches to calculating climate dynamics and damages, and the same change in inputs may produce different magnitude changes in SCC across the three models. Third, it is unknown how the likely changes interact with one another, as most preliminary studies have analyzed the impacts of changing a single assumption at a time. As a result of interactive effects within the IAMs, it is possible that two changes modeled together could produce a higher SCC than the additive impact of modeling each change individually. The reverse could also be true. Finally, the studies which describe how the magnitude of the SCC might change as a result of changing inputs typically report a change for a single year (e.g., 2020) at a single discount rate. Changes to inputs may have different impacts at different points in time, meaning that an input change that triples the SCC at a 3 percent discount rate may not necessarily triple the SCC at a 2 percent discount rate (for example, it could double or quadruple the SCC at a 2 percent discount rate).

All that said, we observe that changes to certain assumptions in isolation, on a single IAM, have produced SCCs 1.7 to 7.0 times higher than the current Federal IWG SCC calculated at a 3 percent discount rate (i.e., a $49 per short ton cost would be in the range of 1.7 X $49 ≈ $100 per short ton or 7.0 x $49 ≈ $300 per short ton).[51] If we assume that these new assumptions to inputs would produce the same change in SCC in every IAM and for every discount rate, and that the changes to assumptions were applied one-at-a-time and had no interactive effects, we would find that the SCC recommended in AESC

[50] Friends of the Earth U.S. and Applied Economics Clinic. June 2021. *Comments on 2021 Guidance Towards Updating the U.S. Social Cost of Greenhouse Gases*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0039; Rennert, K. J. June 2021. *RFF's Implementation of Near-Term Recommendations of the National Academies of Sciences, Engineering, and Medicine to Improve the Estimation of Social Costs of Greenhouse Gases*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0059; *Comments to the Office of Management and Budget on the Social Cost of Greenhouse Gases.* June 2021. Institute for Policy Integrity, New York University School of Law. Available at https://www.regulations.gov/comment/OMB-2021-0006-0074.

[51] Given the high-level nature of this estimate, we round to the nearest $100 per short ton avoid false precision.

2021 of $128 per short ton could be the range of 1.7 X $128 ≈ $200 per short ton or 7.0 x $128 ≈ $900 per short ton. This suggests that an updated recommendation for the Commonwealth should be in the range of $200 to $900 per short ton, even without making adjustments to the discount rate.

Potential updates to discount rate assumptions

Because benefits and costs do not always take place during the same time period, and because benefits that occur sooner are generally regarded as being more valuable, discount rates are frequently used to account for the time value of money.[52] This practice allows for a more consistent valuation of short-term versus long-term costs and benefits. The lower the discount rate, the larger the resulting stream of costs or benefits. Conversely, higher discount rates lead to smaller total streams of costs or benefits.

Intergenerational social discounting

Discount rates used in the SCC are different than the discount rates used for other, more immediate purposes. In a 2003 document seminal in the topic of intergenerational discounting, the federal Office of Management and Budget (OMB) stated that:

> Special ethical considerations arise when comparing benefits and costs across generations. Although most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations. Future citizens who are affected by such choices cannot take part in making them, and today's society must act with some consideration of their interest.[53]

Social discount rates applied to a social cost (like the SCC) should by necessity take a long-range view. Because the costs produced by the IAM models cover a period of centuries, relevant social discount rates should not be based on inputs that cover a relatively small time period. If financial indicators are used to as inputs to a social discount rate, they should be drawn from financial parameters that span a suitably long period of time. Basing inputs for a social discount rate on just a few years-worth or decades-worth of data may reflect anomalously low treasury bill rates that may not hold over a longer term. In contrast, the financial discount rate described in the *AESC 2021 Study* and the discount rate described by Massachusetts DPU in its 2021 guidelines are intended for application to measure savings that exist for about a decade, on average.[54] These short-term discount rates are calculated using information on the latest projections for 10-year treasury bills, and as a result, are consistent with the stream of costs to which they are applied. To summarize: *social* discount rates, which are applied to costs that extend centuries into the future, are inherently different than shorter-term *financial* discount

[52] See "Discount rates" section in OMB Circular A-4 (2003) for a discussion on the fundamentals of discounting. Available at https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/.

[53] See section 4 "Intergeneration Discounting" in OMB Circular A-4 (2003) at https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/.

