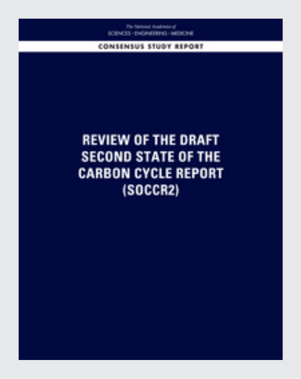

Review of the Draft Second State of the Carbon Cycle Report (SOCCR2)

DETAILS

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REVIEW OF THE DRAFT SECOND STATE OF THE CARBON CYCLE REPORT (SOCCR2)

Committee to Review the Draft Second State of the Carbon Cycle Report

Board on Atmospheric Sciences and Climate
Division on Earth and Life Studies

A Consensus Study Report of

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This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report:

David Archer, University of Chicago
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Roger Schmidt (NAE), Syracuse University, IBM Corporation (emeritus)

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by **Charles F. Kennel,** University of California, San Diego, and **Andrew R. Solow,** Woods Hole Oceanographic Institution. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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Summary

The second "State of the Climate Cycle Report" (SOCCR2) aims to elucidate the fundamental physical, chemical, and biological aspects of the carbon cycle and to discuss the challenges of accounting for all major carbon stocks and flows for the North American continent. This assessment report has broad value, as understanding the carbon cycle is not just an academic exercise. Rather, this understanding can provide an important foundation for making a wide variety of societal decisions about land use and natural resource management, climate change mitigation strategies, urban planning, and energy production and consumption.

SOCCR2 is part of a broader suite of assessment activities carried out within the U.S. Global Change Research Program's (USGCRP) National Climate Assessment activities. To ensure that SOCCR2 is scientifically credible and effectively communicates, the USGCRP asked the National Academies of Sciences, Engineering, and Medicine to review the draft document (during the same time period in which the draft SOCCR2 report was available for public comment). The Academies appointed an ad hoc expert Committee to conduct this review, and offered here are the Committee's findings and recommendations.

The Committee finds that the draft SOCCR2 report is an admirable effort to distill a huge volume of research into a helpful overview of the available data and the current state of knowledge. Many of the individual chapters are well written and organized. In most cases, the key findings are clearly stated and are amply supported with evidence. The report provides a good sense of how the relevant science has advanced since the first SOCCR report was released a decade ago. At the same time, the Committee finds many ways the draft report could be improved (as is often the case for scientific reviews of draft assessment reports).

For all of the draft report chapters, a variety of suggestions are made herein for editing, clarifying or expanding key points. A few chapters raised particular concerns among the Committee, however, which we highlight here:

- **Executive Summary.** The draft report Summary should be more concise and more accessible to a general audience. Many instances of technical jargon and confusing wording could be improved with the services of a good science writer.
- **Chapter 3 (Energy).** This chapter should be organized more tightly on the issue of energy as a source of carbon emissions and on the potential for mitigation of energy sector emissions. The Committee has suggested some figures that would help in this regard.
- **Chapter 6 (Social Science).** There should be a clear acknowledgement that this chapter does not address economics research and focuses only on a few components of the carbon cycle. The chapter would be improved by less discussion about social science "process" issues and more examples of the actual insights being gained from this research. The chapter may fit better later in the report (after Chapter18).
- **Chapter 7 (Tribal Lands).** This chapter lacks depth of treatment of many key issues. Given the challenges of integrating Traditional Knowledge with assessment approaches that rely heavily on peer reviewed literature, and the wide diversity of tribal communities across the U.S., Canada, and Mexico that must be considered, it may be better to re-focus this chapter more on exploring how to support and empower indigenous communities to advance sustainable carbon management policies and programs.

- **Chapter 13 (Terrestrial Wetlands).** This is the only chapter in which the SOCCR2 authors did their own original numerical analyses of primary data and used these analyses as basis for their assessment. The Committee believes it would be better to instead focus on presenting results from the available published literature. There is also a need to address several statements in the Chapter that appear inaccurate or poorly worded.

The most significant cross-cutting suggestions for improving the report are described here in general terms. Details and specific examples are provided within the body of our review.

- There are many places in the draft report where flux estimates and other numbers are inconsistent within chapters (e.g., between the text and the figures), among different chapters, and between the Executive Summary and some chapters. There are also numerous instances of inconsistencies in the units of measurement used across different parts of the draft report—for instance when discussing carbon fluxes and energy issues. It is critical that the draft report be carefully checked to identify and address such inconsistencies. It may be helpful for the SOCCR2 organizers to convene representatives from across the different chapter teams, to construct a diagram that puts all the different types of flux estimates into one framework. Figure ES2 could be a starting point for such a diagram, if it were more directly connected to, and inclusive of, the different types of flux values presented across the report chapters.
- The use of terms "C uptake", "C sequestration", "C emission of –xx Tg", "C sink of –xx Tg", "C sink of xx Tg" are used variably through the draft report, particularly with respect to discussion of forests, soils, and agriculture. The SOCCR2 authors must find a way to standardize the definitions and usage of these terms across all chapters.
- The Committee has concerns with how carbon fluxes related to inland and coastal waters in particular are presented. Figure ES5 presumably shows total (background + perturbation) net (difference between incoming and outgoing) fluxes, which could lead to a mis-impression that the forest sink is countered mainly by outgassing from inland waters, and that the net CO_2 flux from North America approximately equals the fossil fuel flux. This would appear to contradict, for example Figure ES2, and Chapter 2 that one-quarter to one-half of North American fossil fuel source is removed by natural sinks. Furthermore, the contributions by forests, agriculture, wetlands, and arctic boreal systems do not add up to -937 shown in Figure ES2. The numbers need to be consistent throughout the draft report.
- The geographic scope in the draft report is ambiguous. The assessment aims to address North America as a whole but the inclusion of Canada and Mexico is very uneven. The Executive Summary in the draft SOCCR2 report states that the geographic scope includes Hawaii and U.S. territories, yet these areas are not mentioned anywhere else in the document. The draft report should be revised to provide more clarity about the intended geographic scope, and where possible, to provide a more even treatment of the regions included in the chapter discussions.
- The Committee disagrees with the practice of assigning confidence levels to direct factual information, such as the observations that atmospheric concentrations of CO_2 and CH_4 are increasing. This actually undermines these incontrovertible observations. In some cases, this could be clarified by ascribing confidence levels to specific parts of a finding, rather than to the finding overall.
- The research needs identified in the draft report cover a very broad array of possible research topics. The recommendations should be better focused on prioritizing specific advances that could be feasibly made over the coming few years with sufficient research investments.

- Key Findings throughout the draft report place considerable emphasis on noting that research has progressed ("we've learned a lot about…."). Emphasis should instead be placed on explaining what new insights have actually been learned from this research, in quantitative terms where possible.
- The SOCCR2 authors should reconsider presenting numbers with 3 or 4 significant digits, as this overstates the confidence one should have in such numbers. The authors should also convey more consistently the confidence and uncertainties in estimates that are presented.
- There are several places where new figures could be added to the draft report to help illustrate key concepts, and a number of edits/improvements are also suggested herein for several of the existing figures.
- A few topics should be better addressed in this assessment, including: important recent research on U.S. methane sources and sinks; integrated assessment modeling research; impacts of climate change, especially of changing precipitation patterns, on carbon cycle dynamics; and Arctic coastal zones as a potentially important biogenic carbon source. Also the report Summary should more clearly frame ocean carbon dynamics as a critical part of the global carbon system, since the magnitude of the North American carbon sink is constrained by the magnitude and geographic distribution of the ocean sink

Below are some additional issues that the Committee believes should be considered, although we recognize that some might be challenging to fully address in the limited time available for the SOCCR2 authors to complete their report revisions. At a minimum, these issues could be acknowledged as important considerations within the SOCCR2 report—perhaps in a short section about "future challenges". Some suggestions might be taken as suggestions for shaping the next round of assessment work (SOCCR3).

- The draft report discussion of management decisions that affect carbon dynamics is uneven. For instance, there is discussion of how urban-scale actions can affect carbon emissions but little comparable discussion of actions at state, federal, and international levels. There is extensive coverage of decision-making regarding Agriculture, Forestry, and other Land Uses (AFOLU), but little discussion of how this integrates with other components of the carbon cycle to support decisions about CO_2 mitigation. There is very limited explanation of the opportunities that exist for more effective management of carbon sources and sinks. The Committee strongly encourages the authors address such gaps, as this would greatly enhance the usefulness of the assessment for informing governance and management decisions that affect carbon sources and sinks.
- The Committee recommends re-examining the policy that all chapters must have some minimum number of key findings, as it results in many findings that are obvious statements that do not offer specific new insights or do not convey a clear message to the reader.
- Discussions of future emissions scenarios should consider a wider array of scenarios, including scenarios that examine the actions needed (by reducing certain carbon emissions, enhancing certain carbon sinks) to avoid a 2°C global temperature increase.
- Some biological, physical, and societal processes discussed in the draft report are treated as isolated subjects that are not well-connected to each other or to the central issue of understanding the carbon cycle. For instance, it is important to discuss how warming temperatures and changing precipitation patterns affect carbon emissions from key terrestrial

and aquatic ecosystems; how expanding biofuel production affects the management of grasslands, forestry, agriculture; and how energy use contributes to the carbon budget overall. Giving greater attention to these integration concerns will help assure the overall report is more than just the sum of its individual pieces, and that the report may be useful for informing mitigation and adaptation policies and management decisions.

- The Committee understands that time to make revisions is short, but if there were sufficient time—and certainly for a future report (SOCCR3)—it would be desirable to consider an alternative organization in which social science research issues are woven throughout the report, rather than presented as a stand-alone subject. There should also be consideration of relevant economics research that provides important insights about human influences on the carbon cycle—for instance, regarding costs as a key determinant of behavior related to energy use and resulting carbon emissions.

Finally, the Committee notes some issues related to the relationship between SOCCR2 and the fourth National Climate Assessment, Volumes *1 [Climate Science Special Report]* and 2 [*Climate Change Risks, Impacts, and Adaptation, NCA4]*. The efforts to avoid overlap with NCA reports leads to some frustrating limitations in the SOCCR2 scope—for instance, regarding the discussion of carbon emission mitigation strategies, and of the consequences of rising CO_2 levels. For future USGCRP assessment efforts, consideration should be given to whether the carbon cycle should be more interwoven into other assessment products, or whether there are better ways to structure future SOCCR reports to be more distinct from other products.

The Committee commends the SOCCR2 authors on the tremendous amount of work that went into the production of this assessment, and we hope the suggestions offered herein will help assure the final report is as robust and as useful as possible to a wide variety of stakeholders.

Introduction

The Second State of the Carbon Cycle Report (SOCCR2) is an assessment that examines the U.S. and North American carbon cycle processes, stocks, fluxes, and interactions with global-scale carbon budgets. It encompasses consideration of carbon dynamics in soils, water (including freshwater and near-coastal oceans), vegetation, aquatic-terrestrial interfaces (e.g., coasts, estuaries, wetlands), human settlements, agriculture, and forestry. The first SOCCR assessment was released in 2007, and this second assessment examines the progress in scientific understanding that has been made in the decade since then. While SOCCR2 does not prescribe or recommend policy, the draft report states that "it is intended to help inform mitigation and adaptation policies and management decisions related to the carbon cycle, supporting improved coordination for pertinent research, and monitoring and management activities for responding to global change".

SOCCR2 is one component of a broader suite of work carried out under the umbrella of the Fourth National Climate Assessment (NCA4). This assessment was led by the U.S. Global Change Research Program's (USGCRP) Carbon Cycle Interagency Working Group (CCIWG). The development of SOCCR2 was guided by a Federal Steering Committee composed of senior federal scientists, and was built upon the contributions of over 200 lead and contributing authors.

To help assure the quality and rigor of this assessment, the National Academies of Sciences, Engineering, and Medicine (NASEM) was asked to convene a Committee to carry out an independent peer review of the draft document, concurrent with the open public review period. The Committee comprises 12 people with a variety of expertise related to issues discussed in SOCCR2. The Committee was given the following official Statement of Task.

> The Committee will conduct an independent review of the SOCCR2 report. The review will provide an overall critique of the report and address the following questions:
>
> 1. Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?
> 2. Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?
> 3. Are the findings documented in a consistent, transparent and credible way?
> 4. Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?
> 5. Are the research needs identified in the report appropriate?
> 6. Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?
> 7. Are the document's presentation, level of technicality, and organization effective?
> 8. What other significant improvements, if any, might be made in the document?

To address this charge, committee members were assigned to small teams to focus on evaluating individual chapters within the draft SOCCR2 report, while everyone examined the Executive Summary and the draft report's key messages. The Committee held one in-person meeting in late November 2017, where members discussed the draft report in closed session, and also spoke with several of the SOCCR2 authors (to ask clarifying questions) in open session. This document provides the

Committee's review, including their consensus views on the draft report overall (organized primarily around the Statement of Task questions); and it includes a compilation of all the chapter-specific comments—which also focused (where feasible) on the Statement of Task questions, and which ranged from major substantive concerns to minor editorial suggestions.

While the Committee does offer numerous suggestions for improving various parts of the draft report, these are offered in the spirit of constructive criticism, with great admiration for and appreciation of the huge amount of work that the SOCCR2 authors have put into this assessment, and with shared hopes that the final report will provide a valuable resource for decision makers, scientists, and many others across the country.

Report Overview Analysis

The SOCCR2 assessment is a valuable overview of the available data and the current state of knowledge about the global and the North American carbon cycle, drawing upon a very large and diverse body of scientific research. The Committee found that many aspects of this draft report were well done, and also found that many aspects could be improved. Many of these issues are highlighted below, framed around the specific questions in the Statement of Task. Further details and examples of these issues are provided in the chapter-specific reviews later in this document.

[1] Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?

The audience for SOCCR2 is described in the Preface as *"a diverse audience that includes scientists, decision makers in the public and private sectors, and communities across the United States, North America, and the world".* This definition could potentially encompass just about anyone, so in that sense is not clearly described. That said, it is a standard audience definition for these sorts of assessment reports, thus refining further may not be a critical priority.

The primary goals for SOCCR2 are articulated in the three questions listed below (taken from the Summary, p.21). The Committee finds that the draft report has mixed success in responding to these questions.

> *(i) How have natural processes and human actions affected the global carbon cycle on land, in the atmosphere, in oceans and freshwater systems, and at the interfaces of ecosystems (e.g., land and water)?*
>
> Overall the SOCCR2 assessment provides a broad, helpful overview of how human and natural processes are affecting the global carbon cycle. There are however, places in the draft report where there could be improvements in the descriptions of these processes and actions (discussed later, in the context of specific chapter reviews), and places where there are inconsistencies across figures in the data presented. The discussion of fluxes in several chapters should be careful in distinguishing anthropogenic fluxes from total (background or pre-industrial plus anthropogenic) fluxes. The Committee acknowledges that the separation could be difficult; however, the conflation of total and anthropogenic fluxes within the same summary figure (e.g. Figure ES5) or discussion could easily lead to mis-interpretation.
>
> *(ii) How have socioeconomic trends and management decisions affected the levels of CO_2 and CH_4 in the atmosphere?*
>
> The current SOCCR2 draft has an important omission in addressing this question. In particular, the question references socio<u>economic</u> trends and management decisions, yet there is no review or discussion of relevant economics research in the draft report. The chapter should explain this omission at the outset, and acknowledge this as a front on which assessment work needs to be expanded.
>
> The draft report's descriptions and analyses of management decisions that affect carbon dynamics are uneven. For instance, there is some discussion of how local/urban-scale actions can affect carbon emissions but no comparable discussion about actions at state or federal levels. There is extensive coverage of decision-making regarding Agriculture, Forestry, and

other Land Use (AFOLU), but little discussion of how it is integrated with other components of the carbon cycle to support decisions about CO_2 mitigation. There also is very limited explanation of the opportunities that exist for more effective management of carbon sources and sinks (more discussion of these issues below).

(iii) How have species, ecosystems, natural resources, and human systems been affected by increasing GHG concentrations, the associated changes in climate, and management decisions that affect CO_2 and CH_4?

The assessment addresses this question only partially. It discusses a few specific ways that increasing CO_2 concentrations alone can affect ecosystems (e.g., through CO_2 fertilization effects and ocean acidification), but neglects to discuss the much broader array of impacts (on species, natural resources, human systems) that will inevitably stem from concomitant climate change itself. The report should point out that climate change, as discussed in the draft Fourth National Climate Assessment, could modulate or reverse the effects of CO_2 alone. The report does not address, but could expand the discussion of, the economic or other social impacts of management decisions taken to affect CO_2 and CH_4.

Geographic limitations. The draft report is ambiguous as regards its geographic scope. The assessment aims to address North America as a whole—including U.S., Canada, and Mexico—but the actual report content addressing Canada and Mexico is very spotty and inconsistent. This inconsistency apparently stems from the decision of Canada and Mexico to pursue their own independent assessment efforts this time, and the limited participation of Canadian and Mexican scientists, at least for some of the chapters. Furthermore, it is stated in the Summary [p.21] that "*the geographic scope of the U.S. analysis includes the conterminous United States, Alaska, Hawaii, and U.S. territories*"; and this idea is reinforced in Figure ES1. Yet Hawaii and the U.S. territories are not mentioned anywhere else in the document. These regions should either not be called out as an explicit part of the assessment scope, or they should be discussed in appropriate places throughout the assessment.

[2] Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?

On the whole, the draft report does a reasonably good job of reflecting the relevant scientific literature; the studies that are cited throughout the report seem well-chosen and accurately described. One issue worth consideration is the balance of attention given in SOCCR2 to terrestrial versus aquatic sciences. A main goal of this assessment work is to advance accounting of carbon sources and sinks of North America, in order to facilitate engagement in policy frameworks that address greenhouse gas emissions (such as the UN Framework Convention on Climate Change). It is thus reasonable that the bulk of attention be paid to continental carbon sources and sinks, especially those that can potentially be controlled through various policies, practices, and technological applications. Carbon sources and sinks in coastal waters and the open ocean cannot be claimed as part of the "emissions inventory" of any one nation—and one could thus argue this topic is relatively less important to the SOCCR assessment efforts. However, ocean system dynamics are such a critical part of the global carbon cycle that they must be carefully assessed and understood. In particular, accurately quantifying cumulative ocean carbon uptake is critical for constraining the carbon budget overall, since the magnitude of the terrestrial sink is not independently constrained.
There are also a number of topics that the Committee sees as "critical content" that are not well captured in this assessment, listed below.

- Because the field has been evolving so rapidly, the treatment of methane should be expanded to include 2016 and 2017 papers on trends in U.S. methane sources and sinks.
- The report lacks coverage of relevant economics research, and of integrated modeling studies that encompass emission drivers, climate and other physical and biological consequences, and resulting economic effects (discussed below).
- The report needs more discussion of how climate change, especially of changes in precipitation patterns (seasonality, intensity, duration) may influence carbon cycle dynamics.
- Studies of trends in atmospheric O_2 concentration should be added as an "incontrovertible line of evidence" regarding the role of fossil fuel burning in atmospheric CO_2 trends.
- Arctic region coastal zones (Alaskan/Canadian) should be given attention, given their potential importance as a major biogenic carbon source.
- The report would benefit from a clear explanation of how humans can influence carbon dynamics at global scales—since this is a question often raised in public debate about climate change (i.e., the argument that humans cannot possibly cause global-scale changes).
- The report needs more discussion about the practical opportunities for effective management of carbon sources and sinks (discussed below, under question #7).
- Given the paucity of peer-reviewed publications regarding the state of the carbon cycle on tribal lands, Chapter 7 could instead explore how to more actively engage and support indigenous communities, in harnessing their traditional practices and knowledge to inform polices and programs that affect carbon flux.

[3] Are the findings documented in a consistent, transparent, and credible way?

Most of the chapter findings are well-documented, in a reasonably transparent and credible way. However, in many places the authors simply offer a citation as justification for a particular conclusion or important analysis result. To strengthen and clarify these points, wherever possible (when the statement is an important one), the report should include a brief summary of the critical evidence in that citation—given that very few readers will chase down the original publications.

One place that raised concerns is Key Finding 2 in Chapter 13, which bases major conclusions on the results of original data analyses by the chapter authors. To maintain the credibility of the report as a review and summary of current knowledge, their results should be compared to related findings in the published literature, or else not presented.

[4] Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?

The presentation of key findings throughout the draft report could be improved, for example:

- The findings are unbalanced among chapters in terms of their detail and clarity. Many of the findings seem "forced" in that they are obvious statements that do not offer specific new insights or information, or convey a clear message relevant to the topic of the chapter. (Several examples are cited in the chapter summaries). If this practice flows from an editorial requirement that all chapters have some minimum number of key findings, the Committee suggests re-examining that policy.

