Establishing a Value of Carbon

GUIDELINES FOR USE BY STATE AGENCIES

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Record of Revision

Revision Date	Description of Changes
June 2021	For consistency with IWG interim estimates released in February 2021, estimates of the values for carbon dioxide, methane, and nitrous oxide are revised to reflect the usage of the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9.
June 2021	For consistency with the IWG approach, the values for methane and nitrous oxide have been rounded to two significant figures and a recalculation of estimates using the PAGE model to exclude a small number of model runs in which a climate discontinuity is triggered in the marginal run but not the baseline run, leading to spuriously high values.
October 2021	Correction of a typo in the Executive Summary stating the central value for the value of nitrous oxide was $142,000 per ton was changed to $42,000 per ton.
May 2022	Added values for hydrofluorocarbons (HFCs), updated text to describe these values, and provide an example. Updated the description of federal policy regarding global versus domestic SCC.
August 2023	Added values for an additional HFC (HFC-236fa) and sulfur hexafluoride (SF6), updated text to describe these values, and provided both formats used by the federal government (Tables 1-11 in this document and Tables A1-A11 in the Appendix.

Contents

Executive Summary

The Climate Leadership and Community Protection Act directed the Department of Environmental Conservation (the Department or DEC) to establish a value of carbon for use by State agencies. This guidance document provides a recommended procedure for using a damages-based value of carbon along with a general review of the marginal abatement cost approach. This guidance provides damages-based values as a tool to aid state agencies in the consideration of greenhouse gas emissions and climate change in their decision-making. In some decision-making contexts, particularly those that have a history of valuing carbon such as the New York electric industry, alternative approaches may be more appropriate for both resource valuation and benefit-cost analyses.

This guidance document is designed to provide accessible and practical assistance to State agencies and authorities for applying a damages-based value of carbon where it is useful and appropriate. It is not the intention of the Department that this guidance be interpreted as establishing a requirement on any public or private entity.

Where appropriate, the Department is recommending the use of the federal U.S. Interagency Working Group's (federal IWG) damages-based value of carbon, also referred to as the social cost of carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons (HFCs). Resources for the Future, under contract to the New York State Energy Research and Development Authority (NYSERDA), provided the federal IWG values in 2020 dollars per metric ton of emissions (adjusted for inflation) along with estimates based on additional discount rates for carbon dioxide, methane and nitrous oxide. Estimates for sulfur hexafluoride and seven HFCs, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, and HFC-236fa were developed by the Department using the federal IWG's methodology and are provided in 2020 dollars per metric ton of emissions (adjusted for inflation) along with estimates based on additional discount rates. Recommendations are also provided for assessing other greenhouse gases and public health impacts.

The Department specifically recommends that State entities provide an assessment using a central value that is estimated at the 2 percent discount rate as the primary value for decision-making, while also reporting the impacts at 1 and 3 percent to provide a comprehensive analysis. State agencies should look at the full range as a method that is consistent with the federal government's guidance for using a damages-based value of carbon. This range translates into a 2020 value of carbon dioxide of $51-406 per ton, with a central value of $121 per ton; a 2020 value of methane of $1,500-6,400 per ton, with a central value of $2,700 per ton; a value of nitrous oxide of $18,000-130,000 per ton, with a central value of $42,000 per ton. Tables 1-11 below contain the values calculated for these gases reported in five-year increments through 2050. The full set of values for 2020-2050 emission years for each gas is provided in an Appendix to this document.

In September 2022, the USEPA proposed new social cost values for carbon dioxide, methane, and nitrous oxide based on updated modeling and a revised approach to discounting.[1] DEC considers EPA's proposal to be the best available information and the new approach to discounting addresses public concerns regarding intergenerational equity. DEC will consider adopting EPA's final values once they are issued as well as apply the updated methodology to additional GHGs.

Various jurisdictions have used the damages-based value of carbon as part of cost benefit analyses, rulemaking processes, environmental assessment, and for demonstrating the benefits of climate change policies. These and other applications are reviewed along with simplified examples in this document. State agencies and authorities may apply this guidance in those contexts or identify additional applications for the Value of Carbon and develop additional guidance. DEC and NYSERDA staff are available to assist in addressing any technical or implementation questions related to this guidance or the Value of Carbon. Please contact the DEC Office of Climate Change at 518-402-8448 or climatechange@dec.ny.gov.

I. Purpose of this Guidance

The Climate Leadership and Community Protection Act, Chapter 106 of the Laws of 2019 (CLCPA) provides direction to all State entities regarding actions to address climate change. This guidance is intended to address the following directive, as added to the Environmental Conservation Law:

> *§ 75-0113. VALUE OF CARBON.*
>
> *1. No later than one year after the effective date of this article, the Department, in consultation with the New York State Energy Research and Development Authority, shall establish a social cost of carbon for use by State agencies, expressed in terms of dollars per ton of carbon dioxide equivalent.*
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> *2. The social cost of carbon shall serve as a monetary estimate of the value of not emitting a ton of greenhouse gas emissions. As determined by the*

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[1] https://www.epa.gov/environmental-economics/scghg

> *Department, the social cost of carbon may be based on marginal greenhouse gas abatement costs or on the global economic, environmental, and social impacts of emitting a marginal ton of greenhouse gas emissions into the atmosphere, utilizing a range of appropriate discount rates, including a rate of zero.*
>
> *3. In developing the social cost of carbon, the Department shall consider prior or existing estimates of the social cost of carbon issued or adopted by the federal government, appropriate international bodies, or other appropriate and reputable scientific organizations.*

This guidance establishes a value of carbon based on an estimate of net damages incurred as a result of climate change, which also formed the basis of the U.S. federal government's "social cost of carbon."[2] This guidance also considers the types of State activities for which this approach may be best suited and discusses some key considerations.

State agencies may find the damages-based value of carbon provided in this guidance useful for describing the global value of policies, programs, or projects or for estimating global damages in an assessment of benefits and costs. However, other values of carbon may be established by the Department or other State entities for other purposes. In particular, the marginal abatement cost has been used in some instances, including by New York State in the electric power sector, to aid in planning to meet discrete greenhouse gas reduction goals.

The guidance is broken down into seven parts, including this Part that describes the purpose. Part II lists definitions for terms used throughout this guidance. Part III describes the "value of carbon" concept in a broad sense and explains the differences between the two approaches referred to in the CLCPA: (i) the damages approach used to establish the federal social cost of carbon and the primary focus of this guidance; and (ii) the marginal abatement cost approach. Part IV provides additional details on the damages approach, how it was calculated by the federal government, and how it may be updated. Part V explains when a damages-based value of carbon could be used by State entities and reviews the key considerations that would need to be addressed. Part VI describes how the damages approach may be applied to all of the greenhouse gases that are subject to the CLCPA, which are all special cases of the social cost of carbon. Part VII provides example scenarios in which the greenhouse gas emissions associated with a project and a policy are evaluated using the damages-based value of carbon.

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[2] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. 2016. Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.

A separate Appendix document provides the estimates for the value of carbon that is described in this guidance.

This guidance establishes a value of carbon that can be used by State entities to aid decision-making and used as a tool for the State to demonstrate the global societal value of actions to reduce greenhouse gas emissions. The Department recommends that a value of carbon be used as part of a full and transparent assessment of environmental, economic, and social impacts, wherever appropriate. This guidance does not impose a compliance obligation or fee on any entity; the imposition of any such new compliance obligation or fee on any entity would require separate State action.

II. Definitions

Discount Rate – a reduction (or "discount") in value each year as a future cost or benefit is adjusted for comparison with a current cost or benefit[3]; a higher rate places a higher value on the present.

Greenhouse Gas – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride (SF_6), and any other substance emitted into the air that may be reasonably anticipated to cause or contribute to anthropogenic climate change.[4]

Marginal Greenhouse Gas Abatement Cost – a monetary estimate of the cost, usually in dollars per ton of carbon dioxide, associated with the last unit (the marginal cost) of emission abatement for varying amounts of greenhouse gas emissions reduction.[5]

Social Cost (of Carbon) – an estimate, in dollars, of the present discounted value of the future damage caused by a metric ton increase in emissions of a specific greenhouse gas into the atmosphere in that year or, equivalently, the benefits of reducing emissions of that gas by the same amount in that year. It is intended to provide a comprehensive measure of the net damages—that is, the monetized value of the net impacts—from global climate change that result from an additional ton of emissions.[6]

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[3] 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. doi: 10.17226/24651

[4] Environmental Conservation Law § 75-0101(7).

[5] e.g., Kesicki, F and Strachan, N. 2011. Marginal abatement cost (MAC) curves: confronting theory and practice. Environmental Science and Policy 14:1195-1204

[6] National Academies. 2017. op cit.

Value of Carbon – any representation of monetary cost applied to a unit of greenhouse gas emissions, expressed in terms of the net cost of societal damages (i.e., social cost of carbon), marginal greenhouse gas abatement cost, or using another approach.

III. What is a Value of Carbon?

A value of carbon is a monetary representation of the impact of a marginal change in greenhouse gas emissions. This value is usually expressed in terms of dollars per ton of a specific gas, such as carbon dioxide. Placing a value on greenhouse emissions can be a useful tool for policymaking and for decisions regarding proposed projects, as it allows the costs associated with emissions, and the benefits of avoided emissions, to be compared to other monetary values.

The CLCPA directed the Department to consider two approaches for establishing a value of carbon.[7] The first approach is based on the monetary cost of damages that would result from an incremental increase in emissions as a result of climate change, commonly referred to as the social cost of carbon. The second approach, the marginal abatement cost, establishes a value of carbon with reference to a specific emissions reduction goal. In other words, what would be the cost to reduce, or *abate*, the last metric ton of emissions by the amount needed to meet a particular emissions target at least cost.

The Damages Approach and the Social Cost of Carbon

The damages approach provides a monetary estimate of the impacts on society from activities that are a source of greenhouse gas emissions. Greenhouse gas emissions are often described as a negative externality in the economy and as a market failure, as there are costs to society from such emissions that are not accounted for in market prices. A market may in turn allow greenhouse gas emissions to exceed socially optimal levels. A damages-based value of carbon puts the effects of climate change into economic terms to help decisionmakers understand the economic impacts of decisions that would increase or decrease emissions.

A damages-based value of carbon can be used on its own, such as an informational item, or compared to other monetary values in a cost-benefit analysis. The most common damage

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[7] There are additional ways to establish a monetary value for a ton of greenhouse gas emissions. For example, the Regional Greenhouse Gas Initiative, 6 NYCRR Part 242, establishes a market-based compliance cost on carbon dioxide emitted from certain power plants and the Public Service Commission Clean Energy Standard, Case 15-E-0302, sets Tier 1 compliance costs based on the results of competitive solicitations for renewable energy generation projects. These costs could also be incorporated into the development of a marginal abatement cost.

valuation in use in the U.S. is the federal government's "social cost of carbon" metric,[8] which was first established in 2007 as an estimate of the global, net damages from an additional ton of carbon dioxide added to the atmosphere. The federal Interagency Working Group on the Social Cost of Greenhouse Gases (or "federal IWG") established this metric specifically for use in the cost-benefit analyses that are required as part of regulatory actions by the federal government. The federal government later established social cost values for methane, nitrous oxide, and certain HFCs for the same purposes. The Department has strongly supported the use of these metrics by federal agencies to more fully account for the benefits of reducing greenhouse gas emissions, particularly when measured as global damages.[9] The U.S. Governmental Accountability Office reviewed the history and status of the federal IWG metrics and the prospects for future improvements.[10] A previous federal administration also appropriately suggested that the federal IWG metrics could be used to inform environmental reviews.[11] This could be federal environmental reviews conducted under the National Environmental Policy Act, or state reviews conducted under state law analogs, such as the New York State Environmental Quality Review Act. U.S. States have also used the federal IWG social cost of carbon as an informational item to accompany climate change planning documents.[12]

There is a large volume of literature describing the limitations of the federal social cost of carbon, which include the uncertainty inherent in predicting long-term economic, demographic, and climatic changes. Such limitations also include many of the issues that are common to environmental cost-benefit analyses, such as the difficulty in putting a monetary cost on non-monetary values, such as human health, and in selecting a discount rate. Approaches for addressing these issues are described later in this guidance.

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[8] Interagency Working Group op cit.

[9] See e.g., Comments of the New York State Department of Environmental Conservation. October 26, 2018. National Highway Traffic Safety Administration (NHTSA) Proposed Rule: The Safer Affordable Fuel-Efficient Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks. NHTSA-2018-0067-11905.

[10] GAO. 2020. Identifying a Federal Entity to Address the National Academies' Recommendations Could Strengthen Regulatory Analysis. GAO-20-254

[11] Council on Environmental Quality. 2016. Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews.

[12] See e.g., California Air Resources Board. 2017. Estimated Social Costs of Evaluated Measures. California's 2017 Climate Change Scoping Plan.

The Marginal Abatement Cost Approach

An alternative approach to valuing carbon included in the CLCPA reflects the cost of a marginal reduction in emissions. Marginal abatement cost typically is derived from a “marginal abatement cost curve,” which can be generated either by plotting abatement measures along an increasing scale of cost per emission reduction or by using economic or energy models to evaluate the level of emissions reductions across an economy or a sector resulting from the imposition of a carbon price. The marginal abatement cost is the highest cost required to meet the emission reduction goal.

Whereas the damages approach is intended to establish a value of carbon for all sectors, marginal abatement costs are typically estimated for sector-specific technologies, markets, and emission reduction goals. That is, the marginal abatement approach requires an analysis of the relevant economic sector or sectors and policy options of interest for the relevant timeframe, which could result in multiple values of carbon that differ between economic sectors or policies. In New York State today, the electric power sector is best positioned to apply marginal abatement approaches, due to available cost information and its longer history of effective emissions reductions policies. In its recent review of the federal IWG social cost of carbon, the U.S. Government Accountability Office referred to the marginal abatement cost as a type of “target-consistent approach” to valuing emissions, which reflects the fact that this approach establishes a value that depends in part on the relevant emission reduction target.[13]

Many public and private entities have used marginal abatement cost curves to aid decision making. The federal government, for example, has used marginal abatement curves to describe policy options for reducing non-CO_2 gases.[14] Most notably, the marginal abatement cost approach has been used by some jurisdictions to guide climate change planning at the national level.[15] As in the case of the damages approach, the underlying assumptions can be highly uncertain. For example, marginal abatement costs are sensitive to rates of technological improvements and the costs of and potential for abatement, changes that may not be easily predicted. However, policymakers may regularly update and refine their estimate of marginal abatement costs to address these changes. In this way, the marginal abatement approach can

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[13] GAO 2020 op cit.

[14] Most recently in Environmental Protection Agency. 2019. Global Non-CO_2 Greenhouse Gas Emission Projections and Mitigation Potential: 2015-2050.

[15] See examples for France and the United Kingdom described in GAO 2020 op cit.

be used along with other metrics in an adaptive planning process and adjusted as needed on a regular basis, for example as new and lower-cost technologies are made available.

General Recommendations for Establishing a Value of Carbon

For the purposes of this guidance, the Department is establishing a value of carbon for state agencies based on the damages approach. The rationale for utilizing a damages approach is three-fold. First, the damages approach provides a set of values that can be used by any State entity in a wide variety of contexts to describe the value of any emission reduction, without additional analysis. Secondly, the damages approach is already in use by the State's counterparts in the federal government for similar types of decisions, such as in the development of regulations and the assessment of environmental impacts. Finally, the Department is not seeking to establish an economic cost, compliance cost, or fee on any entity through this guidance, which would require specific, targeted analyses of the relevant sectors. Instead, the purpose of this guidance is to provide information that can be readily applied by State entities when estimating the greenhouse gas reduction value of their actions.

With regard to the use of other approaches to the value of carbon, including the marginal abatement cost approach, the Department may provide additional guidance at a later date. In the interim, the Department provides the following general recommendations for applying any value of carbon:

- In applying a value of carbon, the Department recommends that the full scope of the emission sources that are subject to the CLCPA be considered whenever possible. For example, the CLCPA includes emissions outside of the state associated with imported fossil fuels and electricity.[16]
- Although the value of carbon is most frequently applied only to carbon dioxide, all relevant greenhouse gases should be assessed. No policy intended to reduce one greenhouse gas should unintentionally increase emissions of other greenhouse gases or result in the "leakage" of emission sources into other jurisdictions, if avoidable.
- The value of carbon should be considered as part of a full assessment of the impacts described within the CLCPA, including to disadvantaged communities, as well as to public health and the environment, per the State Environmental Quality Review Act.[17]

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[16] ECL § 75-00101(13)

[17] See ECL Article 8, 6 NYCRR Part 617.

- Careful consideration should be applied when combining different values of carbon and applying the net total to the same marginal ton of emissions as they may represent contradictory or redundant valuations, such as a global damages estimate versus a market-based allowance price. If multiple approaches are used within a decision or planning context, the results should be treated as distinct pieces of information.

IV. Establishing a Damages-Based Value of Carbon

The values derived from the damages approach can be used to help understand the economic impacts of policies or projects that would result in a change in emissions. Policies or projects that would result in increased emissions would have economic costs, while policies or projects that reduce emissions result in economic benefits. When compared against other costs, such as the capital costs associated with a project, the damages-based value of carbon can help determine if a project or policy provides a net benefit or a net cost to the State.

There is extensive literature available that describes the damages-based approach, its uses, and key considerations. Informative documents include the federal IWG technical support document,[18][19] the National Academies of Science 2016[20] and 2017[21] reviews and recommendations for future improvements, the 2020 review provided by the U.S. Government Accountability Office.[22] and the 2021 Regulatory Impact Analysis for phasing down HFCs by the U.S. Environmental Protection Agency.[23] In addition, work is ongoing from organizations such as Resources for the Future, the Climate Impact Lab, and New York University's Institute for Policy Integrity, among others.

At a high-level, the damages approach uses Integrated Assessment Models (IAMs) to translate a marginal increase in emissions into a change in atmospheric greenhouse gas concentrations, a resulting change in the global climate, and then subsequent economic impacts. Some of the

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[18] IWG op cit.

[19] IWG. 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990

[20] National Academies of Sciences, Engineering, and Medicine. 2016. Assessment of Approaches to Updating the Social Cost of Carbon: Phase 1 Report on a Near Term Update. Committee on Assessing Approaches to Updating the Social Cost of Carbon, Board on Environmental Change and Society. Washington, DC: The National Academies Press. doi:10.17226/21898

[21] 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. doi: 10.17226/24651

[22] GAO 2020 op cit.

[23] U.S. Environmental Protection Agency. 2021. Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs). Establishing the Allowance Allocation and Trading Program under the American Innovation and Manufacturing Act. EPA-HQ-OAR-2021-0044-0227.

considerations when applying the damages approach include the selection of IAM, the geographic scope and timeframe, and the discount rate applied to the model output to describe costs in a common present value.

At this time, the Department recommends that State entities apply the methods that the U.S. federal IWG used to establish the social costs of greenhouse gases for use by federal agencies.[24] For this guidance, DEC developed estimates of the social costs of carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, and seven hydrofluorocarbons (HFCs) using federal IWG methods, in 2020 dollars per metric ton of emissions (adjusted for inflation) along with estimates based on additional discount rates. DEC worked in conjunction with Resources for the Future, under contract to NYSERDA, and the U.S. EPA. The information below explains how the federal government addressed certain key considerations. Further guidance is provided later in this document as to how State entities may approach these considerations in their own processes and how a comparable metric may be established for the other greenhouse gases that are listed in the CLCPA.

The U.S. Interagency Working Group on the Social Cost of Carbon

The federal IWG[25] applied the damages approach in order to establish social cost of carbon values that would be used by federal agencies in cost-benefit analyses. The federal IWG's approach to four key considerations is described below: model selection, geographic scope, timeframe, and the discount rate.

<u>Model Selection</u>: The federal IWG utilized the outputs of three IAMs: DICE (Dynamic Integrated Climate and Economy[26]), PAGE (Policy Analysis of the Greenhouse Effect[27]), and FUND (Climate Framework for Uncertainty, Negotiation, and Distribution[28]). These models translate: (1) marginal emissions into atmospheric greenhouse gas concentrations, (2) greenhouse gas concentrations into changes in temperature, and finally (3) changes in temperature into various economic damages. By incorporating the outputs of multiple models, the federal IWG was able

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[24] IWG op cit.

[25] Initially the Interagency Working Group on the Social Cost of Carbon, later renamed the Interagency Working Group on the Social Cost of Greenhouse Gases

[26] e.g., Nordhaus, W.D.. 2017 Evolution of assessments of the economics of global warming: Changes in the DICE model, 1992-2017.National Bureau of Economic Research. Working Paper 23319.

[27] e.g., Hope, C. 2006. The marginal impact of CO2 from PAGE 2002. Integrated Assessment Journal. 6:9-56; Dietz S., Hope C., Patmore N. 2007. Some economics of 'dangerous' climate change: Reflections on the Stern Review. Global Environmental Change. 17:311-325.

[28] e.g., Anthoff D., Tol R.S. 2011. The uncertainty about the social cost of carbon: A decomposition analysis using FUND. Climatic Change. 117.

to consider changes in net agricultural productivity, property damages from increased flood risk, human health, energy systems costs, and other aspects of the economy, in order to provide a comprehensive estimate of impacts from climate change.

<u>Geographic Scope</u>: The initial work of the federal IWG considered the global impacts of climate change, and this is the approach utilized by the Department in this guidance.[29] A previous federal administration applied a domestic rather than global scope, or damages that occurred in the United States alone. Under the CLCPA, New York State is required to consider global damages.[30] Furthermore, the global cost is the most appropriate value to use due to the global nature of climate change and the economy. Greenhouse gas emissions have an effect on climatic changes worldwide, regardless of where the source of emissions is located. Emissions in New York State will cause damages outside the State and emissions from other jurisdictions will impact the damages experienced in New York State.