[54] Massachusetts Department of Public Utilities. Energy Efficiency Guidelines §3.4.6.

rates that may be applied to the costs and benefits of utility or ratepayer investments likely to accrue over about a decade.

The OMB document goes on to say:

> Some believe, however, that it is ethically impermissible to discount the utility of future generations. That is, government should treat all generations equally. Even under this approach, it would still be correct to discount future costs and consumption benefits generally (perhaps at a lower rate than for intragenerational analysis), due to the expectation that future generations will be wealthier and thus will value a marginal dollar of benefits or costs by less than those alive today. Therefore, it is appropriate to discount future benefits and costs relative to current benefits and costs, even if the welfare of future generations is not being discounted. Estimates of the appropriate discount rate appropriate in this case, from the 1990s, ranged from 1 to 3 percent per annum.

This OMB document is the origin of the discount rate used in the Federal IWG's current central estimate for the SCC of 3 percent. Per OMB's direction, this 3 percent discount rate was calculated in 2003 using a combination of consumer price index (CPI) data and 10-year U.S. Treasury Yields over a 30-year period from 1973 to 2002. We observe that if this calculation were performed with modern data—using 30 years of data from 1991 to 2020—the resulting discount rate would be 2 percent.[55] We also observe that OMB specifically identifies a 1 percent discount rate as being at the lower range of what it views as being an acceptable discount rate for intergenerational discounting.

Considerations for a lower social discount rate

Soon after publication of the first Federal IWG SCC recommendation, the 3 percent discount rate chosen for the central value became a target for criticism. This body of criticism has grown larger in subsequent years and has been expanded in the comments to the *Federal Register* that were submitted in May–June 2021.

In its February 2021 Technical Support Document, the Federal IWG holds 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 Federal 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."[56] This Technical Support Document identifies several ways the Federal IWG may be bounding the central discount rate it plans to use in the upcoming SCC update.

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[55] For more on this calculation, see the *AESC 2021 Study*, footnote 205 on page 178.

[56] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. February 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*.

First, as described above, if the Federal IWG were to use exactly the same methodology for calculating a central discount rate as it did in its original SCC estimate, an update to input data would yield a discount rate of 2 percent, rather than 3 percent. As a result, we can view 2 percent as being an effective ceiling on the likely discount rate used for a central estimate in the upcoming January 2022 update to the Federal IWG's SCC.

Second, the literature being considered by the Federal IWG points to a lower discount rate. The Federal IWG observes that, "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."[57] In addition, one 2018 study cited by the Federal IWG (also cited in AESC 2021, page 178) surveyed approximately 200 experts and found a mean recommended social discount rate (SDR) of 2 percent. [58] For this survey, economists were also asked about the range of social discount rates they were comfortable with, in addition to a primary recommended value.[59] Per this study, "[m]ore than 90 percent [of economists] are comfortable with a[n] SDR somewhere in the interval of 1 percent to 3 percent." This range of 1 percent to 3 percent is not a confidence interval, but instead a range of social discount rates that 90 percent of surveyed economists are in agreement on.[60] As there is no meaningful distinction in importance between a mean value and a value agreed to by 90 percent of a group of experts, this suggests that a 1 or 3 percent discount rate is just as appropriate as a 2 percent rate.

Literature cited elsewhere by the federal government also suggests that a discount rate for long-run intergenerational valuation is roughly 1 percent. In a January 2017 report by the Council of Economic Advisors, the authors cited one 2015 study of long-term leases in the United Kingdom and Singapore which pointed toward with discount rates of about 1 percent in real terms.[61] Other economists submitting comments in the *Federal Register* recommend discount rates ranging from 0.5 to 2

Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email. Page 17.

[57] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. February 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email. Page 20.

[58] Drupp, M.A., M.C. Freeman, B. Groom, F. Nesje. 2018. "Discounting Disentangled." *American Economic Journal: Economic Policy*, November, page 33.

[59] Specifically, economists were asked questions about ranges of parameters that they were comfortable with, with the parameters being used to generate social discount rates. See this paper's section Ramsay discounting (page 17) for more information about these parameters.

[60] Drupp et al. Pages 20-21.