- Some of the key findings are about methodology, and not about what has been learned. The Committee suggests emphasizing specific advances in understanding of the North American carbon cycle, rather than simply noting that "understanding has improved". Also, establishing confidence levels should be limited to estimates of fluxes and inventories, or to advances in understanding; not to methodological issues (e.g. the fact that data and models do not agree). For example, Chapter 2 Finding 5 assigns high confidence to the finding that top-down and bottom-up estimates of carbon sinks are comparable, despite the large uncertainties of the two approaches. Similarly, high confidence is assigned to the poor characterization of anthropogenic urban methane emissions (Chapter 4, Finding 5), and to the divergence between inverse model and empirical estimates (Chapter 8, Finding 2; Chapter 11, Finding 4). These findings do not advance the readers' understanding of the carbon cycle; they could be re-worded or eliminated.
- There are several places where improvements and additions to the report graphics are needed. Specific suggestions are made in the individual chapter reviews.
- Research recommendations presented as key findings could be coordinated across the chapters to articulate a specific research agenda for the next decade.

[5] Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?

The draft SOCCR2 assessment does not present many new statistical analyses or syntheses (with the exception of Chapter 13), but instead provides more of a synthesis of existing work in the published literature. Overall, this seems to be done reasonably well, but there are places where data are inadequately described or are used as the basis for questionable conclusions, and where their handling is inconsistent across chapters. For instance:

- Many of the carbon budget numbers presented in the draft report provide no uncertainty values. Furthermore, many of the numbers are presented with 3 or 4 significant digits, and thus overstate the confidence anyone should have in them. The authors must convey confidence and uncertainties more explicitly and more consistently across the report. Expressing uncertainties in model projections can be particularly challenging of course, and the variations among model results should be included together with the median where possible (e.g. Figure 19.8).
- A general problem throughout the draft report is the inconsistency in units. For instance, when discussing carbon fluxes and energy issues, the authors use Pg, Tg, and other units of carbon, CO_2, CO_2-e, and CH_4—making it difficult for most readers to compare values across different chapters, figures, etc. The Committee recommends this be standardized across chapters, with TgC as the key unit (or include TgC in parentheses) whenever possible.
- The draft report is inconsistent in terms of the time periods that are used in different figures and different parts of the discussion. In particular, the end date of observational records is highly variable across the chapters. Of course this stems largely from differences in the actual observational data records available, but the authors should use a consistent time period, where possible, across the critical data records shown in the report.

- Another inconsistency is found in the different references to soil depth, which changes from one chapter to another. This may be constrained by the observational data used in the syntheses. As there is little link across the chapters regarding soil depths, explicit mention of depth should be included where possible in the text, tables, and figures.
- It would be helpful to the reader if the discussion of carbon sources, sinks, and flows in individual chapters were placed into a common framework that provides context relative to the overall carbon cycle. Figure ES2 nominally provides this sort of overview, but it is not linked to information provided in the report chapters. Representatives from across the different chapter teams could be convened to construct a diagram that puts all the different types of flux estimates made in different chapters into one framework.

[6] Are the document's presentation, level of technicality, and organization effective?

Most of the chapters are well written, comprehensive, and well organized, presenting useful information drawn from appropriate sources. In some chapters, however, it is hard to "see the forest for the trees" because small details are often mixed with major concepts with little to distinguish between them, and also because much information is not put into a useful context with respect to the overall carbon cycle. This points to a general concern of the Committee about insufficient integration of some key topics into the overall assessment. The Committee acknowledges the real challenges for fostering seamless integration among numerous related topics in an assessment process such as this one, where each chapter is produced by an independent team of authors, but greater attention to these integration concerns is needed to assure that the overall report is more than just the sum of its individual pieces.

Some topics seem to be treated as isolated subjects that are not connected clearly to the main focus on understanding the carbon cycle. Likewise, some biological, physical, and societal processes that are in fact highly coupled are treated as isolated subjects. For instance, the report should discuss how physical environmental changes can affect key biological systems (e.g., how warming temperatures and changing precipitation patterns might affect the carbon emissions from certain terrestrial and aquatic ecosystems). It is likewise important to illustrate how energy policy and technology decisions can affect other sectors (e.g., how expanding biofuel production can affect the management of grasslands, forestry, agriculture), and how energy use contributes to the carbon budget overall.

Integrated assessment analyses—which consider the social and economic factors driving greenhouse gas emissions, the biogeochemical cycles that determine the fate of those emissions, and the resultant impacts on climate and human welfare—provide a framework for looking more holistically at the pieces addressed in different parts of the SOCCR2 report. Adding discussion of this research literature could thus greatly help convey the crucial role of carbon cycle science in environmental management.

A particular concern is Chapter 6 (*Social Science Perspectives on Carbon*) and Chapter 7 (*Tribal Lands*) and their integration into the rest of the report. Carving out two separate chapters, with the exclusion of economics from social science, and the neglect of discussion regarding the particular challenges and opportunities pertaining to carbon fluxes on tribal lands, make the chapters read like "add ons" to the assessment. Also, useful social science insights are overlooked in other relevant parts of the report. For instance, the Energy chapter should include consideration of how social and behavioral science insights are critical for the design of measures to encourage the adoption of energy efficiency practices and technologies. Major changes to report organization to include these issues may be infeasible at this late stage, but in planning the next round of SOCCR assessments, the organizers should consider possible alterative models wherein social science research findings and needs that consider the diversity of populations and institutions are woven throughout relevant chapters of the report.

[7] What other significant improvements, if any, might be made in the document?

Noted below are some other improvements that could be made to the report. Most of these issues are discussed in greater depth in the chapter-specific review material.

- The Committee recommends adding a figure to Chapter 3 (*Energy Systems*) that shows the U.S. energy flow chart and associated CO_2 emissions (e.g., see: http://flowcharts.llnl.gov).
- The Committee recommends reconsidering the idea of assigning confidence levels to direct factual information—such as the atmospheric concentrations of greenhouse gases. Saying there is "high confidence" that atmospheric concentrations of CO_2 and CH_4 are increasing actually undermines the fact that this is an incontrovertible observation. Where appropriate, confidence levels could be ascribed to specific parts of a finding, rather than to the finding overall.
- The use of terms "C uptake", "C sequestration", "C emission of –xx Tg", "C sink of –xx Tg", "C sink of xx Tg" are used variably (and defined very loosely) through the report, particularly with respect to discussion of forests, soils, and agriculture. Efforts should be made to standardize the definitions and usage of these terms across all chapters.
- In the discussions of future emissions scenarios (Chapter 19), it would be helpful to consider a wider array of scenarios, including ones that reflect major efforts to avoid a 2°C temperature increase—i.e., what sorts of changes to the carbon cycle (reducing particular emissions, enhancing particular sinks) would be needed to achieve this scenario.
- The draft report Executive Summary should be more concise and more accessible to a general audience. The many instances of technical jargon and confusing wording could be improved with the services of a good science writer.
- Some of the chapters seem longer than necessary, and this may stem in part from situations where the chapter authors did not have clear guidance on what information is most critical to convey in that chapter, and thus they included everything that seemed potentially relevant. For instance, Chapter 3 (*Energy Systems*) could be organized much more tightly by focusing more squarely on the issue of energy as a source of carbon emissions.
- Much of the draft SOCCR2 assessment focuses on elucidating fundamental physical and biological aspects the carbon cycle, and the challenges of accounting for all major carbon stocks and flows for the North American continent, which is appropriate given the mandate of the U.S. Carbon Cycle Science Program. A major concern of the Committee however, is that the report does not also provide adequate explicit discussion of carbon management issues—that is, the actions that can be taken to reduce carbon emissions (e.g., through new energy policies and technologies) and to enhance carbon sinks (e.g., through effectively managing certain terrestrial or aquatic coastal habitats). The draft report's Executive Summary has some discussion about carbon management needs and challenges, but this does not seem to be based on material found in the body of the report. These shortcomings are important because a central reason why scientists study the carbon cycle is to help inform efforts to manage carbon source and sinks, and to identify the "levers" where effective changes can be made. The lack of

coherent discussion of such issues limits the usefulness of the report for people who are making governance and management decisions that can affect carbon sources and sinks.

- In the discussion of research needs, some of the chapters provide long generic laundry lists. It would be more helpful to instead offer some sense of prioritization, highlighting critical research advances that could most feasibly be made in the coming years.

BOX 1
RELATIONSHIP BETWEEN SOCCR2 AND THE NCA REPORTS.

In reviewing the draft SOCCR2, The Committee struggled with understanding the intended and the actual relationship between this report relative to that of the fourth National Climate Assessment, Volume *1* (*Climate Science Special Report, CSSR*) and Volume 2 (*Climate Change Risks, Impacts, and Adaptation, NCA4*). The draft SOCCR2 report Preface contains some discussion about the relationship among SOCCR2, CSSR, and NCA4 (see p.6) – including Figure P1 which illustrates the areas of overlap/separation among the reports, and Table P1 which illustrates the intended "crosswalk" between specific chapters of SOCCR2 and NCA4. This explanatory material is helpful, and it indicates that there were efforts at the outset to define clear relationships among these different reports. However, this appears to be based on the originally intended plans, wherein the SOCCR2 report is completed in time to serve as foundational technical input to NCA. In reality, due to delays in the SOCCR2 production timeline, it was released at the same time that the CSSR was published in final form and the draft NCA4 was released for review. Thus the value of SOCCR2 now rests more as a stand-alone document rather than as a foundation piece for a broader assessment. The explanatory Preface material should be revisited and updated to better reflect the reality of how the different reports did or did not actually feed into one another.

More generally, there is the need to consider how the SOCCR2 authors determined what topics to exclude from their scope in order to avoid overlap with the CSSR and NCA4 reports. The strategy appears to emphasize avoiding redundant efforts, which is reasonable, yet it also has the effect of constraining the discussion in ways that may be confusing to many readers. This is a reasonable strategy to avoid redundant efforts, yet it constrains the discussion in ways that may be confusing to many readers. This problem is reflected, for instance, in the very limited discussion in the draft SOCCR2 of "Consequences of Rising CO_2" (Chapter 17), which presumably resulted from trying to avoid overlap with NCA4 discussions about climate change impacts. This is also reflected in the narrow discussion in the draft SOCCR2 of strategies to better manage carbon sources and sinks, which presumably resulted from trying to avoid overlap with NCA4 discussions about mitigation strategies.

It is worth careful consideration of how best to incorporate carbon cycle science into future USGCRP assessment efforts. A determination should be made about whether the carbon cycle should be more interwoven into other assessment products, or how to best structure future SOCCR reports to be more distinct from future NCA reports. The rationale for these scoping decisions could be more clearly articulated in both the SOCCR2 and NCA4 reports, so that the reader is not left to speculate about why certain topics are or are not covered in either report.

Further, because the National Academies reviews of SOCCR2 and of NCA4 were conducted by independent committees (who only focused on evaluating their respective report), the Committee recommends that leaders of the SOCCR2 and the NCA4 reports coordinate a careful look across both USGCRP reports as they work to finalize them, to assure consistency in the information, analyses, and messaging presented, and to look for important issues that may have slipped between the cracks of these two assessment efforts.

Comments on the Executive Summary

The draft SOCCR2 Preface states that the report Summary is "designed for a broader, more general audience". The Committee appreciates the challenges involved in distilling such a long, technically-oriented assessment down to a short, readable overview. Nonetheless the Summary is quite lengthy (27 pages), and in many places contains language and statistics that will be difficult for a lay reader to grasp. The text should be carefully edited by someone with a "popular science" writing background, to help make it more concise and more readable for the intended audience.

In many places, the Summary reads like an accounting exercise, which may be reasonable given its focus on characterizing carbon stocks and flows. But it would be helpful to readers to offer more context and guidance on why it is important to know more about carbon cycle dynamics. There is some good text to this effect in report Chapter 1 that could be adapted for use in the Summary.

Also, the Executive Summary misses some opportunities to integrate the physical and biological aspects of carbon cycle science and to integrate the natural science with social science, decision making, and actionable items. It would also be helpful to distinguish more clearly between carbon sources and sinks that one can control (e.g., urban emissions) and those that one cannot control directly (e.g., climate feedbacks).

The Summary should also be carefully reviewed to ensure consistency within the body of the SOCCR2 report. There are a few places where numerical values presented in the Summary do not match the related numbers presented in later report chapters (examples are provided below). There are a number of points raised in the Summary that seem to bear no clear connection to material in the later report chapters. This should be carefully checked. Also, a 2017 carbon budget has been released by the Global Carbon Project, and a summary on U.S. greenhouse gases up to 2015 has been released by the US EPA (EPA, 2017), and so the SOCCR2 numbers should be consistent with these reports where appropriate.

General Suggestions for the Summary Key Findings

Overall the Summary key findings come across as rather bland, in part because many of them focus primarily on the message that "we have learned a lot" about some aspect of carbon cycle science. It would be more informative to focus on articulating what has actually been learned (i.e., focus more on the actual outcomes of the research than on the research process itself). Further, statements such as "we have improved understanding of …." or "knowledge gaps remain" are vague. Does improved understanding mean improved accuracy, or new mechanisms, or something else? The Committee suggests providing quantitative information, including uncertainties, where possible.

Where possible, social science and decision-making concepts that are discussed in the body of the report could be woven into the key findings.

It is suggested that confidence levels should reflect the insights and not the methodology. For example, it is not helpful to show high confidence that data and models do not converge on some estimate.

The time period covered by the assessment should be stated clearly at the outset of the Summary.

It would be helpful to start with a finding that provides context about global CO_2 and CH_4 trends (i.e., CO_2 now exceeds 400ppm; atmospheric CH_4 has more than doubled), including some explanation of how we know that these trends are driven by anthropogenic emissions. These can link back to the National Climate Assessment report.

This finding can be followed by a clear statement about North American carbon budgets, that identifies the most important processes contributing to sources and sinks (e.g., for CO_2, biogenic versus energy-related sources; for CH_4, the importance of wetlands and estuaries), and that conveys the totality of changes in North American carbon flux (i.e., what is the net balance in terms of sources/sinks?). Figures ES1 and ES5 in principle provide this information, but they are not consistent and not described clearly in the text. There should be a separate key finding about methane.

Many topics discussed in the body of the report are not reflected anywhere in these key findings. While of course hard choices must be made regarding what is and is not critical to include in key findings, the following topics are worth reconsidering to add somewhere in this list:

- the point that terrestrial land sinks play a critical role in helping to offset anthropogenic emissions;
- the issue of decreasing capacity for land and ocean carbon sinks (i.e., describe the current sink capacity, the possible degradation of these sinks by land use changes and disturbances, and the levers available to protect these sinks);
- a statement reflecting the report's discussion of tribal lands;
- a statement about the importance of greenhouse gas emissions from agriculture;
- a clear explanation of CO_2 and CH_4 contributions from the energy sector;
- a statement to convey some sense of what carbon sources/sinks we can and cannot control (i.e., what are the levers in the carbon cycle that we have opportunities to better manage?).

Comments on Specific Summary Key Findings

FINDING 1. *Emissions from fossil fuels have declined slightly over the last decade, largely a result of decreasing reliance on coal, increasing reliance on natural gas, the global recession, and increased vehicle fuel efficiency standards. Economic productivity has continued to increase, demonstrating that CO_2 emissions can be decoupled at least partly from economic activity.*

- Insert "North America" to avoid confusion with the global emissions, which have grown.
- The reference to economic "productivity" would be better worded as "activity", assuming the authors are really talking about economic output measures such as GDP.
- Suggest dropping the reference to the recession here as that was too short-term of a change to have a major effect on global atmospheric concentrations.
- Add to this finding or add a new finding: North American fraction of global fossil emissions, and the trend since SOCCR1. CO_2 and CH_4 contribution from the energy and agricultural sectors.

FINDING 2. *The results from top down and bottom up approaches to estimating the magnitude of the land carbon sink are converging because of improvements in data and methodology, though significant uncertainties remain in both approaches. The land sink appears to be persistent, but future impacts from land use change and disturbances, both natural and human induced, may diminish this sink.*

- Starting with the "top down versus bottom up" message overemphasizes scientific process, as opposed to the actual information that people need to know. Suggest deleting this first sentence.
- This Finding should give quantitative estimates (including uncertainties) of the North American carbon budget and updates since SOCCR1.

- . Acknowledge here the fact that the estimates for Mexican forest fluxes have changed sign since SOCCR1, including discussion about the uncertainties in this finding.
- 'Future impacts' should include climate change.

***FINDING 3**. There have been marked improvements in the understanding of North America's carbon sources and sinks and the partitioning of carbon forms in water environments, as well as the importance of carbon transfers in inland water environments and across land water interfaces. Significant emissions from inland waters and a large carbon sink in the coastal ocean have been quantified.*

- This is another example of focusing on the process ("we've had improvements in understanding") rather than focusing on what has actually been learned. Give quantitative estimates of fluxes and inventories in water environments, including uncertainties.
- Need to mention that fluxes associated with inland waters and coastal ocean include pre-industrial or background fluxes, and that there is significant lateral transport.

***FINDING 4.** Understanding of the CH_4 budget has much improved, although there are important knowledge gaps. Overall, observations indicate that global atmospheric concentrations of CH_4 are increasing, while North American CH_4 emissions are relatively stable.*

- It is vague to say "understanding of the budget has improved" and "there are knowledge gaps". Offer some concrete sense of what things we have learned, and what still needs to be learned. Be quantitative where possible.
- It is confusing to conflate the global and national emission trends. Better to focus on global emission numbers at the start of the key findings list, and then focus just on North American emission trends.
- It is not really clear what the point of this finding is. What do these stated trends mean? Can we link the North American CH_4 emission trend to mechanisms/drivers?
- Need to discuss the findings of significant methane emissions from oil/gas producing regions, and the existing discrepancies between emission observations with the apparently decreasing overall atmospheric methane trends.

***FINDING 5.** Analyses of social systems and how carbon is embedded in them demonstrate the relevance of carbon cycle changes to people's everyday lives and reveal feasible pathways to reduce GHGs.*

- The Committee questions whether this sort of statement really needs to be highlighted as a "key finding", as it seems rather hollow.
- While explicit policy recommendations are not part of the mandate for the SOCCR2 assessment, it is reasonable to discuss the implications of policy decisions on the carbon cycle. Perhaps this is something that can be better addressed in the next SOCCR assessment.

***FINDING 6.** Urban areas in North America represent the primary source of anthropogenic carbon emissions, as well as an indirect source of carbon from the emissions associated with goods and services produced outside city boundaries for consumption by urban dwellers. Therefore, carbon monitoring and budgeting in urban environments is increasingly important, including the avoidance of double counting with sectoral data on CO_2 fluxes.*

- This finding illustrates the problem of singling out urban regions as an emissions category. Given that the finding does not highlight other major sectors such as forests and agriculture, it is not obvious why "urban" is highlighted. The urban focus would make more sense if the finding identifies how particular components of carbon emissions are best controlled at the urban level (e.g., through steps such as restructuring urban development patterns to reduce driving), and if it is better integrated with the "decision making" discussion (Chapter 18) by identifying opportunities to effectively manage carbon emissions at the different governance levels (local/state/federal) or different system levels (forest, freshwater, etc).

- The finding could be improved by incorporating some of the information articulated in Box ES5—for instance, the point that monitoring could help inform the emission reduction pledges made by cities.

FINDING 7*. Overall, research has led to an improved ability to attribute observed changes in the carbon budget to specific causes, including social and economic factors, technological change, climate variability, and management practices. Understanding these processes and their interactions aids in projecting future changes in the carbon cycle and developing adaptive capabilities. One projection is of significant concern the 5% to 15% of the carbon stored in soil pools in the circumpolar permafrost zone is considered to be vulnerable to release to the atmosphere by the year 2100, considering the current trajectory of global and Arctic warming.*

- The last sentence of this finding is the critical point to emphasize. The first two sentences are perhaps not even needed.
- It would help to delineate here the potential impacts of permafrost thaw on CO_2 and on CH_4 separately (rather than on carbon collectively), and to translate the percentages into absolute amounts (Pg, Tg of carbon) and/or into ppm in the atmosphere.
- Add a finding about projections – decreasing capacity of land and oceans to absorb CO_2.

FINDING 8. *There are still regions and ecosystems that are less well understood that would benefit from additional research and monitoring (e.g., the Arctic and boreal regions, grasslands, wetlands, inland waters, and tropical ecosystems among others described in SOCCR 2). Uncertainties for particular sources, sinks, and fluxes must be reduced to provide consistent and accurate inventory (bottom up) and verification (top down) estimates. Filling these gaps will be important milestones for the third SOCCR a decade from now.*

- This finding offers little substance. A finding focused on research needs could be useful if it avoids being a vague list that could potentially encompass anything. Instead it could identify specific knowledge gaps that could feasibly be addressed with a focused research agenda.
- This Finding should include consideration of what research and support is needed to advance our understanding of carbon cycling and resource management on Tribal Lands, and to advance the integration of social science with the natural sciences of the carbon cycle.