<u>Timeframe</u>: The federal IWG estimates damages through 2300 to represent long-term damages, but there is substantial uncertainty when forecasting future damages. Some portion of carbon dioxide emissions will persist in the atmosphere for more than a century. As such, the resulting damages must be modeled over that entire period. However, climate change affects every aspect of the environment and the uncertainty in predicting those effects will increase as projections extend further into the future. Furthermore, each greenhouse gas has a different atmospheric lifespan, and some are much shorter or much longer in duration than carbon dioxide. Methane, due to its role as an ozone precursor, is also associated with both climate impacts and impacts to public health that may occur over different timeframes.

<u>Discount Rate</u>: Discounting is a common and useful aspect of economic analyses that allows for the balancing of present versus future value, and it has been widely discussed in the literature, particularly in its application to the federal social cost of carbon. However, the selection of the discount rate has a large effect on the estimate of the value of carbon, and there is no consensus or uniform scientific basis for the selection of a discount rate. The federal IWG compared a descriptive approach to establishing public preferences, based on observations of consumer behavior for example, to a normative approach, based on a consideration of the social or ethical implications of discounting damages to future generations.[31] The federal IWG's

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[29] Presidential Executive Order 13783 disbanded the IWG in 2017.

[30] ECL § 75-0113(2).

[31] As reviewed in the National Academies reports op cit. e.g., IWG. 2010. "F. Discount Rate". Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. Page 18.

approach to discounting was primarily based on observations of consumer behavior, as measured through market rates of return. It applied a social discount rate, which reflects the rate at which society as a whole is willing to trade off a value received at one point in time (e.g., today) with a value received at another point in time (e.g., the future).

The federal IWG utilized real discount rates of 2.5, 3, and 5 percent per year in order to reflect a range of decision contexts, and as a reflection of reasonable judgments under both the descriptive and normative approaches described above. The federal IWG's central value applies a 3 percent discount rate that is consistent with the economics literature and in the federal government's Circular A-4 guidance for the consumption rate of interest. The 3 percent discount rate is also roughly equal to calculations of the after-tax riskless interest rate. The 5 percent discount rate was intended as an upper value that represents the possibility that climate damages are positively correlated with market returns. This higher rate may also be justified by the high interest rates that consumers use to smooth consumption across time periods. The lower 2.5 percent discount rate was intended to address the concern that interest rates have a high degree of uncertainty over time. Additionally, if climate investments are negatively correlated with the overall market rate of return, then a lower discount rate is more justified. Subsequent analyses suggested that the values adopted by the federal IWG are relatively high, and that lower values would be more appropriate for the consumption rate of discount in general[32] and in particular when addressing the impacts of climate change.[33] The purpose of the discount rate when applied to actions by public entities should be, in part, to reflect public preferences as to costs as well as to public safety, welfare, and environmental protection. As such, the Department has considered additional, lower discount rates as well, as discussed further below in Part V.

Value of Carbon Estimates

The following tables provide the U.S. Social Cost of Greenhouse Gases values adjusted for New York State as described in this document. These values are provided in the format used by the federal government or rounded to two significant figures. The raw values are also available in a separate Appendix.

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[32] Council of Economic Advisers. 2017. Discounting for public policy: Theory and recent evidence on the merits of updating the discount rate. Issue brief. Washington, DC. https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf

[33] e.g., van den Bergh, J.C.J.M., Botzen, W.J.W. 2015. Monetary valuation of the social cost of CO_2 emissions: A critical survey. Ecological Economics. 114:33-46.

Table 1: *Social cost of carbon dioxide (CO_2), 2020-2050 (in 2020 dollars per metric ton CO_2)*

	Recommended Discount Rates			
Year	**3%**	**2%**	**1%**	**0%**
2020	53	130	420	2,200
2025	59	130	430	2,200
2030	64	140	450	2,200
2035	70	150	460	2,100
2040	76	160	470	2,100
2045	81	170	480	2,100
2050	88	180	490	2,000

Table 2: *Social cost of methane (CH_4), 2020-2050 (in 2020 dollars per metric ton CH_4)*

	Recommended Discount Rates			
Year	**3%**	**2%**	**1%**	**0%**
2020	1,500	2,800	6,600	24,000
2025	1,800	3,100	7,100	25,000
2030	2,000	3,500	7,600	25,000
2035	2,300	3,800	8,100	26,000
2040	2,500	4,200	8,700	26,000
2045	2,900	4,600	9,200	27,000
2050	3,200	5,000	9,700	27,000

Table 3: *Social cost of nitrous oxide (N_2O), 2020-2050 (in 2020 dollars per metric ton N_2O)*

	Recommended Discount Rates			
Year	**3%**	**2%**	**1%**	**0%**
2020	19,000	45,000	140,000	680,000
2025	22,000	48,000	150,000	690,000
2030	24,000	52,000	150,000	690,000
2035	27,000	56,000	160,000	700,000
2040	29,000	60,000	170,000	700,000
2045	32,000	64,000	170,000	710,000
2050	34,000	68,000	180,000	710,000

Table 4: *Social cost of HFC-125, 2020-2050 (in 2020 dollars per metric ton HFC-125)*

	Recommended Discount Rates			
Year	**3%**	**2%**	**1%**	**0%**
2020	210,000	410,000	1,000,000	4,000,000
2025	243,248	460,000	1,100,000	4,100,000
2030	276,673	510,000	1,200,000	4,200,000
2035	312,777	560,000	1,300,000	4,300,000
2040	351,877	620,000	1,400,000	4,400,000
2045	391,086	670,000	1,500,000	4,500,000
2050	432,231	730,000	1,500,000	4,600,000

Table 5: *Social cost of HFC-134a, 2020-2050 (in 2020 dollars per metric ton HFC-134a)*

Year	Recommended Discount Rates 3%	2%	1%	0%
2020	88,000	160,000	380,000	1,400,000
2025	100,000	180,000	420,000	1,500,000
2030	120,000	200,000	450,000	1,500,000
2035	140,000	230,000	490,000	1,600,000
2040	150,000	250,000	530,000	1,600,000
2045	170,000	280,000	560,000	1,700,000
2050	190,000	300,000	600,000	1,700,000

Table 6: *Social cost of HFC-143a, 2020-2050 (in 2020 dollars per metric ton HFC-143a)*

Year	Recommended Discount Rates 3%	2%	1%	0%
2020	270,000	560,000	1,500,000	6,300,000
2025	310,000	620,000	1,600,000	6,500,000
2030	340,000	680,000	1,700,000	6,600,000
2035	380,000	740,000	1,800,000	6,800,000
2040	430,000	810,000	1,900,000	6,900,000
2045	470,000	870,000	2,000,000	7,000,000
2050	520,000	940,000	2,100,000	7,100,000

Table 7: *Social cost of HFC-32, 2020-2050 (in 2020 dollars per metric ton HFC-32)*

Year	Recommended Discount Rates 3%	2%	1%	0%
2020	39,000	68,000	160,000	600,000
2025	46,000	78,000	170,000	620,000
2030	53,000	89,000	190,000	640,000
2035	62,000	100,000	210,000	660,000
2040	71,000	110,000	230,000	690,000
2045	82,000	130,000	250,000	710,000
2050	93,000	140,000	260,000	730,000

Table 8: *Social cost of HFC-152a, 2020-2050 (in 2020 dollars per metric ton HFC-152a)*

Year	Recommended Discount Rates 3%	2%	1%	0%
2020	5,300	9,500	22,000	86,000
2025	6,400	11,000	25,000	89,000
2030	7,400	12,000	27,000	92,000
2035	8,700	14,000	29,000	95,000
2040	10,000	16,000	32,000	98,000
2045	12,000	18,000	35,000	100,000
2050	13,000	20,000	38,000	110,000

Table 9: *Social cost of HFC-227ea, 2020-2050 (in 2020 dollars per metric ton HFC-227ea)*

	Recommended Discount Rates			
Year	**3%**	**2%**	**1%**	**0%**
2020	190,000	380,000	990,000	3,800,000
2025	220,000	430,000	1,100,000	3,900,000
2030	250,000	470,000	1,100,000	4,000,000
2035	280,000	520,000	1,200,000	4,100,000
2040	320,000	570,000	1,300,000	4,200,000
2045	350,000	620,000	1,400,000	4,300,000
2050	390,000	670,000	1,400,000	4,400,000

Table 10: *Social cost of HFC-236fa, 2020-2050 (in 2020 dollars per metric ton HFC-236fa)*

	Recommended Discount Rates			
Year	**3%**	**2%**	**1%**	**0%**
2020	640,000	1,600,000	5,700,000	27,000,000
2025	710,000	1,700,000	6,000,000	28,000,000
2030	790,000	1,900,000	6,200,000	28,000,000
2035	870,000	2,000,000	6,500,000	28,000,000
2040	960,000	2,200,000	6,800,000	28,000,000
2045	1,100,000	2,300,000	7,000,000	28,000,000
2050	1,200,000	2,500,000	7,300,000	28,000,000

Table 11: *Social cost of sulfur hexafluoride (SF6), 2020-2050 (in 2020 dollars per metric ton SF6)*

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	1,700,000	4,500,000	18,000,000	110,000,000
2025	1,800,000	4,800,000	19,000,000	110,000,000
2030	2,000,000	5,200,000	20,000,000	120,000,000
2035	2,300,000	5,600,000	21,000,000	120,000,000
2040	2,500,000	6,100,000	22,000,000	120,000,000
2045	2,700,000	6,500,000	23,000,000	130,000,000
2050	3,000,000	6,900,000	24,000,000	130,000,000

V. Guidelines for Applying a Damages-Based Value of Carbon

When do these guidelines apply?

The purpose of this guidance is to aid State entities in decision making by establishing a monetary value of greenhouse gas emission reductions or increases that reflects global societal impacts. This guidance does not itself establish a price or fee on emissions, and the value of carbon presented here is not the only value that may be used by the State. Alternative methods for establishing a value of carbon may be used by State entities, including the Department, as needed to achieve the goals and requirements of the CLCPA as well as other State goals, such as to protect public safety, welfare, and the environment.

The damages approach to establishing a value of carbon may be best suited to the following types of actions:

- Cost-Benefit Analysis, such as may be used to evaluate alternatives as a part of rulemakings or environmental assessments
- Describing the societal benefits of strategic plans, programs, or policies that will reduce greenhouse gas emissions
- Evaluating other types of decisions, such as those regarding State procurements, contracts, grants, or permitting

Recommended Procedure

The Department recommends that State entities apply the methods adopted by the federal IWG when utilizing a damages-based approach to valuing greenhouse gas emissions, along with the recommended steps below.

1. Estimate the emissions for all relevant greenhouse gases.

Almost all of the literature regarding the value of carbon is focused on carbon dioxide, which is the greenhouse gas that has had the greatest impact on global climate change. However, the scope of the CLCPA encompasses carbon dioxide and other major greenhouse gases,[34] other substances that affect climate change, the co-pollutants that are typically associated with greenhouse gas emission sources, as well as the “leakage” of greenhouse gases in other jurisdictions. This guidance is intended to aid in the use of a value of carbon using the damages approach. State entities may require additional assessments when evaluating actions to meet the requirements of the CLCPA.

A first step in determining the impacts of a given decision will be to determine which of the major greenhouse gases are likely to be associated or affected by the project, policy, or program in question and then to estimate the emissions of those gases for each year (Table 12). This may already be determined as part of other requirements, e.g., for permits or environmental assessments, or may be informed by other available guidance.[35] A review of all available data and methods for estimating greenhouse gas emissions would be beyond the scope of this

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[34] See definition of greenhouse gas in ECL 75-0101 which includes additional substances

[35] New York State Department of Environmental Conservation. 2009. DEC Policy: Assessing Energy Use and Greenhouse Gas Emissions in Environmental Impact Statements. https://dec.ny.gov/regulations

document. However, State entities can consult with the Department and NYSERDA to locate additional resources, as needed.

Table 12: Examples of Greenhouse Gas Emission Sources

Greenhouse gas	Examples of primary sources
Carbon dioxide	Fossil fuels, Land management
Methane	Fossil fuels, Land management, Waste, Livestock
Nitrous oxide	Fossil fuels, Soil management, Wastewater
Hydrofluorocarbons (HFCs) and Hydrofluoroolefins (HFOs)	Substitutes for Ozone-Depleting Substances; Refrigeration, Heating and Cooling, Manufacturing
Perfluorocarbons (PFCs)	Manufacturing
Sulfur hexafluoride	Electricity transmission and distribution, Manufacturing
Nitrogen trifluoride	Manufacturing, Research

2. Consider the fullest geographic scope of damages.

The CLCPA directs the Department to establish a value of carbon that considers global damages, which would best protect the public and the environment. As such, the Department recommends that the State use the global estimation of damages established by the federal IWG, as updated through the work of NYSERDA and its consultant Resources for the Future.

3. Apply the most up-to-date, peer-reviewed information available.

The federal IWG social cost of carbon was established using the best available models and information available at the time, but regular updates will be needed to improve the estimation of global damages and to integrate up-to-date information on atmospheric greenhouse gas concentrations along with economic, demographic and other parameters. The National Academies of Science laid out an approach for updating and improving the federal IWG's values[36] and multiple research teams are actively working to address these recommendations and to make additional improvements to the relevant science. The Department recommends that State entities stay apprised of new updates and apply the most up-to-date values available. To support this objective, the Department will synthesize and provide updated values as appropriate, including through updates to the Appendix document.

4. Apply an appropriate discount rate.

Importantly, because the damages-based value of carbon described here is not intended to levy an actual cost or fee on any entity, the selection of discount rate should not be interpreted as

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[36] National Academies op cit.

having an actual, direct cost to the public. Since the damages-based value of carbon is used primarily for societal decision making, the correct discount rate to use in its calculation is a social discount rate, which reflects the rate at which society as a whole is willing to trade off a value received today with a value received in the future. As has been the case with the use of the social cost of carbon by federal agencies, the range of discount rates can be used to describe the potential impacts of global climate change and to compare this alongside other economic and environmental costs and benefits.

The CLCPA requires the Department to consider "a range of appropriate discount rates, including a rate of zero" when establishing a value of carbon.[37] Based on an assessment of the literature and consultation with State partners and stakeholders, the Department recommends that State entities present the damages-based value of carbon using estimates calculated at a range of discount rates from 1 to 3 percent, with a central value that is estimated at the 2 percent discount rate, as discussed further below. Resources for the Future, under contract to NYSERDA, provided New York State with values in 2020 dollars per metric ton of emissions for the federal IWG social cost of carbon, methane, and nitrous oxide at discount rates of 0, 1, 2, and 3 percent (see Appendix document). 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. These estimates were calculated using the same peer-reviewed models that were used by the federal IWG.

Fundamentally, the Department is recommending State agencies consider a lower range of discount rates than recommended by the federal IWG. The federal IWG's central discount rate of 3 percent should be considered as a maximum discount rate. A rate of 2 percent should be used as the central value and a rate of 1 percent should be considered as the lower bound to ensure that State agencies are properly informed in their decision-making.

The Department recommends the use of a central discount rate to establish a central value of the potential impacts from the marginal increase in emissions. This central rate should be used as the primary value for decision-making purposes. Using a discount rate of no more than 2 percent to establish a central value is recommended for three reasons.

First, although higher discount rates may be appropriate for guiding the long-term investment of private funds, they are less appropriate for decisions regarding public safety and welfare, particularly when considering the scope and scale of the impacts to the public from global

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[37] ECL § 75-0113(2).

climate change. If a damages-based value of carbon is used within the context of the CLCPA, then a lower range of discount rates is needed compared to those used by the federal government.

Second, multiple lines of research have concluded that the discount rates used by the federal IWG underestimate the value of avoided damages from greenhouse gas emissions. Experts now generally consider a range of 1-3 percent to be more acceptable.[38]

A lower discount rate may help address the underestimation of the potential damages from climate change. One of the fundamental critiques of the IAMs is that they do not properly account for the possibility of large-scale singular events or irreversible climatic tipping points, many of which are difficult to monetize. Ideally, this source of uncertainty would be addressed within the damage models rather than in the application of a discount rate. However, until this aspect of the modeling can be resolved, it is fair to assume that potential damages have been underestimated and using a lower discount rate can accommodate for this shortcoming in the existing models.

Finally, the Department is not recommending that a discount rate of zero be applied to the damages-based estimate that is provided here. Consistent with the requirements of the CLCPA a rate of zero is among the range of discount rates considered as part of developing this guidance document. A discount rate of zero treats present value and future value equally and assumes that the public has no preference regarding value over time periods or based on the relative wealth of a society, which may not be valid. As reviewed by the National Academies of Science, additional approaches to discounting may be taken up by the federal government that address the uncertainty and risks associated with discounting and climate change damages.[39] These approaches require further development and review before the Department can provide guidance for their usage. Additional approaches such as declining discount rates and providing estimates at the 95th percentile of the central value could also be considered by the Department in the future as more review and refinement of the estimates occur.

Until such time, it is more appropriate to report a range of values, including estimates at a low discount rate of 1 percent, as this recognizes that the public may have differing preferences and acknowledges that there is no one correct value. Federal agencies similarly report the social

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[38] Drupp M.A. et al. 2018. Discounting disentangled. American Economic Journal: Economic Policy. 10:109-134

[39] National Academies of Science 2017 op cit.

costs using multiple rates.[40] An additional benefit of considering multiple rates is that the impact of the discount rate is made apparent and a wider range of potential benefits may be considered.

VI. Guidelines for Assessing Multiple Greenhouse Gases

The CLCPA emission reduction requirements cover seven types of greenhouse gases that are commonly included in international climate policy: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride, and nitrogen trifluoride.[41] The federal IWG provided an estimation of the damages from the first three gases, as these represent the majority of global emissions and are associated with the economic activities of primary interest, namely fossil fuel combustion. However, all these gases, as well as synthetic gases of emerging importance like hydrofluoroolefins (HFOs), are relevant to planning and State decision-making under the CLCPA. In some cases, policies and projects that would reduce the emissions of one gas may lead to increases in other emissions. These types of interactions should be anticipated and, where possible, assessed using a comparable level of assessment. The damages-based approach may assist State entities in evaluating conflicts and potential tradeoffs.

Establishing a value of carbon for different greenhouse gases is complicated by two factors: (i) each gas affects climate change differently; and (ii) some gases are associated with additional impacts unrelated to climate change (e.g., local human health impacts). All of the greenhouse gases included in the CLCPA are well-mixed gases that contribute to atmospheric warming. However, methane and most HFCs have shorter atmospheric lifetimes than carbon dioxide, sulfur hexafluoride, or nitrous oxide. As such, the long-term damages associated with the climate impacts of these different greenhouse gases should be expected to vary. Besides impacts caused by climate change, carbon dioxide and methane emissions may also be associated with other impacts, such as changes in agricultural productivity or local impacts on air quality and human health.

Recommended Approach

The federal IWG models and parameters have been used to develop social cost estimates for carbon dioxide, methane, nitrous oxide, and the most important HFC compounds. These values are available in the social cost tables in the Appendix to this guidance. The same methods can

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[40] See examples in the Federal register, such as NHTSA-2014-0132

[41] 6 NYCRR Part 496 per ECL § 75-0101(7).

be applied to other well-mixed GHGs including the synthetic greenhouse gases sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). This guidance may be updated as evaluations of the social costs of these and other greenhouse gases are completed. Work is also underway to understand the social costs of the hydrofluoroolefins (HFOs) that are potential replacements for HFCs in some applications.

Establish a value for each greenhouse gas using best available information.

The Department recommends that, where appropriate, State entities use the updated estimates of the federal IWG social costs of each GHG following the guidelines provided in Part VI. Each of these estimates represents a gas-specific, but comparable, assessment of the value of a marginal ton of these greenhouse gases in terms of global damages related to climate change.

In September 2021, the EPA released the “Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs)” that includes estimates of the social costs of different HFCs.[42] In 2022, the Department developed social cost estimates using the lower range of discount values (0, 1, 2, and 3%) for six main HFCs by using the Mimi framework[43] developed by Resources for the Future’s Social Cost of Carbon Initiative and applying EPA’s methodology for HFCs. These values may vary slightly from those in the EPA’s Regulatory Impact Analysis due to independent model runs. These values are provided in the updated appendix of this guidance document.

In 2023, this approach was also applied to sulfur hexafluoride (SF6) and HFC-236fa. However, these gases are much longer-lived than the other HFCs previously analyzed with this method; HFC-236fa has an atmospheric lifetime of 213 years and SF_6 of 1,000 years. The models used by the IWG to estimate the social cost of a greenhouse gas emission do not capture the impact of the marginal damages that occur after the year 2300. As such, only a portion of the damages caused by these long-lived pollutants can be estimated using this approach. For example, a pulse emission of SF_6 that occurred in 2020 will maintain a tail of elevated concentration that extends far into the future such that 75% of the emission pulse (in ppb-years) will occur after the year 2300 and only 25% can be captured during the period that is assessed by the IWG’s models (2020-2300). An artifact of terminating the damages assessment in year 2300 is that emissions that occur in later years have slightly lower social costs than emissions in earlier years because the damages have a shorter amount of time to accrue. DEC addressed this

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[42] HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, and HFC-43-10mee. EPA (2021) op. cit.

[43] https://www.mimiframework.org

issue by adding the appropriate number of additional years' worth of marginal damages to the social costs of emissions that occur after 2020.