[61] *Discounting for Public Policy: Theory and Recent Evidence on the Merits of Updating the Discount Rate*. January 2017. Council of Economic Advisers Issue Brief. Available at https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf. Page 8.

percent.[62] In its comments in the *Federal Register*, New York DEC (the source of AESC 2021's recommended 2 percent discount rate) noted that, "DEC ultimately recommended that New York State agencies report the impacts at 1 and 3 percent with a central rate of 2 percent as the primary value for decision-making. We specifically recommended lower rates and the consideration of 1 percent because of public concern that discounting at higher rates does not appropriately account for the intergenerational nature of climate change."[63] New York's Office of the Attorney General also submitted comments to the *Federal Register* on the discount rate, which were also signed by attorneys general and other agencies in 13 other states, including Massachusetts.[64] This document makes note of DEC's recommended 2 percent discount rate, and goes on to say:

> As IWG considers final revisions for the SC-GHG, the undersigned states support consideration of discount rates even lower than 2%. In the context of investments intended to improve quality of life over a multi-generational timespan, even a 2% discount rate results in a rapid devaluation of human life. For reference, applying a 2% discount rate, the value of the life of a person born today would be twice the value of a person born in 2055. Across very long timeframes, the value of a human life declines dramatically when using any non-zero discount rate. IWG should consider applying a 0% discount rate, or perhaps a very low but non-zero discount rate, when assessing the value of saving human lives far into the future.[65]

This indicates that attorneys general from over a dozen states, Massachusetts included, support a discount rate of no higher than 2 percent, and the consideration of discount rates lower than 1 percent or perhaps even as low as 0 percent.

The Federal IWG is also considering the implementation of several complex techniques to capture uncertainty in long-term social discounting. These include:

- Declining discount rates: Some have argued that because discount rate uncertainty grows over time, analysis should apply a relatively high discount rate to modeled values in the near future, and a gradually lower discount rate to modeled values in the

[62] Howard, P. and Schwartz, J. A. June 2021. *About Time*. Institute for Policy Integrity, New York University School of Law. Available at https://www.regulations.gov/comment/OMB-2021-0006-0074; Bauer, M. D. and Rudebusch, G. D. June 2021. *The Rising Cost of Climate Change: Evidence from the Bond Market*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0026; and Friends of the Earth U.S. and Applied Economics Clinic. June 2021. *Comments on 2021 Guidance Towards Updating the U.S. Social Cost of Greenhouse Gases*. Available at https://www.regulations.gov/comment/OMB-2021-0006-0039.

[63] New York State Department of Environmental Conservation. June 2021*Re: Document Citation 86 FR 24669, Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. Page2. Available at https://www.regulations.gov/comment/OMB-2021-0006-0036.

[64] *Comments of the Attorneys General of the States Of New York, Colorado, Connecticut, Delaware, Illinois, Maryland, Minnesota, New Jersey, North Carolina, Oregon, Vermont, And Wisconsin, the Commonwealth of Massachusetts, and the California Air Resources Board*. May 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0040.

[65] Id, page 23.

future.[66] In their comments to the *Federal Register*, the attorneys general of New York, Massachusetts, and other states stated, "A declining discount rate would reflect the reality that assumptions about long-term economic growth become more tenuous over longer timeframes" and that the Federal IWG should "should consider use of a discount rate that declines over time to a value approaching 0%."[67] The Federal IWG notes that the practical steps of implementing a declining discount rate are challenging and still an area of active research. As a substitute, in earlier SCC estimates, the Federal IWG elected to simply model a static but lower-than-central discount rate to represent a declining discount rate.[68] As a result, if the Federal IWG elects to consider declining discounting (or an approximation thereof) in its January 2022 update, we can expect the applicable discount rate to be lower than its current central value.

- Ramsey discounting: The Federal IWG is also considering the use of the Ramsey equation to dynamically estimate discount rates in each model run. The Ramsey equation is specifically deployed in situations where a discount rate is highly uncertain. This equation relies on inputs related to pure time preference (sometimes called "impatience"), the decreasing marginal utility of consumption (sometimes called a "risk aversion" parameter), and future per capita economic growth. While the first two parameters are uncertain, they can and have been empirically estimated.[69] However, the future-per-capita-economic-growth parameter is endogenous to a model run and cannot ordinarily be calculated outside of a model. We note that there is some criticism of the Ramsey approach in the literature that suggests using it may lead to erroneously high discount rates.[70]

The literature is clear that a reasonable social discount rate should be no higher than 2 percent. There are mixed recommendations on social discount rates of 0 percent. Meanwhile, a 1 percent social discount rate is both outright identified as reasonable in the literature, and also approximates the

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[66] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. February 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email. Page 36.