Comments on Summary Figures / Tables

Figure ES1: This figure shows that the domain of this report includes Puerto Rico, Hawaii, and U.S. Pacific islands, yet the report provides little information about these locations. The authors should re-draw ES1 to exclude these places, or mention in the text their carbon significance.

Figure ES2: This is potentially a helpful figure, but the following improvements are suggested:

- Augment to also show lateral fluxes of carbon – especially given how the report emphasizes these lateral fluxes as one of the important scientific advances of recent years.

- The box labeled "Atmosphere" should be "Global Atmosphere". As is, one could mis-interpret the +1032 to refer to atmosphere over N America. The authors may wish to consider putting parenthesis around (+1032) to indicate that it is an estimated quantity.
- The figures are reported with too many significant digits. The numbers should include uncertainties.
- The caption is unclear, and needs to distinguish between inventory and fluxes (e.g., arrows are fluxes).

Figure ES3: The graphics should be improved in several respects:

- The figure is missing information about the CO_2 source. It should show CO_2 and CH_4 separately. Most importantly, the CO_2 figure should show fossil fuel carbon and land use emissions over time.
- It shows emissions as "negative sinks", which will be very confusing to most readers.
- Many readers may be unfamiliar with the "micromole per mole" units used. The report should include a note about units for reporting gases and consistently use one type of unit that is most familiar to lay readers (perhaps ppm and ppb).

Figure ES4:

- Change left Y-axis label to "Annual emissions (PgC)", as now it only indicates unit, but not parameter/variable.
- Figure legend: Change "North America" to "North America Total", to make this more clear.
- The figure graphic quality can be improved, for example, by adding x-axis major tick marks for every 5 years, and leaving space between symbols and letters in the legend.

Figure ES5 should be re-considered. This figure pertains to the total fluxes into or out of the atmosphere, but one could easily mis-interpret this figure to say that the North American net CO_2 flux is approximately equal to the emissions from fossil sources—as the forest sink and coastal ocean sink are countered by outgassing from inland waters. This figure would appear to contradict the terrestrial sink (land and water components). Other suggestions:

- y-axis label should be "Carbon dioxide fluxes (Tg C per year)"
- change x-axis category labels
- change from "Fossil fuels" to "Fossil fuel emissions"
- change from "Forest sector" to "Forests"
- change "Inland water outgas" to "Inland water"
- change "Arctic/boreal" to "Arctic/boreal permafrost"

In Figure ES2, ES4, and ES5, check the numbers/units for consistency. Even within the Executive Summary figures, there is inconsistency in the units used (a mix of Pg, Tg, other units).
The Committee recommends adding a figure showing the changes in the mix of energy sources and associated CO_2 emissions over time (at least in Chapter 3 [*Energy Systems*], if not in the Executive Summary).

Table ES1 on trends, indicators, drivers from the energy system seems oddly placed in the Summary, given that there is nothing comparable presented for trends, indicators, drivers, impacts of other major components of the carbon cycle (e.g, forestry, agriculture, land use changes).

Line-Specific Comments

P18, Line 16-17 [Preface]
CO_2e is defined relative to a time horizon, typically 100 years or 25 years. Most usage in the chapters assumes 100 years, though some mentions a shorter time horizon. This has to be consistent throughout the report. Here, it would be useful to give actual numbers for methane and N_2O for the two time horizons.

P21, Line 12-13
Interestingly, this statement is an expression of world views characteristic of those held by indigenous communities—interconnectedness of humans and the environment. Additionally, it may be worth combining with text at p.25, l16.

P21, Line 15
Replace “improved understanding” with “advances in our understanding”.

P21, Line 28
It should be possible to quantify these. Can estimates be provided?

P21, Line 30
Discussion of ecosystem impacts is sparse. These impacts are complex and multi-faceted, involving spatial, temporal, and place-resource dependent considerations. Factors such as species displacement and migration, alteration of phenological behavior, impacts of water timing and availability, extreme events, and impacts such as introduction of genetic strains are not addressed.

P23, Line 20 – P25, Line 15
These main findings are disconnected from the final few pages of this chapter (beginning with p.38).

P27, Line 4
Forests typically are sinks, so reverse the analogy.

Box ES2, paragraph 2.
Some of the chapters use different units [g/m^2]. More consistency is needed. Also methane units need to be included. Definition of CO_2e should include the time horizon (typically 100 years).

P28, Line 29-36
This is largely repetitive of concepts presented at p.23, lines 9-16.

P29, Line 8-18
While the numbers appear consistent with those in the literature, information on the significance of these increases would be valuable for a lay audience. For example, what is the importance of these increases for ecological processes, human health, food supplies, quality of life, and habitability? Might these statistics be more effectively presented at p.32?

P29, Line 5-28
These concepts are described in detail in other USGCRP documents, is it necessary to repeat in SOCCR2?

P29, Line 2
Suggest changing to "Evidence strongly suggests that changes…." (add "that").

P29, Line 10
The unit for the atmospheric CO_2 concentration here (ppm) is different from the one in Figure ES3 (umol/mol).

P31, Line 5-7
The confidence statement used here should clarify that the *magnitude* of sources/sinks contains uncertainty, but not the *process*.

P31, Line 12
Discuss methane after this line.

P32, Line 22-30
Need to mention that CO_2 fertilization is transient storage, as it is followed by greater litter inputs and enhanced decomposition and CO_2 efflux from soils.

P33
This section should have a sub-section on CO_2 and one on methane. Here methane sources and sinks appear as a single bullet (p.35) interspersed between CO_2 fluxes and stocks. The methane subsection should include the recent studies of U.S. methane sources (e.g., Kort et al., 2014) and other references listed below for Chapter 2). Contrary to p.36, line 2, Turner et al. (2016) finds a trend in U.S. emissions.

P33, Line 2
Shouldn't the focus be on carbon flux instead of atmospheric concentration when discussing sources and sinks?

P33, Line 22
The use of "now" refers to what period? 2004-2013?

P33, Line 22
An important factor is the declining trend in North American contributions as a percent of global emissions; this deserves some elaboration.

P35, Figure ES5
It is not clear how one gets 634 Tg from Figure ES2. Please check numbers and ensure their compatibility across the document.

P35, Line 11-14.
This contradicts Key Finding 3 of Chapter 2 (between ¼ and ½ of fossil fuel emissions were offset by natural sinks on North American land and adjacent coastal ocean. The authors should re-think how to present the information.

P36, Line 13
As stated this sentence indicates that "land" sinks include inland waters and the coastal ocean. The word "land" here should be eliminated, or perhaps replaced with "continental".

P36, Line 36-37
Why is the term "reservoirs" used? Is there an intended difference from sinks?

P37, Line 1-4
Carbon storage and risks of greenhouse gas and soot emissions from forests is heavily dependent on vegetative management practices, such as prescribed burning, mechanic removals, and species manipulation.

P37, Line 13
Why aren't tillage practices mentioned?

P37, Line 35
Why isn't methane emission from reservoirs mentioned ?

P37, Line 21-22
The results and findings presented here are inconsistent with ones in Chapter 13: the stated net carbon sink from terrestrial wetlands of 64 TgC/yr (36 TgC/yr by nonforested wetlands, plus 28 TgC/yr by forested wetlands) is different from the value of 53 Tg/yr presented as Key Finding 2 in Chapter 13—despite the fact that the Executive Summary indicates Chapter 13 as source for that information. The authors need to check for consistency with the latest version of relevant chapters of the report.

P37, Line 25
The methane source from terrestrial wetlands [21 Tg CH_4/yr] is different than in Key Finding 2 of Chapter 13 [18 Tg CH_4/per year].

P38 [section: *"A systems approach to linkages between the carbon cycle and society"]*

- Despite the definition of "systems" in the footnote, there is no discussion of economics in this section or throughout Chapters 6 and 18.
- As this section provides background information and little new insight, it could be shortened significantly.
- The discussion of CO_2 from urban areas confuses the terms "drivers" and "sources". Urban populations drive CO_2 emissions elsewhere. (Page 40 – The CO_2 that is emitted locally from urban areas are from transportation and natural gas consumption at residential and commercial establishments. CO_2 from fossil fuel combustion is released at power plants far away).

P38, Line 1-6
Consider adding discussion of impacts of carbon on plankton production and food chains, ocean acidification, hypoxia (related to land use and chemical fertilizer application), and harmful algal blooms.

P38, Line 8-24
Much of this appears to be repetitive.

P39, Figure ES6
In the Box "Climate Drivers", delete "annual" from weather.

P40, Line 41 – P42, Line 18
These projections seem to be based on the scenarios that have socio-economic responses embedded into physical climate models. Should references be included?

P40 [Section: *“Projections of the Future …”*]

- Is important to mention that the capacity of the land and oceans to act carbon sinks decreases with projected climate change.
- Need to include projection of methane.

P41, Line 16-21
Is important to mention that CO_2 fertilization effects are likely overwhelmed by climate change effects.

P42, Line 10-18
Perhaps note the challenges in carbon accounting involving the world commons. Under IPCC rules, coastal states do not get credit for ocean sinks.

P42, Line 19-40
This discussion seems disconnected from SOCCR2. Issues of carbon management, systems of governance, etc. could be more fully integrated with discussions in other chapters. While the authors understandably shy away from prescriptive statements, SOCCR2 could usefully inform decision makers about actions that make significant contributions to reducing GHG emissions.

P43, Box ES.3
This box is a bit perplexing. Why is the discussion limited to cities? The presence of states, businesses, and tribal governments at Bonn and participating in various climate-related initiatives is likely more substantial and significant. As indicated in Chapter 4, a main obstacle to the ability of cities to influence carbon-flux is jurisdictional fragmentation and the lack of a multi-level system of carbon governance.

P43, Line 8
The 3rd option involves storage in geologic reservoirs as well.

P43, Line 8
The reference to geoengineering needs to be more carefully worded to avoid giving a mis-impression that solar radiation management techniques could directly affect the level of carbon gases in the atmosphere (they cannot).

P45, Table ES.1
Why is this included while corresponding treatment for other chapters is absent?

P46, Line 37
This statement suffers from the paucity of data on effects of tribal management practices on carbon fluxes and the lack of a means to “upscale” actions to determine their significance.

P47, Line 2-37
These co-benefits and trade-offs suggest the existence of an integrated cross-boundary economic and jurisdictional system, which does not exist. Should the focus instead be on multi-level integration

involving local communities, urban areas, regional, national and international carbon accounting and decision-support systems?

Chapter 1: Overview of the Global Carbon Cycle

Overview/Main Issues

This chapter contains high-level background on the importance of the global carbon cycle, the major pools and fluxes of carbon, what's changed over time, and perturbations of the carbon cycle. It also has a section that pertains specifically to the North American carbon cycle. The chapter represents a considerable effort on the part of the authors to distill the literature and key points. While it does a good job giving a high-level overview, it could be improved by the harmonization of the data in the text with the figures and other chapters in the draft report as well as by adding new conceptual figure(s) and a table. Some other general suggestions include:

The chapter is not balanced between CO_2 and CH_4. There needs to be a key finding about CH_4. The term "carbon" often refers only to CO_2, and not methane (e.g. Section 1.3.2).

For methane, it is important to mention recent studies that have used "top down" observations to derive emission estimates that are higher than the "bottom up" EPA inventory estimates (e.g., Kort et al., 2014; Miller et al., 2013; Turner et al., 2016). Studies that have fused large collections of airborne, ground-based, and satellite data should be given particular attention.

Further editing to clarify and shorten the key findings as well as some of the text would also improve the chapter.

There was not always a consistent mention of cement production and inland waters as important sources of carbon emissions to the atmosphere. And there is some problem with consistency for fluxes within this chapter and Figure 1.1, as well as across other chapters.

Some sections are not well organized or clearly written. For example, Section 1.1 should have, at a minimum, a much stronger introductory sentence that illustrates the fundamental importance of the carbon cycle. See, for example Cole, 2013.

Some of the headers are ambiguous and, in some cases, do not describe well the content of the paragraphs that follow. For example: Section 1.1 (The Role of Carbon)—where, and for what? Section 1.2 (The Natural Carbon Cycle)—the 2nd paragraph talks about human influence on the carbon cycle.

The Chapter is missing a conceptual figure to illustrate feedbacks. The nature and magnitude of feedbacks are likely to be crucially important, which is identified in the text

Statement of Task Questions

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

One of the major new pieces of information for SOCCR2 is the emissions contribution from inland waters. This was not highlighted in the key findings, but should be. The authors should be careful to explain that this flux includes the background flux, not just fluxes in response to anthropogenic emissions. Also the discussion of methane is very slim and should be enhanced.

- *Are the findings documented in a consistent, transparent and credible way?*

The suggestion that "global emissions became slightly more uncoupled from economic growth"…requires a synthesis figure and/or references to support this finding.
Often time frames are missing (see above and line comments)

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

It would be helpful to add:

- a figure (conceptual or more specific) that shows carbon cycle feedbacks;
- a figure or table illustrating Key Finding 3, "uncoupled from economic growth"
- a table or figure that show the relative radiative forcings of greenhouse gases (including non-carbon) as per Key Finding 2—although the authors may wish to consider whether discussion of radiative forcing is even appropriate for this report, or whether that topic should instead be restricted to the NCA report.

- *Are the research needs identified in the report appropriate?*

They were not explicitly part of this chapter.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

Yes, with the exception of Key Finding 3, about which it is not possible to tell.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

Some improvements are necessary, see above.

- *What other significant improvements, if any, might be made in the document?*

In addition to figure and table suggestions noted above, it would be good to add an explanatory sentence or two about radiative anthropogenic forcing on page 5, should the authors decide to keep radiative forcing in this report.

- *Are the key findings in your chapter well stated and supported by the detail provided in the chapter?*

In general, we find the key findings are unnecessarily long, and a few are not as clear as they could be. Specific suggestions include the following:

Key Finding 1.

- Make clear time frames; e.g., give year or range of years.
- This should echo key finding in the NCA report: CO_2 over 400 ppm, highest during human history, fastest growth rate, etc. Same for methane.

Key Finding 2.

- The authors should discuss whether radiative forcing belongs in SOCCR2, or whether that topic should be restricted to the NCA report. If this topic is not removed altogether, then the Key Finding should mention other (non-carbon) GHGs here and their contribution to total radiative forcing. For this message, the unmatched time frames are confusing (e.g., relative to year 1750, and then 1880-2012).
- There was no citation in the supporting evidence for the "high confidence" relationship between radiative forcing and increase in global average temperature.

Key Finding 3.

- If this "uncoupling" between economic growth and fossil fuel emissions is taken from published studies and syntheses, a figure or table should be included in support of the statement.
- There was no mention of CO_2 emissions associated with cement production and changes over time, although they are part of Figure 1.1. Are they assumed to be part of the global fossil fuel emissions?
- "Growth in emissions (of) -0.1%" could easily be misconstrued by some readers. How about "For 2015 and 2016 emissions remained constant at ...". It is best to avoid negative signs that given an impression of a net sink.
- The authors should provide quantitative information. For instance, noting the current fossil fuel carbon emissions and cumulative emissions since pre-industrial would help tie this to Key Finding 5.

Key Finding 4.

- The numbers in this key message do not appear to match the numbers in Figure 1.1.
- Missing in the text is mention of the flux to the atmosphere from inland waters, which is identified as an important new piece of information and also appears in Figure 1.1. Note that the flux estimate is different from what is identified in the inland water section. This also needs to be consistent with Key Finding 1.
- The statement that the magnitude of the future ocean sink is uncertain "because the responses of the carbon cycle to future changes in climate are uncertain" could use more nuance. The magnitude of the future ocean sink also depends on other factors such as what GHG emissions pathway is followed, possible ocean circulation changes, and natural internal system variability.

Key Finding 5.

- The message could be edited for clarity. There is an important reference to feedbacks here, ergo the suggestion to include a conceptual feedback figure which details some of the feedbacks of concern.
- The first sentence (regarding T response per 1000 PgC) could be deleted, as this is a better fit for the NCA report.
- This is an important Key Finding but the message is blurred and most will not grasp the meaning of "this limit could be reached in as little as 20 years." Is that to mean all fossil fuel CO_2 emissions world-wide must go to zero by 2037? Or that emissions then can only be those that are matched by say equal ocean uptake, etc?

Line-Specific Comments

P49, Line 14-20
Please reference years or range of years in Key Finding 1 as is done for Key Finding 2.

P49, Line 35
Change "slowed" to "decreased", since there is a negative value for percentage change.

P49, Line 36
Flat growth is an oxymoron, it seems.

P50, Line 8-9
Please clarify, e.g., mitigation activities, such as…

P50, Line 13-15
This wording is awkward, rewording is suggested.

P49, Line 13 – P50, Line23
Missing from the findings are a direct reference to (1) new global emissions estimates from inland waters and (2) the proportion of cement production emissions contributing to global CO_2. The data for (1) are in Fig 1.1

P50, Line 24
This chapter should start with some introductory text.

P50, Line 24 – P51, Line 15
This section should be edited for content and clarity. (Role of Carbon—where, for what?)

P50, Line 25-27
The first couple of sentences are vague. See Cole, 2013.

P51, Line 16-21
Some background discussion about the Earth system would be helpful here: for instance, give % marine, %land, % terrestrial, % freshwater, % ice.

P51, Line 16-21
Missing from the system discussion and from Figure 1.1 are feedbacks; this should be included.

P51, Line 38-40
Add temporal reference for slow carbon cycles and geologic reservoirs.

P52, Line 4-11
Mention spatial extent of carbon stored in soils, permafrost, etc.

Page 52, Line 29
The Southern Ocean is the largest region of carbon sink (e.g. Gruber et al., 2009). It is more diffuse than the North Atlantic, but acts over a much larger area. It should be mentioned here for

completeness. Also, "top-down" estimates of the North American CO_2 sink are tied to the highly uncertain magnitude of the Southern Ocean sink.

Page 52, Line 31
While small interannual variability of the ocean is what Wanninkhof et al., 2013 suggests, newer information suggests that the variability is likely substantially larger than previously thought (Landschützer et al., 2015).

P52, Line 37-38
This reads as if El Nino of 2016 is the only driver.

P53, Line 4
Add time frame

P53, Line 7
Why "note?"

P53, Line 36
Many of these natural processes are anthropogenically influenced or are a results of feedbacks.

P54, Line 6
Since 1870? From when to 1870? Is the time frame 1870-2014?

P54, Line 7-11
Need references and or a synthesis figure to support this assertion.

P54, Line 27-28
It seems odd to include the reference on how to avoid emissions here.

P54, Line 29-32
Name major sources of OH, to provide more context for this sentence.

P54, Line 22-32
This paragraph mixes emissions and reduction of emissions strategies and processes.

P55, Line 20
What time frame is used for the cumulative emissions discussion?

P55, Line 33-39
The accounting is not clear as written. North American emissions (from fossil fuel burning and cement production only—not inland waters?) are being compared to the terrestrial sink in North America?

P56, Line 3-4
Where is the boundary vis-à-vis ocean uptake? Is any part of that considered a North American sink? This is unclear.

P56, Line 16
The text would benefit from a figure showing feedbacks and how they may interact to influence the future carbon cycle.

P56, Line 25-27
As is pointed out elsewhere in the document, the situation is not quite as direct as CO_2 causing a direct fertilization effect.

P56, Line 32-35
This paragraph is rather superficial. In particular, deeper discussion of the likely future response of the ocean sink is needed, as it is not as simple as suggested here. There is substantial uncertainty in future uptake, as a function of ocean circulation, warming, chemical changes (Lovenduski et al., 2016; Randerson et al., 2015). The sensitivity of the ocean sink to emission pathways needs more study. The idea of a continually growing sink in the ocean only applies under a high emission trajectory. If a low emission trajectory is taken, the ocean should outgas carbon, particularly in the subtropics where waters with high anthropogenic carbon content are circulating in the upper ocean (DeVries et al., 2017).

P56, Line 4
The title for this subsection is mismatched with content.

P57, Line 26
Safe for what?

P59, Line 4-5
There are too many "furthermores" used here.

P60, Line 14
This should be estimates of cumulative carbon emissions, correct?

P61, Line 22-26
It would be helpful to see a summary figure showing the economic and emissions data.

P61, Line 35-39
This is a vague paragraph.

P62, Line 15-17
What about emissions from inland waters?

Page 62, Line 15-26
The presentation here suggest equal uncertainty in the land and ocean sinks, which is not the case (Le Quéré et al., 2016; 2017). In addition, the approach to estimation of the ocean sink is mis-represented. The cumulative ocean sink is best constrained using ocean interior data (DeVries, 2014; Khatiwala et al., 2009; 2013; Sabine et al., 2004; Sabine and Tanhua, 2010), surface ocean pCO_2 data can provide independent confirmation of the magnitude of the mean sink (Landschützer et al., 2013; 2014; 2015; 2016; Takahashi et al., 2009). There remains substantial uncertainty with respect to interannual variability in the global carbon cycle, with models believed to strongly underestimate the actual

variability (Landschützer et al., 2015). These models are quantitatively tied to the estimates from interior ocean data and surface ocean pCO_2.