For the remaining greenhouse gases, the Department considers the peer-reviewed scientific literature to be the best source of information for supplementing the federal IWG values. In some cases, there may be an estimation of damages for specific gases that may be useful even if the underlying methods are not identical to that used by the federal IWG. For example, Shindell et al. (2015[44]) provided an estimation of damages from multiple pollutants based on one of the damage models used by the federal IWG. This includes values for pollutants that were not named in the CLCPA that may be of interest, such as black carbon. When work on these additional gases is comparable to the work of the federal IWG, the Department may supplement this guidance with additional information that will help State entities apply new research.

The method that has been widely discussed in the literature is to adjust the federal IWG values using carbon dioxide-equivalence, as determined by the Intergovernmental Panel on Climate Change (IPCC)'s Global Warming Potential metric (or GWP; Table 13). The GWP weighs the radiative forcing of a gas against that of carbon dioxide over a specified time frame.[45] The GWP metric is a useful heuristic for policymakers as it provides a simplified framework for emissions accounting. However, as the IPCC has discussed, the GWP is not a full representation of the physical properties of each gas or its potential impacts, and it is a relative value that is heavily influenced by the IPCC's estimation of current concentrations of carbon dioxide.[46] Additionally, the underlying approach for modeling climate change is fundamentally different from the IAMs used to estimate global damages. There would have to be a number of assumptions made to equate the underlying concept of relative radiative forcing with the approach to modeling economic damages, including that temperature change and economic damages are simultaneous, that all of the underlying modeling is comparable and considers the same time intervals, and that there would be no additional discounting applied.[47] Thus, simply adjusting the

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[44] Shindell, D.T. 2015. The social cost of atmospheric release. Climatic Change 130:313-326.

[45] Commonly 100-years, but the CLCPA defines carbon dioxide-equivalence in terms of 20-years. ECL § 75-0101(2). As the IPCC has stated, the choice of time horizon is subjective. Like the discount rate, the difference reflects a preference for weighing near-term versus long-term impacts.

[46] As discussed by Working Groups 1 and 3 in the Fifth Assessment Report

[47] Marten, A.L. et al. 2015. Incremental CH_4 and N_2O mitigation benefits consistent with the U.S. government's SC-CO_2 estimates. Climate Policy 15: 272-298.

federal IWG’s social cost of CO_2 values by the relative GWP of a given greenhouse gas in order to determine the social cost of that gas is not necessarily appropriate.

Although there is broad consensus that using the GWP is not appropriate for this purpose, using the approach is still recommended by some authors as an alternative to omitting an assessment of these gases altogether, or essentially treating these gases as if they have no impact or a value of zero.[48] The Department recommends that every effort be made to assess the damages of each gas and that peer-reviewed research on damages be applied whenever possible (see above). State entities and partners should also undertake additional analyses of any additional gases that may be associated with policies of interest to ensure that actions to reduce one gas do not inadvertently increase other gases with the unintended outcome of undermining the ability of the policy to achieve the requirements of the CLCPA. When including damage estimates for other gases, agencies should indicate how the value was determined, either through application of the GWP metric or by referencing the relevant publication, and consideration should be made as to whether the analysis is likely to have over or under-estimated actual damages.

It is also important to note that two of the types of gases listed in the CLCPA, HFCs and perfluorocarbons (PFCs), represent multiple separate gases that would impose different impacts. Table 13 provides information for some gases, but the most recent IPCC Assessment Report should be consulted with regards to the full suite of greenhouse gases. There are greenhouse gases that may be relevant to State entities that are not named in the CLCPA. For example, HFCs were introduced to replace ozone-depleting substances, which are greenhouse gases[49] that are subject to a separate international phase-down. These gases may continue to be used until the available supply is diminished. State entities may wish to assess the benefits of further, more accelerated reductions and would be able to demonstrate these benefits using the damages approach.

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[48] e.g., Marten et al. 2015 and National Academies 2017 op cit.

[49] e.g., the 20-year GWP of CFC-12 is 11,400 and HCFC-22 is 5690, which are two commonly used substances.

Table 13. Example Global Warming Potential Values

Greenhouse gas	Lifespan (years)	IPCC AR5 100-YEAR GWP	IPCC AR5 20-YEAR GWP	IPCC AR6 100-YEAR GWP	IPCC AR6 20 YEAR GWP
Carbon dioxide (CO_2)	~100[50]	1	1	1	1
Methane (CH_4)	11.8	28	84	27.9	81.2
Nitrous oxide (N_2O)	109	265	264	273	273
Hydrofluorocarbons (HFCs)					
HFC-134A	14.0	1300	3710	1530	4140
HFC-125	30	3170	6090	3740	6740
HFC-32	5.4	677	2430	771	2690
HFC-143A	51	4800	6940	5810	7840
Perfluorocarbons (PFCs)					
PFC-14	50,000	6630	4880	7380	5300
PFC-116	10,000	11100	8210	12400	8940
PFC-218	2,600	8900	6640	9290	6770
PFC-318	3,200	9540	7110	10200	7400
Sulfur hexafluoride (SF_6)	3,200	23500	17500	24300	18200

Seek comparable, damages-based values for additional impacts.

Carbon dioxide and methane impose other damages in addition to those damages caused by climate change. For example, the federal IWG’s estimates of the social cost of carbon dioxide include some consideration of the effect that elevated carbon dioxide has on agricultural production as this is a specific feature of the FUND model. However, the federal IWG’s estimates for methane do not include other known damages, particularly the role that methane plays as a precursor to ozone formation, which has direct impacts on human health. As in the case of the additional effects of carbon dioxide, it is possible to estimate additional damages from methane so they can be more easily integrated into cost benefit analyses or in the description of the benefits of emission reduction policies. The Department recommends consideration of such estimates if available in the peer-reviewed literature.[51]

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[50] Some portion of emitted CO_2 is taken up by the biosphere and some portion will persist in the atmosphere for the full lifespan of the gas.

[51] Shindell, D.T., Fuglestevedt, Collins, W.J. 2017. The social cost of methane: theory and applications. Faraday Discussions. 200:429.

VII. Example Applications

The following hypothetical examples are provided to illustrate how State entities could use a damages-based value of carbon in different decision contexts. These examples are intentionally over-simplified and are intended to illustrate the utility of the value of carbon at a high-level. Real world examples can also be found in the record of federal decisions, such as by searching for the "social cost of carbon" in the Federal Register. The Department also seeks public input on other applications of the value of carbon by state entities.

Each of the examples below uses the updated social costs of carbon dioxide, methane, and nitrous oxide as provided by NYSERDA and Resources for the Future and the social costs of HFCs provided in this document (see separate Appendix). These are provided in 2020 dollars. Agencies can update these values with inflation as needed. However, these values will remain static otherwise until the Department provides an update based on new peer-reviewed models.

Estimating the emission reduction benefits of a plan or goal.

An agency has developed a strategic plan with the goal of reducing carbon dioxide emissions 50% over ten years from current levels, or 50,000 metric tons over 10 years. In order to determine the benefits to society in terms of avoided damages, the agency will need to determine the annual level of emission reductions (or emissions avoided) compared to a no action scenario. If split evenly across all 10 years, the annual reduction is 5,000 metric tons per year (see table).

Greenhouse gas	Emissions in 2020 (kt)	Reduction 2030	Annual Emission Reductions 2020-2030 (kt)
Carbon dioxide	100	50%	5

The net present value of the plan is equal to the cumulative benefit of the emission reductions that happened each year (adjusted for the discount rate). In other words, the value of carbon is applied to each year, based on the reduction from the no action case, 100,000 tons in this case. The Appendix provides the value of carbon for each year. For example, the social cost of carbon dioxide in 2021 at a 2% discount rate is $123 per metric ton. The value of the reductions in 2021 are equal to $123 times 5,000 metric tons, or $615,000; in 2022 $124 times 10,000 tons, etc. This calculation would be carried out for each year and for each discount rate of interest. The results for all three recommended discount rates are provided below.

Based on this assessment, the net present value of the plan by the end of 2030 ranges from $13.1-$108.5 million or $31.7 million using the central discount rate of 2%. It may be that actions to reduce carbon dioxide will affect the emissions of other greenhouse gases as well. The net present value of those impacts may be estimated and combined with the net present value of the avoided carbon dioxide.

Annual and Cumulative Value of CO_2 Reductions
(Totals May Not Sum Due to Independent Rounding.)

Year	Annual CO_2 Emission Reduction (Kt)	Total CO_2 Emission Reduction (Kt)	Annual Benefits ($K) [Total CO_2 Emission Reduction * Value]		
			3%	2%	1%
2021	5	5	260	615	2,045
2022	5	10	530	1,240	4,110
2023	5	15	810	1,890	6,210
2024	5	20	1,100	2,560	8,320
2025	5	25	1,400	3,225	10,450
2026	5	30	1,710	3,930	12,630
2027	5	35	2,065	4,620	14,805
2028	5	40	2,400	5,360	17,040
2029	5	45	2,745	6,120	19,260
2030	5	50	3,100	6,850	21,500
10-Year Cumulative Value			16,120	36,410	116,370
Net Present Value			13,094	31,689	108,536

Net costs and benefits in an environmental assessment or rulemaking.

An agency is tasked with assessing the net costs of a project or policy and a no-action alternative. A separate assessment has determined that the other monetary costs, which may include the costs of compliance with the policy or the capital costs of the project, will be $100,000 per year for 5 years and that the end result will be a reduction of methane of 500 metric tons.

Greenhouse gas	Emission Reduction 2020-2025 (mt)	Reduction per year (mt)	Total Cost ($K)	Cost per year ($K)
Methane	500	100	500	100

As in the example above, the benefits in terms of avoided damages from climate change can be estimated by multiplying the emission reduction in each year by the relevant value (i.e., the federal IWG social cost of methane). As discussed in the guidance, methane emissions are also associated with damages related to public health that are not included in the federal IWG value for methane, but these could be included in the overall net cost. The example table below includes a placeholder for additional health-related damages. If the health-related damages are omitted the net benefit of the action (or benefits minus costs) ranges from $2 million to $9.5 million. The net present value ranges from $1.8 million to $9.2 million with a central value of $3.6 million. The net value of the no-action alternative may be considered to be the inverse of the cumulative benefit, or a cumulative *cost* to society of up to $10 million.

Cumulative And Net Costs and Benefits from Methane Reductions
(Totals May Not Sum Due to Independent Rounding.)

Year	Total CH_4 Emission Reduction (Mt)	Annual Benefits ($K) 3%			Annual Benefits ($K) 2%			Annual Benefits ($K) 1%		
		CLIMATE	HEALTH	TOTAL	CLIMATE	HEALTH	TOTAL	CLIMATE	HEALTH	TOTAL
2021	100	150			280			640		
2022	200	320			560			1,300		
2023	300	480			870			1,980		
2024	400	680			1,160			2,680		
2025	500	850			1,500			3,400		
Cumulative Benefit		2,480			4,370			10,000		
Cumulative Cost		-500			-500			-500		
Cumulative Net Value		1,980			3,870			9,500		
Net Present Value		1,766			3,591			9,155		

Describing the benefits of a procurement plan.

An agency plans to replace three fleet vehicles with new, zero-emission electric vehicles and would like to describe the societal benefits of this plan. The agency has estimated that the lifecycle carbon dioxide emissions associated with the new vehicles are up to 80% lower than its current sedans, when powered by the electricity grid in upstate New York.[52] A lifecycle value would be appropriate as the CLCPA directs agencies to reduce emissions associated with imported fossil fuels and electricity.

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[52] Example comparing a Chevrolet Bolt with a Chevrolet Cruze from: Nigro N., Walsh A. 2017. EV Smart Fleets. Electric Vehicle Procurements for Public Fleets. Atlas Policy. https://atlaspolicy.com

Greenhouse gas	Annual Emission Reduction Per Vehicle (mt)	Annual Emission Reduction All Vehicles (mt)
Carbon dioxide	2.5	7.5

By applying the value of carbon provided in the Appendix tables, the agency can estimate the total annual benefit of the new vehicles, plus the total value over 5 years or longer. In this example, the full 7.5 tons of reductions are realized in the first year and repeated in each subsequent year. The estimated benefit of the new vehicles in the first five years range from $1,988 to $15,420. Fossil fuels and electricity generation are also associated with methane and nitrous oxide emissions, the value of which could be estimated as well.

Annual and 5-Year Cumulative Value of CO_2 Reductions
(Totals may not sum due to independent rounding.)

Year	Annual CO_2 Emission Reduction (mt)	Annual Benefits ($) [$CO_2$ Emission Reduction * Value]		
		3%	2%	1%
2020	7.5	383	908	3,045
2021	7.5	390	923	3,068
2022	7.5	398	930	3,083
2023	7.5	405	945	3,105
2024	7.5	413	960	3,120
5-Year Cumulative Value		1,988	4,665	15,420
Net Present Value		1,873	4,483	15,116

Comparing alternative technologies

This example applies the value of carbon for HFCs, which are used as refrigerants in many types of equipment. In this case, there are multiple alternative types of heat pump systems and refrigerants. This example illustrates the different social costs when choosing between alternative refrigerants. This example does not compare heat pumps to other types of appliances that they may replace (i.e., fossil fuel boilers or furnaces, air conditioning). Such a comparison would also consider emissions from the combustion of fossil fuels and from the electricity used to power a heat pump or air conditioning equipment.

The building manager for a 5-floor multifamily residential building with 40 apartments solicited bids for retrofitting the building with heat pumps. They received 4 bids for systems that each have an average lifetime of 16 years. The building's efficiency manager uses the following information about each system to calculate and compare the social costs of the hydrofluorocarbon (HFC) and hydrofluoroolefin (HFO) refrigerants emitted by each proposed system. These costs represent the economic damages caused by leakage of each of these greenhouse gases into the atmosphere over the heat pump lifetime. The building manager ranks highest the bid that has the lowest net present value of these cumulative costs (see table below). Each bid is described in detail in the text below. Note: The Appendix provides the costs per ton for each HFC, which have been converted to a cost per kg for this example. For the non-HFC alternative, HFO-1234ze(e), the value of CO_2 is used as a placeholder (see Bid #4). Information on charge size, leak rates, and end-of-life leakage are from NYSERDA (2021).[53]

Comparative Costs of Refrigerant Leakage Value of HFC Emissions at the Central 2% Discount Rate	
	Net Present Value ($)
Bid #1 Multisplits with R-410a	-47,382
Bid #2 VRF with R-410a	-60,468
Bid #3 Multisplits with R-32	-7598
Bid #4 Multisplits with R-1234ze*	-18

Bid #1 includes 40 individual multisplit heat pumps that contain R-410a refrigerant, with one rooftop condenser and two heads per apartment. Each heat pump contains (2.69 kg) of R-410a refrigerant, which is 50% HFC-32 and 50% HFC-125. The average refrigerant leakage from each heat pump is 6.3% of the initial charge per year (0.17 kg/year) and the end-of-life loss rate is assumed to be 80% of the charge remaining (2.02 kg). The net present value of the damages accrued from HFC leakage during the lifetime of the 40 heat pumps ranges from negative $23,685 at a 3% discount rate to negative $120,934 at a 1% discount rate, and negative $47,382 at the 2% or central discount rate. The social cost of the HFC leakage for each year is presented in the table below.

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[53] NYSERDA. 2021. “Hydrofluorocarbon Emissions Inventory and Mitigation Potential in New York State,” Report Number 21-28. Prepared by Guidehouse, Inc. Albany, NY, USA: New York State Energy Research and Development Authority. https://www.nyserda.ny.gov/publications.

Annual and Cumulative Value of HFC Refrigerant Leakage
Bid #1: Multisplit heat pumps with R-410a

Year	Annual R-410a Leakage (kg) for 40 units	Annual Costs ($) for 40 units [Total Cost HFC-32 and HFC-125]		
		3%	2%	1%
2022	6.8	886	1704	4310
2023	6.8	926	1744	4310
2024	6.8	964	1785	4310
2025	6.8	971	1826	4310
2026	6.8	1008	1866	4344
2027	6.8	1049	1907	4344
2028	6.8	1052	1948	4683
2029	6.8	1093	1989	4717
2030	6.8	1130	2033	4717
2031	6.8	1137	2073	4717
2032	6.8	1178	2114	4751
2033	6.8	1215	2158	4751
2034	6.8	1256	2199	5124
2035	6.8	1262	2240	5124
2036	6.8	1303	2274	5124
2037	87.6	17333	30201	66530
16-Year Cumulative Cost		33761	60060	136164
Net Present Value		-23685	-47382	-120934

Bid #2 includes 5 large VRF (variable refrigerant flow) systems that contain R-410a refrigerant, with one unit installed per floor. Each VRF unit is charged with 27.22 kg of R-410a. The systems have an average annual leakage of 10% of the initial charge per year (2.72 kg/year) and an end-of-life loss of 20% of the remaining charge (4.90 kg). The VRF systems leak more R-410a refrigerant over their lifetime than the multisplit heat pumps proposed in the first bid. The net present value of the damages accrued from HFC leakage during the heat pumps' lifetime ranges from negative $30,533 at a 3% discount rate to negative $153,409 at a 1% discount rate, and negative $60,468 at the central 2% discount rate. The social cost of the HFC leakage for each year is presented in the table below.

Annual and Cumulative Value of HFC Refrigerant Leakage **Bid #2: VRF heat pumps with R-410a**				
Year	Annual R-410a Leakage (kg) for 5 units	Annual Costs ($) for 5 units [Total Cost HFC-32 and HFC-125]		
		3%	2%	1%
2022	13.6	1776	3416	8641
2023	13.6	1857	3497	8641
2024	13.6	1932	3579	8641
2025	13.6	1946	3660	8641
2026	13.6	2021	3742	8709
2027	13.6	2102	3824	8709
2028	13.6	2109	3905	9389
2029	13.6	2191	3987	9457
2030	13.6	2266	4076	9457
2031	13.6	2279	4157	9457
2032	13.6	2361	4239	9525
2033	13.6	2436	4327	9525
2034	13.6	2517	4409	10274
2035	13.6	2531	4491	10274
2036	13.6	2613	4559	10274
2037	38.1	7544	13145	28957
16-Year Cumulative Cost		40482	73012	168573
Net Present Value		-30533	-60468	-153409

Bid #3 includes 40 individual multisplit heat pumps that contain R-32, with one rooftop condenser and two heads per apartment. Each heat pump contains (1.91 kg) of R-32 refrigerant (100% HFC-32), which is pitched to the manager as ‘eco-friendly refrigerant’ and requires less charge than the R-410a multisplit system. The average refrigerant leakage from each heat pump is 3.15% of the initial charge per year (0.06 kg/year) and the end-of-life loss rate is assumed to be 80% of the charge remaining (1.48 kg) (NYSERDA 2021). For this bid, the net present value of the damages accrued from HFC-32 leakage during the heat pumps’ lifetime ranges from negative $4,009 at a 3% discount rate to negative $17,831 at a 1% discount rate, and negative $7,598 at the central 2% discount rate. The social cost of the HFC leakage for each year is presented in the table below.

Annual and Cumulative Value of HFC Refrigerant Leakage
Bid #3: Multisplit heat pumps with R-32

Year	Annual R-32 Leakage (kg) for 40 units	Annual Costs ($) for 40 units [Total Cost HFC-32]		
		3%	2%	1%
2022	2.4	99	173	410
2023	2.4	104	178	410
2024	2.4	106	183	410
2025	2.4	111	188	410
2026	2.4	113	193	434
2027	2.4	118	198	434
2028	2.4	120	202	434
2029	2.4	125	207	458
2030	2.4	128	214	458
2031	2.4	133	219	458
2032	2.4	137	224	482
2033	2.4	140	231	482
2034	2.4	145	236	506
2035	2.4	149	241	506
2036	2.4	154	241	506
2037	61.6	4070	6784	13568
16-Year Cumulative Cost		5952	9914	20362
Net Present Value		-4009	-7598	-17831

Bid #4 includes 40 individual multisplit heat pumps that contain R-1234ze, with one rooftop condenser and two heads per apartment. Each heat pump contains (3.23 kg) of R-1234ze refrigerant (HFO-1234ze(E)). The average refrigerant leakage from each heat pump is 3.15% of the initial charge per year (0.10 kg/year) and the end-of-life loss rate is assumed to be 80% of the charge remaining (2.50 kg) (NYSERDA 2021). The social costs of HFO-1234ze(E) have not been assessed yet, so the manager substitutes the social cost of CO_2 for HFO-1234ze(E), knowing that the GWP of HFO-1234ze(E) is similar to that of CO_2. The net present value of the damages accrued from HFO-1234ze(E) leakage ranges from negative $7 at the 3% discount rate to negative $64 at the 1% discount rate, with a value of negative $18 at the 2% central discount rate.

Annual and Cumulative Value of HFC Refrigerant Leakage **Bid #4: Multisplit heat pumps with R-1234ze**				
Year	Annual R-1234ze Leakage (kg) for 40 units	Annual Costs ($) for 40 units [Total Cost HFO-1234ze(e)*]		
		3%	2%	1%
2022	4	0.22	0.50	1.67
2023	4	0.22	0.51	1.69
2024	4	0.22	0.52	1.69
2025	4	0.23	0.53	1.70
2026	4	0.23	0.53	1.71
2027	4	0.24	0.54	1.72
2028	4	0.24	0.55	1.73
2029	4	0.25	0.55	1.74
2030	4	0.25	0.56	1.75
2031	4	0.26	0.57	1.76
2032	4	0.26	0.57	1.77
2033	4	0.26	0.58	1.78
2034	4	0.27	0.59	1.79
2035	4	0.27	0.59	1.80
2036	4	0.28	0.60	1.81
2037	104.4	7.30	15.53	46.49
16-Year Cumulative Cost		11	24	73
Net Present Value		-7	-18	-64

Appendix: Annual Social Cost Estimates

2023 Update, NYS Value of Carbon Guidance

The following tables provide the U.S. Social Cost of Greenhouse Gases (SC-GHG) values adjusted for New York State as described in the DEC (2020) Value of Carbon guidance. Model outputs for each 5-year interval 2020-2050 have been rounded to two decimal points and annualized by averaging between intervals.