[67] *Comments of the Attorneys General of the States Of New York, Colorado, Connecticut, Delaware, Illinois, Maryland, Minnesota, New Jersey, North Carolina, Oregon, Vermont, And Wisconsin, the Commonwealth of Massachusetts, and the California Air Resources Board*. May 2021. Available at https://www.regulations.gov/comment/OMB-2021-0006-0040. Page 24.

[68] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. February 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf?source=email. Pages 21-22. This is the genesis of the 2.5 percent discount rate modeled by the Federal IWG in its previous studies.

[69] Rennert, K. J. et al. June 2021. *RFF's Implementation of Near-Term Recommendations of the National Academies of Sciences, Engineering, and Medicine to Improve the Estimation of Social Costs of Greenhouse Gases*. Resources for the Future. Available at https://www.regulations.gov/comment/OMB-2021-0006-0059.

[70] Drupp, M. et al. June 2021. Comment on: "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates Under Executive Order 13990." Available at https://www.regulations.gov/comment/OMB-2021-0006-0030.

outcome of a discount rate that starts high and declines to 0 percent.[71] As a result, we recommend the use of a 1 percent social discount rate for the SCC in Massachusetts.

2.3. Updated recommendation for the social cost of carbon

Based on this updated review of the SCC literature, we find that the SCC recommendation previously set forth in the AESC 2021 report is too low.

Instead, there is substantial evidence that leads us to recommend a higher SCC value based on a social discount rate equal to 1 percent. Reasonable social discount rates using the latest literature and information are unlikely to exceed 2 percent, and they are unlikely to approach 0 percent. As a result, we recommend an SCC based on the Federal IWG estimate, but calculated with a 1 percent discount rate. This is equal to 393 per short ton on a levelized basis.[72] A time series of the updated SCC recommendation is shown in Table 1.

Importantly, we note that the modifications to other inputs and parameters that the Federal IWG is likely to make or consider making to its methodology are more likely to increase the social cost of carbon—perhaps significantly—than to decrease it. These increases are separate and additional to any increases in the SCC caused by the adoption of a lower discount rate. Because the exact impacts of these non-discount rate updates are difficult to ascertain but almost certainly point to a higher estimated SCC, we recommend that the MA EE PAs rely on the current Federal IWG estimate using a 1 percent discount rate.

Because the SCC is being re-evaluated by the Federal IWG at the time of this writing, we also recommend that the MA EE PAs and other parties in the Commonwealth review the federal government's comprehensive update after it is published in January 2022, as well as other SCC analyses and values expected to be analyzed and issued by others in the future.

[71] As an example, a discount rate that starts at 2 percent in 2020 and declines linearly to 0 percent by 2300 would yield an average discount rate of 1 percent. Discount rate trajectories that start at a level lower than 2 percent, that decline faster than linearly, or that reach 0 percent sooner than 2300 produce average discount rates lower than 1 percent. Conversely, discount rate trajectories that start at a level higher than 2 percent, that decline slower than linearly, or that reach 0 percent later than 2300 produce average discount rates higher than 1 percent.

[72] We note that this number, and the stream of values from which it is calculated (see Table 1), differs from the analogous values appearing in AESC 2021 (page 179, Table 78). These differences result from updates published by New York DEC since the release of the *AESC 2021 Study* (see https://www.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf and https://www.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf). New York DEC updated its SCC estimates in June 2021 to be more consistent with and reflective of the inflation rates published by the Federal IWG in February 2021. These new values are about 3 percent lower than those originally published by New York DEC and described in the *AESC 2021 Study*.

Table 1. Social cost of carbon recommended in this supplemental study (2021 dollars per short ton)

	Values originally recommended in AESC 2021 *(a)*	Updated recommendation *(b)*
2020	$116	$376
2021	$118	$378
2022	$119	$380
2023	$120	$383
2024	$122	$385
2025	$124	$387
2026	$125	$390
2027	$127	$391
2028	$129	$394
2029	$130	$396
2030	$131	$398
2031	$133	$401
2032	$135	$403
2033	$136	$404
2034	$138	$407
2035	$140	$409
2036	$142	$411
2037	$143	$413
2038	$144	$415
2039	$146	$417
2040	$148	$419
2041	$150	$422
2042	$152	$425
2043	$154	$427
2044	$155	$429
2045	$157	$432
2046	$158	$434
2047	$160	$436
2048	$162	$437
2049	$163	$439
2050	$165	$440
15-year levelized	**$128**	**$393**

Sources and notes: Values in column (a) are from Table 78 in AESC 2021. Values in column (b) are obtained from https://www.dec.ny.gov/docs/administration_pdf/vocapprev.pdf, adjusted to reflect differences in units (2021 dollars and short tons). Values in column (a) are levelized using a 2 percent discount rate, while values in column (b) are levelized using a 1 percent discount rate.