Chapter 2: The North American Carbon Budget: Past, Present, and Future

Overview/Main Issues

This chapter nicely summarizes and synthesizes the latest scientific information on the North American carbon budget by incorporating terrestrial, anthropogenic, aquatic, and coastal margin CO_2 and CH_4 dynamics. Starting with a historical context, the chapter summarizes current understanding of the magnitudes and trends of carbon stocks and fluxes at the continental scale. It also provides a regional context by stratifying the continent to countries and climate assessment regions and discusses the societal drivers, impacts, and carbon management decisions. Knowledge gaps and research needs are also identified. This chapter is well-written and clearly organized, and provides a broad context beyond individual chapters. Some of the main ways the chapter can be improved include the following:

- some work is needed on the Key Findings (discussed below);
- the goals and objectives should be explicitly described;
- critical content areas missing from the chapter are interannual variability of carbon fluxes and impacts of severe and extended droughts;
- indicators and feedbacks are missing from Section 2.4;
- consistent use of units is recommended;
- numbers with 3-4 significant digits over-state the confidence the reader should have, and all numbers should include uncertainties.

And one broader concern to note: This chapter follows the global overview in Chapter 1, where "sinks" are sinks in the cycle perturbed by anthropogenic CO_2 and CH_4, and the assumption is that globally, the net unperturbed background sinks are zero summed across all reservoirs. Yet in this chapter, "sinks" are net fluxes out of the atmosphere, background + perturbation. For the coastal ocean, inland waters, etc.—where lateral transport is significant—these sources and sinks include background/pre-industrial fluxes that are balanced by fluxes elsewhere. These distinctions must be made clear so that the reader is not given an impression of a greater or lesser sink for anthropogenic CO_2 than is there (e.g., P74, lines 4-6).

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

The goals and objectives of this chapter are described in an implicit way at the end of the Introduction section. It would be better to rephrase that paragraph to clearly outline the goals and specific objectives. The intended audience is not clearly described. But this is perhaps something that only needs to be described in the Executive Summary. The report meets its stated goals to a large extent, with one exception—indicators and feedbacks are not clearly described.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

The report accurately reflects the scientific literature to a large extent. For part of the Introduction and the Historical Context section, it is appropriate to cite some older but classical studies (e.g., Caspersen et al., 2000; Goodale et al., 2002, etc) for the historical context of the North American carbon cycle studies. One more recent study could be useful here is Zhang et al. (2012), which shows that on average the carbon sink in the conterminous U.S. forests from 1950 to 2010 was Tg C/yr with 87% of the sink in living biomass.

Two critical content areas missing from Chapter 2 are the interannual variability of the terrestrial carbon sink and the impacts of drought. It would be better to have a section to address the interannual variability of carbon fluxes. Besides disturbances, drought has significant impacts on ecosystem carbon uptake and has been studied extensively using modeling and upscaling methods in North America.

Another critical content area missing is indicators and feedbacks. The title of Section 2.4 is "Indicators, Trends, and Feedbacks", but the section does not really touch on indicators or feedbacks. These two components should be added or strengthened; alternatively, the title should be changed to "Trends".

Discussion of the methane budget should be expanded and updated in a few ways:

- Throughout the chapter, "carbon" refers to CO_2 and not methane. The chapter should mention the difficulty of unravelling methane sources and sinks, given that there are so many sources.
- The chapter should include references for fossil fuel methane emissions: e.g., Hendrick et al. (2016), Jacob et al. (2016), Kort et al. (2014), Turner et al. (2016). The chapter should also mention that there is not agreement about whether U.S. methane emissions or methane sinks are under-estimated or not; e.g., see Bruhwiler et al. (2017), Miller et al. (2013), Turner et al. (2015), and Wecht et al. (2014).
- Table 2.1 of the 2017 EPA report (EPA 430-P-17-001) shows 2015 has lower total emissions than 2005. The upticks in "natural gas systems" and "manure management" are nearly cancelled by downturns in emission from landfills. This has important information for managing the methane budget. Where possible, the numbers and conclusions should be consistent with this EPA report; departures from and updates of that report should be highlighted.

Coastal oceans were reported as a carbon source in SOCCR1 but as a carbon sink in SOCCR2. This can perhaps be considered as a key finding. In addition, it would be useful to have a key finding on CH_4 budget.

- *Are the findings documented in a consistent, transparent and credible way?*

The way that Key Finding 5 is documented needs a bit of work. "Significantly" is typically associated with a statistical test. Is the average carbon sink estimated by top-down approaches not statistically higher than that by bottom-up estimates? If a test couldn't be done, "significantly" should be replaced with something like "quite" or "substantially".

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Key Finding 1 is undoubtedly true but this has been known for a long time, thus it may be unnecessary as a key finding. It includes a new estimate (1,032 Tg C per year), but this number is already reflected in Key Findings 2 and 3. Note also this should say "net source of CO_2" (not carbon).

Key Finding 4 should reflect the fact that there is significant interannual variability in the carbon sink. Also it is unclear what "natural terrestrial carbon sink" actually refers to. Does this include natural ecosystems such as forests and grasslands? Are agricultural soils included? Even forests/grasslands are managed to a large extent. Does this include wood products, land use changes, etc., which may be considered anthropogenic rather than natural? The authors should either specify what is included (in parenthesis following "natural terrestrial carbon sink") or slightly rephrase the term as something like "land/ecosystem sink". This also applies to Key Finding 3.

Key Finding 4 and 5 should include quantitative estimates and uncertainties. No need to emphasize the approach (top-down, bottom-up), just focus on the actual outcomes.

In the regional context, it would be good to add a figure to quantitatively illustrate how much the size of the carbon sink is in each national climate assessment region, how much fossil fuel emissions are released in each region, and what percentage of the emissions is offset in each region.

- *Are the research needs identified in the report appropriate?*

Research needs could include how to better integrate modeling approaches with observations and how to reduce the uncertainty in carbon sink/source estimates.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

As mentioned above, the authors should test whether the mean of the carbon sink estimates from top-down approaches is not significantly higher than that of the sink estimates from the bottom-up methods. Otherwise, the statement should be rephrased accordingly. In addition, both Tg C and Pg C are used for carbon fluxes (larger than 1,000 Tg C or 1 Pg C). It would be better to use the same units (Tg C) throughout the chapter. In addition, both Tg C per year (p. 80, line 11) and Tg CH_4/yr (Figure 2.4) were used. While this is commonly done in the scientific literature, it may be helpful to include in parenthesis CO_2-equivalent for both CO_2 and CH_4.

- *Are the document's presentation, level of technicality, and organization effective?*

There are repetitions or mistakes in sentences. For example, the statement on p. 82, Lines 14-16 is essentially the same as the first two sentences of the following paragraph. These two paragraphs should be combined and modified. In addition, Key Finding 1 is exactly the same as Key Finding 5 and should be corrected.

This chapter can be difficult to read at times, with awkward use of language in many places (e.g. Key Finding 2: "a level of magnitude"). The chapter would benefit from editing.

- *What other significant improvements, if any, might be made in the document?*

- For Section 2.4, the first two paragraphs would fit better into Section 2.3.
- Section 2.4 should also discuss the interannual variability of carbon fluxes besides indicators and feedbacks.
- Section 2.5.2 should quantitatively describe the regional carbon sinks, fossil fuel emissions, and the percentage of fossil fuels emissions are offset by ecosystem carbon uptake.

- The discussion throughout the chapter on "top-down" and "bottom-up" is not informative to the general readership of the report, and could be shortened considerably.
- The authors are advised to carefully check the "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015"[1], and see whether the estimates of emissions and sinks should be compared against SOCCR2 estimates and whether there are nice figures that can be used in SOCCR2.

Line-Specific Comments

P71, Line 21-25
Why not use Pg C here, as is used elsewhere (e.g., p.73, Line 41). Having more consistency in units will make the report less confusing to the audience.

P71, Line 30-33
This key finding ignores the previous research findings showing interannual variability in ecosystem carbon fluxes caused by drought and disturbances.

P72, Line 5
Change "3 centuries" to "three centuries".

P72, Line 9-10
This statement needs to be rephrased. Continental carbon sources are only partly offset by sinks from natural and managed ecosystems.

P72, Line 21
The focus here should not be North American carbon balance, but North American carbon sink, or the carbon sequestration capacity of North American ecosystems.

P72, Line 23-25
Since this statement is put in the historical context, it is better to cite some older and classical studies (e.g., Caspersen et al., 2000; Goodale et al., 2002).

P72, Line 38
The authors should mention that atmosphere-based estimates provide limited information on the exact location of carbon sinks/sources.

P74, Line 6
Change "50%" to a specific number (in units of teragrams).

P74, Line 9
The phrase "be of sufficient magnitude" is redundant and can be removed.

P75, Line 29-42
This paragraph is somewhat disconnected. The first two sentences are on the missing components of synthesis efforts, while the following sentences are on inventories or methane. Is methane one of missing components? This paragraph should be modified to improve logical flow.

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[1] EPA 430-P-17-00: https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf

P76, Line 18-21
It would be better to briefly summarize how the estimates across various scaling approaches were reconciled.

P76, Line 22
It is better to switch “fluxes” and “stocks” in the section title because the first paragraph is on stocks, not on fluxes.

P76, Line 41
“There is very high confidence that” can be removed.

P77, Line 32-33
What is the difference between “uncertainty and “error”? It would be good to make this clear.

P78, Line 20
Starting the paragraph with “Figure 2.3” makes the paragraph look like a figure caption. (May be confusing to readers).

P78, Line 27
“-274 Tg C per year” should be changed to “274 Tg C per year”.

P80, Line 25 – P81, Line 24
These two paragraphs are not on indicators, trends, or feedbacks (except the last couple of sentences of the latter paragraph). Perhaps integrate these paragraphs into Section 2.3?

P80, Line 33-35
This is actually something new and could be considered a key finding of the chapter.

P81, Line 17-19
The so-called “browning” and “greening” trends should not be interpreted as evidence for vegetation carbon gains or losses. These trends are based on the normalized difference vegetation index (NDVI). They can indicate trends in photosynthetic activity or gross primary productivity, but not net carbon uptake.

P84, Line 2-6
Surprisingly, drought was not mentioned here or anywhere else in the chapter.

P86, Line 20
The authors should provide a few examples of observational networks, particularly those that have emerged since SOCCR1.

P86, Line 21-29
Perhaps provide an example about how interoperability can benefit carbon management decisions?

P86, Line 34
Why is “very likely” used here? This should be definitely true.

P87, Line 20-21
This statement should be reflected in Key Finding 4.

P88, Line 10
"land and water fluxes" should be changed to something like "carbon fluxes from land and water" to avoid confusion. Water fluxes are generally used to indicate evapotranspiration, river discharge, etc.

P88, Line 15-19
These sentences clearly indicate that there is large interannual variability in ecosystem carbon fluxes, which contradicts Key Finding 4 (that the magnitude of the terrestrial carbon sink has persisted at a similar magnitude over time). The interannual variability in ecosystem carbon fluxes is overlooked in this chapter and should be highlighted. Upscaling of flux observations and biosphere modeling studies also show significant interannual variability.

P90, Line3-5
Key Finding 1 here is exactly the same as Key Finding 5.

P103, Figure 2.1.
Figure Legend: Spell out NCA; change "Forest" to "Managed Forest"?; change "Other Land" to "Other Land Ecosystems"?

P104, Figure 2.2.
The graphics can be improved. Change left vertical axis label to "Fossil fuel emissions (PgC)".

P105, Figure 2.3.
Figure caption: The numbers for net carbon uptake (top to bottom) are written in the opposite direction to those for carbon release (bottom to top), which makes the figure a hard to read. Why not show all these numbers in the same direction (from bottom to top)?

P106, Figure 2.4.
Figure caption: change "million tons" to "Tg"
Wetland CH_4 emission of 47 Tg is much higher than the value in Chapter 13 (18 Tg CH_4/yr) and the Executive Summary (21 Tg CH_4/yr).

P109, Table 2.2.
In the heading, change "central estimates" to "Median Estimates" (or some other appropriate description).

Chapter 3: Energy Systems

Overview/Main Issues

Chapter 3 achieves its stated goal to assess the contribution of the North American energy system to the global carbon cycle. It does so by citing a great many statistics from well documented and reliable sources. The chapter is clearly written, comprehensive and well organized. What it does not do is present a clear accounting for the energy sector's role in the processes, stocks, fluxes, and interactions with the global carbon cycle. As a consequence, it is difficult for the reader to see the forest for the trees. We discuss below some options for addressing this concern.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*
- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

A great many detailed statistics are presented, but how they fit into the overall concept of the carbon cycle is difficult to discern. One solution might be a diagram (such as a Sankey diagram) that shows the energy system in the context of the overall carbon cycle or a pictorial illustration of energy system stocks and flows by source similar to Figure ES2 (e.g., https://flowcharts.llnl.gov/commodities/carbon) that represents the major components within the context of the global carbon cycle. A summary graphic might help the reader see the big picture and more readily understand how this important chapter fits into the carbon cycle. This might also help to reduce the level of detail necessary by linking the chapter with other chapters that treat the carbon cycle contribution of the energy sector.

Another opportunity is to make greater use of the Kaya identity, which is presented early in the chapter but never used as an analytical tool later on. The Kaya identity categories are actually not "drivers" of emissions change as asserted in the text (e.g., p.123, line 24; p.131, line 13), but rather ex-post accounting categories that are useful for quantitatively decomposing trends. There are several recent decomposition analyses of U.S. and global energy and carbon emission trends that could have been used in conjunction with the Kaya identity to quantitatively analyze recent trends in energy and carbon emissions in North America (e.g., EIA, 2017; Feng et al., 2015; Shahiduzzaman and Layton, 2015; Vinuya et al., 2010).

The chapter is written at an appropriate level for researchers and others with a technical knowledge of the energy sector.

The practice of presenting economic and physical quantities to 4 or 5 significant figures gives an incorrect impression of the accuracy of the estimates and is inconsistent with the discussion of uncertainty.

A minor omission but one that should have been mentioned is the fact that a portion of the nation's N_2O emissions are a result of fossil combustion.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*
- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

The Energy chapter accurately reflects the scientific literature on the subject. The authors know the relevant data sources well, understand them thoroughly, and use the data appropriately. The presentation of data is comprehensive, accurate, unbiased, and well referenced. Two areas that could be improved are (i) the potential for mitigation of the sector's carbon emissions and (ii) the range of future scenarios presented, each discussed below.

Statements are made about the existence of cost-efficient energy efficiency technologies, followed by selected examples of such technologies. A more effective approach would have been to refer to the peer-reviewed literature on the subject of mitigating carbon emissions from energy use. There is enough that is new since the last report to make this worth considering. Summarizing such studies would better document the potential for mitigation and would provide a context for discussing the extent to which mitigation actions are likely to be cost effective.

The future scenarios presented do not include any that seriously attempt to meet national and international goals for limiting global warming. Carefully constructed scenarios are available from credible sources such as the IEA, EIA, IIASA and IPCC. The *Global Energy Assessment* is one such comprehensive study that certainly should have been referenced (GEA, 2012*).* Scenarios that attempt to meet national goals also provide useful information about mitigation potentials and the roles of energy efficiency, low carbon energy sources, prices and behavior in managing carbon flows from the energy system.

The discussion of management of the carbon cycle is accurate but should include a discussion of the time constants for change for different management actions. Section 3.7 on carbon management overlooks the most important effort of all: the UN Framework Convention on Climate Change (UNFCCC), and most recently the Paris Accord. The discussion of the efforts and policies of the three countries should include the Nationally Determined Contributions (NDCs) of Canada and Mexico and the ambiguous position of the U.S., especially now that the U.S. is the only nation not to sign on to the Paris Accord.

The omission of the economic dimension of the energy sector's role in the carbon cycle is very surprising and a serious oversight. This is especially so given that economics is not included in the chapter on social science perspectives. The economics literature on the energy sector's carbon emissions and the potentials for mitigation, sequestration and other sinks is vast and deserves attention, especially if assertions are made about cost-effectiveness.

- *Are the findings documented in a consistent, transparent and credible way? Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

All of Chapter 3's findings, except those pertaining to the potential for cost-effective mitigation, are well-supported by the evidence presented and the evidence has been well and clearly documented. The key messages are the very large role of the energy system as a source of carbon and the large potential for mitigation. The energy system's major role as a source of carbon is thoroughly documented with data from the most authoritative sources. The relatively non-quantitative treatment of mitigation potential discussed above does not provide adequate support for the existence of a large potential for cost-effective mitigation. However, as noted above, the literature on this subject is substantial and could have been used to support such a finding. Including evidence from the literature of energy economics and engineering would allow a valuable discussion of the cost-effectiveness of various levels of carbon mitigation and their dependence on future technological advances.

- *Are the research needs identified in the report appropriate?*

Although there is not a distinct listing of research needs, the research needs identified are appropriate and well supported by evidence. However, once again, the inventory is not complete because the quantification of mitigation potential and its cost-effectiveness has been left out. There are important research needs concerning technological, economic, and behavioral potentials. In addition, the challenge of achieving a large-scale energy transition, which appears to be necessary to meet ambitious carbon mitigation goals, poses many new research questions.

We recommend the following improvements to the chapter:

- In Key Findings 1 and 2, quantitatively connect the energy system to the carbon cycle. For example:
  - Since 17XX the North American (or U.S.) energy system has emitted XXX petagrams of fossil C into the atmosphere. Of that amount, YYY petagrams remain increasing the global concentration of CO_2 in the atmosphere by ZZ parts per million. This represents W% of the total increase in atmospheric CO_2 since 17XX.
  - The North American (or U.S.) energy system emitted x petagrams of fossil C in 2016(?). Of that amount, y petagrams will remain in the atmosphere through 2zzz, (account for the fate of the rest).
- A third finding should use the results of recent decomposition analyses (e.g., EIA, 2017; Feng et al., 2015; Shahiduzzaman and Layton, 2015; Vinuya et al., 2010) to quantify the factors responsible for recent trends in carbon emissions from the North American energy system.
- Use the graphical representation of decomposition analysis to effectively illustrate the factors responsible for recent trends in carbon from the U.S. energy system.
- Construct a Sankey diagram showing the sources (e.g., sector, energy type) of carbon emissions from the U.S. energy system and their fates at a very general level of detail (e.g., similar to Figure ES2; for example, see link above).
- If possible, a fourth finding should address the kinds of changes in the energy system that would be necessary to reduce the North American (or U.S.) energy system's emissions of carbon to levels consistent with international objectives for constraining the increases in global average temperatures. Any reasonable and scientifically supported level could be chosen (e.g., 2°, 2.5°, 3° C). Appropriate research needed to support such a large-scale energy transition should be identified.
- Section 3.7 discusses carbon management decisions at international, national, and state and urban levels but provides no quantification of the impacts of these decisions on the carbon cycle. A quantitative discussion of impacts should be added. Any quantification will be uncertain to some degree, but estimates exist in the literature, and there are ways to describe uncertainty.

Line-Specific Comments

P110, Line 152
The chapter contains a wealth of statistics, which makes it difficult to see the forest for the trees. Perhaps a figure illustrating the role of energy systems in sources (mostly) and sinks (to a much lesser degree) would be helpful. It could be accompanied by a discussion of how energy systems fit into the overall framework of the carbon cycle. In a similar vein, the chapter introduces the Kaya Identity as an organizing concept but then doesn't use it, either as an organizing concept for presenting status and trends or analyzing them. More specific recommendations are made separately.

P110, Line 152
The treatment of mitigation is unsatisfying for several reasons:

- impacts, past and potential future, of management actions are not quantified;
- the critical role of increased energy efficiency in all sectors is given inadequate attention, especially since there have been and are important initiatives in place in North America;
- the challenge of transforming the energy system to a low carbon system (energy transition) is also not adequately discussed and analyzed;
- none of the projections of future energy use come close to achieving climate stabilization goals, a critical issue for the future of the energy system.

If North America seriously attempts to mitigate climate change, the energy system and its role in the carbon cycle will change profoundly. This should be a key topic of the chapter, but it is not.

P111
Add footnote on energy units.

P111, Line 10
What is land-based carbon?

P112, Line 9-29
The historical context discussion reads like it's all about recessions. Recessions have been important but so have energy prices and energy efficiency regulations. Attributing changes in carbon emissions via the Kaya identity would show this. Specific recommendations on sources of decomposition analyses of trends in carbon emissions from energy are suggested separately.