Contents

Table A1: Social cost of carbon dioxide (CO_2), 2020-2050 (in 2020 dollars per metric ton CO_2)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	53.43	125.41	420.92	2,205.80
2021	53.43	127.08	423.38	2,200.19
2022	54.71	128.75	425.84	2,194.58
2023	55.98	130.42	428.29	2,188.97
2024	57.25	132.09	430.75	2,183.35
2025	58.52	133.75	433.21	2,177.74
2026	59.80	135.46	435.70	2,172.44
2027	61.07	137.17	438.19	2,167.15
2028	62.34	138.88	440.68	2,161.85
2029	62.34	140.59	443.16	2,156.55
2030	63.61	142.30	445.65	2,151.25
2031	64.88	144.01	448.02	2,145.66
2032	66.16	145.72	450.40	2,140.07
2033	67.43	147.44	452.77	2,134.48
2034	68.70	149.15	455.14	2,128.89
2035	69.97	150.86	457.52	2,123.30
2036	71.25	152.60	459.89	2,117.90
2037	72.52	154.35	462.26	2,112.50
2038	73.79	156.09	464.64	2,107.11
2039	75.06	157.83	467.01	2,101.71
2040	76.33	159.57	469.39	2,096.32
2041	77.61	161.62	472.20	2,091.59
2042	77.61	163.67	475.01	2,086.86
2043	78.88	165.72	477.82	2,082.13
2044	80.15	167.78	480.63	2,077.40
2045	81.42	169.83	483.44	2,072.67
2046	82.70	171.47	485.38	2,066.12
2047	83.97	173.11	487.33	2,059.56
2048	85.24	174.75	489.27	2,053.00
2049	86.51	176.40	491.21	2,046.45
2050	87.78	178.04	493.16	2,039.89

See DEC (2020) “Establishing a Value of Carbon”

Table A2: Social cost of methane (CH_4), 2020-2050 (in 2020 dollars per metric ton CH_4)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	1,526.68	2,782.39	6,578.26	24,279.83
2021	1,526.68	2,848.42	6,676.07	24,373.36
2022	1,653.91	2,914.44	6,773.88	24,466.89
2023	1,653.91	2,980.47	6,871.69	24,560.42
2024	1,781.13	3,046.50	6,969.50	24,653.95
2025	1,781.13	3,112.53	7,067.31	24,747.48
2026	1,781.13	3,184.26	7,174.71	24,865.78
2027	1,908.35	3,255.99	7,282.11	24,984.08
2028	1,908.35	3,327.72	7,389.51	25,102.37
2029	2,035.58	3,399.46	7,496.91	25,220.67
2030	2,035.58	3,471.19	7,604.31	25,338.97
2031	2,035.58	3,546.60	7,711.17	25,443.37
2032	2,162.80	3,622.01	7,818.03	25,547.77
2033	2,162.80	3,697.42	7,924.90	25,652.17
2034	2,290.03	3,772.83	8,031.76	25,756.58
2035	2,290.03	3,848.24	8,138.62	25,860.98
2036	2,417.25	3,928.56	8,252.31	25,978.92
2037	2,417.25	4,008.88	8,366.00	26,096.86
2038	2,544.47	4,089.20	8,479.68	26,214.81
2039	2,544.47	4,169.51	8,593.37	26,332.75
2040	2,544.47	4,249.83	8,707.06	26,450.69
2041	2,671.70	4,323.91	8,809.43	26,548.44
2042	2,671.70	4,397.99	8,911.80	26,646.19
2043	2,798.92	4,472.06	9,014.17	26,743.93
2044	2,798.92	4,546.14	9,116.54	26,841.68
2045	2,926.14	4,620.22	9,218.91	26,939.43
2046	2,926.14	4,696.42	9,318.22	27,012.59
2047	3,053.37	4,772.62	9,417.53	27,085.75
2048	3,053.37	4,848.82	9,516.85	27,158.91
2049	3,180.59	4,925.02	9,616.16	27,232.07
2050	3,180.59	5,001.22	9,715.48	27,305.23

See DEC (2020) “Establishing a Value of Carbon”

Table A3: Social cost of nitrous oxide (N_2O), 2020-2050 (in 2020 dollars per metric ton N_2O)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	19,083.55	44,726.93	140,765.69	683,805.96
2021	19,083.55	45,425.59	142,030.60	684,725.57
2022	20,355.79	46,124.25	143,295.52	685,645.17
2023	20,355.79	46,822.92	144,560.43	686,564.78
2024	20,355.79	47,521.58	145,825.34	687,484.38
2025	21,628.02	48,220.24	147,090.25	688,403.99
2026	21,628.02	48,958.38	148,408.61	689,382.51
2027	21,628.02	49,696.52	149,726.96	690,361.04
2028	22,900.26	50,434.66	151,045.32	691,339.56
2029	22,900.26	51,172.80	152,363.68	692,318.09
2030	24,172.50	51,910.94	153,682.04	693,296.62
2031	24,172.50	52,663.35	154,997.56	694,184.96
2032	24,172.50	53,415.77	156,313.08	695,073.30
2033	25,444.73	54,168.18	157,628.61	695,961.64
2034	25,444.73	54,920.59	158,944.13	696,849.99
2035	26,716.97	55,673.00	160,259.66	697,738.33
2036	26,716.97	56,456.24	161,588.46	698,488.07
2037	26,716.97	57,239.47	162,917.27	699,237.80
2038	27,989.21	58,022.70	164,246.07	699,987.54
2039	27,989.21	58,805.93	165,574.87	700,737.28
2040	29,261.44	59,589.16	166,903.68	701,487.01
2041	29,261.44	60,405.80	168,257.92	702,244.16
2042	29,261.44	61,222.44	169,612.16	703,001.30
2043	30,533.68	62,039.09	170,966.39	703,758.44
2044	30,533.68	62,855.73	172,320.63	704,515.58
2045	31,805.92	63,672.37	173,674.87	705,272.73
2046	31,805.92	64,522.93	175,055.50	705,975.04
2047	33,078.15	65,373.50	176,436.12	706,677.36
2048	33,078.15	66,224.06	177,816.75	707,379.68
2049	33,078.15	67,074.63	179,197.37	708,082.00
2050	34,350.39	67,925.19	180,577.99	708,784.32

See DEC (2020) “Establishing a Value of Carbon”

Table A4: Social cost of HFC-125, 2020-2050 (in 2020 dollars per metric ton HFC-125)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	212,148.05	412,381.77	1,036,559.21	3,960,590.50
2021	218,368.07	421,813.69	1,052,113.72	3,982,416.16
2022	224,588.08	431,245.61	1,067,668.24	4,004,241.82
2023	230,808.10	440,677.52	1,083,222.76	4,026,067.48
2024	237,028.12	450,109.44	1,098,777.27	4,047,893.14
2025	243,248.13	459,541.36	1,114,331.79	4,069,718.80
2026	249,933.06	469,604.32	1,130,698.27	4,092,093.77
2027	256,617.99	479,667.28	1,147,064.75	4,114,468.74
2028	263,302.93	489,730.24	1,163,431.23	4,136,843.70
2029	269,987.86	499,793.20	1,179,797.72	4,159,218.67
2030	276,672.79	509,856.16	1,196,164.20	4,181,593.64
2031	283,893.58	520,244.98	1,212,220.76	4,201,615.03
2032	291,114.37	530,633.79	1,228,277.33	4,221,636.41
2033	298,335.15	541,022.60	1,244,333.90	4,241,657.80
2034	305,555.94	551,411.42	1,260,390.47	4,261,679.19
2035	312,776.73	561,800.23	1,276,447.04	4,281,700.57
2036	320,596.84	573,176.22	1,294,659.89	4,309,630.77
2037	328,416.94	584,552.21	1,312,872.74	4,337,560.97
2038	336,237.04	595,928.20	1,331,085.59	4,365,491.17
2039	344,057.14	607,304.19	1,349,298.44	4,393,421.37
2040	351,877.25	618,680.18	1,367,511.29	4,421,351.57
2041	359,718.92	629,580.52	1,384,138.32	4,444,656.21
2042	367,560.59	640,480.86	1,400,765.35	4,467,960.86
2043	375,402.26	651,381.19	1,417,392.38	4,491,265.50
2044	383,243.92	662,281.53	1,434,019.41	4,514,570.14
2045	391,085.59	673,181.87	1,450,646.44	4,537,874.79
2046	399,314.73	684,403.96	1,466,636.71	4,553,095.31
2047	407,543.86	695,626.05	1,482,626.98	4,568,315.84
2048	415,772.99	706,848.14	1,498,617.25	4,583,536.36
2049	424,002.13	718,070.23	1,514,607.52	4,598,756.89
2050	432,231.26	729,292.32	1,530,597.79	4,613,977.41

See DEC (2020) “Establishing a Value of Carbon”

Table A5: Social cost of HFC-134a, 2020-2050 (in 2020 dollars per metric ton HFC-134a)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	87,578.65	160,376.46	382,580.22	1,421,550.02
2021	90,480.56	164,632.90	389,438.18	1,431,933.09
2022	93,382.46	168,889.35	396,296.14	1,442,316.17
2023	96,284.36	173,145.80	403,154.09	1,452,699.25
2024	99,186.27	177,402.24	410,012.05	1,463,082.33
2025	102,088.17	181,658.69	416,870.01	1,473,465.41
2026	105,240.81	186,274.32	424,312.23	1,485,092.21
2027	108,393.45	190,889.95	431,754.45	1,496,719.01
2028	111,546.09	195,505.58	439,196.66	1,508,345.81
2029	114,698.73	200,121.22	446,638.88	1,519,972.61
2030	117,851.37	204,736.85	454,081.10	1,531,599.41
2031	121,284.47	209,521.67	461,315.21	1,541,518.79
2032	124,717.57	214,306.49	468,549.32	1,551,438.18
2033	128,150.67	219,091.32	475,783.43	1,561,357.57
2034	131,583.77	223,876.14	483,017.54	1,571,276.96
2035	135,016.87	228,660.96	490,251.65	1,581,196.35
2036	138,696.92	233,755.12	497,807.84	1,590,844.79
2037	142,376.96	238,849.27	505,364.02	1,600,493.23
2038	146,057.01	243,943.43	512,920.20	1,610,141.67
2039	149,737.06	249,037.59	520,476.39	1,619,790.11
2040	153,417.10	254,131.74	528,032.57	1,629,438.55
2041	157,033.65	258,910.98	534,721.71	1,636,726.26
2042	160,650.20	263,690.22	541,410.85	1,644,013.97
2043	164,266.75	268,469.46	548,099.99	1,651,301.68
2044	167,883.30	273,248.70	554,789.14	1,658,589.39
2045	171,499.85	278,027.94	561,478.28	1,665,877.10
2046	175,333.04	283,048.26	568,291.20	1,672,160.53
2047	179,166.23	288,068.59	575,104.12	1,678,443.96
2048	182,999.42	293,088.91	581,917.04	1,684,727.39
2049	186,832.61	298,109.23	588,729.95	1,691,010.82
2050	190,665.80	303,129.55	595,542.87	1,697,294.25

See DEC (2020) “Establishing a Value of Carbon”

Table A6: Social cost of HFC-143a, 2020-2050 (in 2020 dollars per metric ton HFC-143a)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	268,971.96	560,361.37	1,530,523.55	6,326,251.88
2021	276,213.51	571,930.16	1,551,398.47	6,362,134.03
2022	283,455.05	583,498.95	1,572,273.39	6,398,016.19
2023	290,696.60	595,067.74	1,593,148.32	6,433,898.34
2024	297,938.15	606,636.53	1,614,023.24	6,469,780.49
2025	305,179.69	618,205.32	1,634,898.16	6,505,662.65
2026	312,873.40	630,267.85	1,655,500.72	6,533,052.42
2027	320,567.11	642,330.38	1,676,103.28	6,560,442.19
2028	328,260.82	654,392.91	1,696,705.84	6,587,831.95
2029	335,954.52	666,455.44	1,717,308.40	6,615,221.72
2030	343,648.23	678,517.97	1,737,910.96	6,642,611.49
2031	351,900.04	690,886.33	1,758,107.96	6,667,235.39
2032	360,151.85	703,254.68	1,778,304.95	6,691,859.28
2033	368,403.66	715,623.03	1,798,501.95	6,716,483.17
2034	376,655.47	727,991.39	1,818,698.95	6,741,107.07
2035	384,907.28	740,359.74	1,838,895.95	6,765,730.96
2036	393,674.31	753,409.79	1,859,771.97	6,789,400.28
2037	402,441.34	766,459.84	1,880,647.99	6,813,069.61
2038	411,208.37	779,509.88	1,901,524.01	6,836,738.93
2039	419,975.40	792,559.93	1,922,400.03	6,860,408.25
2040	428,742.42	805,609.98	1,943,276.05	6,884,077.58
2041	437,768.60	818,502.77	1,963,171.17	6,904,996.89
2042	446,794.77	831,395.57	1,983,066.29	6,925,916.20
2043	455,820.94	844,288.36	2,002,961.41	6,946,835.52
2044	464,847.11	857,181.15	2,022,856.53	6,967,754.83
2045	473,873.28	870,073.95	2,042,751.65	6,988,674.14
2046	483,413.69	883,656.66	2,063,441.35	7,009,814.07
2047	492,954.10	897,239.37	2,084,131.05	7,030,954.00
2048	502,494.51	910,822.08	2,104,820.75	7,052,093.93
2049	512,034.92	924,404.79	2,125,510.45	7,073,233.85
2050	521,575.34	937,987.50	2,146,200.16	7,094,373.78

See DEC (2020) “Establishing a Value of Carbon”

Table A7: Social cost of HFC-32, 2020-2050 (in 2020 dollars per metric ton HFC-32)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	38,606.83	68,248.04	159,737.46	595,939.89
2021	39,993.75	70,210.42	162,776.89	600,208.16
2022	41,380.67	72,172.79	165,816.32	604,476.43
2023	42,767.59	74,135.17	168,855.75	608,744.70
2024	44,154.51	76,097.54	171,895.18	613,012.97
2025	45,541.43	78,059.92	174,934.60	617,281.24
2026	47,041.91	80,163.13	178,135.38	621,621.44
2027	48,542.40	82,266.35	181,336.16	625,961.63
2028	50,042.89	84,369.56	184,536.93	630,301.83
2029	51,543.38	86,472.77	187,737.71	634,642.02
2030	53,043.87	88,575.99	190,938.48	638,982.22
2031	54,824.53	90,989.41	194,467.47	643,588.57
2032	56,605.18	93,402.83	197,996.46	648,194.91
2033	58,385.84	95,816.26	201,525.45	652,801.26
2034	60,166.50	98,229.68	205,054.44	657,407.61
2035	61,947.16	100,643.10	208,583.42	662,013.95
2036	63,851.86	103,217.50	212,344.92	667,099.65
2037	65,756.57	105,791.89	216,106.41	672,185.35
2038	67,661.27	108,366.29	219,867.90	677,271.05
2039	69,565.98	110,940.68	223,629.39	682,356.74
2040	71,470.68	113,515.08	227,390.88	687,442.44
2041	73,521.82	116,159.70	231,009.30	691,584.25
2042	75,572.96	118,804.32	234,627.72	695,726.05
2043	77,624.10	121,448.94	238,246.13	699,867.86
2044	79,675.24	124,093.57	241,864.55	704,009.67
2045	81,726.38	126,738.19	245,482.97	708,151.47
2046	83,904.30	129,543.57	249,312.08	712,609.25
2047	86,082.22	132,348.94	253,141.20	717,067.03
2048	88,260.14	135,154.32	256,970.31	721,524.81
2049	90,438.06	137,959.70	260,799.42	725,982.59
2050	92,615.98	140,765.08	264,628.53	730,440.37

See DEC (2020) “Establishing a Value of Carbon”

Table A8: Social cost of HFC-152a, 2020-2050 (in 2020 dollars per metric ton HFC-152a)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	5,388.14	9,478.99	22,415.04	86,259.85
2021	5,583.49	9,752.35	22,833.45	86,806.94
2022	5,778.83	10,025.71	23,251.86	87,354.02
2023	5,974.18	10,299.07	23,670.27	87,901.11
2024	6,169.53	10,572.43	24,088.68	88,448.20
2025	6,364.88	10,845.79	24,507.09	88,995.28
2026	6,576.88	11,140.42	24,953.55	89,583.36
2027	6,788.87	11,435.04	25,400.01	90,171.44
2028	7,000.86	11,729.67	25,846.47	90,759.52
2029	7,212.86	12,024.29	26,292.93	91,347.60
2030	7,424.85	12,318.92	26,739.39	91,935.67
2031	7,679.62	12,660.58	27,228.02	92,490.91
2032	7,934.38	13,002.25	27,716.64	93,046.15
2033	8,189.15	13,343.91	28,205.26	93,601.38
2034	8,443.91	13,685.57	28,693.88	94,156.62
2035	8,698.68	14,027.24	29,182.51	94,711.85
2036	8,971.31	14,392.75	29,711.54	95,394.98
2037	9,243.93	14,758.27	30,240.57	96,078.12
2038	9,516.56	15,123.78	30,769.60	96,761.25
2039	9,789.19	15,489.30	31,298.63	97,444.38
2040	10,061.82	15,854.81	31,827.66	98,127.51
2041	10,391.18	16,284.75	32,440.24	98,984.81
2042	10,720.54	16,714.69	33,052.82	99,842.10
2043	11,049.90	17,144.62	33,665.39	100,699.40
2044	11,379.27	17,574.56	34,277.97	101,556.70
2045	11,708.63	18,004.50	34,890.55	102,413.99
2046	12,056.16	18,455.81	35,520.86	103,227.41
2047	12,403.68	18,907.12	36,151.17	104,040.83
2048	12,751.21	19,358.44	36,781.48	104,854.24
2049	13,098.73	19,809.75	37,411.79	105,667.66
2050	13,446.26	20,261.06	38,042.11	106,481.08

See DEC (2020) “Establishing a Value of Carbon”

Table A9: Social cost of HFC-227ea, 2020-2050 (in 2020 dollars per metric ton HFC-227ea)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	194,270.73	384,623.52	986,579.25	3,833,077.81
2021	199,815.41	393,118.88	1,000,769.63	3,853,290.66
2022	205,360.09	401,614.25	1,014,960.01	3,873,503.52
2023	210,904.77	410,109.62	1,029,150.39	3,893,716.38
2024	216,449.45	418,604.99	1,043,340.77	3,913,929.24
2025	221,994.13	427,100.35	1,057,531.15	3,934,142.10
2026	227,935.82	436,103.22	1,072,140.61	3,952,573.17
2027	233,877.52	445,106.09	1,086,750.06	3,971,004.24
2028	239,819.22	454,108.96	1,101,359.52	3,989,435.32
2029	245,760.91	463,111.83	1,115,968.98	4,007,866.39
2030	251,702.61	472,114.70	1,130,578.44	4,026,297.46
2031	258,106.55	481,402.87	1,145,012.17	4,043,437.30
2032	264,510.49	490,691.05	1,159,445.90	4,060,577.13
2033	270,914.44	499,979.22	1,173,879.63	4,077,716.97
2034	277,318.38	509,267.40	1,188,313.36	4,094,856.80
2035	283,722.32	518,555.57	1,202,747.09	4,111,996.64
2036	290,583.22	528,530.46	1,218,410.34	4,132,642.71
2037	297,444.11	538,505.35	1,234,073.59	4,153,288.78
2038	304,305.00	548,480.23	1,249,736.85	4,173,934.85
2039	311,165.89	558,455.12	1,265,400.10	4,194,580.92
2040	318,026.78	568,430.01	1,281,063.36	4,215,226.99
2041	324,942.03	578,033.35	1,295,405.49	4,231,923.22
2042	331,857.27	587,636.69	1,309,747.63	4,248,619.46
2043	338,772.51	597,240.03	1,324,089.77	4,265,315.69
2044	345,687.76	606,843.36	1,338,431.90	4,282,011.92
2045	352,603.00	616,446.70	1,352,774.04	4,298,708.16
2046	359,954.55	626,630.26	1,367,798.69	4,315,502.53
2047	367,306.10	636,813.82	1,382,823.34	4,332,296.90
2048	374,657.65	646,997.38	1,397,847.99	4,349,091.27
2049	382,009.21	657,180.94	1,412,872.64	4,365,885.65
2050	389,360.76	667,364.50	1,427,897.29	4,382,680.02

See DEC (2020) “Establishing a Value of Carbon”