3. APPLYING THE SCC

Section 8.3. *Applying non-embedded costs* of the *AESC 2021 Study* provides information on how the SCC should be applied to calculate avoided costs. This chapter is an abbreviated version of that text, with a focus on how to apply the recommended SCC value depicted above in Table 1.

3.1. Electric sector

AESC 2021 embeds three electric-sector regulations in New England in its forecast of avoided energy costs: one (RGGI) is modeled regionwide, while two (310 CMR 7.74, a mass-based, declining cap on in-state CO_2 emissions, and 310 CMR 7.75, the Clean Energy Standard) apply only to Massachusetts and are used to represent a reasonable and current estimate for the cost of compliance for the Massachusetts GWSA regulations. In AESC 2021, we sum these embedded costs (all three for Massachusetts, RGGI only for the other five states) then subtract the annual values from the relevant marginal abatement cost (see Table 2).

Table 2. Interaction of non-embedded and embedded CO_2 costs.

Component description	Formula
Marginal abatement cost (including non-embedded components)	a
Non-MA allowance price (embedded components, including RGGI)	b
MA allowance price (embedded components RGGI, 310 CMR 7.74, 310 CMR 7.75)	c
Externality cost (non-MA)	d = a - b
Externality cost (MA)	e = a - c

Note: This is Table 79 in the AESC 2021 Study.

The resulting cost stream (measured in dollars per short ton) can then be multiplied by a marginal emissions rate (measured in short tons per MWh) to be converted into dollars per MWh. In this context, a "marginal" emission rate refers to the emission rate associated with the resources that change their output (e.g., ramp up or ramp down) as more demand is added or removed from the grid.[73] AESC 2021 describes both short-run and long-run emission rates, each of which has separate implications for the resulting dollar-per-MWh values. Short-run and long-run marginal costs may both be applied to measures that decrease electricity consumption (e.g., energy efficiency) the same way they are applied to measures that increase electricity consumption (e.g., heat pumps). See Section 8.3. *Applying non-embedded costs* of the *AESC 2021 Study* for detail on the difference between short-run and long-run marginal emission rates. We observe that for Massachusetts, the two approaches yield identical

[73] This can be contrasted with an "average" emissions rate, which refers to the total emissions produced by the grid over a long period of time (often a year) divided by the total generation output by the grid. This emissions rate includes many resources (e.g., nuclear, hydro) that do not economically respond to changes in demand.

emission rates.[74] Table 3 shows how embedded costs would be subtracted from the SCC, and how marginal emission rates would be applied in order to generate non-embedded CO_2 costs for Massachusetts' electric sector.

Table 3. Illustrative application of the social cost of carbon in Massachusetts' electric sector, using annual average marginal emission rates

	AESC 2021 Non-Embedded CO2 Cost	Embedded Cost of RGGI	Embedded Cost of Compliance for CMR 7.74	Embedded Cost of Compliance for CMR 7.75	Non-embedded Cost of Compliance (MA)	Annual Average Marginal Emissions rate	Non-embedded Cost of Compliance (MA)
	(a)	*(b)*	*(c)*	*(d)*	*(e) = (a) – [(b) + (c) +(d)]*	*(f)*	*(g) = (e) x (g) / (2000 x 1000)*
	2021 $/short ton	*2021 $/short ton*	*2021 $/short ton*	*2021 $/short ton*	*2021 $/short ton*	*lb/MWh*	*2021 $/kWh*
2021	$378.46	$6.00	$0.62	$0.00	$371.84	779	$0.14
2022	$380.31	$6.29	$0.06	$0.00	$373.96	754	$0.14
2023	$383.09	$6.60	$0.00	$0.00	$376.48	783	$0.15
2024	$384.94	$6.93	$0.00	$0.00	$378.01	841	$0.16
2025	$386.79	$7.26	$0.00	$0.00	$379.53	855	$0.16
2026	$389.56	$7.62	$0.00	$0.00	$381.95	829	$0.16
2027	$391.41	$7.99	$0.00	$0.00	$383.42	784	$0.15
2028	$394.19	$8.38	$0.00	$0.00	$385.81	739	$0.14
2029	$396.04	$8.79	$0.00	$0.00	$387.25	732	$0.14
2030	$397.89	$9.22	$0.00	$0.00	$388.67	685	$0.13
2031	$400.67	$9.67	$0.00	$0.00	$391.00	696	$0.14
2032	$402.52	$10.15	$0.00	$0.00	$392.37	698	$0.14
2033	$404.37	$10.64	$0.00	$0.00	$393.73	707	$0.14
2034	$407.14	$11.16	$0.00	$0.00	$395.98	712	$0.14
2035	$409.00	$11.71	$0.00	$0.00	$397.28	721	$0.14
15-Year Levelized (2021-2035)							**$0.15**