P113, Line 10 – P114, Line 36
The focus on proved reserves gives a misleading impression of the potential for future carbon emissions from combustion of fossil fuels, especially for petroleum. As the box on the subject acknowledges, proved reserves are a very conservative measure of potential future resources. There is a large literature on this subject that could be summarized as follows: Proved reserves are mainly a stock that energy entities maintain to insure adequate production in the near future. At a global scale, for example, proved oil reserves relative to current production have changed very little over decades. Resources have various definitions, but as a very broad generalization, technological advances have consistently overcome depletion of fossil fuel resources. This is likely to continue. Why is this important? Utilizing resources beyond proved reserves holds enormous potential for increasing the carbon concentrations in the atmosphere.

P114, Line 21-27
Renewable generating capacity is mentioned but not renewable resource estimates. This might be a useful addition with relevance to how the carbon cycle might be changed.

P116, Line 19-22
The residential and commercial emissions of CO_2 do not seem to include emissions from electricity generation, or at least they are not consistent with the EIA's data, which indicate 1.1 Pg for residential and 0.9 Pg for commercial in 2013 [https://www.eia.gov/environment/data.php#summary] .

P118, Line 2
This opening sentence is one of many examples of a "topic sentence" that doesn't really convey the main point of the section.

P119, Line 7
"As demonstrated,…" is arguable and unneeded.

P119, Line 11-20
Why does this section not mention technologies identified by the EPA/DOT rulemaking for increasing light-duty vehicle fuel economy through 2025, and medium and heavy-duty fuel economy as well. This is all thoroughly documented in the rulemaking and supporting documents. And what about other transportation modes?

P123, Line 16-30
Isn't the right way to present information on the carbon cycle role of biofuels to quantify the emissions from biofuel combustion as a source and the production as a source and sink?

P124, Line 34-35
"more than an estimated 18.6 million" is confusing unless the intention is that 18.6 is an absolute lower bound.

P124, Line 31 – P126, Line 9
Shouldn't this section be attempting to quantify the sources, sinks and flows of carbon in the biofuel system, including uncertainty bounds?

P126, Line 11
What is a "feedback mechanism scenario"?

P127, Line 6
Please cite the projection referenced.

P128, Line 1
The Kaya equation can also include sectoral structure (summing over sectors). Why not add that? It is disappointing that the authors do not use the identity or cite the work of others using the identity to decompose trends into components.

P130, Line 31
Total vehicle miles traveled in the U.S. has increased every year since 2011 according to the Federal Highway Administration (FHWA1).[2] We are not able to match the other data in this paragraph (e.g., fuel economy/energy intensity) to the FHWA data either.

P131, Line 14
This section deals with carbon intensity and refers to F/E (amount of CO_2 emitted per unit of energy produced). The authors do not provide U.S. data for carbon intensity of transportation, however. This will depend on the carbon intensity assigned to ethanol, which is controversial/uncertain.

P132, L 32 - P133, Line 8
Should CCS be considered a carbon sink in the framework of the carbon cycle or a determinant of carbon intensity (as is done here)?

P136, L 36 – P137, Line 1
The rulemaking documents provide reasonable estimates of the carbon source reductions that would be achieved by GHG emission regulations under the Clean Air Act.

P137, L19 – P138, Line 11
California's comprehensive GHG reduction plan and legislation deserves mention here along with other states that have such plans (less comprehensive and potent, in my opinion). California has a cap and trade system, Zero Emission Vehicle and Low Carbon Fuel standards, among a suite of comprehensive policies.

P138, Line 12 – P140, Line 18
None of the scenarios discussed correspond to a serious attempt to reduce GHG emissions to levels that would stabilize global warming at target levels proposed by climate scientists (e.g., 2°C, 2.5°C, etc.). All are variations on business as usual. In a report of this nature at least one serious mitigation scenario should be included, as such scenarios do exist.

P141, Line 6-12
The list in this paragraph has to include increasing energy efficiency. And in addition to decreasing the use of carbon-intensive fuels it should include a transition to low-carbon energy sources.

P142, Line 1 – P143, Line 5
It is good that this sidebar acknowledges the different definitions of resources and reserves. However, the discussion in the text focuses almost exclusively on proved reserves, which is a less relevant measure than the other discussed in the sidebar.

P144, Line 18-19
The 3% number is relevant for electricity production but because the CO_2 reduction for CH_4 use in transportation vehicles is only about 15-20%, only about a 1% leakage rate will eliminate GHG benefits.

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[2] Table VM-1: https://www.fhwa.dot.gov/policyinformation/statistics/2015/vm1.cfm.

P145, Line 32-33
See previous comment.

P151, Line 30-33 (also on P111).
It seems odd to rate a finding that net carbon effects may be positive, negative or neutral as having "high confidence". The authors are perhaps saying they are certain that we don't know the net effect for biofuels as a whole. Likewise, with respect to CH_4 as a fuel (overwhelmingly of fossil origin at the present) we know for certain that fugitive emissions reduce the overall carbon benefits. Considering the report recognizes that biofuels vary in their carbon impacts, we suggest rephrasing this finding or present it in a different way.

Chapter 4: Urban

Overview/Main Issues

This chapter provides a comprehensive overview of research focused on carbon budget associated with urban areas. It summarizes active research aimed to quantify spatial and temporal variability in carbon emissions at fine scales needed to understand the drivers of those emissions and document efficacy of management strategies. It provides a very good discussion of governance and management at the urban scale that influence carbon emissions, and it distinguishes what is controllable from what is uncontrollable due to decisions being made at larger state to national scale or the long turnover time of built infrastructure.

This chapter, which follows the Energy chapter that focuses on energy **production,** would be strengthened by including a brief discussion of energy **consumption** patterns in North America and by sharpening the introductory section so that the rationale for singling out urban areas is highlighted. Somewhere in SOCCR2, there needs to be a discussion about carbon management choices at state and national levels that mirrors the excellent section in the urban chapter. Instead of leaving off at stating there are factors that can't be controlled at urban level, provide some discussion elsewhere on what the options are and what is being done to better understand them.

The urban chapter stresses the observation that urban emissions contribute disproportionately to anthropogenic emissions of carbon relative to their land area, which is true but not as illuminating as starting from the observation that urban areas concentrate population and economic activity that are responsible for carbon emissions. This point isn't made until p.175, Line26. It would make an effective starting point for the introduction. Follow up by noting how urban emissions diverge from a constant per capita value. It is precisely the divergence from constant per capita emissions that make urban emissions especially interesting and provides the reason to study them as a separate entity. As the text points out (at the end of the 3rd paragraph in the introduction) there is a need "to explore how urban infrastructure and urban morphology will influence current and future energy consumption and development." A figure could be added here to show the range of per capita carbon emissions for different cities or as a function of population density. Because there are emission differences, there are opportunities to influence them and a research need for understanding what causes those differences.

The chapter is right to point out that some of the differences in emission strength between urban areas decrease when the indirect emissions (energy, goods, and services consumed in the urban area that were produced and counted as emissions elsewhere) are considered. Discussions about emission intensity correlating with various factors need to caution against basing mechanistic understanding on correlations and trends alone.

The chapter makes in important point that urban structure and infrastructure investments influence carbon emissions and that governance structures that operate at the urban level are either not present or very different at state and national levels. This point needs to be noted early in the text and given a strong emphasis.

Wherever possible the discussion and estimates of what has been and might be accomplished in the future in terms of managing the carbon cycle at the urban level should be more quantitative.

Also of interest but not discussed quantitatively are the time constants for changes to be effected. The notion of turnover times for infrastructure is alluded to by the phrase "infrastructure lock-in", but this could be expanded in a more quantitative way by noting typical lifetimes for different classes of infrastructure. Infrastructure isn't necessarily locked, but it's difficult to replace before the end of its designed life. Past experience provides some guidance on issues like how quickly the vehicle fleet is updated compared to time constant for appliances, housing stock, transportation networks, and energy delivery. This is not to suggest that the concept of infrastructure lifetime needs to be exhaustively reviewed in the chapter. It needs to be highlighted as critical factor with a rich history to guide our understanding of how quickly emission changes can be accomplished.

The urban chapter has a very thorough section documenting Societal Drivers, which seems to provide the specific examples of carbon being embedded in societal activities that is the key finding for chapter 6. Is there sufficient cross reference between these chapters?

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

Although the chapter does meet several goals that can be identified by reading through the text, the goals and objectives are not articulated clearly enough and the intended audience is not specified. Having a summary of the objectives and audience in the introduction would guide the reader and provide a focus to sharpen the remainder of chapter.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

The chapter covers scientific literature up to the onset of writing and chapter review. However, there are a few recent papers that could be incorporated to illustrate some key new results. Notably, the emerging field of using satellite observations to quantify emissions from large urban regions is not given enough attention. Hakkarainen et al. (2016) demonstrate the ability to quantify CO_2 emission hotspots from satellite observations and provide a very good illustration of how anthropogenic carbon emissions are concentrated into urban areas.

- *Are the findings documented in a consistent, transparent and credible way?*

Yes, the chapter provides excellent documentation of its key findings.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

The graphics have room for improvement. Neither of the two figures that are in the chapter are quantitative, and they don't effectively provide information beyond what is in the text. At the very least, it would help to have a graphic artist review them with an eye toward making them more effective in the web-published version of the report.

It would help to add a figure in the introduction illustrating the sharply focused carbon emissions from urban areas, based on left-most panel of Figure 1 in Hakkarainen et al. (2016) that shows CO_2 hotspots together with NO_2 concentrations and emission inventory. The point that urban emissions do not follow a constant per capita ratio could be effectively presented by figures adapted from recent reports that show emission per density, or that have aggregated different urban areas and ranked them by emission.

Figure 4.2 doesn't clearly show the relationships described in the text that refers to this figure. Need to clarify the point that figure is supposed to illustrate and revise accordingly. If all the icons represent GHG emissions it is confusing to include a wind turbine in the electricity generation. How does water fit into GHG emission?

Comments on specific Key Findings:

Key Finding 1. The confidence in this finding seems to be understated and could be "high confidence and very likely", rather than medium. The first sentence in of the introduction section clearly states that carbon fluxes resulting from urban activities account for 80% of the total North American anthropogenic CO_2 flux to the atmosphere. The key finding statement would be improved by making it more quantitative (e.g., replace "large proportion" with a number). Consider rephrasing the statement so the result and its reason are given together. Urban areas are a primary source of anthropogenic carbon emissions because humans and human activity are concentrated there. In addition, they are an indirect source of emissions embedded in goods and services consumed by urban dwellers.

Key Finding 2. This would be a logical point to frame the issue in context of infrastructure turnover time. Urban infrastructure is built to last decades if not longer. Major changes are difficult if not impossible and expensive as well as an additional carbon emission associated with demolition and new construction. Infrastructure improvements could be evaluated in terms of payback time. The support for this finding presents a long list of citations, but it would help the reader to present a brief summary of the overall results that are common to those studies.

Key Finding 5. The statement could be phrased positively to focus on what has been learned instead of what we don't know. CH_4 emissions have been poorly characterized, but the combination of improved instrumentation, modeling tools, and heightened interest in the problem is defining the range of emission rates and highlighting infrastructure characteristics that affect CH_4 emission.

- *Are the research needs identified in the report appropriate?*

The research needs to have improved information on fluxes and their drivers, and improved understanding of successful mitigation (as identified in Section 4.7) are appropriate, but more details should be provided. For example, how is the urban carbon flux projection capability expected to improve in the future? How should the various approaches for estimating urban carbon fluxes be integrated and reconciled? Emerging technologies—for example, connected and automated vehicles—potentially will have a large impact on urban emissions and ought to be identified as a topic for future research. Future research needs is another place where the use of satellite observations should be noted as an emerging approach.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

Yes, though the chapter lacks a summary figure or table that presents a quantitative bottom line for carbon stocks, budgets, and transfers.

- *What other significant improvements, if any, might be made in the document?*

Suggestions on ways to sharpen the introduction are noted earlier. Overall the chapter would be more useful if it included specific quantitative statistics on the magnitudes of carbon fluxes/stocks and their trends at the national and continental scale. Some additional figures would be very helpful. The first additional figure would show a map of emission fluxes. A second would rank total carbon flux or per capita flux for specific urban areas. The table of urban carbon budget studies might be accompanied by a table that summarized some quantitative results from those studies.

Line-Specific Comments

P175, Line 4
One should not aim to *improve* urban heat islands.

P175, Line 18
Better explanation of the respiration component is needed. In part, for top-down budgeting from atmospheric measurements, respiration needs to be estimated and separated from total urban CO_2 emission to get the fossil carbon component. In a full C budget if respiration is included in the emissions the carbon uptake from growing the food that is respired needs to be counted as well

It is not clear from the text whether respiration is being treated consistently with the agricultural products that are being consumed. Notably, the executive summary mentions that the biomass in agricultural systems isn't included in the budget (presumably because it has short lifetime, though this is not explicitly stated).

P174, Line 28-32
An observation pertaining to the structure of the report overall: Energy efficiency is clearly a major driver of urban carbon emissions. However, as the chapter points out in several places, urban governments have some leverage over energy efficiency (and the carbon intensity of energy), but it is limited. Probably the majority of the capacity to change energy efficiency and carbon intensity in urban areas belongs to federal and state governments. But the report does not have a logical place to discuss these carbon management capabilities and policies, unless it is chapter 3. As a consequence, energy efficiency improvement and transition to low-carbon energy sources are generally under-represented in this report.

P175, Line 26-27
Punctuation, Change ";" to ",".

P179, Line 7-8
Has any estimate been reported for Mexico?

P180, Line 34-41
Why so many examples for UK? It is better to use examples of North America.

P180, Line 21
Extra "," before the citation should be removed.

P180, Line 29 – P181, Line 6

In the behavior section it could be noted that residents in different cities or geographical regions also have different lawn management practices (e.g., fertilization, watering).

P182, Line 23 – 30
This section could just be labeled Climate. The examples in the text cover large-scale climate as much as local climate moderated by heat island.

P182, Line 35-36
A source is needed for the national growth rate numbers.

P182, Line 31-36
This section is mainly qualitative, and more quantitative trend analyses are needed.

P184, Line 19
Presumably this sentence means positively correlated; that should be stated explicitly, or phrased as consumption increases with area per person, or is it more informative to state that consumption is inversely proportional to urban density?

P186, Line 3- P188, Line 26
The ability to discuss energy efficiency improvement and low-C energy is limited by constraining the scope to the governance capacities of urban areas. As noted on P186, lines 34-37, mitigation is strongly affected by vehicle energy efficiency, but this has been addressed at the national level almost exclusively (efforts of the CARB, and of cities, states or provinces to enact feebates would be an exception). Vehicles with lower emissions due to energy efficiency improvement can accomplish as much CO_2 mitigation as transition to low carbon energy (see, e.g., NRC, 2013).

P190, Line 30-32
This statement shows that the level of confidence for Key Finding 1 (Lines 3-6 on this page) should be high confidence and very likely rather than medium confidence and likely.

P190, Line 27
TBD is not really acceptable at this stage.

P190, Line 3-6
Give quantitative estimates.

P190, Line 27
Says TBD. Was there something to fill in for the likelihood of impact, or is that component not appropriate for this finding?

P191, Line 27-30
The challenge could be expanded to include the actual data collection. It is not just analysis and uncertainty quantification of multiple carbon flux approaches that is challenging. Designing and executing urban flux studies is far from routine.

P212, Figure 4.2.
In this chapter it wasn't exactly clear how agricultural products are treated. Agriculture is noted explicitly as a city process, but doesn't clearly show up as an upstream process. The accounting could all be correct, it is just that the text is not always clearly indicating that agricultural biomass is being treated consistently across all sectors.

Chapter 5: Agriculture

Overview/Main Issues

This chapter examines the role of agriculture in the carbon cycle. It quite justifiably emphasizes the role of below-ground processes, particularly changes in soil organic carbon (SOC). This chapter also deeply examines how human decision making affects carbon cycling in agro-ecosystems, including trends in food production, management, economic drivers, and dietary choices. There is also a good discussion of methane emissions associated with agriculture, especially animal husbandry.

The potential for agro-ecosystems to mitigate atmospheric carbon is addressed, with an emphasis on managing methane emissions from livestock. Climate change effects on agro-ecosystems are discussed. In this context, the stimulation of carbon mineralization in soils by elevated temperature is an important feedback to the climate system. The authors acknowledge the significant co-benefits of managing agro-ecosystems for increasing SOC, which include improved water holding capacity and nutrient status.

The chapter is generally well-constructed and the major conclusions are amply supported by cited references; however, some improvements could be made. For instance, consideration of role of Mexican and Canadian agro-ecosystems in the carbon cycle are given short shrift, and there are a few statements that, if taken out of context, could be misleading.

Statement of Task Questions

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

There are a few statements in this chapter that are not entirely consistent with common understanding of carbon cycling in agro-ecosystems and may be misleading. For example, the authors claim that leaving land fallow tends to lead to carbon losses (p.218, line 15). Relative to land under intensive tillage, fallow land (particularly if occupied by perennial vegetation) tends to build SOC. If the authors disagree, they should strengthen their case with proper references. The authors also claim that crops are carbon neutral because after they are harvested, they grow again in the subsequent year (p.227, line 7). This is inconsistent with common understanding that intensive row-crop agriculture, by stimulating soil carbon mineralization, is a net source of carbon to the atmosphere. The authors should reconsider these statements or provide additional explanation.

Changes in soil carbon in agriculture is in part controlled by inputs from above- and below-ground biomass. From the 1930s to today, there have been enormous increases in crop yields, with relatively small changes over this time period in the allocation of biomass within a crop between grain and aboveground biomass. Consequently, biomass inputs have gone up at same time that yields have increased, and both yield and biomass are projected to increase well into the future. High yields today already are producing more stover than can be assimilated into the soil. It would be useful if the authors gave some consideration of how projected increases in yield and biomass may affect SOC.

A major driver of changes in SOC, particular in the rain-fed Midwest U.S., is soil drainage. Expansive areas of the corn belt are underlayed by tile drains, and the installation of these drains, along with intensive tillage, were responsible for dramatic losses of SOC beginning in the 19th century. Some discussion of how the interaction between changing precipitation regimes and tile drainage affect SOC in the future would be interesting.

- *Are the findings documented in a consistent, transparent and credible way? Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Yes on both

- *Are the research needs identified in the report appropriate?*

While this chapter addresses "gaps" and "uncertainties", the authors do not clearly articulate future research needs in this chapter.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

This chapter is largely synthetic and as such, relies on statistical treatment of data from the primary literature, rather than applying de novo statistical tests, such as meta-analysis.

- *What other significant improvements, if any, might be made in the document?*

The discussion of the role of no-till agriculture (p.225) as a modulator of SOC does not seem well balanced. Measuring changes in SOC over relatively short periods of time—a decade or less—is problematic. Spatial variation often swamps temporal trends in SOC. The best indicator of how management/crop type/land use change effects SOC may be eddy covariance—a direct measurement of Net Ecosystem Exchange. One study of how cropping affects SOC (Bernacchi et al., 2005) demonstrated rather convincingly that no-till agriculture and clay-rich mollisols builds SOC.

See also the line-specific suggestions below.

Line-Specific Comments

P214, Line 21-25
Would be interested to learn more about temp effects on SOC.

P217, Line 3-17
Include references from Bernacchi and Robertson

P217, Line 17
Include references by Bernacchi

P217, Line 21
What is forage productivity?

P218, Line1
Drainage has a major impact on SOC

P218, Line 1-2
Extent and efficiency of drainage?

P218, Line 15-18
How? Not sure this is believable.

P223
More discussion of how expected increases in temperature will affect SOC would be useful. See a recent paper by Black et al. (2017).

P224, Line 20-22
Why add on for Canada and not Mexico? Scope?

P225, Line 13-14
Two is not numerous

P225, Line13
Delete "Numerous authors and models have reported that…"

P225, Line 41-42
Very difficult to measure SOC changes directly; preferable is data from eddy covarience. (See Bernacchi et al., 2005)

P226, Line 1-20
The authors may wish to acknowledge that while perennial, cellulosic biofuel feedstocks still suffer from high costs of conversion, they have enormous potential to build SOC. Some of these crops increase SOC by as much as 1 Mg/yr after removal of aboveground biomass.

P226, Line 14-20
There is enormous potential of perennial bioenergy crops to restore SOC and reduce N_20

P227, Line 7-8
Not consistent w/effects of intensive agriculture on SOC

P227 Line 33-34
Remove "such as nitrates" from the end of the sentence and place before "also"

P233, Line 37
Delete the word "managing"

P248, Figure 5.1.
The axes are unclear—both left and right y-axes state million acres. Also, an additional y-axis labelled with hectares would be helpful, since the text uses hectares.

P251, Figure 5.4.
The authors should be explicit in the legend that negative values represent a flux of carbon from the atmosphere to soil, and positive values represent the opposite.