Table A10: Social cost of HFC-236fa, 2020-2050 (in 2020 dollars per metric ton HFC-236fa)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	640,137.76	1,604,171.58	5,713,622.51	27,489,570.34
2021	654,784.67	1,630,187.73	5,764,319.67	27,498,450.11
2022	669,431.58	1,656,203.88	5,815,016.82	27,507,329.88
2023	684,078.49	1,682,220.03	5,865,713.98	27,516,209.65
2024	698,725.40	1,708,236.18	5,916,411.14	27,525,089.43
2025	713,372.32	1,734,252.33	5,967,108.30	27,533,969.20
2026	728,934.02	1,761,568.73	6,018,980.15	27,540,477.25
2027	744,495.72	1,788,885.13	6,070,852.00	27,546,985.30
2028	760,057.42	1,816,201.53	6,122,723.85	27,553,493.35
2029	775,619.13	1,843,517.94	6,174,595.69	27,560,001.40
2030	791,180.83	1,870,834.34	6,226,467.54	27,566,509.45
2031	807,883.45	1,899,061.97	6,278,208.86	27,569,771.27
2032	824,586.07	1,927,289.61	6,329,950.18	27,573,033.10
2033	841,288.69	1,955,517.24	6,381,691.50	27,576,294.92
2034	857,991.31	1,983,744.87	6,433,432.81	27,579,556.74
2035	874,693.93	2,011,972.51	6,485,174.13	27,582,818.56
2036	892,346.65	2,041,482.27	6,537,857.27	27,583,263.62
2037	909,999.36	2,070,992.04	6,590,540.41	27,583,708.67
2038	927,652.08	2,100,501.80	6,643,223.54	27,584,153.72
2039	945,304.80	2,130,011.56	6,695,906.68	27,584,598.77
2040	962,957.52	2,159,521.33	6,748,589.82	27,585,043.82
2041	981,362.10	2,189,296.68	6,800,135.49	27,580,904.27
2042	999,766.69	2,219,072.03	6,851,681.16	27,576,764.72
2043	1,018,171.27	2,248,847.38	6,903,226.83	27,572,625.16
2044	1,036,575.85	2,278,622.73	6,954,772.51	27,568,485.61
2045	1,054,980.44	2,308,398.08	7,006,318.18	27,564,346.06
2046	1,074,201.62	2,339,101.76	7,057,614.02	27,552,971.50
2047	1,093,422.81	2,369,805.44	7,108,909.85	27,541,596.95
2048	1,112,644.00	2,400,509.12	7,160,205.69	27,530,222.40
2049	1,131,865.19	2,431,212.80	7,211,501.53	27,518,847.84
2050	1,151,086.37	2,461,916.48	7,262,797.37	27,507,473.29

See DEC (2020) “Establishing a Value of Carbon”

Table A11: Social cost of sulfur hexafluoride (SF6), 2020-2050 (in 2020 dollars per metric ton SF6)

	Discount Rate			
Year	**3%**	**2%**	**1%**	**0%**
2020	1,652,241.63	4,478,900.56	17,799,508.10	110,210,122.96
2021	1,688,863.98	4,550,046.46	17,983,888.29	110,900,033.43
2022	1,725,486.33	4,621,192.35	18,168,268.48	111,589,943.90
2023	1,762,108.69	4,692,338.25	18,352,648.68	112,279,854.37
2024	1,798,731.04	4,763,484.15	18,537,028.87	112,969,764.84
2025	1,835,353.40	4,834,630.05	18,721,409.07	113,659,675.31
2026	1,875,517.50	4,913,802.34	18,927,819.36	114,420,697.96
2027	1,915,681.61	4,992,974.63	19,134,229.64	115,181,720.61
2028	1,955,845.72	5,072,146.91	19,340,639.93	115,942,743.26
2029	1,996,009.83	5,151,319.20	19,547,050.22	116,703,765.91
2030	2,036,173.93	5,230,491.49	19,753,460.50	117,464,788.56
2031	2,079,897.05	5,313,961.29	19,966,159.12	118,215,585.08
2032	2,123,620.17	5,397,431.09	20,178,857.74	118,966,381.59
2033	2,167,343.29	5,480,900.90	20,391,556.36	119,717,178.10
2034	2,211,066.41	5,564,370.70	20,604,254.99	120,467,974.62
2035	2,254,789.53	5,647,840.50	20,816,953.61	121,218,771.13
2036	2,298,858.44	5,729,131.09	21,014,016.39	121,872,086.04
2037	2,342,927.34	5,810,421.68	21,211,079.18	122,525,400.95
2038	2,386,996.25	5,891,712.26	21,408,141.97	123,178,715.86
2039	2,431,065.16	5,973,002.85	21,605,204.76	123,832,030.77
2040	2,475,134.07	6,054,293.44	21,802,267.55	124,485,345.68
2041	2,522,264.49	6,138,963.28	22,004,374.66	125,124,829.49
2042	2,569,394.91	6,223,633.12	22,206,481.78	125,764,313.30
2043	2,616,525.33	6,308,302.96	22,408,588.90	126,403,797.12
2044	2,663,655.75	6,392,972.80	22,610,696.02	127,043,280.93
2045	2,710,786.17	6,477,642.64	22,812,803.13	127,682,764.74
2046	2,759,624.71	6,564,512.26	23,016,089.19	128,305,623.85
2047	2,808,463.25	6,651,381.87	23,219,375.25	128,928,482.95
2048	2,857,301.79	6,738,251.49	23,422,661.31	129,551,342.06
2049	2,906,140.33	6,825,121.10	23,625,947.36	130,174,201.16
2050	2,954,978.87	6,911,990.72	23,829,233.42	130,797,060.27

See DEC (2020) “Establishing a Value of Carbon”

Estimating the Value of Carbon: Two Approaches

Prepared by the New York State Energy Research and Development Authority (NYSERDA) and Resources for the Future (RFF)

October 2020 (Revised April 2021)

Record of Revision

Revision Date	Description of Changes	Revision on Page(s)
April 2021	Replacement of text instances of "CLCPA" with "Climate Act"	multiple
April 2021	Text additions and modifications to reflect the Value of Carbon Guidance released by the NYS Department of Environmental Conservation in December 2020	p. 1, p. 5
April 2021	For consistency with IWG interim estimates released in February 2021, estimates of SC-CO2 are revised to reflect usage of the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9	p. 4 (Table 1), p. 29 (Table C1) and text on multiple pages
April 2021	Text additions and modifications to reflect Executive Order 13990 and the associated release of IWG interim estimates.	p. 4
April 2021	Updates to the reference list to include Executive Order 13783, Executive Order 13990, IWG interim estimates, the BEA implicit price deflator, and NYS Department of Environmental Conservation Value of Carbon Guidance.	p. 23, 24
April 2021	For consistency with the IWG approach, estimates of SC-CH4 and SC-N2O are revised to reflect usage of BEA implicit price deflator, rounding to two significant figures, and recalculation of estimates using the PAGE model to exclude a small number of model runs in which a climate discontinuity is triggered in the marginal run but not the baseline run, leading to spuriously high values.	p. 27, p. 29, Tables C2, C3
April 2021	Correction of text to reflect that each model was run 50,000 times rather than 10,000 times as originally written.	p. 29
April 2021	Inclusion of Appendix I, 2020-2050 annual values of SC-CO2, SC-CH4, and SC-N2O for discount rates of 3%, 2%, and 1%	p. 36

Contents

1. Introduction

The value of carbon is a monetary estimate of the value associated with small changes in emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs). Pursuant to the Climate Leadership and Community Protection Act (Climate Act), the New York State (NYS) Department of Environmental Conservation (the Department), in consultation with the New York State Energy Research and Development Authority (NYSERDA), is directed to establish a value of carbon for use by NYS agencies,[1] expressed in terms of dollars per ton of carbon dioxide equivalent (CO_2e).[2]

In establishing a value of carbon for NYS, the Climate Act requires the Department to consider the two main analytic approaches for quantifying the dollar value of avoided CO_2 emissions. These are:

- The *social cost of carbon* (SCC) approach, or *marginal damages approach*, provides monetary estimates of the future environmental and social impacts caused by a small (1 metric ton) increase in greenhouse gas emissions in a given year. Equivalently, the SCC approach values the economic benefit that results from reducing greenhouse emissions by the same amount in that year.

- The *marginal abatement cost* (MAC) approach, or *target-consistent approach*, provides monetary estimates for greenhouse gas emissions based on the marginal abatement cost for achieving a given emissions reduction target—that is, the cost of abating the last metric ton of carbon dioxide needed to meet a particular emissions target at least cost to society.

The value of carbon is an important analytic input in policy deliberations and appraisal, including for benefit-cost analysis and regulatory impact assessment of policies that affect emissions and for estimating the economic benefits of existing climate policy. In applying the value of carbon, NYS policymakers can also be expected to evaluate policy options based on criteria such as their ability to deliver the specific emissions reductions required by the Climate Act and whether they will deliver such reductions at lowest cost.

In support of the Department's issuance of guidance on the value of carbon, this memo reviews both the SCC approach and the MAC approach to carbon valuation, with attention to specific considerations for the application of each approach to inform policy analysis and decision-making in NYS. This memo also presents associated estimates for the value of carbon, and certain other GHGs, issued and adopted by the US federal government, US states, and several European countries, including estimates that are calculated at a range of discount rates. Though the SCC and MAC approaches provide distinctly different information, they may play complementary roles in the NYS policy process to drive emissions reductions.

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[1] Governor Andrew Cuomo signed the *Climate Leadership and Community Protection Act (*Climate Act*)* into NYS law on June 18, 2019. Section 75-0113 of the Climate Act addresses the value of carbon. Since the initial preparation of this memo, the Department issued value of carbon guidance on December 30, 2020 (New York State Department of Environmental Conservation. n.d.).

[2] The emissions from various greenhouse gases are converted to carbon dioxide equivalent (CO_2e) by multiplying by their global warming potential (GWP) over a specific timescale. As discussed in this memo, the social cost of carbon dioxide (SC-CO_2) is the $ damage per ton of CO_2. Any other greenhouse gas, such as methane (CH_4), would be multiplied by its respective GWP value to determine its CO_2 damage equivalent (e.g., tons CH_4/ton CO_2) and derive its $ per ton CO_2e. This memo suggests using direct estimates for the social cost of methane and the social cost of nitrous oxide, and developing direct estimates for the social cost of other common greenhouse gases, while using $ per ton CO_2e when a gas-specific estimate of social cost has not been established.

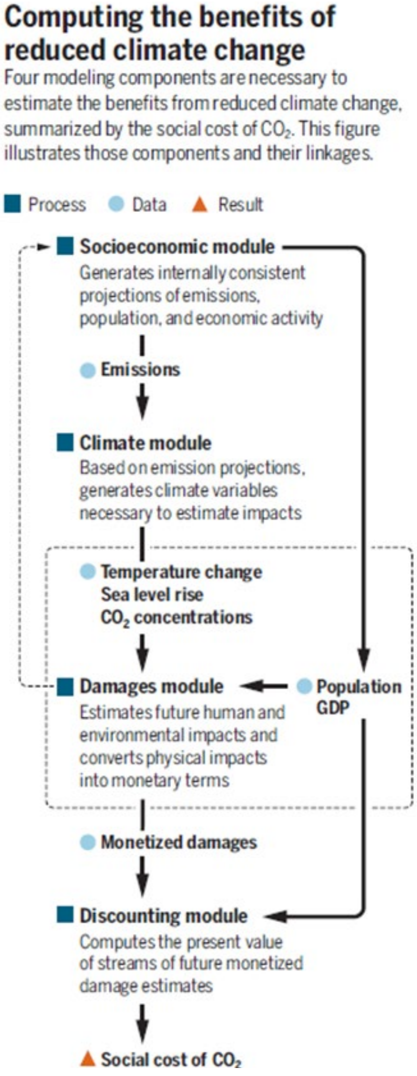
2. Social Cost of Carbon: Valuing Damages from Climate Change

In evaluating energy- and climate-related policy options, multiple NYS agencies currently use a *social cost of carbon* estimate[3] developed from a methodology that has been subject to broad stakeholder and peer review and issued by a US federal interagency working group. This section describes the mechanics of the SCC approach as well as ongoing research to refine this methodology. It identifies key decisions in its use, with specific focus on considerations for discounting and for non-CO_2 gases. The term SCC is used in this memo in a general sense to refer to the estimation of the marginal damages resulting from GHGs. The specific application of the SCC approach to evaluate the social costs of carbon dioxide, methane (CH_4), and nitrous oxide (N_2O) is referred to as SC-CO_2, SC-CH_4, and SC-N_2O, respectively.

The SCC for a given year is "an estimate, in dollars, of the present discounted value of the future damage caused by a 1 metric ton increase in carbon dioxide (CO_2) emissions into the atmosphere in that same year or, equivalently, the benefits of reducing CO_2 emissions by the same amount in that year" (NAS 2017). It is intended to be a comprehensive measure of net damages due to climate change from one additional ton of CO_2, including changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services (IWG 2010). SCC calculations take into account future costs because CO_2 emitted today will have consequences for centuries into the future.

SCC estimates are calculated using integrated assessment models (IAMs), such as the Dynamic Integrated Climate-Economy model (DICE); the Climate Framework for Uncertainty, Negotiation, and Distribution model (FUND); the Policy Analysis of the Greenhouse Effect model (PAGE); and the Regional Integrated model of Climate and Economy (RICE). The vast majority of SCC estimates in the academic literature use one or more of these models (Isacs et al. 2016). These IAMs link together a global economic model and a global climate model (Figure 1). IAMs simulate the cost of the expected incremental damage along an emissions pathway due to a small increase in CO_2 emissions released at a certain point in time. The IAMs account for future economic growth, population growth, and technological change, from which emissions trajectories are defined. These trajectories are translated to climate

Figure 1. Schematic of the Modeling Approach Taken by Integrated Assessment Models to Estimate the SCC



Source: Reproduced from Pizer (2017).

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[3] The NYS Public Service Commission, Department of Public Service, and NYSERDA use the SC-CO_2 average estimate at the 3 percent discount rate that was issued by the federal Interagency Working Group in 2016, as discussed in this memo. These NYS agencies have used this value of carbon in setting zero-emission credit (ZEC) payments to at-risk nuclear generation power plants; to guide avoided CO_2 cost compensation to clean distributed generators; in benefit-cost analyses of utility energy efficiency programs and other utility expenditures that may impact CO_2 emissions; and in a range of analytic studies, such as to assess the statewide potential for increased adoption of energy efficiency and renewable energy technologies and to inform NYS policy on offshore wind energy and the Clean Energy Standard.

impacts and then to monetized damages, with future damages converted into their present-day value by using a discount rate. The SCC is estimated as the net difference in total damage cost between the baseline case and the case with a small additional amount of CO_2 emissions. The model is typically run hundreds of thousands of times to evaluate the uncertainty of the estimates.

2.1. SCC at the Federal Level

Established by the US federal government in 2009, the Interagency Working Group (IWG) on the Social Cost of Greenhouse Gases developed estimates of the social cost associated with CO_2 emissions for use by federal agencies in regulatory impact analysis. The IWG last developed SCC estimates in 2016; it was disbanded in 2017 and subsequently re-established in January 2021.[4]

The IWG used three integrated assessment models—DICE, FUND, and PAGE—to estimate the global damages caused by GHG emissions. The IWG ran the three models through the year 2300 using five emissions scenarios: four business-as-usual trajectories featuring different technology assumptions, plus one policy trajectory in which atmospheric CO_2 concentrations stabilized at 550 parts per million. The IWG then averaged the results across the models and trajectories to produce four SCC values, three of which are based on the average SCC from the three IAMs at discount rates of 2.5, 3, and 5 percent. The fourth value represents the 95th-percentile SCC estimate across all three models at a 3 percent discount rate. The final value was included to capture the damages associated with lower-probability but higher-impact outcomes from climate change, which would be particularly harmful to society.

SCC estimates are subject to both structural uncertainty (related to the functional form of the underlying models) and parametric uncertainty (related to the values employed for the primary parameters). The IWG approach was intended to mitigate or characterize such uncertainty to the extent possible (NAS 2017).[5] Examples of uncertain elements in the SCC estimates include very long-run projections of socioeconomic variables, such as economic growth, population, and emissions; aspects of the climate system, including how sensitive it is to emissions; and the inadequate representation of catastrophic "tipping elements" in the climate system (Lenton et al. 2008). The IAMs only partially account for, or omit, many significant impacts of climate change that are difficult to quantify or monetize, including ecosystems, increased fire risk, the spread of pests and pathogens, mass extinctions, large-scale migration, increased conflict, slower economic growth, and potential catastrophic impacts (Howard 2014; Institute for Policy Integrity 2019; IWG 2010; NAS 2017). Further uncertainty comes from the extrapolation of damage functions to temperature increases above 2.5^0 to 3^0C (Isacs et al. 2016). To the extent that the IAMs are used to estimate an SCC that is based on optimal climate policy, additional uncertainties lie in the abatement costs as well.

Table 1 shows the SC-CO_2 estimates developed by the IWG in 2016 (since adjusted for inflation and issued in 2021), at five-year intervals through 2050, expressed in 2020$ per metric ton of CO_2. Although the average estimate at the 3 percent discount rate is presented as the "central estimate," the IWG emphasizes the

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[4] The IWG originally published SCC estimates in 2010, and subsequently issued four updates, all of which followed the 2010 methodology. The IWG estimates have been used for applications ranging from vehicle emission and fuel economy standards, to emission standards for industrial manufacturing and power plants, to energy efficiency standards. These estimates are also often applied at the state or local level and have been used internationally.

[5] The National Academies (NAS 2017) further assessed sources of uncertainty in the SCC estimates and offered extensive recommendations for both reducing them and improving their characterization. These specific recommendations are currently in the process of being implemented by RFF's Social Cost of Carbon Initiative.

importance of considering all four values for capturing uncertainty in the SCC estimates in regulatory impact analysis. The IWG also developed estimates for the social cost of methane and the social cost of nitrous oxide (Appendix A).

The range of IWG values shows the sensitivity of the SCC estimate to the discount rate assumption. The IWG's 2016 update expanded the discussion of other sources of uncertainty about the SCC estimates, including presentation of quantified sources of uncertainty in the form of frequency distributions for the SCC estimates in 2020 (Appendix B) as well as discussion of model limitations and research gaps (IWG 2016).

Table 1. Social Cost of CO_2, IWG Estimates (2020$/metric ton CO_2)

Year of emissions	Average estimate at 5% discount rate	IWG central estimate: Average estimate at 3% discount rate	Average estimate at 2.5% discount rate	High-impact estimate: 95th percentile estimate at 3% discount rate
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Source: Federal interim social cost of CO_2 estimates provided by the IWG under Executive Order 13990 (IWG 2021).

Presidential Executive Order 13783 disbanded the IWG in 2017 and removed the requirement for federal agencies to employ a harmonized set of SCC estimates in their regulatory analyses. Federal agencies subsequently relied on a set of estimates based on the IWG methodology but with two modifications that significantly alter SCC values: attempting to calculate only damages occurring within the United States rather than global damages, and employing discount rates of 3 and 7 percent in their central analyses. At the 7 percent discount rate, the estimate for domestic SCC is just $1 per metric ton of CO_2. This estimate is inconsistent with the Climate Act's direction to consider the global impacts of GHG emissions; moreover, it is methodologically flawed in that the existing IAMs do not model relevant interactions among regions (e.g., global migration, economic and political destabilization, impacts on trade, potential for reciprocity in climate mitigation) in the manner that would be necessary for more thoroughly estimating a domestic impact.

In January 2021, Presidential Executive Order 13990 reestablished the IWG and set a schedule requiring the publication of an interim set of SC-CO_2, SC-CH_4, and SC-N_2O estimates within thirty days and a final set of estimates in January 2022. The interim estimates, published in February 2021, are identical to the estimates previously provided by the IWG in its 2013 and 2016 Technical Support Documents, adjusted for inflation. The interim estimates therefore reflect global damages and discount rates of 5%, 3%, and 2.5%, as well as a high-impact estimate derived from the 95th percentile estimate at a 3% discount rate (IWG 2021).

2.2. SCC at the State Level

Multiple states continue to use the IWG global SCC estimates in conducting cost-benefit analysis of energy-related regulations and other actions, including California, Colorado, Illinois, Maine, Maryland, Minnesota, Nevada, New Jersey, New York, and Washington. The majority of these states use the IWG central estimate at the 3 percent discount rate, yielding an SC-CO_2 value of $51 per metric ton for emissions occurring in 2020.

The state of Washington in April 2019 passed a law requiring utilities to use the IWG SCC estimate at the 2.5 percent discount rate (i.e., an SC-CO_2 value of $76 per metric ton for 2020 emissions) when developing "lowest-cost analyses" for its integrated resource planning and clean energy action plans. The use of the 2.5 percent discount rate reflects the view that the IWG estimate does not capture the total future cost of CO_2 emissions because of omitted damages and uncertainty (Paul et al. 2017).

California's Air Resources Board and Public Utilities Commission both use the IWG SCC. The former cites the SC-CO_2 and SC-CH_4 in its scoping plan for its updated climate change policy, adopting estimates at a range of discount rates from 2.5 to 5 percent. The latter requires use of the IWG SCC for evaluating distributed energy resources; utilities must conduct a societal cost test using the 3 percent SCC estimate and the high-impact estimate.

In December 2020, the New York State Department of Environmental Conservation (n.d.) adopted value of carbon guidance that recommends that New York State agencies use central values for SC-CO_2, SC-CH_4, and SC-N_2O that are estimated at the 2 percent discount rate as the primary value to inform decision-making (in appropriate contexts), while also reporting the impacts at 1 and 3 percent to provide a comprehensive analysis.[6]

Additional information on use of the SCC in state policymaking is compiled by the Institute for Policy Integrity at NYU School of Law (see http://www.costofcarbon.org/states) (Paul et al. 2017; Grab et al. 2019) and is provided in a report issued by the US Government Accountability Office (GAO 2020).

2.3. Updating the SCC

In January 2017, the National Academies of Sciences, Engineering, and Medicine (NAS) published recommendations on updating SCC methodologies, prepared at the request of the IWG. The report provides extensive guidance to improve the scientific basis, provide more transparency, and better address uncertainties (NAS 2017). It also recommends instituting a process for updating SCC estimates approximately every five years, an update cycle that would balance the benefit of incorporating the latest research with the need for a thorough process.