Note: The AESC 2021 User Interface performs the above calculation for all selected states and marginal emission rates (e.g., short-run versus long-run and seasonal / peak period). Levelization calculations use the 0.81 percent default discount rate in the AESC 2021 Study.

[74] Separately, we note that Massachusetts Executive Office of Energy and Environmental Affairs (EEA) has issued emission rate guidelines. The purpose of these EEA emission rates is for calculating GHG reductions relative to the statewide goal, not for benefit-cost testing. These EEA emission rates are annual (rather than hourly), are issued for two years only (2025 and 2030), and are average emission rates rather than marginal emission rates. See Massachusetts EEA. July 15, 2021. "Greenhouse Gas Emissions Reduction Goal for Mass Save" guideline. Available at https://www.mass.gov/doc/greenhouse-gas-emissions-reduction-goal-for-mass-save/download.

3.2. Non-electric sectors

The approach for the non-electric sectors is simpler. The dollar-per-ton non-embedded value is simply multiplied by the relevant non-electric emissions rate (measured in tons per MMBtu) to produce dollar-per-MMBtu values. These emission rates may be fuel- and sector-specific (see Table 17 and Table 18 in the *AESC 2021 Study* for more information on non-electric emission rates). Because policies such as RGGI and RPS only impact the electric sector, they should not be taken into account when calculating non-electric sector impacts (i.e., they are not embedded). Table 4 depicts how this calculation would be done for measures that displace distillate fuel oil, using the emission rates shown in the *AESC 2021 Study's* Table 17. Estimates using this same calculation can be made for natural gas, residual fuel oil, propane, or any of the other end-use fuels covered in AESC 2021. See the *AESC 2021 User Interface* for a complete set of calculations for all end use fuels.

Table 4. Illustrative application of the social cost of carbon to distillate fuel oil

	AESC 2021 Non-Embedded CO2 Cost *(a)* *2021 $/short ton*	Distillate fuel oil *(b)* *lb/MMBtu*	GHG Cost of Compliance for distillate fuel oil *(c)* *2021 $/MMBtu*
2021	$378.46	161	$30.47
2022	$380.31	161	$30.61
2023	$383.09	161	$30.84
2024	$384.94	161	$30.99
2025	$386.79	161	$31.14
2026	$389.56	161	$31.36
2027	$391.41	161	$31.51
2028	$394.19	161	$31.73
2029	$396.04	161	$31.88
2030	$397.89	161	$32.03
2031	$400.67	161	$32.25
2032	$402.52	161	$32.40
2033	$404.37	161	$32.55
2034	$407.14	161	$32.78
2035	$409.00	161	$32.92
15-Year Levelized (2021-2035)			**$31.67**

Note: The AESC 2021 User Interface performs the above calculation for all selected states and marginal emission rates (e.g., short-run versus long-run and seasonal / peak period). Levelization calculations use the 0.81 percent default discount rate in the AESC 2021 Study.

3.3. Non-energy avoided greenhouse gases

Several measures reduce GHG emissions by directly decreasing the emission of these pollutants themselves, rather than by reducing the combustion of fuels which then reduces the emission of these pollutants. One hypothetical measure might be a new efficient refrigerator which reduces the emission

of chlorofluorocarbons (CFCs) relative to an old existing refrigerator. As with non-electric savings, these measures utilize the "simple" version of the SCC (i.e., they do not remove any costs related to RGGI or other programs). GHG reductions from these measures are typically expressed in terms of metric tons; as a result, the *AESC 2021 User Interface* multiplies the SCC described in Table 1 by a factor of 1.102 to convert the results into 2021 dollars per metric ton.