Chapter 6: Social Science Perspectives on Carbon

Overview/Main Issues

The SOCCR2 organizers are to be commended for making considerable new efforts to expand the presence of social science perspectives within this assessment. There are however ways that such efforts should be improved. The chapter suffers from its attempt to introduce social science insights into analysis of the carbon cycle while explicitly ignoring economic aspects of the influence of "people". As a result, the text intends to "go beyond" economics, but it does not provide an indication of the baseline of economic analysis it is intended to correct or supplement. As a result, it does not give insight into the contribution of more behavioral-science-based research and analysis.

With its focus on the demand for energy services (a main aspect of "embeddedness") the chapter does not consider the social science aspects of energy supply (e.g., fuel choice, technological innovation, access, infrastructure), and the influence of the supply system on carbon emissions. Also, the chapter's focus on regulated electric power leaves out other sectors (e.g., transport, industry), giving the impression that there are no (non-economic) social science aspects of carbon in these sectors. As a result of this choice of focus, the text fails to give sufficient attention to the main source of social concern with the carbon cycle, which is via climate and the influence of carbon emissions on climate change.

In addition, much of the chapter is focused on the conduct of social science research rather than on lessons learned from it. We urge the authors to focus less on the general state of social science research and more on areas where it could inform decision making, and on constructive directions for future research.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

The goal of this chapter is not clearly stated, and appears only as a passing comment in *6.10 Conclusions*: that is, to provide perspectives of social science research and analysis that "have gone beyond" much of available carbon science work that is "sector based and economically minded"—work that is yet not sufficiently reflected in carbon cycle studies. This goal, and the exclusion of economics from the chapter's definition of social science, should be stated explicitly at the start of the text.

Also, the reader should be alerted at the start that there is no attempt to be comprehensive—to consider an integrated picture of society-carbon interaction that produces CO_2 emissions. The authors could reference the recent Academies report on the *Social Cost of Carbon* (NASEM, 2017), which covers damages from climate change. The chapter's focus is on demand for energy services and studies of individual consumer behavior in regulated (electric) utilities, and it does not deal with social science dimensions of other sectors (e.g., transport, industry, and agriculture, forestry and soils). The text does not make a connection to CO_2 emissions and the overall carbon cycle through fuel choice, carbon intensity, etc. The initial statement of goals should make clear that examples are selected to illustrate the social science methods that the chapter promotes.

- *Does the report accurately reflect the scientific literature? Are there any critical areas missing from the report?*

Since "social science" is defined as excluding economics, large parts of the relevant literature—that provides the background for the sociological and behavioral research (which often in the text is promoted as correcting behavioral assumptions of economic analysis)—are not reflected. As a result, the material that is covered lacks context. Examples are to be found in Sections 6.2, 6.4 and 6.5.

In Section 6.2 on *Energy Behavior and Embedded Carbon*:

- Statements about the lack of study of the structure and evolution of energy demand (e.g., p.256, lines 2-4) are not correct
- The text largely ignores price/cost as one determinant of the behavior of "the people" that are the focus of the chapter, and does not place the behavioral science in the context of decades of work on price and income elasticity (e.g., p.56, lines 23-34).
- The cited work in behavioral economics (e.g., p.257, lines 20-31) fails to make the distinction between studies based on experiments with small numbers of individuals versus empirical analysis of populations in actual market circumstances.
- The discussion of rebound effects fails to put the discussion in the context of a history of empirical analysis of rebound behavior observed in particular markets.

Section 6.4 on *Scenarios* provides an inadequate description of the field:

- Incorrectly the text ties all work in the area to cases developed to support IPCC activities (IS92, SRES, RCPs) and ignores the efforts of the EIA, IEA, industry groups (e.g., Shell, Exxon, BP) and the large literature of the community of integrated assessment modelers.
- Incorrectly it also says the scenarios are developed largely for inputs to Earth System Models and ignores another main use as a basis for policy studies.
- Though the citations are provided, the discussion could convey a better understanding of the reason for the structure of the RCPs (i.e., to avoid the time disjunction between the emissions projections and climate runs in the IPCC process), and the original purpose of the SSPs (to seek coherence between socioeconomic assumptions in emissions projections and in analysis of impacts and vulnerability).

Section 6.5 on *Vulnerability* does not set the context of the large body research in this area. There are scattered references, but the text pays to little attention to work of the Impacts, Adaptation and Vulnerability (IAV) community. There is also scant recognition of U.S. efforts in particular cities, particular industries, etc., or of the role of social science analysis of this process.

Also, in Section 6.7 on *Sociological Transitions*, the economic context is missing when it is declared that, "Well-developed systems are unlikely to be overthrown . . . through market processes" absent strong government policies. The statement is contradicted by many obvious historical examples (whale oil for lighting? hand-picking of cotton?).

- *Are the findings documented in a consistent, transparent and credible way?*

The nature of this chapter, which provides "perspectives" on the potential role of under-represented areas of research and analysis, means it does not yield "findings" akin to those of other chapters, and several of those provided seem "forced". The authors were presumably required to come up with at least 4 or 5 key findings, even though the text does not seek to describe new learning or research, or to present empirical results.

One new finding that would be consistent with the goal of the chapter and the arguments in the text would be one constructed around the observation that there are useful applications of (non-economic) social and behavioral science that are not sufficiently exploited in current efforts to understand the carbon cycle.

Comments on specific key findings:

Key Finding 1 (Embedded Carbon). The statement that "carbon is embedded in almost all societal activities" is obviously correct (e.g., given that we live on carbon-based foods, and that we have developed an economy based on fossil fuels). But this concept seems better presented as common knowledge, not as key finding of research and analysis.

Key Finding 2 (Systems Approach). Without further definition, the term "centered on people" does not add to the description. Also, the fact that systems approaches can reveal options for emissions reduction is correct, but this is not a research finding but a restatement of common knowledge.

Key Finding 3 (Social Dependence). The evidence base for this finding, and indeed the text as a whole, does not highlight areas of social dependence on the C-cycle other than climate change. Therefore, climate should be clearly stated as the main point in this finding (with subsequent re-consideration of the assigned level of confidence in the finding).

Key Finding 4 (Transitions). Absent a quantitative definition of "low carbon", and an accompanying definition of "feasible", the finding is meaningless. No such definitions are provided, and the examples cited in this finding do not help. Also, without inclusion of economics in the coverage of social science it will not be possible to back up such a finding. Finally, with such a weak definition of a "transition" there is no basis for the confidence level assigned.

- *Are the report's key messages and graphics clear and appropriate? Specifically, to they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

There are no graphics, or messages requiring them. The chapter is chiefly about the nature of social science research that has relevance to the carbon cycle and the areas where the authors believe that additional research is needed.

- *Are the research needs identified in the report appropriate?*

The chapter summarizes the general objectives of research in this area, but does not provide specific work by discipline, or suggest priorities and how they relate to larger carbon cycle issues. Much of the discussion regarding findings (e.g. in Sections 6.2.2 and 6.3.2) seem generic and could benefit from concrete examples for North America. The objectives cited for research going forward (Section 6.10) also appear generic.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

The text lacks specification of specific data sets that would contribute to research and analysis of social science aspects of the carbon.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

Presentation and technical level are appropriate for the intended audience. However, there are several terms that appear to be in-house terminology, e.g., "systems approach", "behavioral potentials" (p.260, line 7). In place of these terms, which may not be familiar to the reader, the text should be expanded to briefly explain what is intended. The text should be screened for other examples that may need further definition, and more importantly, further articulation of what the points are.

- *What other significant improvements, if any, might be made in the document?*

It would be useful to recruit an additional member of the author team who is familiar with the economic literature integrated analysis of the carbon cycle, to help prepare the missing areas of context identified above.

Some issues of concern in the Chapter can be enriched by cross-references to Chapter 7 (Tribal Lands).

This focus on social science perspectives does not fit comfortably within the chapters that focus on the particular sectors and geographical regions where carbon fluxes and stocks are accounted. It may be more appropriately placed toward the end of the report, e.g., between Chapter 18 on support for decision-making and Chapter 19 on future projections.

Line-Specific Comments

P254, Line 30-31
Not clear why vulnerability research is an exception.

P255, Line 20
Vague. Be clear what specific theory is referred to.

P255, Line 30
Define systems order policy.

P255, Line 33-35
Statement inappropriately limited to energy sustainability arena.

P256, Line 1-4
Statement is incorrect unless meant to exclude economics research. Please clarify.

P256, Line 19-21
The statement should be qualified in that all of the costs are not intangible.

P257, Line 16-19
It is not true that this research is "defined by short-term policy objectives, or that it ignores the sources of energy use.

P257, Line 33
"Recognized need…" is imprecise. State by whom it is recognized, and based on what evidence?

P258, Line 1 - P260, Line 28
The authors miss an opportunity to make the point that energy appears to be an area where markets do not function as predicted by rational economic behavior, so that much economics analysis has fallen far short of providing understanding and guidance for decision makers.

P258, Line 17-19
Statement is incorrect, and ignores analysis of price elasticity

P258, Line 24-28
Statement is empty unless provide alternative "labels" and explain what is meant by policy perspective and priorities.

P258, Line 37
Not clear what is meant by "regulated energy efficiency industry". Provide examples to clarify.

P258, Line 31-32
There are no "traditional" definitions of efficiency, but different definitions depending on the context (engineering, economic; energy, labor, all factors).

P259, Line 20
Again, what is the efficiency industry?

P260, Line 29
Multifaceted seems another example of jargon, without meaning in this context.

P262, Line 16-17
Why single out transportation? Industry? Commerce?

P263, Line 12
What is meant by "sustainability" of the carbon cycle? The cycle is not threatened.

P263, Line 26
What alternative organizing force is imagined, to make this a question?

P263, Line 33-35
Not clear what is meant by "engagement with the normative dimensions . . . "

P264, Line 4-7
Potential confusion in the writing: the scenarios are not "tools" but the result of the application of tools.

P264, Line 39-41
Not correct. Vulnerability research covers many other sectors and concerns (e.g., species survival, ecosystem damage).

P265, Line 30-31
Not clear what alternative design is suggested.

P270, Line 35-37
As with P256 / Lines 19-21, the statement should be qualified in that the costs are not all intangible or unknown.

Chapter 7: Tribal Lands

Overview/Main Issues

This chapter discusses how diverse tribal communities in the U.S., Canada, and Mexico affect and are affected by changes to the carbon cycle. It explores the unique challenges and opportunities these communities face in advancing land and natural resource management practices that are often guided by traditional knowledge. This is a much needed discussion, but one that faces formidable challenges, including the following:

- Peer-reviewed publications and data pertaining to carbon fluxes at the scale of these communities are virtually non-existent. This makes mechanical aspects of carbon accounting, such as establishment of baselines and determination of changes in carbon fluxes, problematic, leaving treatment within the context of the SOCCR2 noticeably forced. Impacts at the scale of indigenous communities are often obscured in datasets relating to carbon fluxes and climate change. Further, these communities face challenges in accessing and interpreting the accuracy and uncertainty of downscaled model-based projections and in up-scaled evaluation of the impacts of their actions on carbon fluxes.
- These communities are culturally distinct, with their own languages, traditions, practices, and cross-generational traditional sciences that define their interconnected relationships to local environments and resources. Decisions give great weight to long-term stewardship to protect the interests of future generations.
- Their histories, rights, authorities, and forms of governance are influenced by economic, cultural, moral, and spiritual perceptions of values and risks, which often bound up in unique ways with neighboring governments and the nation states in which they reside. Choices and information are not readily available in terms that are relevant to decision making in indigenous communities. Policies and actions that affect indigenous communities are often made by neighbors and nation states, outside the decision domains of indigenous peoples and often beyond the reach of political influence because of marginalization due to relatively small population sizes and economic power. This also indicates that the ability to build and sustain working partnerships will be needed to influence carbon fluxes.
- Limitation to “tribal lands” limits consideration on property boundaries without consideration of differences between types of land tenure (e.g., tribal, allotted, fee, trust, fractionated, surface vs. subsurface) and ignores rights and interests in much broader territories stemming from aboriginal, unextinguished claims, treaties, and applicable law.

These, among other factors, strongly indicate that a cohesive focus and comprehensive treatment of these communities in relation to the SOCCR2 within the page limit established for treatment is simply not feasible. Some information comparing tribal peoples in the U.S., Canada and Mexico in the introductory section of this chapter provides context, but the text and commentary are largely devoted to presenting various sorts of statistics by country, region, population sizes, land areas, with an emphasis on potentials for resource development and extraction. There are numerous opinions, hypotheticals, and assertions regarding comparisons with neighboring lands presented for little apparent purpose. The synthesis and actionable steps relating to the carbon cycle lack depth of treatment. This approach is distracting and adds little of substance to the purpose of the report.

In sum, as drafted the chapter misses the mark and an opportunity. Contributions to SOCCR2 could be improved and strengthened by integration with Chapter 6. This could be accomplished by restructuring and revising the chapter to center on supporting the active engagement and support of indigenous communities in the development and implementation of policies, programs, and projects that affect the carbon flux in the U.S. Focusing the discussion on the U.S. would also be consistent with Canada and Mexico developing their own assessments. This would help strengthen linkages between Chapter 7 and coverage in the executive summary (p 40 line 16—challenges facing indigenous communities and p. 46 line 37—learning from tribal peoples).

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

No, these are not clearly stated.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

Scientific literature relating to carbon fluxes in indigenous communities in peer reviewed journals is sparse to non-existent. This is not surprising given culturally-based differences in transmitting science and knowledge in indigenous communities which rely largely on oral traditions, community vetting, and learning by doing. Reliance on peer-reviewed "science" limits consideration of information, values, and wisdom potentially available from indigenous communities as well as proprietary knowledge held by other entities, such as private enterprise.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence include an assessment of likelihood, and communicate effectively?*

The key messages are hard to detect amid the attempt to cover a broad spectrum of issues and circumstances confronting indigenous communities and carbon science. Key messages relating to carbon fluxes are few. Comparisons to practices on neighboring lands lack a quantitative basis for support. Figures 7.1 and 7.2 illustrate cultural insights but not their relationships to the carbon flux. Appendix 7A is not comprehensive, and its relevance to the carbon cycle is tenuous at best. Table 7.1 does not contain information on potential sources to carbon sources on tribal lands in the U.S., while tending to steer the focus toward economic potentials of extractive activities.

- *Are the research needs identified in the report appropriate?*

There are more fundamental issues that need to be addressed that are of higher priority than "research needs." Indigenous communities in the U.S., Canada and Mexico are often economically disadvantaged, suffering from persistent poverty, unemployment, substance abuse, under-developed infrastructure (including health, sanitation, and educational systems), and lack of ready access to information sources. Consideration of research needs should be discussed within the larger context and focus on ways to empower indigenous communities to support their engagement in matters within their decision domains and spheres of influence that affect the carbon cycle. Research could usefully be directed at unique circumstance and needs of indigenous communities. Among particular needs are:

- Evaluation of impacts of traditional practices and governance systems on carbon fluxes and development of methods for quantification, e.g., food sovereignty, uses of traditional foods and medicines, management of water, soil cultivation and enrichment, periodic burning of forests and grasslands (particularly carbon sequestration and risk of GHG emissions from wildfire), use of plants with high moisture or temperature tolerance.
- Evaluation of potential changes in carbon fluxes from site-specific application of carbon capture and sequestration efforts and development of methods for quantification of actions such as biochar, soils enrichment, blue carbon, solar, wind and renewable energy.
- Assessment of carbon fluxes arising from collaborative partnerships to address environmental problems. For instance, note the Tulalip Tribe's involvement in the Qualco anaerobic digester in operation since 2008 which utilizes animal waste, trap grease and other pollutants (thus keeping them from landfills, drains and illegal dumping) and burns methane to create renewable energy . This process helps clean the air and water, helps farmers keep their dairies operating, protects salmon streams, and provides environmentally-friendly compost.
- Opportunities to deploy innovative technology and practices that can potentially affect carbon fluxes at the community level, e.g., renewable energy, energy-efficient substitutions, sanitation and waste disposal and treatment, local sourcing, energy-carbon based purchasing policies, carbon markets.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

No. See comments regarding major concerns.

- *Are the key findings in your chapter well stated and supported by the detail provided in the chapter?*

Key findings do not directly relate to description of the state of carbon fluxes. Key Finding 1 ("managing land and natural resources poses unique challenges") appears to contradict Key Finding 3 ("Indigenous communities are managing carbon stocks and fluxes..."). In Finding 1, the challenge is not tribal community values (p.286, line 11), but reconciling those values with past policies external to the communities and their impacts. The authors may wish to re-order the Findings, to lead with 2 and 3, and then 1, 4, 5.

- *Are there any broader questions, such as the selection of the evidence and findings, weight of evidence, or the consistency of the application of uncertainty language?*

The attempted scope of the draft chapter is so broad that important messages are missing or obscured, leaving discussion of the synthesis and actions relating to SOCCR2 with little substance. The chapter provides scant treatment of the circumstances confronting indigenous communities of Alaska or the U.S. Pacific or Caribbean Islands (also part of the U.S.). Discussion is lacking on issues such as: seminal differences regarding issues relating to self-determination or sovereignty; land tenure systems; political, policy, and legal constraints affecting the capacity to control factors that affect carbon and the environment, and fiduciary obligations; impacts of sub-par educational, public safety, health care systems; and access to investment capital. These are heady but important and relevant factors. Some are touched upon in various places in the chapter, but are buried so their significance is lost.

Comprehensive treatment of Tribal Lands can be extremely complex. It is not feasible to attempt to deal with these types of interconnected issues in a variety of contexts in the U.S., Canada, and Mexico, much less at the level of individual indigenous communities. Since Canada and Mexico are apparently developing their own assessment activities, it would be appropriate to limit discussion to the U.S. Nor is it feasible to try to tie mostly unquantified impacts of tribal land management on reserved lands or within their territories to global climate change processes. An alternative approach would thus be worth considering. This might start by providing a broad overview of the following issues:

- Indigenous communities are among the most vulnerable to climate change, due to their dependence on place and natural resources—as indicated by NCA3, the draft NCA4, and many other publications. Numerous examples could be presented, including the specific challenges faced by populations in the Arctic, in tropical, lowland, and island areas, etc.. Contextual circumstances such as relative isolation from infrastructure, information, capital, and expertise, depressed economic status, sub-standard health and education systems, etc., should also be considered.
- The cultural and ecological diversity of indigenous communities is adapted to local environments, resources, and social, economic, and spiritual/cultural systems. These are distinct communities with their own perceptions of values and risks. Consequently, the policies and practices that affect emissions and accumulation of carbon are community specific. Quantitative estimates about greenhouse gas emissions, and potential for mitigation through land uses such as agriculture, forestry, cultural heritage sites, and future development of resources (water, coal, gas, oil, or minerals) are sparse.
- Impacts of policies of colonialism, dependency, paternalism, forced displacement from ancestral territories, termination, assimilation and attempts to displace cultures, and coercive exploitation have impacted tribal lands and divided indigenous communities. This includes factors contributing to inequities in environmental justice and transport/disposal of hazardous waste. The juxtaposition of poverty and environmental protection is very controversial and palpable in indigenous communities. History and policies leave legacies that affect the impacts of tribal lands and resources on carbon fluxes. In the U.S., because of land tenure complexities (small parcel sizes, frequently with a large number of undivided fractional ownerships), deficiencies in federal administration, chronic underfunding to fulfill fiduciary trust responsibilities, and lack of access to capital, the productivity of tribal lands and resources is frequently far below their potential, including their capacity to store and sequester carbon. This discussion could become quite involved and context sensitive for both indigenous communities and nation states, so treatment should be kept centered on their resilience and adaptation to changing locales under externally imposed political systems.
- The importance of recognizing that cultural and spiritual foundations of indigenous communities differ from those held by other communities. In non-indigenous communities, the focus tends to be on individual perspectives, formulated in terms of rational, informed choice to act in individual best interest. In contrast, in indigenous communities, behavior is rooted in community and culturally embedded moral ethos linking past, present, and future actions, in a context of stewardship responsibilities for the welfare of future generations.

- Differences in world views regarding science and human relationships with the environment between those held by indigenous peoples and western society; different ways of knowing and thinking. These differences are apparent in development of the SOCCR2 report itself, as a reductionist analysis of component of environmental systems, which is fundamentally incompatible with holistic interconnectedness thinking characteristic of indigenous peoples.
- Differences in communicating and transmitting knowledge (traditions, practices, songs, stories, art & language) including traditional knowledges and indigenous resource management practices, including implications of lack of infrastructure to provide internet access to disadvantaged communities. Instead of the western model of relying on publication in peer reviewed journals, knowledge transfer in indigenous communities occurs individually and contextually, through teachings and "showing by doing" with validity determined by deliberation among those most familiar with local circumstances. Consequently, those outside indigenous communities must contend with intrinsic barriers to awareness, understanding, and consideration of indigenous science.
- Complexities and limitations of sovereign authorities of governments of indigenous communities including reserved rights, public health and safety, and intergovernmental relations, tax policies, and the ability to protect and control use of land, water, fish, wildlife, mineral, and cultural resources. It would be worth pointing out important differences between the U.S., Canada, and Mexico. For example in the U.S., tribes have the ability to enact their own laws and regulations pertaining to land use and resource management (including regulation of air and water quality); to develop and manage resources within their reservations; and for tribes with federally reserved rights, to control water rights and co-manage shared resources like fish, wildlife, and plants.
- Fragmentation of property and jurisdictional boundaries and complexities, lead to challenges in building partners for collaboration and cooperation at a landscape scale.