The NAS report proposes four modules, each corresponding to a step in SCC estimation, and an overall framework that integrates the modules and considers their various interdependencies. The NAS panel

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[6] Expressed in 2020 dollars per metric ton of emissions, this range translates into a 2020 value of carbon dioxide of $51-406 per ton, with a central value of $121 per ton; a 2020 value of methane of $1,500-6,400 per ton, with a central value of $2,700 per ton; and a value of nitrous oxide of $18,000-130,000 per ton, with a central value of $42,000 per ton. Resources for the Future provided New York State with estimates that were calculated using the same peer-reviewed models that were used by the federal IWG, at constant discount rates of 0, 1, 2, and 3 percent, revised here for consistency with IWG interim estimates released in February 2021. See Appendix C for a description of how these estimates were modeled.

suggests that using a common module for key steps in the SCC estimation framework, rather than averaging the results for different IAMs (as the current IWG methodology does), can improve transparency, consistency, and control over uncertainties. Each of the modules would allow for uncertainties, resulting in a distribution of estimates rather than a single value. As summarized below, for each module the NAS panel recommended changes that could be implemented in two to three years.

Socioeconomic module and emissions projections. These should use statistical methods and expert judgment for projecting distributions of future population growth and gross domestic product, which contribute to generation of GHG emissions projections. Potential modules should be evaluated according to time horizon, future policies, disaggregation, and feedbacks.[7]

Climate modeling. This module should use a simple Earth system model to properly capture the relationships among CO_2 emissions, atmospheric CO_2 concentrations, and global mean surface temperature change and sea-level rise; it should also incorporate their uncertainty.

Climate impacts and damages estimation. This module translates a time series of socioeconomic variables and physical climatic variables into estimates of physical effects and the associated yearly monetary value of net climate damages. It should be based on current models but include updated individual sectoral damage functions, transparent and quantitatively characterized damage function calibrations, recognition of any correlations between damage formulizations, and a summary of disaggregated damage projections.

Discounting. To explicitly recognize the uncertainty surrounding discount rates over long time horizons, the discounting module should incorporate the relationship between economic growth and discounting using a Ramsey-like formula.

The NAS report further proposes longer-term research to improve each module and incorporate various feedback mechanisms that could have a significant effect on the resulting estimates.

Resources for the Future (RFF) and the Climate Impact Lab (the Lab) have begun to implement NAS recommendations in their research on the SCC.

RFF created the Social Cost of Carbon Initiative to advance the NAS framework proposals. This effort, focused on improving the scientific quality and transparency surrounding SCC estimates, involves a network of partners—RFF, UC Berkeley, Harvard, Princeton, University of Washington, PennState, and others (https://www.rff.org/scc). In partnership with David Anthoff and a research team at UC Berkeley, RFF hosts an open-source software platform and tools to run and adapt climate IAMs (www.mimiframework.org/Mimi.jl/stable/). RFF's research efforts to implement the NAS recommendations include building a new set of long-run projections of economic growth, population, and emissions; updating the climate model used in SCC calculations; building new climate damage functions from the best available literature; and implementing a Ramsey-like discounting framework. RFF plans to release updated SCC estimates that are responsive to the full set of near-term recommendations of the NAS by the end of 2020.

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[7] Projections should extend far enough in the future to provide inputs for estimation of the vast majority of discounted climate damages; account for the likelihood of future emissions mitigation policies and technological development; and provide the sectoral and regional detail in population and economic conditions necessary for damage calculations. The module should incorporate feedbacks from the climate and damages modules.

The Climate Impact Lab is working to leverage recent advances in sciences and economics to develop empirically derived climate damages and ultimately an SCC estimate. The Lab's approach includes gathering global climate and socioeconomic data to understand the relationship between climate and society, developing damage functions using outcome data, and using those observations to project the relationship where outcome data are not available. The Lab has created a web-based platform that presents the results of local assessments of climate impacts and is updated on an ongoing basis (http://www.impactlab.org/map/). It also plans to generate the first empirically derived estimate of the SCC based on a series of reports providing partial SCC estimates for a number of impact sectors, including mortality (Carleton et al. 2018), agriculture, conflict, labor, electricity demand. A broad timeline of 2021–2022 has been set to complete this work.

2.4. Choosing a Discount Rate

Economic discounting is the process of converting a value received in a future time period (e.g., 1, 10, or even 100 years from now) to an equivalent value received immediately. For example, a dollar received 50 years from now may be valued less than a dollar received today—discounting measures this relative value. The choice of the discount rate used to calculate the SCC has a large influence on the estimate, with a higher discount rate resulting in a lower SCC value.

The Climate Act directs consideration of a range of appropriate discount rates, including a rate of zero. At NYSERDA's request, RFF has employed the IWG methodology to calculate the SC-CO_2 for a range of constant discount rates (2, 1, and 0 percent) for comparison with values generated using the IWG's selected discount rates (5, 3, and 2.5 percent). Results from these sensitivity analyses are presented in Appendix C. Additional sensitivity analyses could apply a Ramsey-like approach to discounting (discussed below and in Appendix D).

The discount rate is a particularly important parameter for the social cost of carbon dioxide because the warming effects of emissions released today linger for hundreds of years into the future. Over such long time horizons, even modest changes in the discount rate can lead to large changes in the present value of long-term effects (Appendix C). It is not simply the sensitivity of the results that suggests careful consideration of the discount rate. Discounting over long time horizons also gives rise to other conceptual issues that affect the appropriate choice of the discount rate, such as intergenerational equity and uncertainties about the appropriate discount rate for the distant future.

2.4.1. Consumption Discount Rate

The social cost of carbon is used primarily for societal decision making, particularly as an input to benefit-cost analysis. The correct discount rate to use in a societal benefit-cost analysis is the social discount rate, which reflects the rate at which society as a whole is willing to trade off a value received at one point in time (e.g., today) with a value received at another point in time (e.g., the future). The IAMs used to generate the estimates of climate damages for SCC calculations report their output in terms of consumption-equivalent impacts, which are intended to reflect the effect on people's consumption (as opposed to investment). Therefore, and as explained in the NAS (2017) report, the correct discount rate to apply to these impacts is the consumption rate of discount.

Although the consumption discount rate is the appropriate one to use for the social discount rate in calculating the SCC, the analyst must still determine the right value to use for this rate. Broadly speaking, there are two approaches to choosing the social discount rate: descriptive and prescriptive. This memo focuses principally on the descriptive approach because it forms the basis of most US federal government guidance on discounting. The prescriptive approach primarily involves ethical judgments applied in the so-called Ramsey framework and is discussed below in the context of RFF's implementation of the NAS recommendations.

2.4.2. Market Data and Expert Surveys

Descriptive approach using observed market data. The descriptive approach is based on looking at people's observed behavior, as measured through market rates of return, and is the primary basis for US federal guidance on rulemaking procedures. For example, if households are willing to accept a 3 percent rate of return, this indicates that they are willing to trade off $1 today for $1.03 next year. Long-standing guidance in the Office of Management and Budget's (OMB) Circular A-4 directs federal agencies to use rates of 3 percent (reflecting the consumption rate of interest) and 7 percent (reflecting the pretax return to capital), based on observed historical market rates. Conceptually, the lower consumption rate of discount is appropriate for evaluating effects (costs or benefits) on consumption.[8] OMB guidance also allows the use of additional lower discount rates as a sensitivity analysis if benefits or costs accrue to future generations over long time horizons.

When estimating the social cost of carbon for federal rulemaking, the IWG used a 3 percent central rate, a 2.5 percent "low" rate, and a 5 percent "high" rate. The 3 percent discount rate corresponds with OMB's Circular A-4 consumption rate of interest. The 2.5 percent rate approximately accounts for uncertainty in future interest rates (and hence discount rates), which suggests using a lower interest rate for long time horizons (Weitzman 1998; Newell and Pizer 2003). The 5 percent rate was included to account for the possibility that climate damages are positively correlated with interest rates. These low and high rates were considered appropriate adjustments to approximate the implications of more complex discounting rules while retaining the constant discount rate approach.

The empirical basis for OMB's rates of 3 and 7 percent is dated, and a 2017 US government report issued by the Council of Economic Advisers (CEA) examined recent trends in interest rates, finding support for using discount rates of "at most 2 percent" for the consumption rate of discount used in US federal policymaking (CEA 2017). This is based on the persistent decline in interest rates over the past two decades; prices in futures markets that suggest rates will remain below 4 percent over the next ten years or more.

Although the 2017 CEA report on interest rates primarily pertains to short-run forecasts (over the coming 10 years), interest rates in the far future (decades and centuries hence) are actually more relevant to discounting long-term climate change impacts. Although long-run interest rates are typically difficult to measure, a novel approach based on 100-year real estate leases suggests how investors discount values in the very long run (Giglio et al. 2015a),[9] with estimates implying discount rates "below 2.6 percent for 100 year claims." Because real estate investments are not risk free, the risk-free rate may actually be overstated (Giglio et al. 2015b).

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[8] In contrast, the return to capital is often proposed as the rate to use when private investment may be affected. This is a simplification of the more conceptually sound "shadow price of capital" approach, whereby effects on investment are converted to "consumption equivalents" and then all effects are discounted at the consumption rate of interest. In addition, Li and Pizer (2018) show that simply using the investment return is also problematic over long time horizons, and that under the shadow price of capital approach, the appropriate effective rate converges to the consumption rate over time.

[9] Specifically, they compare the market prices of 100-year real estate leases to the prices of owning equivalent properties in perpetuity. The difference in those prices reflects the discounted value of investment returns beyond 100 years, from which the authors infer the long-run discount rate that investors use.

This again suggests support for using long-run discount rates below 3 percent and probably closer to 2 percent, in line with the conclusion in the 2017 CEA report.

Expert surveys. An alternative way of determining discount rates is through surveying professional economists with relevant expertise and asking them to recommend values for the social discount rate. This approach relies on expert judgment, where the experts may implicitly or explicitly use a combination of descriptive and prescriptive approaches.

Weitzman famously conducted a survey of 2,160 professional economists, asking, "What real interest rate do you think should be used to discount over time the (expected) benefits and (expected) costs of projects being proposed to mitigate the possible effects of global climate change?" (Weitzman 2001). At that time, the responses showed a skewed distribution with a mean of about 4 percent, a median of 3 percent, and a mode of 2 percent.

Views in the economics profession have, however, shifted toward lower discount rates over the past two decades. Drupp et al. (2018) conducted a similar survey of more than 200 economists with expertise in discounting, finding median and mean recommended social discount rates of 2.0 and 2.3 percent, respectively. These results are in line with the range of 2 to 3 percent suggested by CEA (2017) and Giglio et al. (2015a). In addition to asking respondents to recommend a specific discount rate, the authors also inquired about the maximum and minimum rates they would feel comfortable recommending. The median (mean) upper bound recommended was 3.5 percent (4.1 percent) and the median (mean) lower bound was 1.0 percent (1.1 percent).[10]

In summary, existing relevant guidance and recent empirical and survey evidence suggest support for using a central discount rate for the SCC of 3 percent, 2 percent, or some value within this range.

2.4.3. Ramsey Approach

One NAS recommendation for improving the SCC estimation process was to bring the descriptive and prescriptive approaches to the discount rate together by choosing "parameters for the Ramsey formula that are consistent with theory and evidence and that produce certainty equivalent discount rates consistent, over the next several decades, with consumption rates of interest" and using "three sets of Ramsey parameters, generating a low, central, and high certainty-equivalent near-term discount rate" (NAS 2017).

As part of its Social Cost of Carbon Initiative, RFF is implementing these NAS recommendations by determining the level of near-term discount rates using the descriptive approach and implementing them as part of a Ramsey-like framework (Appendix D).

For the near-term rates based on descriptive market information, RFF is focusing on central, low, and high discount rates of 3, 2, and 5 percent, respectively. The central 3 percent rate is consistent with current OMB guidance. RFF's lower 2 percent rate is on the lower end of the range supported by the evidence and lower than the lowest value previously deployed by the IWG (2.5 percent). RFF's high rate of 5 percent is based on OMB's rate of return to capital of 7 percent, with an adjustment for taxes. This is because OMB's 7 percent represents the pretax return to investment, but as explained above, the correct rate is the rate of return that

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[10] However, it should be noted that these are averages of the responses; some individual respondents recommended discount rates ranging from 0 to 10 percent, and an upper bound as high as 20 percent.

consumers actually face. Since consumers must pay taxes on this 7 percent return, the corresponding rate of return actually available to consumers is about 5 percent.[11]

Under the Ramsey approach, the discount rate is given by two components, which are added together. The first component is called the rate of pure time preference, which is how much society discounts the welfare of people in the future. The second component represents an adjustment for how much the value of an incremental dollar declines as society grows wealthier.

If the intention behind the Climate Act's required consideration of a "discount rate of zero" relates only to the rate of pure time preference between future and current generation's welfare, and not to the adjustment for values accruing to wealthier individuals, then the effective discount rate under a Ramsey-like approach would simply equal the latter component. Using RFF's preliminary estimates of the size of this component, the effective near-term discount rate would equal about 1.7 percent (Appendix D). Germany has adopted a Ramsey-like approach to develop social cost of carbon estimates, including a high-impact estimate for use in sensitivity analysis that sets the rate of pure time preference at zero. In Germany's high-impact estimates, the effective discount rate starts near 2 percent and declines to 1 percent by 2250 (GAO 2020).

2.5. Social Costs of Other GHGs

In addition to carbon dioxide, the Climate Act covers methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), as well as "any other substance emitted into the air that may be reasonably anticipated to cause or contribute to anthropogenic climate change." In valuing carbon, the analytic tools employed by NYS should account for the contributions of these additional non-CO_2 gases to future economic damages as part of a consistent analytical framework.

The different physical characteristics of other greenhouse gases compared with CO_2, as well as their distinct interactions within the atmosphere and biosphere, are important for the estimation of resulting damages. For example, the gases differ in their *radiative efficiency*—how much energy can be absorbed at a time on a per molecule basis. The physical and chemical processes that remove each gas, once emitted, from the atmosphere also differ, causing substantially different residence times in the atmosphere. Further, the physical and chemical interactions of these gases are also distinct, both in the atmosphere and with the biosphere. This section discusses two general approaches to account for these differences and generate values for the social costs of non-CO_2 greenhouse gases.

2.5.1. Global Warming Potentials

To facilitate comparison of characteristics across disparate greenhouse gases, climate scientists and economists often use the *global warming potential* (GWP). The GWP for a gas is calculated as the ratio of the cumulative energy absorbed by that gas over a particular time period, compared with a reference gas (CO_2). The GWP metric expresses combined information about the radiative efficiency and the atmospheric lifetime of the gas relative to that of CO_2. By construction, GWP values greater than 1 indicate greater warming than

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[11] See IWG (2010, 20). Although the IWG also used a 5 percent "high" rate, this was to approximately account for the potential positive correlation of the discount rate and climate damages, which the IWG did not model explicitly. RFF's ongoing work explicitly models this correlation, implying the IWG's rationale for using 5 percent is no longer applicable. It is simply a coincidence that the after-tax return to capital also happens to be about 5 percent.

from CO_2. For any two gases, the one with the higher GWP causes more warming over the specified time horizon.

GWPs for greenhouse gases for both 20- and 100-year time horizons are calculated and reported by the Intergovernmental Panel on Climate Change (IPCC) in its assessment reports (Table 2).[12] The potential for strong dependence of GWP on the selection of time horizon, particularly for relatively short-lived gases such as methane, is evident.

Table 2. Global Warming Potentials and Lifetimes of Select Non-CO_2 Greenhouse Gases

Gas	Lifetime (years)	20-year GWP	100-year GWP
CH_4 (methane)	12.4	84–86	28–34
N_2O (nitrous oxide)	121	264–268	265–298
SF_6 (sulfur hexafluoride)	3,200	17,500	23,500
HFC-134a (hydrofluorocarbon)	13.4	3,710–3,790	1,300–1,550
PFC-14 (perfluorocarbon)	50,000	4,880	6,630

Source: IPCC (2013, chapter 8). Where ranges are given, the upper (lower) values represent the GWP with (without) climate-carbon feedbacks. Climate-carbon feedbacks are not included for the values presented for SF6 and PFC-14 (Myhre et al. 2013). HFC-134a and PFC-14 are examples of HFCs and PFCs that are in common use, but HFCs and PFCs as categories comprise many more compounds that vary widely in GWP and atmospheric lifetime.

It would seem straightforward to estimate the social costs of non-CO_2 greenhouse gases by multiplying their GWP for a given time horizon by the SC-CO_2. Using GWP in this manner, however, mischaracterizes the relationship between the residence time of a gas in the atmosphere and the time profile of discounted future damages.

When the models used to estimate the SC-CO_2 calculate the undiscounted damages for a future year in response to an initial pulse of emissions, such damages depend on how much of the original pulse still resides in the atmosphere in that year. After estimating undiscounted future damages, they calculate the net present value of all future damages by discounting and summing them. The much shorter atmospheric residence time of methane, for example, means that a pulse of methane in a given year will have largely been removed from the atmosphere in a decade. Undiscounted damages associated with that initial pulse of emissions should therefore diminish more rapidly than damages from CO_2.[13] Converting the value of the SC-CO_2 to a value for SC-CH_4 by multiplying by the GWP of CH_4 implicitly (and incorrectly) imposes the longer atmospheric lifetime of CO_2 on the calculation of the SC-CH_4, mischaracterizing the relationship between its atmospheric lifetime and the net present value of damages from the initial emissions pulse.

Further complications from applying GWP in this context arise from the fact that other physical interactions considered in some of the models are not shared across the gases. One example is CO_2 fertilization: the

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[12] GWPs are published as part of the IPCCs Working Group I assessments and were most recently updated in 2013 as part of the IPCC's Fifth Assessment Report. The Working Group I contribution to the IPCC's Sixth Assessment Report is scheduled to be finalized in 2021.

[13] Among other effects, properly accounting for this relationship implies a relatively narrower difference between the higher and lower discount rates for CH_4 when compared with CO_2.

presence of elevated levels of CO_2 in the atmosphere enhances the growth of certain plants. Elevated levels of CH_4 and N_2O do not share this effect with CO_2, but using GWP imputes such benefits to those gases, thereby underestimating their net damages.

Another inconsistency arises when using GWP to estimate the social cost of gases for future years. GWPs of various gases are calculated by the IPCC based on the energy absorption capacity of an additional ton of emissions relative to their *current* concentrations. In later years, the strength of the energy absorption of a given gas relative to CO_2 may change based on future emissions pathways. Using today's GWP therefore may not properly reflect the relative radiative forcing of these gases in the future.

2.5.2. Gas-Specific Marginal Damages

In 2016, the IWG followed the approach put forward by Marten et al. (2015) and published direct estimates for the SC-CH_4 and SC-N_2O.[14] This approach modified the IAMs employed in the calculation of the SC-CO_2 to directly model pulses of the other gases in a manner reflecting their disparate physical properties and behaviors in the atmosphere and also incorporating the inputs and other assumptions employed as part of the IWG methodology.[15] Appendix C provides values for the SC-CH_4 and SC-N_2O based on the IWG methodology and rates of discount, along with additional estimates for 2, 1, and 0 percent constant rates of discount generated by RFF for NYSERDA.

The differing results from the IWG and GWP approaches can be measured by evaluating the "damage-ratio" for the former and comparing it with the relevant GWP for a particular time horizon. The damage ratio is the ratio of the value for the SC-CH_4 or SC-N_2O to the value for the SC-CO_2 for a given discount rate. Table 3 shows representative damage ratios for CH_4 and N_2O, calculated using the IWG framework, for a set of discount rates, which may be compared with the GWPs for CH_4 and N_2O presented in Table 2. Damage ratios that are higher (lower) than a given GWP indicate that the IWG methodology would yield a higher (lower) value for the SC-CH_4 or SC-N_2O than the GWP approach. Notably, direct estimates of the SC-CH_4 have a damage ratio of 29 for the 3 percent discount rate used for the IWG's central estimate, which falls within the range of GWPs reported by the IPCC for the 100-year time horizon. Estimating the SC-CH_4 using a GWP calculated over a 20-year time horizon, however, would lead to an estimate nearly a factor of 3 greater than the IWG direct estimates.

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[14] The IWG's initial 2010 issuance of the federal government's guidance for the SC-CO_2 did not publish estimates of non-CO2 gases, citing the limitations of the GWP approach as well as the paucity of estimates of social costs of non-CO_2 gases in the academic literature at that time.

[15] An idealized implementation of this approach would involve perturbing the emissions pathways for each of the two gases in the same way that the SC-CO_2 is calculated. However, in the versions of the models used by the IWG, only the FUND model features an explicit representation of emissions of other greenhouse gases other than CO_2. In the versions of DICE and PAGE used by the IWG, the effects of other greenhouse gases are represented by exogenous radiative forcing pathways. Rather than explicitly modeling a pulse of CH_4 or N_2O emissions in DICE and PAGE, the pulse of emissions was instead represented by the equivalent increase in radiative forcing that would result from a one-ton pulse of such emissions. To calculate the amount of increased radiative forcing in these models and account for the time evolution of CH_4 and N_2O, a separate simple gas cycle model was used in which the emissions of CH_4 and N_2O could be perturbed directly. For a full discussion of the methodology and review of other estimates of SC- CH_4 and SC- N_2O see Marten et al. (2015).

Table 3. Damage Ratios for SC-CH_4 and SC-N_2O in 2020

Discount rate	SC-CH_4 / SC-CO_2	SC-N_2O / SC-CO_2
5%	46	408
3%	29	367
2%	22	358

Damage ratios of the social cost estimates for a given gas using the IWG methodology to the value for the SC-CO_2 for a given discount rate. A comparison of damage ratios and GWPs for a given gas allows for a comparison of the relative effects of the two approaches for estimating the social costs of that gas.

The academic literature on direct estimates of non-CO_2 gases beyond CH_4 and N_2O is sparse overall and particularly limited for the NYS context.[16] At present, no direct estimates that are fully consistent with the IWG methodology have been put forward by the IWG or reported in the academic literature for greenhouse gases beyond CO_2, CH_4, and N_2O.

Direct estimates of additional non-CO_2 gases consistent with the Marten et al. (2015) approach could be generated and made consistent with the IWG framework through additional research. Implementing the Marten et al. approach for additional gases would require estimates of the temporal profile of additional radiative forcing that would result from a 1 ton pulse of the specified gases in a given year, potentially generated by expanding the simple gas cycle model employed to represent additional gases.[17] A potentially more expedient research approach would be to use estimates of marginal radiative forcing generated by the IPCC for its calculations of GWP for an extensive range of gases.[18]

2.6. Considerations for Using the Marginal Damages Approach in NYS

In its consideration of the establishment and usage of value of GHG estimates based on a marginal damages approach, the Department will need to address the following decision and guidance points.

Use of a peer-reviewed methodology. If the Department follows a marginal damages approach to value carbon and GHG emissions, NYSERDA views the SCC methodology developed by the IWG as the most

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[16] Shindell (2015) estimated the “Social Cost of Atmospheric Release” for HFC-134a along with other short-lived greenhouse gases by calculating the temperature effects of pulses of these gases using a simplified climate model and estimating the resulting damages from such temperature perturbations based on the DICE model. Shindell’s method also accounts for non-climate effects on human health via degraded air quality, which is not natively accounted for in the Marten et al. approach. Waldhoff et al. (2014) used the FUND model to directly model estimates of the SC-SF_6. These papers are limited in that they each utilize only one of the three models employed by the IWG and use different discounting assumptions and different underlying socioeconomic, climatic, and damage functions than the IWG used.

[17] For full consistency with the IWG methodology, the marginal effects of the gases would be modeled along emissions pathways for each gas that are consistent with the socioeconomic scenarios used by the IWG.

[18] A limitation of this approach is that the IPCC assumes that future atmospheric concentrations and climate remain fixed at their current levels in its GWP calculations, so the marginal radiative forcing estimates are not fully consistent with the emissions scenarios employed by the IWG.

credible marginal damage cost approach for NYS agencies to use in the near term, since it has been subject to broad stakeholder and peer review.

Consideration of global impacts. The Climate Act instructs the Department to account for the global impacts from GHG emissions in establishing a value of carbon, rather than accounting only for the harm experienced within US or NYS borders. The IWG methodology accounts for global impacts.[19]

Application of the IWG SCC "central" estimate. As discussed in this memo, uncertainty is pervasive in SCC estimates and the estimates omit or do not fully account for many important damage categories. In partial recognition of this uncertainty, the IWG issued a range of four values to be used in regulatory impact analysis, ranging from $14 to more than $150 per metric ton of CO_2 emitted in 2020. NYSERDA suggests that the Department treat the current IWG "central" SCC estimate (at $51 per metric ton of CO_2 in 2020) as a lower bound for damages, consider adopting a higher central SCC value for use by NYS agencies, and develop guidance on when to use a range of SCC values in analysis.

Time horizon. NYSERDA suggests adopting or modeling marginal damages estimates that account for impacts through the year 2300, consistent with the IWG method and the NAS (2017) findings.

Discount rate. The choice of the discount rate used to calculate the value of carbon has a large influence on the estimate, with a higher discount rate resulting in a lower value. The Climate Act directs consideration of a range of appropriate discount rates, including a rate of zero. Though no consensus exists on what approach or rate to use for discounting uncertain climate impacts over long time horizons, multiple lines of research as well as large-scale surveys of economists suggest support for using long-run discount rates below 3 percent, likely closer to 2 percent. In NYSERDA's view, it is appropriate that the discount rate used in estimating value of GHG reductions using the marginal damages approach ultimately incorporate both empirical data and public interest value judgments.

Non-CO_2 GHGs. The approach taken by the IWG in estimating the SC-CH_4 and SC-N_2O addresses many of the limitations of the GWP approach. If the Department follows the IWG's marginal damage approach to value CO_2, NYSERDA suggests that it should also follow the IWG approach to directly estimate the value of CH_4 and N_2O, modified as appropriate to meet the requirements of the Climate Act. For other GHGs of relevance for which fully consistent estimates using the IWG approach are not currently available (PFCs, HFCs, SF_6), NYSERDA suggests that NYS facilitate near-term research to generate IWG-consistent estimates for these gases following one of the research approaches identified while establishing interim estimates based on multiplying the SC-CO_2 by the 100-year GWP for each gas. NYSERDA notes that the Climate Act requires the usage of a 20-year time horizon for GHG accounting purposes; however, experience with the SC-CH_4 and SC-N_2O, including the damage ratio comparisons discussed in this memo, suggests that damage estimates based upon a 100-year GWP are likely to be most comparable to those that would be derived from direct estimates for these gases.[20]

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[19] The IWG approach implicitly places the same weight on a dollar loss in the US as a dollar loss in the poorest regions in the world. An alternative approach discussed in the literature, and applied in Germany (GAO 2020; Bünger and Matthey, n.d.), produces an "equity weighed SCC" value that weights a dollar loss in poor regions more than a dollar loss in richer regions. Simply put, such an approach explicitly acknowledges that an incremental or decremental dollar has a larger welfare impact to a poor person than it does to a wealthy person.

[20] The discrepancy between using the GWP approach and direct estimates is expected to be considerably less than the expected error introduced by leaving such gases out of analyses, thereby implicitly assigning a value of zero for damages from those gases. Leaving known greenhouse gases out of analyses would also run directly counter to the directives and intent of the Climate Act.

Updating of SCC estimates. This memo discusses two major research efforts that are under way to improve on the IWG methodology and merit consideration for future updates. NYS, along with other governments and entities, can benefit from researchers' ongoing efforts to refine SCC estimates.

NYSERDA suggests that the NYS agencies also develop companion materials that provide tips, examples, and FAQs to assist analysts who need instructions for applying the SCC estimates. For example, companion materials specific to energy sector analysts could be developed by NYSERDA and the NYS Department of Public Service, in consultation with the Department, to address points such as how to account for inflation, how to combine an SCC estimate derived using a given discount rate with different discount rates for other cost and benefit streams, and how to aggregate SCC estimates with energy costs that incorporate some portion of the cost of CO_2 emissions. As such materials are developed or revised, NYSERDA encourages NYS agencies to work with the Department to facilitate their sharing among relevant agencies.

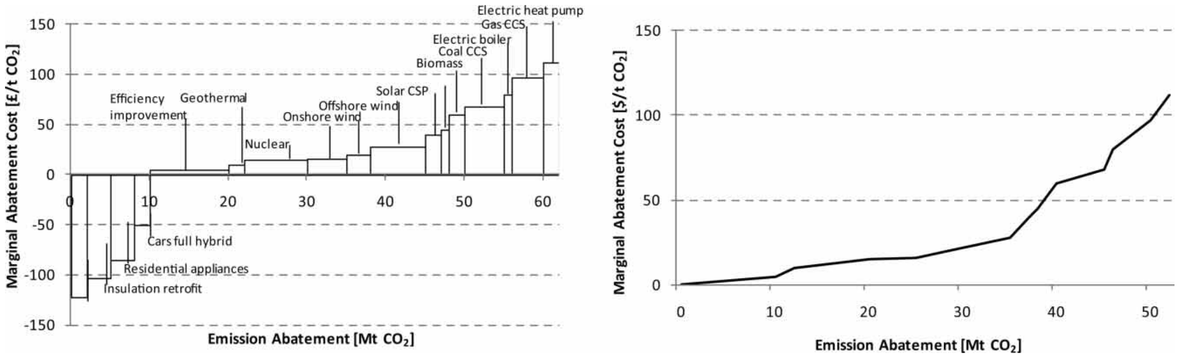
3. Marginal Abatement Cost: Evaluating Costs to Meet a Target

To achieve specified emissions goals at lowest overall cost, it is instructive to consider the marginal *costs* of reaching a specified emissions reduction target. The *marginal abatement cost* (MAC) approach has been incorporated by a number of governments in support of achieving their emissions targets. This *target-consistent approach* provides monetary estimates for greenhouse gas emissions based on the marginal abatement cost for achieving a given emissions reduction target—that is, the cost of abating the last metric ton of carbon dioxide needed to meet a particular emissions target at least cost to society (GAO 2020).. This section discusses the mechanics of the MAC approach, compares it with the marginal damage approach, and highlights relevant methodologies and estimates from three countries that have implemented a MAC approach. The section concludes by identifying relevant considerations if NYS incorporates the MAC approach to carbon valuation in policies or programs to achieve the emissions reductions required under the Climate Act.

The MAC approach relies on marginal abatement cost curves that represent the amount of GHG abatement that is available at a given "cost." A MAC curve is a graph that indicates the marginal cost (the cost of the last unit) of emissions abatement for varying amounts of emissions reduction. A MAC estimate is typically derived from the marginal cost associated with the last reduced unit of emissions in the target year, which also equals the carbon price needed to meet the target (Isacs et al. 2016).

One approach to generating such MAC cost curves is to conduct a bottom-up assessment, in which experts evaluate individual abatement opportunities and costs across a set of relevant sectors and technologies. Abatement measures are arranged in order of cost per ton of emissions abated, from least to most expensive, to generate a marginal abatement cost curve. A stylized example of a MAC curve developed through such a bottom-up assessment is provided in the left panel of Figure 2.

Figure 2. Stylized Depictions of MAC Curves Drawn from Expert-Based Approach (left) and Models (right)



Source: Reproduced from Kesicki and Elkins (2012).

Alternatively, top-down MAC curves can be generated by using economic or energy models to evaluate the level of emissions reductions across an economy or a sector resulting from the imposition of a carbon price. A MAC curve can be generated in this way by varying the level and trajectory of the carbon price across multiple runs of the model and assessing the level of reductions driven at each price. MAC curves produced through modeling studies, as depicted in the right panel of Figure 2, generally lack the level of detail about specific abatement opportunities available that are provided by expert-based studies (Kesicki and Ekins 2012). Modeling studies, however, offer the potential to account for interactions between sectors that are not accounted for with expert-based studies. Despite the significant differences between the two approaches, a review of the MAC literature found no consistent directional effect on estimated MAC curves based on the underlying modeling approach (Kesicki 2013).

Marginal abatement costs also have been determined based on historical and projected behavior in carbon markets such as the European Union's Emissions Trading System (ETS) (see "MAC in Other Countries," below).

3.1. MAC and SCC, Compared

The relative values of the MAC approach and the marginal damage approach for analysis of climate mitigation have been discussed and debated in the academic literature (Isacs et al. 2016) as well as in official government policy documents (Department of Energy and Climate Change 2009). The selection of approach has additionally fallen along geographic lines. The governments of the United States, Canada, and Mexico rely primarily on the marginal damage approach in the form of the SCC to support benefit-cost analysis in regulatory analysis (US Climate Alliance n.d.). Several European countries, each with clearly defined emissions targets, have adopted the MAC approach.

The MAC approach and its supporting analysis can be tailored to align closely with country, state, or regional requirements for greenhouse gas reductions. This attribute has been commonly cited as imperative by countries that have adopted the MAC approach, as well as the related ability to support a consistent policy framework across a suite of government actions (DECC 2009; Ministère de la Transition écologique et solidaire 2018).

When considered in isolation, the MAC approach avoids certain uncertainties that affect SCC estimates (DECC 2009). For example, the MAC cost curve does not depend on a representation of the climate system; it is dictated solely by cost estimates to reach a specified target or atmospheric concentration.[21] Similarly, the MAC curve is not subject to uncertainty from translation of climate change to economic damages. Both of these sources of uncertainty have been shifted and subsumed into the policy decision of what the appropriate emissions targets and trajectories should be (Isacs et al. 2016).

Estimates of MAC curves are subject to a number of sources of uncertainty distinct from those present in the estimation of the SCC. These include uncertainty related to rates of technological improvements over time, the costs of available abatement, and the overall available potential for abatement, among others. MAC curves additionally share sensitivity to some of the same parameters as the SCC—namely, the selection of the reference case against which abatement costs are measured and the discount rate employed. MAC curves offer potential for more targeted and frequent updates as new information on technology costs and other costs of abatement is revealed in the marketplace, however, which could be expected to reduce uncertainty.

MAC curves also have limitations that should inform their development and use (Kesicki and Ekins 2012; Isacs et al. 2016). Cost curves in many cases lack a full accounting of costs, often excluding system costs and the costs of policy implementation, leading to an underestimate of the costs of abatement. MAC curves typically represent a snapshot in time, so they do not account for intertemporal uncertainty. Notably, MAC curves

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[21] Note that the translation of emissions to atmospheric concentration does involve associated uncertainty.

derived from the individual assessment of abatement measures do not typically account for economic interactions between sectors.

The following section discusses three countries' experience in choosing the MAC approach as their preferred strategy for carbon valuation: the United Kingdom, France, and Ireland. As summarized in Table 4, the countries' monetary estimates increase significantly over time, reflecting that abatement costs will rise over time as emissions targets become more stringent and as more expensive abatement measures will need to be employed, according to officials interviewed by the GAO (2020).

Table 4. Monetary Estimates for Greenhouse Gases based on the MAC Approach Developed by France, Ireland, and the UK (2020$/metric ton CO_2e)

	France	Ireland	UK (non-traded sectors, central value)	UK (ETS sectors, central value)
2020	107	55	106	20
2030	309	172	124	124
2050	775	455	355	355

Source: Appendices F-H provide country-specific sources. Estimates converted into 2020$ per metric ton of CO_2e. See Appendix E for exchange rates and inflation adjustment rate used.

The NYS policy context is analogous to the countries discussed, in several ways. NYS is required under the Climate Act to achieve specific levels of emissions reductions, with differentiated requirements for the power sector. The NYS economy is set within a broader context of US states and other countries whose actions to mitigate climate change are dissimilar and largely disconnected. The decision points and actions taken by these countries to develop country-specific MAC curves are illustrative of the types of decisions that would need to be addressed by NYS in incorporating information based on the MAC approach.

3.2. MAC in Other Countries[22]

3.2.1. United Kingdom

The UK government began considering the use of MAC values in 2009, when the Department of Energy and Climate Change (DECC) conducted a major review of its use of the SCC for carbon valuation and laid the foundation for a transition to the MAC approach (DECC 2009). The primary reasons cited for the transition were to eliminate the uncertainty about damage cost estimates and to align UK policies with emissions reductions targets at the national level, as well as targets stipulated by the European Union (EU), and the United Nations. This review was followed by a subsequent policy document in 2012 that built on that foundation to establish the methodology and technical basis for the calculations that are in use today (DECC 2012).

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[22] All carbon values present in the following examples have been converted from their original currencies and inflated into 2020 USD. See Appendix E for the rates used, and Appendices F, G, and H for their original values.

For purposes of carbon price valuation, emissions from UK source categories are divided into those that fall under the European Union's ETS and those that derive from non-ETS sectors. This distinction was made because the two emissions categories are subject to different emissions reduction targets, and emissions reductions between ETS and non-ETS sectors are not fungible. The United Kingdom established separate methods for valuing the costs of abatement between the two, resulting in the evaluation and application of both a short-term "traded price of carbon" for emissions from covered ETS sectors and a short-term "non-traded price of carbon" for non-ETS sectors.

For ETS sectors, DECC in 2009 outlined an approach to generate short-term traded carbon values that would incorporate market information, suggesting that the carbon trading markets offered the best source of information about abatement costs. The proposed approach, implemented in 2012, based a central scenario for abatement costs on futures prices for EU allowances. In addition to the central estimate based on market futures prices, models are used to generate one low-cost and one high-cost trajectory to characterize potential uncertainty about the central estimate.[23] Values for the traded price of carbon based on each of the three scenarios are updated on an annual basis. The most recent low, central, and high values for the year 2020 are \$0, \$20, and \$39 per metric ton of CO_2e (Department for Business, Energy and Industrial Strategy 2019). The full schedule of short-term values is available in Appendix F.

The nontraded cost of carbon estimated for assessing policy actions in non-ETS sectors is based on an assessment of the "feasible technical" abatement options available carried out by the UK's Committee on Climate Change (CCC). In its assessment, the CCC generated six MAC curves based on varied assumptions about the feasibility of abatement opportunities across various sectors. Given the information in these MAC curves, DECC established a lower, central, and upper schedule for the nontraded carbon price. For 2020, the low, medium, and high values were \$53, \$106, and \$160 per metric ton of CO_2e (DBEIS 2019). The relatively higher projected costs of abatement for non-ETS sectors compared with those covered by the ETS reflect the higher cost of abatement in non-ETS sectors, such as transportation, relative to the less expensive abatement options available in ETS sectors, such as power generation.

Beyond 2030, when a comprehensive global trading system is expected to be in place, the values for the traded and nontraded prices of carbon are assumed to converge to a single international carbon price modeled to meet the EU's target of keeping global warming below 2°C. The low, central, and high unified carbon values for 2030 are \$62, \$124, and \$186 per metric ton of CO_2e; and for 2050, the corresponding values are \$177, \$355, and \$532 (DECC 2009).[24]

3.2.2. France

As part of its 2018 update to its national low-carbon strategy (Ministère de la Transition écologique et solidaire 2018), the French government formed a commission to update the shadow price of carbon values employed in the assessment of public investments and climate mitigation opportunities (Quinet 2019). In its report, the commission considered employing the social cost of carbon approach but instead recommended

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[23] Market fundamentals are altered in the models to generate either a low-cost (e.g., chronic oversupply of allowances) or high-cost (e.g., high economic growth) scenario. The MAC curves used in the model-based approach are taken from the Enerdata POLES model, a top-down global sectoral model for the world energy system.

[24] Prices are linearly interpolated, as necessary, between 2020 and 2030 and between 2030 and 2050.

taking a marginal abatement cost approach consistent with delivering France's economy-wide target of net-zero emissions by 2050.

Rather than put forward separate prices for various emissions sectors or categories (e.g. ETS and non-ETS), the commission instead recommended establishing a uniform shadow price across the economy to maximize economic efficiency. It further focused on establishing abatement cost curves for the year 2030 as a relevant "anchor point". 2030 was selected on the basis of its relevance for setting near-term expectations and initiating public and private investments in low-carbon programs as well as the robustness and reliability of economic and technical modeling over that time frame (Quinet 2019).

To assess the abatement cost potential, the commission employed a pair of techno-economic models (TIMES and POLES) and three sectoral macroeconomic models (IMACLIM, ThreeME, and NEMESIS). These models were deemed sufficiently robust to quantify shadow prices supporting up to a 75 percent reduction in emissions from 1990 levels but were considered insufficient to evaluate the deep decarbonization required in the later years of the period. Based on this set of analyses, the commission proposed setting a 2030 shadow price of carbon of \$309 per metric ton of CO_2e, a substantial upward revision from the previous value for the year 2030, \$136 per metric ton of CO_2e, which had been established in 2008. Carbon values for the years between 2018 and 2030 were proposed to rise linearly from the 2018 value of \$67 per metric ton of CO_2e to meet the shadow price established for 2030. See Appendix E for conversion and inflation rates used to translate 2018 EUR to 2020 USD.

Concerns about the ability of the models employed to explore deep decarbonization scenarios led the commission to integrate several approaches to establish values for the shadow price of carbon beyond 2030. The integrated approach included output from the techno- and macroeconomic models through roughly 2040, foresight on the portfolio of enabling technologies required for full decarbonization, and calibration of the shadow price on a Hotelling rule[25] from 2040 for a 4.5 percent rate of discount. The resulting trajectory yielded a \$617 per metric ton of CO_2e carbon value in 2040 and \$957 per metric ton of CO_2e in 2050.

In addition to its exploration of structural uncertainty in the estimates through the use of models of differing types, the commission studied and reported on uncertainty in the estimates related to the level of international cooperation. It evaluated scenarios representing delayed domestic or international action, which would have the effect of increasing the estimates, as well as the potential for increased international cooperation leading to the development of disruptive technologies. The commission did not explicitly publish a range of estimates based on these sensitivities.

3.2.3. Ireland

Ireland has implemented an abatement cost model for use in evaluating potential public investment projects across all sectors of the economy (Kevany 2019). The Irish government opted against the SCC approach, citing concerns over its level of uncertainty. The MAC approach was considered to entail lower overall

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[25] The Hotelling rule indicates that, in order to maximize the present value of a non-renewable resource extracted over a given period, the percentage change per unit time in the net price of the resource should equal the discount rate (Hotelling 1931).

uncertainty, limited to the selection of the appropriate climate target to use and the actual abatement cost of reaching the target (Kevany and Cleary 2018).

Ireland's carbon valuation is based on the estimated societal marginal cost to reach Ireland's 2030 emissions target of 30 percent below 2005 levels by 2030. Estimates made for abatement costs for energy sector measures, as compiled in Ireland's National Mitigation Plan, are a proxy for economy-wide abatement costs. Specifically, the TIMES energy system model was used to create estimated MAC curves, and the price trajectory provided by the model was smoothed over time, starting at $34 per metric ton of CO_2e in 2019, rising to $55 in 2020, and reaching an estimated $172 by 2030. These values apply only to non-EU regulated carbon emissions (Kevany and Cleary 2018).

Ireland's approach does not use MAC curves to estimate values past 2030 in light of increasing uncertainty over technology costs and the potential for their rapid change over longer time horizons. Instead, the value employed is proposed to rise by 5 percent a year beyond 2030, yielding values per metric ton of CO_2e of $220 in 2035, $280 in 2040, $357 in 2045, and $455 in 2050 (Kevany and Cleary 2018).

3.3. Considerations for Using the Marginal Abatement Cost Approach in NYS

As NYS State Agencies evaluate the potential for incorporating MAC information in policy analysis supporting implementation of the Climate Act, the Department will need to work with NYS Agencies to address the following decision and guidance points to ensure a consistent application of the MAC approach, where warranted.