This foundation would provide an opportunity to use examples or case studies of how resource management practices and traditional knowledges (TKs) of indigenous communities affect the carbon cycle. For example, there are practices of light vegetative burning to reduce risk of catastrophic wildfire, store carbon in soils, protect water supplies, and promote vegetative growth and wildlife habitats. Some practices rooted in TKs are attracting attention as possible ways to reduce GHG emissions, such as crop rotation and permaculture, biochar, chinampas, or use of plants that are genetically adapted to drought, variability in phenology, or temperature. These practices were undertaken not because of explicit consideration of what we refer to as the carbon cycle, but rather from an integrated world view in which everything is interconnected.

These pieces would then lay the foundation for actions that could be undertaken to advance substantive engagement of indigenous communities in the carbon cycle, such as:

- Promoting intergovernmental coordination and cooperation between partners to preserve and protect the public trust; and use of special relationships such as fiduciary obligations and consultation requirements, and principles of free, prior, and informed consent (UNDRIP[3]).
- Advancing collaborative efforts to increase awareness and integrate western science and TKs—including facilitation of access to and sharing of data, information, and expertise.

[3] United Nations Declaration on the Rights of Indigenous Peoples.

- Implementing place-based monitoring and systems for recording and reporting environmental observations to establish baselines and provide a history of changes in temperature, humidity, precipitation, phenology, species compositions, etc.
- Reducing economic dependency of indigenous communities on external sources of income, in order to reduce coercion and forced resource exploitation.
- Improving access to funding sources (e.g., grants, foundations, partners) and capital, and eliminating external barriers and constraints that inhibit investment in self-determined culturally-appropriate initiatives and resource development.[4]
- Research directed at unique circumstances and needs of indigenous communities (see specific suggestions noted above).
- Establishing communication networks of indigenous communities and partners to share success stories, information, and experience and avoid or minimize effects of ideologically-driven censorship practices;[5] convening conferences and defraying costs of participation to advance knowledge sharing and help inform the development and implementation of policies, programs, and projects affecting the carbon cycle.

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[4] e.g., https://energy.gov/indianenergy/office-indian-energy-policy-and-programs
[5] e.g., http://talanoa.com.au/; http://cojmc.unl.edu/nativedaughters/storytellers/native-storytellers-connect-the-past-and-the-future; http://www.wisdomoftheelders.org/

Chapter 8: Observations of Atmospheric CO_2 and CH_4

Overview/Main Issues

The chapter has a clear organizing structure and clear findings that summarize the current state of research on monitoring global CO_2 and CH_4 and using inverse analysis to resolve carbon emission and uptake estimates. Discussed below are some suggestions for how the chapter could be augmented to provide a more complete picture of the state of research in this realm—in particular regarding discussion of current understanding of North American trends in CH_4 emissions.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

If the goal of this chapter is to define the stock and trends of CO_2 and CH_4 in the atmosphere and to present best estimates of carbon emissions and sinks at global, continental, and national scales, then yes, it does an excellent job of that. The first paragraph of introduction alludes to that goal "*Atmospheric concentration measurements of these two species provide fundamental constraints on sources and sinks, quantities that need to be monitored and understood in order to guide societal responses to climate change. These atmospheric observations also have provided critical insights into the global carbon cycle and carbon stocks and flows among major reservoirs on land and in the ocean*." However, the paragraph could be phrased to more directly state these as goals. The audience isn't specified, but implicitly it is the same audience as the overall SOCCR2 report.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

Yes, the report accurately reflects the scientific literature. However, more discussion about controversy surrounding inverse analysis of CH_4 emissions in North America is needed.
Mention of the ongoing debate could be merged with discussion about what are the limits on trend detection from inverse analysis using the current array of measurements.

- *Are the findings documented in a consistent, transparent and credible way?*

Yes, the main findings are well documented.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Figure 8.1 needs some work. Putting both CO_2 and CH_4 together in the figure does not work well. It is confusing why only the non-fossil fuel emissions (a negative value, thus a sink) are presented. It would be more informative to show both the fossil fuel source and the non-fossil, net sink, separately for CO_2 and CH_4. Because this is a North American carbon cycle report, it would helpful to separate the North American contribution from the total global contribution. This figure could refer to elsewhere in the chapter for partitioning of the fossil fuel source by energy type if it is presented.

Figure 8.2 shows a good illustration of the expanded CO_2 observation network (not GHG monitoring network as stated in the figure caption). Can a corresponding network of CH_4 observations be presented? Part of reason for not being able to quantify trends in CH_4 could be that the observing network is still too sparse.

Figure 8.3. The CO_2 "emission" panel is not clear. The values are negative, a CO_2 sink. Does that mean this is only the non-fossil fuel contribution as was shown in Figure 8.1. The text does clarify a little that the CO_2 is a sink, nevertheless the figure ought to be able to stand alone to be the main thing some readers will see by looking at the on-line version of the report. This figure would be more informative if it included the fossil fuel source. Although that's not a result from inverse analysis, it puts the net, non-fossil fuel uptake in context.

Figures are referred to in the text out of order.

- *Are the research needs identified in the report appropriate?*

The chapter gives a good overview of research needs and next-generation observations that are coming available now.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

Statistics from multi-model comparisons are used where appropriate. Uncertainty analysis for the individual models isn't summarized.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

Yes, this is reasonably well done.

- *What other significant improvements, if any, might be made in the document?*

One place for improvement would be to recognize that the status of North American trends in CH_4 emissions remains somewhat controversial. The chapter reports an absence of evidence for CH_4 emission trends in temperate or boreal regions. Recent papers suggesting otherwise are not mentioned (e.g. Hendrick et al., 2016; Jacob et al., 2016; Kort et al., 2014; Turner et al., 2016). This finding is controversial, and some other recent literature contradicts it, e.g., see Bruhwiler et al., 2017; Miller et al., 2013; Turner et al., 2015; Wecht et al., 2014. Nevertheless, the chapter should point out the disagreement. The chapter could more strongly highlight the point that there is no apparent trend in North American CH_4 emissions despite clear indication that production and use of CH_4 has been increasing in recent decades. Table 2.1 of the 2017 EPA report (EPA 430-P-17-001) shows 2015 has lower total emissions than 2005, with the 2015 upticks in "natural gas systems" and "manure management" nearly cancelled by downturns in emission from landfills. Recent studies generally report that EPA national inventories and EDGAR global inventories are too low for parts of the U.S. (e.g., Miller et al., 2013). If there is no trend in total CH_4 emission despite increased activity that historically has been an important emission source, that is a very important finding— suggesting an improvement in technology that is reducing leakage and by-product losses. To put this point in perspective, it would help to report what the minimum detection limit would be for quantifying a trend in CH_4 emissions. Is the increase in CH_4 use high enough to exceed the uncertainty in inverse analysis of the sources? Figure 8.3 shows an uncertainty in inverse model estimates of CO_2 and CH_4 source/sink based on standard deviation between models. That is useful, but there are uncertainty analyses presented in the individual inverse analysis papers that provide better quantification of the uncertainty and explore its causes.

The text mentions in several places that the bottom-up inventory estimates of U.S. biospheric CO_2 emissions show less interannual variability than the results from inverse analysis of atmospheric data. The text does note that inventory estimates are based on Forest Inventory and Analysis (FIA) sampling that is only repeated at 5-year or longer intervals. The current approach to estimating U.S. biospheric emissions is simply not designed to provide annual estimates. Comparing the inverse analysis and inventory estimates at annual time steps is not appropriate. A better comparison would be to examine whether decadal averages agree. One can make the point that biospheric CO_2 exchange should be viewed as a multi-year average, but there is no need to belabor the issue. If annual estimates of biospheric CO_2 exchange inventories are desirable, the chapter could point this out as a critical future research need.

Throughout the chapter, the way CO_2 sinks are presented should be checked to ensure consistency with the rest of the SOCCR2 report. Presenting a CO_2 sink as a negative emission value is mathematically correct, but requires the reader to be paying very close attention. Just a note to be sure this is consistent throughout.

There needs to be some additional discussion about the CH_4 sinks. Its lifetime is mentioned, but text doesn't mention that destruction by OH is the main sink.

The SOCCR2 report should somewhere mention the contribution from $^{13}CO_2$ isotopes to our understanding of the carbon cycle. If not in overview chapter, then it could be noted here.

- *Are the key findings well stated and supported by the detail provided in the chapter?*

The three key findings are well stated, sufficiently quantitative, and give a good summary of the supporting evidence and its uncertainties.

Key Finding 1 presents the incontrovertible result that the global atmospheric burdens of CO_2 and CH_4 are increasing. The point made in this finding could be sharpened by giving the pre-industrial values of CO_2 and CH_4 for reference as a final sentence in the finding. Thus the finding would read: "stand at ……, compared to xx ppm and yy ppb for CO_2 and CH_4, respectively in the pre-industrial atmosphere".

Key Findings 2 and 3 present estimates of emissions and sinks for CO_2 and CH_4 in North America estimated by inverse analysis. Key Finding 2 reports a fairly constant CO_2 emission with small variance and a sink that is about 1/3 of the continental source but has nearly 50% variability and suggestion of increasing trend. Inverse analysis for the land sink disagrees with the inventory estimate.

Key Finding 3 is that CH_4 emissions over North America are fairly constant and do not show clear evidence of trends, unlike global emissions which have been growing over the period. In the key finding statement it isn't clear how the inverse analysis results compare to reported emissions because they are given in different units (Tg CH_4 vs CO_2 equivalent-100yr). Please use common units.

Conversion to CO_2 equivalent can be added to the text elsewhere if there is a section comparing the budgets of CO_2 and CH_4.

- *Are there other key findings or critical literature that are missing?*

Turner et al. (2016) and subsequent responses should be mentioned to better characterize the extent of debate in the community about CH_4 emission trends in North America.

P317, Line 28 onwards: Cite Kort et al. (2014) for CH_4 emissions from the Four Corners region of the southwestern U.S.

See comments and references regarding methane budget in Chapter 2.

Line-Specific Comments

P312, Line 24-25
It would be helpful to report the global emission trend and total global sink for the same period in order to address the obvious question of whether the proportion is holding constant or not. Emissions doubled from 5000 Tg in 1980 to 10000 in 2015. Sink increased by 2.5x from 2000 in 1960 to 5000 in 2015

P314, Line 13
There are no CO_2 data yet from the National Ecological Observatory Network (NEON).

P324, Line 8-10
As currently being deployed, the NEON network will NOT be reporting any CH_4 concentrations. They are measured but not going to be computed and reported because the CH_4 calibration was cut. This report would be a good forum to point out this penny-wise pound-foolish decision.

P319, Line 23-25
Does “emission of less than –500 Tg C” mean a greater sink (e.g. of –600 TgC)?

P341, Table 8.1.
Fossil fuel column: boreal and temperate North America do not add up to the North America total.

Chapter 9: Forests

Overview/Main Issues

In this chapter the authors establish that the forests of North America take up more carbon than they release (i.e., are a sink), and this sink is quite variable spatially but resides primarily in the U.S.. Forest regrowth along with nitrogen deposition and elevated CO_2 contribute to the strength of this sink. Working against this sink are timber harvest and escalating disturbance regimes, leading to the prediction that the capacity of North American forests to provide a net uptake of carbon will diminish in the future.

A major new result in this report is the conclusion that Mexican forests now are considered a carbon sink. In the previous assessment (SOCCR1) conducted about 10 years ago, it was reported that forest harvesting in Mexico contributed about 9 Tg C per year to the atmosphere. The more complete accounting presented in this report indicates these forests sequester approximately 41 Tg C per year. This is an important result and it would benefit from further support. Specifically, the authors should address what new process or fluxes have been included, or what values were modified to switch Mexican forests from a source to a sink for atmospheric carbon.

The definition of forest articulated on the first page (line 23) is a bit perplexing. Here forest is defined as having a land area as small as 0.5 ha and a canopy cover of as little as 10%, which seems to be a very "low bar" for defining a forest. Consider alternative definitions of forests, and whether this might affect the major findings of this chapter. (See additional related comment below).

Clarifying the temporal dynamics of carbon fluxes in forests would make this chapter more approachable. One of the challenges in understanding carbon cycling in forests is the time lag caused by the long-term storage of carbon in wood. When a tree is cut down and burned, it causes an immediate release of carbon to the atmosphere. This carbon was removed from the atmosphere over the past one or two hundred years, depending on the age of the tree. This displacement between carbon uptake and release poses a challenge when considering trees for bioenergy. For this reason it is worth considering spatial integration instead of temporal integration to evaluate carbon-budget consequences— i.e., is there enough forest area in recovery right now to offset the carbon release from the areas being harvested or disturbed?

Statement of Task Questions

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

For the most part, this chapter accurately reflects the scientific literature, but see specific comments below.

- *Are the findings documented in a consistent, transparent and credible way?*

Yes, the findings are documented in a consistent, transparent and credible way.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

The embedded text in Figure 9.1 is illegible (too small), and the inclusion of "product partnerships" on the right side of the figure is cluttered and distracting. Similarly, Figure 9.5 is not readable.

The authors should define the meaning of positive and negative signs in Table 9.3.

- *Are the research needs identified in the report appropriate?*

The authors have done an admirable job of identifying knowledge gaps and research needs in 9.8.2. This section would benefit from also discussing the shortcomings of current modeling and inventory approaches because they have large uncertainty in simulations and substantial spread among models.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

The numbers for the magnitudes of carbon sinks/sources and stocks are presented with multiple significant digits and are not associated with uncertainty estimates. It is fairly important to provide some kind of uncertainty estimates or data ranges.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

Yes, the document's presentation, level of technicality, and organization are effective.

Section 9.4: Need to clarify: what are the indicators? what are the feedbacks? are they feedbacks to the climate system? It appears that this section does not contain indicators or feedbacks as its title indicates. These components should be added; otherwise, the title of the section should be modified accordingly.

- *What other significant improvements, if any, might be made in the document?*

It would be helpful if the numbers for magnitudes of carbon sinks/sources and stocks could be compared to those reported in SOCCR1, which can illustrate how the numbers have changed because of various factors (e.g., changes in carbon fluxes/stocks, changes in methods used, differences in components considered).

The second paragraph of the Introduction provides a definition of forests used in this chapter: land greater than 0.5 ha with trees greater than 5 m and canopy cover of > 10%. This is quite different from the definition of forests in widely-used classification schemes for satellite-derived land-cover maps. For classification schemes like IGBP, forests are defined as areas with >60% of tree cover with >2m tree height. Most modeling studies are based on land-cover maps with classification schemes like IGBP and therefore use a different definition of forest compared to this chapter. How were differences in forest definition and the resulting discrepancies in forest area and carbon fluxes/stocks among different approaches and studies reconciled in in this chapter? This should be appropriately addressed.

As indicated by the report, there are still differences in the methods used for estimating carbon stocks and their changes among the three countries. Were these differences explicitly considered and reconciled in this chapter? If yes, how?

Line-Specific Comments

P342, Line 35
Finding 3 is not written very clearly. In order for harvest to offset a part of the net carbon sink in forests the managed forestry must be considered separate from other forest land. Is that what is meant?

P343, Line 4
In point 4, natural disturbance and land conversion are considered together. Conceptually it may be more instructive to keep them separate. A natural disturbance will often be followed by some phase of regeneration, and an appropriate way to think about the disturbance-associated budget term would be as disturbance return interval, relative fraction of land under disturbance, and regrowth rates relative to the rate during the last cycle. Except for fire management intended to reduce fire severity or frequency, there are few opportunities to alter this budget component. Anthropogenic land conversions are different because they are permanent and directly related to management decisions.

P344, Line 14-35
The summary of the forest carbon cycle doesn’t explicitly note the live respiration term but focuses on photosynthesis and death, which partitions into debris, soil organic, and decomposition. Photosynthesis could be described as having multiple allocation pathways, either to new growth, or supporting respiration.

P344, Line 34
In stating which regions store the most carbon, consider distinguishing regions that have large stock because the area is large and those that have high carbon density. This statement would be enhanced by having a figure to indicate the regions, or reference the map in Figure ES1 if that is how regions are defined in this chapter.

P345, Line 2
In this chapter as in others, the units for carbon stocks are used inconsistently.

P345, Line 23
Should the loss of carbon from forest conversion to settlements be cross-checked against the sink for urban trees, to be sure there are no offsets or double counting?

P348, Line 2
The phrase “major contributor to net reductions in atmospheric CO_2” is incorrect. CO_2 is indeed increasing. Please rephrase.

P349, Line 8
When discussing the nitrogen deposition influence on forests the trends in deposition should be mentioned. National Atmospheric Deposition Program (NADP) trends (a good proxy), show declining NO_3 in wet deposition and increasing NH_4–thus indicating a complicated national trend with spatial variations.

P349, Line 14-29
"Tree" and "plant" are used interchangeably in this chapter. It is recommended that the authors stay with "tree" in this chapter.

P349, Line 30-39
The paragraph discussing SOC would benefit from some mention of the role of soil warming. See Melillo et al., 2017.

P350, Line 11-33
Discussion of how disturbance affects forest carbon budget ought to consider whether the overall carbon budget across a landscape or region is or is not at steady state, where steady state can be achieved with a small area being disturbed and offset by larger area that is recovering. Critical considerations are size of disturbed area relative to undisturbed regrowing area, and return intervals. Parts of this paragraph are not adequately quantitative. What are the regrowth rates after disturbance; how delayed is the decomposition? If these numbers are not well understood, then this should be spelled out as a research need.

P351, Line 15
Suggesting that forest sink strength will decline as forests age relies on dogma that old forests aren't strong carbon sinks, but that is not supported by observations from the oldest stands available to study where carbon gain is still strong (Luyssaert et al., 2008).

P352, Line 13
Isn't SCC typically expressed per ton?

P353, Line 13
The consequence of bioenergy doesn't seem to be treated consistently in this chapter. On line 15 it is counted against strategies to reduce fire, but on line 26-27, substituting biofuels for fossil fuel is given as a strategy for reducing carbon emissions.

P354, Line 14-20
It would be useful to discussion whether forest harvesting is compensated by regrowth, considering regional balance as well as temporal balance. One can evaluate the balance by considering a unit of forest area that is harvested and recovers (or not) over many decades (as is done here); or one can take a regional approach where some patches are being harvested each year and the remainder is left alone. Is there enough land in regrowth to compensate for the harvest loss? The point that accelerated disturbances are reducing the carbon sink now should be paired with discussion about whether the land areas recently disturbed are likely to recover and become a large carbon sink in the near future.

P355, Line 28
The authors suggest that a priority for future research is creating a full climate impact assessment for forests, including albedo and methane and nitrous oxide fluxes. It may be prudent to cite Anderson-Teixeira et al. (2012), which provides a computation framework for integrated quantification of the climate regulating value of forests and other ecosystems.

P357, Line 34
The authors state, "*Although the reclassification of land from non-forest to forest… does not… involve emissions or removals of atmospheric carbon, the processes underlying such reclassifications invariable do*." It is unclear why the authors feel that it necessary to draw this distinction.

P379, Table 9.3.
Is "2.Net due to forest land gain and Loss" meant to say "Net FLUX due to…."? (Without clarifying, one might mistakenly interpret the numbers to be areas).

Chapter 10: Grasslands

Overview/Main Issues

In this chapter the authors demonstrate that grasslands typically take up more carbon from the atmosphere than they release (i.e., a sink) and that, unlike forests where carbon is in wood, much of this carbon is stored in soils. Carbon storage in grasslands is sensitive to climate, operating primarily through variation in the length of the growing season; and while there is unrealized potential to store additional carbon in these systems through proper management, with current practices this system is expected to become less of a sink with time.

The authors define grasslands in part as ecosystems that occur in areas where average annual evapotranspiration is greater than precipitation. While appropriate for most grasslands in North America, this definition misses the grasslands of central Florida. These grasslands occupy relatively small area but have a rather large economic impact through beef production. This chapter would benefit by expanding the discussion of southeastern grasslands.

In discussing processes affecting grassland carbon stocks (section 10.3.2), precipitation is identified as very important. Over the past few decades, there have been demonstrable changes in the timing and intensity of precipitation. While the effect of changes in the amounts of precipitation is discussed, a bit more attention to the role of intensification of hydrologic cycle would be useful.