MAC curve development. There is a firm foundation of MAC information on which the NYS power sector can base a MAC curve, but information for other sectors of the State's economy varies in availability and level of detail. In NYS, as in many other jurisdictions, the power sector has led other sectors in emissions abatement. Analysis consistently concludes that the power sector is structurally able to reduce emissions at lower cost than other sectors (Barron et al. 2018). By virtue of its long-standing renewable energy credit (REC) market, NYS has significant experience with assessing real-world cost signals required to deploy targeted levels of renewable electricity. Continued experience with the REC market could be used to update MAC information on an ongoing basis. In addition, the NYS power sector has recently been the subject of a detailed analysis to assess technology costs and renewable resource availability, among other relevant variables, directly in support of policy design to meet its targets for clean and renewable energy, as required by the Climate Act (New York State Department of Public Service and NYSERDA 2020).

NYSERDA also has engaged Energy and Environmental Economics to develop a strategic analysis of the State's decarbonization opportunities. This ongoing analytic work models portfolios of GHG reduction measures that will be needed to achieve the State's economy-wide 2030 and 2050 emissions reduction targets, with focus to date on the electricity, transportation, buildings, and industrial sectors (Energy and Environmental Economics 2020). Inputs to the models used in this work include cost and performance characteristics of both supply-side infrastructure and demand-side technologies. As this analysis is refined to inform the Climate Act policy process, it would allow NYS to accelerate the development of MAC curves for the initial focal sectors. Additional analytic work is needed to improve characterization of noncombustion GHG sources (such as landfills) and associated mitigation opportunities, as well to assess the potential quantity and cost of sustainable bioenergy resources, suggesting that the development of MAC curves for these sectors may take longer.

Multiple curves versus a single curve. A MAC approach could be applied to evaluate policies across the NYS economy, either by applying separate MAC values for policy actions related to specific sectors (e.g., a power sector MAC curve applied to assess power sector policies, and a transportation MAC curve applied to assess transportation sector policies) or by uniformly applying a MAC curve based on abatement cost estimates across the NYS economy to reach the economy-wide targets. In selecting between these two approaches, NYSERDA notes that it is economically rational for policymakers to seek to advance progress in the power sector in a manner that recognizes the relatively low cost at which emissions reductions may be achieved, compared with other sectors.

Holistic view of abatement costs. MAC information should ideally be incorporated in a manner that considers interactions between sectors as well as economy-wide goals. As discussed above, MAC curves are often developed for a particular sector using an approach that does not take into account potentially important interactions with other sectors. For example, meeting renewables targets in the power sector will affect electricity prices, thereby affecting the economics of consumer decisions related to vehicle electrification. Bottom-up MAC curves developed in isolation for the power and transportation sectors, however, typically would not account for this interaction. This underscores the importance of considering how a MAC approach would be applied across multiple sectors and fit coherently with the various policy approaches being taken by NYS.

Updating of MAC curves. MAC curves, once developed, would need to be maintained and periodically revisited to stay current with both the state of technology and evolution of the policy context. The limited applicability of the curves beyond NYS suggests that continual maintenance will likely require an ongoing commitment of resources by NYS and would ideally be planned for in advance.

4. Conclusion

This memo has assessed specific considerations related to analytic approach, discount rates, and prior estimates for valuing carbon in support of the Department's issuance of guidance on the value of carbon for use by NYS agencies.

NYSERDA notes in closing that there is an inherent policy interest in preserving the freedom for NYS policymakers to pursue the most economically rational abatement opportunities to their fullest potential. Although the statutory language in the Climate Act is suggestive of the identification of a uniform value for carbon, NYSERDA suggests that the Department in its guidance could take into account the value of information from both the SCC and the MAC analytic approaches, potentially providing some flexibility in applying the identified value of carbon in policymaking. It may be sensible for NYS agencies to use distinct approaches for different sectors, for example developing a MAC value for the power sector and using an SCC estimate for other sectors, or (in time) developing separate MAC values for policy actions related to specific sectors. It is important that such flexibility be coupled with Department guidance for those different sectors and implementing agencies, with attention to cross-sectoral dynamics and the role for each sector as part of New York State's holistic strategy to drive the economy-wide GHG emissions reductions required under the Climate Act. Relatedly, an outcome to avoid is allowing individual agencies or analysts to select their approaches on a discretionary or case-by-case basis, because of the absence of clear guidance that is rooted in a holistic Climate Act strategy.

Achieving the ambitious requirements of the Climate Act will require deep emissions reductions across the entire NYS economy and will necessitate detailed planning and policy evaluation across a disparate set of economic sectors. Both the SCC approach, with its focus on global societal benefits realized from the reduction of greenhouse gas emissions, as well as the MAC framework, with its focus on costs to achieve the required targets, can provide relevant, and in many ways complementary, information to NYS policymakers in this context.

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6. Appendices

Appendix A. Social Costs of Methane and Nitrous Oxide, IWG Estimates

Table A1. Social Cost of Methane Estimates (2020$/metric ton CH_4)

Year of emission	Average estimate at 5% discount rate	IWG central estimate: Average estimate at 3% discount rate	Average estimate at 2.5% discount rate	High-impact estimate: 95th percentile estimate at 3% discount rate
2020	670	1,500	2,000	3,900
2025	800	1,700	2,200	4,500
2030	940	2,000	2,500	5,200
2035	1,100	2,200	2,800	6,000
2040	1,300	2,500	3,100	6,700
2045	1,500	2,800	3,500	7,500
2050	1,700	3,100	3,800	8,200

Source: Federal interim estimates of the SC-CH_4 (IWG 2021).

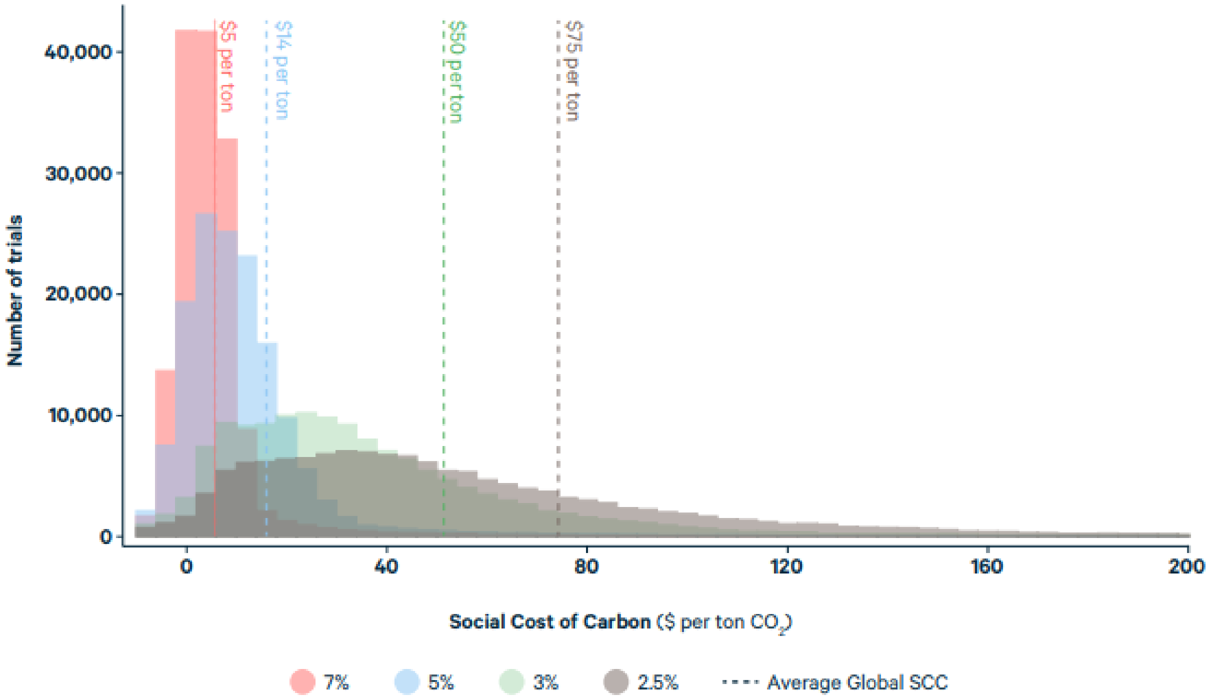
Table A2. Social Cost of Nitrous Oxide Estimates (2020$/metric ton N_2O)

Year of emission	Average estimate at 5% discount rate	IWG central estimate: Average estimate at 3% discount rate	Average estimate at 2.5% discount rate	High-impact estimate: 95th percentile estimate at 3% discount rate
2020	5,800	18,000	27,000	48,000
2025	6,800	21,000	30,000	54,000
2030	7,800	23,000	33,000	60,000
2035	9,000	25,000	36,000	67,000
2040	10,000	28,000	39,000	74,000
2045	12,000	30,000	42,000	81,000
2050	13,000	33,000	45,000	88,000

Source: Federal interim estimates of the SC-N_2O (IWG 2021).

Appendix B. Range of IWG SC-CO_2 Values

Figure B1. Range of Values for SCC in 2020 (2019$/metric ton CO_2)



Source: Reproduced from Rennert and Kingdon (2019)

Appendix C. Estimated SCC of Selected GHGs

The following tables show the social cost of carbon dioxide, methane, and nitrous oxide estimates for the year 2020 at different constant discount rates. Each of the three integrated assessment models and each of the discount rates were run using the same assumptions and scenarios used by the IWG. Each model is run 50,000 times across the random variable space, and the means of the resulting distributions are displayed along with the 95th percentile value as a sensitivity. Consistent with IWG estimates, SC-CO2 values are rounded to the nearest dollar. SC-CH4 and SC-N2O estimates are rounded to two significant figures. Appendix I shows the annual average estimates of SC-CO_2, SC-CH_4, and SC-N_2O for the years 2020 through 2050, at constant discount rates of 3%, 2%, and 1%.

Table C1. 2020 SC-CO_2 with Constant Rate Discounting (2020$/metric ton CO_2)

Model	5%	3%	2.5%	2%	1%	0%
DICE	15	46	70	112	392	2,154
FUND	3	23	41	68	264	1,460
PAGE	25	83	119	183	563	2,776
Average of models	14	51	76	121	406	2,130
95th percentile	43	152	220	338	1,101	5,787

Table C2. 2020 SC-CH_4 with Constant Rate Discounting (2020$/metric ton CH_4)

Model	5%	3%	2.5%	2%	1%	0%
DICE	540	1,200	1,500	2,100	5,600	25,000
FUND	650	1,500	2,100	2,900	7,400	28,000
PAGE	810	1,800	2,300	3,000	6,000	17,000
Average of models	670	1,500	2,000	2,700	6,400	23,000
95th percentile	1,600	3,900	5,200	7,300	18,000	70,000

Table C3. 2020 SC-N_2O with Constant Rate Discounting (2020$/metric ton N_2O)

Model	5%	3%	2.5%	2%	1%	0%
DICE	4,800	16,000	24,000	39,000	140,000	730,000
FUND	4,600	16,000	24,000	39,000	130,000	680,000
PAGE	8,300	25,000	35,000	52,000	140,000	570,000
Average of models	5,800	18,000	27,000	42,000	130,000	660,000
95th percentile	15,000	48,000	70,000	110,000	360,000	1,800,000

Appendix D. Ramsey-Like Discounting Approach

A key recommendation of the NAS report to improve SCC estimates is to introduce a "Ramsey-like" approach to discounting (NAS 2017). Ramsey discounting is a generalization of the "constant" discount rate approach (discussed above) and is based on a seminal paper by Frank Ramsey (1928). Rather than choosing a single discount rate, a Ramsey-like approach would use a discount rate (r) determined by the following formula:

$$r = \delta + \eta \cdot g,$$

where δ is the rate of pure time preference (how much society discounts the utility, or human welfare, of people in the future), η is the elasticity of the marginal utility of consumption (how much the value of an incremental dollar of consumption declines as society grows wealthier), and g is the growth rate of consumption per capita (roughly speaking, the economic growth rate). Both δ and η are typically nonnegative, meaning that the discount rate is not simply a constant number but rather depends on the values of those parameters and the rate of economic growth.

Various methods could be used to choose those parameters. The η parameter determines how we discount effects on future generations because they are expected to be wealthier (assuming economic growth is positive). As a result, this value links the discount rate to the economic growth rate. Typical values for η used in the literature are in the range of 1 to 2. The median and mean values of η from the Drupp et al. (2018) survey are 1.00 and 1.35, respectively. RFF economists Richard Newell, Brian Prest, and William Pizer are currently working to estimate values of δ and η that reconcile the empirically observed behavior of interest rates, and they plan to use the results from that estimation in future updates to the social cost of carbon dioxide. Their preliminary preferred estimates point to a value of $\eta = 1.3$, which is coincidentally very close to the mean of 1.35 reported by Drupp et al. (2018).

The δ term, also called the rate of pure time preference, determines how much the utility of people—who may be alive at different points in time—is discounted. Some economists and philosophers believe this rate should be zero, or at least very small. The original Ramsey (1928) paper argued that this kind of discounting is "ethically indefensible," suggesting a rationale for setting $\delta = 0$, although agreement on this is not universal (Arrow 1999). The Stern (2007) review argued for using a very small δ value of 0.1 percent, simply to account for the possibility that a future generation might not exist (because, say, an asteroid has struck Earth). The survey results from Drupp et al. (2018) imply a median (mean) value of δ of 0.5 percent (1.1 percent) and a modal value of 0 percent. However, they do not find a broad consensus for a near-zero value of δ. In RFF's ongoing work implementing the Ramsey-like framework, δ takes on values of 0.4, 1.4, and 3.4 percent (alongside an η value of 1.3) to target near-term target discount rates of 2, 3, and 5 percent respectively.

Given the common argument for considering the possibility of using a zero rate of pure time preference, $\delta = 0$ could be interpreted as corresponding the Climate Act requirement of considering "a range of appropriate discount rates, including a rate of zero," The rate of pure time preference is the rate at which society discounts utility, so it may be closer to the underlying ethical intent of the Climate Act in assessing a rate of zero than an overall discount rate that also takes into account the lower value of an additional dollar to wealthier people.

If NYS decided to use a value of $\delta = 0$ to represent a "rate of zero" for the rate of pure time preference, then the discount rate would simply equal $r = 0 + \eta \cdot g = \eta \cdot g$. As previously mentioned, RFF's preliminary estimate of η is 1.3, alongside an estimated near-term per capita growth rate (g) of about 1.3 percent. Using these estimates would imply a near-term discount rate of $r = \delta + \eta \cdot g = 0\% + 1.3 \cdot 1.3\% = 1.7\%$, which is close to the 2 percent "low" rate being used by RFF in implementing the NAS recommendations.

Appendix E. Exchange Rates and Inflation Adjustments

To make comparisons of values more straightforward, estimates are given in 2020 USD (2020$) amounts. USD inflation was derived using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9.

Exchange rates for GBP and EUR to USD were found on the Federal Reserve Board's Foreign Exchange Rate History data, using January 2 data in each year, found here:
https://www.federalreserve.gov/releases/h10/hist/default.htm

The following inflators were used:

- 2007USD to 2020USD: 1.228575 (for IWG estimates published in 2016)
- 2018GBP to 2020USD: 1.4143 (for UK traded values)
- 2009GBP to 2020USD: 1.7732 (for UK nontraded values)
- 2018EUR to 2020USD: 1.2349 (for France)
- 2010EUR to 2020USD: 1.7159 (for Ireland)

Appendix F. UK Schedules for Short-Term Carbon Valuation for Traded and Nontraded Sectors

Table F1. Traded Price of Carbon for Sectors in EU ETS (2018GBP/metric ton CO$_2$e)

2018GBP per ton CO$_2$e			
Year	**Low**	**Central**	**High**
2020	0	13.84	27.69
2021	4.04	20.54	37.04
2022	8.08	27.24	46.4
2023	12.12	33.94	55.75
2024	16.17	40.64	65.11
2025	20.21	47.33	74.46
2026	24.25	54.03	83.82
2027	28.29	60.73	93.17
2028	32.33	67.43	102.53
2029	36.37	74.13	111.88
2030	*converges with modeled estimates for non-traded sectors beginning in 2030*		

Source: DBEIS (2019).

Table F2. Traded Price of Carbon for Sectors in EU ETS (2020$/metric ton CO$_2$e)

2020USD per ton CO$_2$e			
Year	**Low**	**Central**	**High**
2020	0.00	19.57	39.16
2021	5.71	29.05	52.38
2022	11.43	38.52	65.62
2023	17.14	48.00	78.85
2024	22.87	57.48	92.08
2025	28.58	66.94	105.31
2026	34.30	76.41	118.54
2027	40.01	85.89	131.77
2028	45.72	95.36	145.00
2029	51.44	104.84	158.23
2030	*converges with modeled estimates for non-traded sectors beginning in 2030*		

Source: RFF conversion of values in Table F1 to 2020USD as described in Appendix E.

Table F3. Nontraded Price of Carbon for Non-ETS Sectors (2009GBP/metric ton CO_2e; DECC 2009)

2009GBP per ton CO_2e			
Year	**Lower**	**Central**	**Upper**
2020	30	60	90
2030	35	70	105
2050	100	200	300

Source: Department of Energy and Climate Change (2009).

Table F4. Nontraded Price of Carbon for Non-ETS Sectors (2020$/metric ton CO_2e)

2020USD per ton CO_2e			
Year	**Lower**	**Central**	**Upper**
2020	53	106	160
2030	62	124	186
2050	177	355	532

Source: RFF conversion of values in Table F3 to 2020USD as described in Appendix E.

Appendix G. France’s MAC Estimates

Table G1. France’s Shadow Price of Carbon, Proposed to Increase Linearly between 2018 and 2030

Year	2018EUR/ metric ton CO2e	2020$/metric ton CO_2e
2018	54	67
2020	87	107
2030	250	309
2040	500	617
2050	775	957

Source: Ministère de la Transition écologique et solidaire 2018. Conversions to 2020USD shown in right column carried out by RFF as described in Appendix E.

Appendix H. Ireland’s MAC Estimates

Table H1. Ireland’s MAC Estimates

Year	2010EUR/metric ton CO_2e	2020$/metric ton CO_2e
2020	32	55
2030	100	172
2035	128	220
2040	163	280
2045	208	357
2050	265	455

Source: Kevany 2019. Conversions to 2020USD shown in right column carried out by RFF as described in Appendix E.

Appendix I. Annual estimates of SC-CO_2, SC-CH_4, and SC-N_2O

The following tables show annual average estimates of SC-CO_2, SC-CH_4, and SC-N_2O for the years 2020 through 2050, at constant discount rates of 3%, 2%, and 1%. See Appendix C for a description of how these estimates were modeled, using the same assumptions and scenarios used by the IWG.

Table I1. Social Cost of CO2 estimates (2020$/metric ton CO_2)

Year of emission	Average estimate at 3% discount rate	Average estimate at 2% discount rate	Average estimate at 1% discount rate
2020	51	121	406
2021	52	123	409
2022	53	124	411
2023	54	126	414
2024	55	128	416
2025	56	129	418
2026	57	131	421
2027	59	132	423
2028	60	134	426
2029	61	136	428
2030	62	137	430
2031	63	139	433
2032	64	141	435
2033	65	142	437
2034	66	144	440
2035	67	146	442
2036	69	147	444
2037	70	149	446
2038	71	151	449
2039	72	152	451
2040	73	154	453
2041	74	156	456
2042	75	158	459
2043	77	160	461
2044	78	162	464
2045	79	164	467
2046	80	166	469
2047	81	167	471
2048	82	169	472
2049	84	170	474
2050	85	172	476

Table I2. Social Cost of CH_4 estimates (2020$/metric ton CH_4)

Year of emission	Average estimate at 3% discount rate	Average estimate at 2% discount rate	Average estimate at 1% discount rate
2020	1500	2700	6400
2021	1500	2800	6400
2022	1600	2800	6500
2023	1600	2900	6600
2024	1700	2900	6700
2025	1700	3000	6800
2026	1800	3100	6900
2027	1800	3100	7000
2028	1900	3200	7100
2029	1900	3300	7200
2030	2000	3400	7300
2031	2000	3400	7400
2032	2100	3500	7500
2033	2100	3600	7700
2034	2200	3600	7800
2035	2200	3700	7900
2036	2300	3800	8000
2037	2300	3900	8100
2038	2400	3900	8200
2039	2500	4000	8300
2040	2500	4100	8400
2041	2600	4200	8500
2042	2600	4200	8600
2043	2700	4300	8700
2044	2700	4400	8800
2045	2800	4500	8900
2046	2800	4500	9000
2047	2900	4600	9100
2048	3000	4700	9200
2049	3000	4800	9300
2050	3100	4800	9400

Table I3. Social Cost of N_2O estimates (2020$/metric ton N_2O)

Year of emission	Average estimate at 3% discount rate	Average estimate at 2% discount rate	Average estimate at 1% discount rate
2020	18000	42000	130000
2021	19000	43000	140000
2022	19000	44000	140000
2023	20000	45000	140000
2024	20000	45000	140000
2025	21000	46000	140000
2026	21000	47000	140000
2027	21000	47000	140000
2028	22000	48000	140000
2029	22000	49000	150000
2030	23000	50000	150000
2031	23000	50000	150000
2032	24000	51000	150000
2033	24000	52000	150000
2034	25000	53000	150000
2035	25000	54000	150000
2036	26000	54000	160000
2037	26000	55000	160000
2038	27000	56000	160000
2039	27000	57000	160000
2040	28000	58000	160000
2041	28000	58000	160000
2042	29000	59000	160000
2043	29000	60000	170000
2044	30000	61000	170000
2045	30000	61000	170000
2046	31000	62000	170000
2047	31000	63000	170000
2048	32000	64000	170000
2049	32000	65000	170000
2050	33000	66000	170000