The encroachment of woody vegetation into grasslands is increasing as the climate warms and as fire is suppressed. The authors acknowledge this trend, but it was unclear how woody encroachment affects carbon stocks and fluxes in grasslands.

Statement of Task Questions

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

The statement that *"… moisture availability exerts more control over variability in productivity and carbon storage in grasslands than does grazing*." (p.386, ln 10) is overstated, and this statement would benefit from appropriate citations.

The authors may wish to include one or more of the following references in their discussion of how cheatgrass affects biogeochemistry and hydrology (paragraph beginning on p.385, ln 12): Obrist et al. (2003); Prater and DeLucia (2006); Prater et al. (2006).

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Do the areas in Table 10.1 represent total area? If so, the area of grasslands would be more appropriate.

- *Are the research needs identified in the report appropriate?*

In the discussion of knowledge gaps (section 10.6.2), another source of uncertainty is the interaction between changes in land use and climate change. There are very few studies that investigated how changes in land use (grazing) in concert with changes in climatic factors (precipitation) will alter carbon processes. This lack of knowledge hinders our capacity to predict the response of carbon storage in grasslands to future climate changes, as we know that ecosystem responses derived from knowledge of single-factor experiments are likely to be misleading. See for instance: Norby and Luo (2004); Templer and Reinmann (2011).

In the discussion of "major uncertainties" (p.395, ln 21), another major uncertainty is how much carbon sequestration in grasslands can be increased through management practices, plant breeding, or genetic modified organisms.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

Most of the uncertainty and statistical analyses are presented in the primary literature cited in this chapter, rather than being applied directly in this synthesis.

Line-Specific Comments

P380, Line 13
Would it be advisable to present the key findings in order of confidence?

P380, Line 32
Start with areal extent of grasslands in the U.S.

P380, Line 33
In discussing the areal extent of grasslands it would be good to open with their coverage in North America rather than globally.

P381, Line 19-20
Using the term "C uptake" without at least specifying if this refers to net or gross carbon uptake is misleading. See for instance, comments under section 10.3.2. It is unclear if references to C uptake always refer to net carbon sink or they are referring to GPP. Need to define what GPP is and that GPP-Reco is NEP. This way one could avoid using less-specific terms such as "all C uptake".

P381, Line 19-21
Should this convention be adopted in all chapters?

P381, Line 20 (and elsewhere)
Phrases such as carbon uptake and loss are used rather loosely. Do the authors mean net or gross? Where possible, it would be best to use standard ecosystem carbon cycling terminology, e.g. GPP, Reco, NEP, NPP, etc.

P381, Line 32-34
One would think this would be extensive to changes in precipitation such as drought. Arid systems will be more vulnerable to reductions in precipitation.

P383, Line 16-28
Does woody encroachment affect carbon cycling in grasslands?

P383, Line 34
Standardize units across chapters.

P385, Line 1-11
.
One could use this study, along with others, to strengthen the idea (raised in section 10.5) that grasslands have potential to sequester additional carbon if managed properly.

P385, Line 12-26
It would be good to comment on precipitation changes expected in the future, and the fact that these changes will have a marked seasonality.

P385, Line 14
The discussion of how growing season "plasticity" and corresponding variation in productivity (NPP?) responds to climate would benefit from consideration of how this variation would affect carbon losses by plant and soil respiration.

P385, Line 19-23
It would be good to also mention carbon losses, and the fact that the inter-annual variation in ecosystem productivity reflects interactions between SM and temperature controls on both "all C uptake" (GPP?) and carbon losses (Reco) - not only on carbon uptake. This would help illustrate that the sensitivity of GPP and Reco to these climate factors will likely differ, and this determines the net carbon sink or source strength of grasslands. This exemplifies how using the term carbon uptake is misleading, as it is unclear whether the authors mean gross or net carbon uptake.

P385, Line 33-36
Might want to add the recent paper Gomez-Casanovas et al. (2016), which shows that grazing increased the carbon sink strength of subtropical pastures. Subtropical grasslands are very important for U.S. beef production (look up Florida in the rankings for beef production); and along with tropical pastures, they are one of the most abundant grassland types across the world.

P386, Line 9-11
This seems like an overstatement—at least if not accompanied by literature. If one of them exerts more control over productivity or carbon storage, it will depend on how much these factors change. Think about increasing the stocking rate from moderate to heavy. That will certainly affect carbon storage, which they acknowledge. Perhaps what is meant is that we can alter grazing intensity to a desired outcome—for instance, increased NEP-C storage in grasslands is more resilient to grazing than to precipitation because theoretically we cannot alter precipitation (although the management practice of "rain harvesting" may allow for this to some degree).

P386, Line 12-15
See papers by Prater cited above.

P387, Line 31
The authors mention that models predict an increase in forest land carbon stocks in the Great Plains by 2050. It would be useful to know what factors are predicted to drive this increase in forest area.

P387, Line 31
The driver for increasing forest is unclear.

P388, Line 35 – P389, Line 4
Is worth mentioning nitrogen (N) deposition in this context, as many grasslands are not fertilized and therefore their only N input comes from deposition.

P388, Line 38 – P389, Line 4
Accurately predicting the response of carbon sequestration to elevated CO_2 and warming depends on the limitation or saturation of ecosystem processes to nitrogen. For instance, if a system is limited, one would expect CO_2 to increase carbon sequestration as biomass increases— and one would expect the opposite if the system is saturated. Predicting if grasslands will be N limited or saturated therefore depends on N deposition rates these systems experience in the future (at least for grasslands that are not fertilized by humans). It is also worth acknowledging that there is a large uncertainty in carbon responses to N deposition, and that this is hindering our capacity to accurately predict grassland carbon response in the future (see for instance Gomez-Casanovas et al., 2016).

P389, Line 18-25
It may be worth mentioning that the responses of carbon storage to changes in precipitation will likely differ in xeric, mesic, and hydric systems, although we are not capable of accurately predicting the magnitude of the response. Need more discussion of timing of precipitation

P390, Line 25 – P392 Line 19
The discussion of "societal drivers" would benefit from a short paragraph stating which other practices along with changes in grazing management and fire regime could potentially increase carbon sequestration in grasslands. It would also be interesting if the authors could link this to the uncertainty in future carbon stocks in grasslands. Mainly, we don't know which and how practices other than grazing and fire could affect carbon sequestration in grasslands.

P391, Line 8
The statement that removal of above ground biomass by grazing reduced soil carbon stocks would benefit from a reference or two.

P391, Line 26-31
How does woody encroachment affect som?

P392, Line 8
Specify annual crops. It is a different story for perennial biofuels.

P392, Line 1-19
The discussion of how converting grasslands to other vegetation types or management regimes (namely crops) needs to be a bit more specific. Some of the pressure on grasslands in the future will come from the expansion of perennial bioenergy crops. While replacing perennial grasslands with

annual row crops typically reduces soil carbon stocks, replacing these systems with high-yielding perennial grasses for energy production can have the opposite effect.

P392, Line 22-31
The synthesis section would be improved by including some mention of grasslands in Southeastern U.S. because these grasslands are grazed and globally, tropical and subtropical grasslands play an important role in the carbon cycle; they store vast amounts of carbon, some of which is emitted to the atmosphere as CH_4. In addition, they are important from an economic perspective as the contribution of beef production in Florida is large.[6]

P393, Line 21
Change "easily" to "readily".

P393, Line 32-33
Is this true even when considering row crops?

P395, Line 21-29
A major uncertainty is how much we can increase carbon sequestration in grasslands through management practices, plant breeding or genetic modified organisms—because of the lack of field data. This seems a crucial point to make in addition to the uncertainty in precipitation patterns.

P411, Table 10.1.
Specify that "approximate area" is referring to grasslands.

[6] See http://www.freshfromflorida.com/Divisions-Offices/Marketing-and-Development/Education/For-Researchers/Florida-Agriculture-Overview-and-Statistics.

Chapter 11: Arctic and Boreal Carbon

Overview/Main Issues

This chapter summarizes the current knowledge in high-latitude (mostly permafrost) carbon storage and dynamics. Arctic and boreal regions contain large carbon stock, especially in permafrost soils. The factors that control carbon storage have been changing rapidly over the last several decades. As a result, this large carbon pool is highly vulnerable for carbon loss in a future warming climate. There are major needs to reconcile model and observations in assessing permafrost carbon balance and in understanding the importance of abrupt thaw of permafrost.

The authors have done a commendable job in providing an updated synthesis of data and knowledge in high-latitude/permafrost carbon dynamics. It is very well written in general. The chapter provides a clear circumpolar/global perspective to provide context for the discussion of North American carbon cycle. The Committee makes the following suggestions to help improve the chapter.

- There is some discussion of long-term carbon accumulation processes (in 11.3.3) and discussion of projected future change in the year 2300 (in 11.4.2), but further discussions of longer-term past and future perspectives would be useful. For example, the permafrost carbon pool has been accumulating and has been relatively stable over the last several thousand years at least, but recent abrupt changes in controlling factors (warming, disturbances) may cause instability and degradation that the system hasn't experienced in thousands of years. See wording suggestions on subsection 11.3.3 and key findings below.
- The key uncertainties are clearly documented, but progress could be enhanced by ranking which research questions are most amenable to solution in the near term. It would also be useful to discuss ongoing research campaigns (i.e., ABoVE[7]) that may contribute to progress, and to provide clearer guidance to federal agencies about where they can most effectively use their resources.
- The writing and organization are clear in general, especially in the early part of the chapter. However, it is uneven in the late half of the chapter when discussing carbon fluxes, suggesting a lack of adequate editing on subsections written by different lead authors. Note that subsection 11.5 is missing. Compared to subsections 11.3.1 and 11.3.2 on soil and vegetation carbon pools, subsection 11.3.3 on carbon pool change lacks detail. To maintain balance with the other two subsections, the authors could expand this subsection into multiple paragraphs, rather than just one densely-packed paragraph. It may be useful to state this is an overview of natural drivers affecting permafrost carbon pool, to distinguish from discussions on carbon fluxes in subsection 11.4.
- The chapter only cites Harden et al. (1992) on the subject of long-term accumulation histories, but there are more recent publications on this subject that could be referred to, at least for permafrost peatlands (e.g., Loisel et al., 2014).

[7] The Arctic-Boreal Vulnerability Experiment, a NASA–led field campaign.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

The goals and objectives of the chapter are clearly stated in the first paragraph, and the chapter meets the stated goals.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

Yes, the chapter's content and key findings accurately reflect the scientific literature. Some suggested references are included in the line comments.

- *Are the findings documented in a consistent, transparent and credible way?*

Yes, the key findings are presented in a consistent, transparent and credible way.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

In general, the chapter key messages and graphics are clear, but see comments below on figures. The key messages reflect supporting evidence, with appropriate assessment of likelihood. The figures/tables are effective in communicating the messages. However, the graphics and resolution of Figure 11.1 needs improvement. Other Figure suggestions are noted below.

- *Are the research needs identified in the report appropriate?*

The research needs are not stated explicitly as part of Key Findings, but are discussed at the end of the chapter (11.7). In particular, the chapter identifies the importance of: (1) reconciling model and observation difference in Artic vegetation greening and soil carbon stock change, and (2) emerging research on disturbance of permafrost soils by abrupt thaw. Timescales appear to be a major factor in discussing vegetation and soils carbon pool change and carbon sequestration. The point that vegetation greening and shrub expansion may have limited or no impact on long-term soil carbon sequestration could be made clearer. Identifying and modeling processes that control long-term carbon balance seem to be important research needs. "Abrupt thaw" is an important disturbance event that causes instability for a system that has been stable over thousands of years.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

Yes. The results and findings are all from the peer-reviewed literature.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

In general this is a well-presented chapter.

- *Are the key findings in your chapter well stated and supported by the detail provided in the chapter?*

Comment on Key Finding 2. Timescales are probably an important parameter to differentiate permafrost carbon pool from forest or other biome biomass carbon pools (or even mineral soils carbon pool). This chapter is a place to put the contemporary carbon cycle in the context of long-term geological carbon cycle dynamics. Indicating the long-term accumulation of permafrost carbon helps put carbon release through recent and future disturbance, especially related to abrupt thaw, into a broader context. The Committee suggests augmenting this finding with a statement such as: "This large soil carbon pool in the permafrost zone has accumulated over hundreds of thousands of years."

Line-Specific Comments

P413, Line 24
Change "145" to "146" to be consistent to 10% of 1460 GtC.

P414, Line 19
Change "Arctic ecosystems" to "the Arctic".

P415, Line 3
Citations can perhaps be changed to "Romanovsky et al., 2010, 2016", without repeating the author names. (A similar formatting change could be made throughout the chapter).

P415, Line 7
It is a bit redundant to say both "the Arctic" and "high Arctic". Rephrase.

P417, Line 29
Perhaps change the subheading to "Characteristics of Permafrost Carbon"?

P418, Line 24
Change "Ice covers" to "Ice sheets cover".

P419, Line 4
Switch order of fluxes and stocks by changing to "Current Understanding of Carbon Stocks and Fluxes", as this is the order of description below. Also, why use different terms "stocks" and "pools" here?

P419, Line 7
Change to "peatlands (>20% carbon)"… and "mineral soils (<20% carbon)", as organic matter rarely contains much more than 50% carbon and it is redundant and inprecise to indicate <1% for mineral soils.

P419, Line 14
Change to "soils of many meters thick".

P420, Line 16-17
Change "sea levels were" to "sea level was".

P422, Line 5-6
The values seem to be inconsistent, as 15.07 PgC may only refer to boreal biome, and tundra vegetation contains another 1.36 PgC (as in Table 11.2) that is not included here.

P422, Line 15
Change heading to "Natural Drivers of Carbon Pool Change" to distinguish from subsection 11.4.

P422, Line 15-40
This paragraph is weak, especially compared to previous two subsections 11.3.1 and 11.3.2. This could be expanded by discussing long-term historical drivers. Focusing on just the past few centuries and millennia is likely too short, as there are many recent synthesis of well-dated peatland records showing that these ecosystems have accumulated carbon over >10,000 years (e.g., Loisel et al., 2014; Treat et al., 2016). See general comments above.

P423, Line 2
Change to "11.4.1 Carbon Fluxes in Recent Decades"?

P423, Line 15-28
May need more discussion of boreal forest in this section, to balance the focus on tundra. Also, perhaps cite some more recent references after the 2012 synthesis, such as Euskirchen et al., 2017.

P424, Line 5-10
Perhaps move this to section on future projections?

P424, Line 18
Delete "soil area".

P427, Line 29
Need more discussion on peatland fires (e.g. drawing upon Turetsky et al. publications).

P427, Line 31-34
There are no discussions of insect outbreaks in the chapter elsewhere. Also, provide an overview of the three approaches used for future projections at the end of this paragraph.

P429, Line 41
This subsection is weak, except perhaps the first paragraph, it is not really focused on upscaling.

P430, Line 6-8
The sentence is unclear.

P430, Line 12-18
Is that more suitable for the overview?

P430, Line 31
Missing subsection 11.5, between 11.4 and 11.6. Reorganization is needed.

P430, Line 32
Should this be indicated as a Case Study in the subsection heading?

P431, Line 15
Change to “Observations and modeling results summarized in this chapter”.

P433, Line 27-35
Two different statements “high confidence” and “very high confidence”. Need more consistency.

P434, Line 10
Gorham (1991) may not be a correct reference for this statement. Please check.

P435, Line 9
Change “Observational data” to “Experimental data”.

P449, Line 4
Change to “Tundra area data”.

P452, Figure 11.3
The Y-axis labels can benefit from adding “/year” on both sides.

P453, Line 5-6
The sentence in the figure caption is unclear. Also, change “carbon with the text” to “carbon in the text”.

P454, Line 9
Change to “(see Table 11.1 for references and data source)”.

P454, Figure 11.5.
The authors may want to use white-color outer band for the category ‘Various (Mineral)’, while leaving Histosol (organic) gray. This way, three first-order subdivisions (Gelisol, Histosol and Various) are represented by three different colored outer bands.

P457, Figure 11.8
Change the Y-axis labels to “Area (km2)” and “Area (acres)”, by showing the variables, rather than just indicating measurement units.

Chapter 12: Soils

Overview/Main Issues

This chapter reports on progress in quantifying North American carbon stocks to depths that corresponding to carbon storage, rather than earlier estimates of surface carbon or carbon at arbitrary depths. New models include improved representation of soil processes, but models continue to differ on the sign and magnitude of soil carbon changes. Recent simulations contain results for high latitude soils that contradict experimental results, suggesting carbon gain while empirical studies suggest loss. Considerable uncertainty remains about the impact of lateral transport, erosion, and riverine movement on eventual carbon storage or release. Numerous studies suggest warming will on balance release soil carbon; but increased agricultural production and CO_2 fertilization may increase storage, thus reducing or counterbalancing this effect. The vast reservoirs of carbon, and their apparent temperature sensitivity, indicate that soils could release large amounts of carbon to the atmosphere, but there are large uncertainties regarding the amount and rate of release.

Some key issues to bring to the attention of the chapter authors:

- The authors state that there is no possibility of improving carbon stock estimates. This seems like a very strong statement, given that improvements have been realized and could be improved with increased effort.
- The authors focus on temperature impacts, but other chapters (e.g. grasslands and agriculture) emphasize rainfall impacts.
- In various places in the chapter, soil carbon stabilization is linked to microbial processes, to inputs from plant growth, and to physical stabilization; but there is no overall conceptual framework for how these different factors interact.
- The organization of the chapter by a mix of process and region means that some information and quantification may be overlapping and can't easily be combined.
- The chapter could use more discussion of experimental studies related to factors such as soil warming, tillage, rainfall enhancement and exclusion. There is a large literature on such matters that is barely referenced.

Statement of Task Questions

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

The report seeks to cover an enormous amount of ground and does not reconcile the many conflicting views about the mechanisms and magnitude of soil carbon changes. In some sections, the report reads like a primer on soil biology rather than a focused assessment. As one example, the section on soil fauna indicates that fauna are important to soil—undoubtedly true, but this does not consider interaction effects of higher trophic levels or ecosystem engineers (e.g. earthworms) on soil carbon changes related to ongoing climate and land use.

The section on nitrogen is weak and does not reflect conflicting evidence on N impacts through plant growth and through soil biological-chemical interactions.

Soil respiration is part of the annual cycle of uptake and release, yet the section on respiration does not distinguish between controls over the amount and phenology of the annual cycle versus decadal trends. Soil respiration is the major mechanism for carbon stock changes, so this section is confusing in conjunction with discussions of stock changes that result from altered respiration (e.g., due to climate change or tillage).

Given the importance of modeling acknowledged in the chapter findings and introduction, the modeling section is weak and sparsely supported by literature. Some of the relevant literature is covered in the agriculture chapter, but the vast body of work from the leading soil modeling groups (e.g., USGS, Colorado State, DOE) is poorly captured compared to the far less mature Earth System Model literature. Limiting the modeling section to the ESMs does not fully portray the state of knowledge.

- *Are the findings documented in a consistent, transparent and credible way?*

The regional and continental budget numbers are not reconciled into a North American budget. Are U.S., Canadian, and Mexican numbers consistent with overall continental budgets?

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Do the areas in Table 10.1 represent total area? If so, the area of grasslands would be more appropriate.

- *Are the research needs identified in the report appropriate?*

The research needs identified seem fairly generic and not well linked to the key uncertainties identified. There would seem to be at least two major classes of uncertainty that could be targeted in the chapter: (i) the uncertainty in stocks and fluxes as a basis for understanding soil feedbacks to atmospheric CO_2, and (ii) the impact of region- and ecosystem-specific management practices on SOC enhancement or sustainment. Regarding the later, the significant literature on modeling of management regimes to assess impacts on SOC storage seems underrepresented.

- *Are there other key findings that are missing? Any critical literature missing?*

The literature cited lacks depth in soil modeling, the nitrogen section is light, and the discussion of methane is very brief given the soil origin of this gas. The literature review on high latitude soils, identified as a key issue, seems sparse and does not fully reflect relevant literature, including inference from experiments and observational studies and the growing literature based on flux and atmospheric measurements. Are the results here consistent with discussions of the Arctic/Boreal Zone elsewhere in the report?

In a number of sections (e.g., on the Arctic/Boreal Zone), the literature review emphasizes papers from 5-10 years ago and does not seem to include recent papers based on extensive research efforts by NASA and DOE. For instance, see publications stemming from the NASA-led programs such as the Arctic-Boreal Vulnerability Experiment (ABOVE) and the Soil Moisture Active Passive (SMAP) satellite mission, and from DOE-led programs such as the Next Generation Ecosystem Experiment (NGEE), and Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE).[8]

- *Are there any broader questions, such as the selection of the evidence and findings, weight of evidence, or the consistency of the application of uncertainty language?*

Key Finding 2 notes the wide range of Earth System Model projections, which would indicate low confidence in model projections. High confidence should be applied to the result or not to the discrepancy among approaches. This could instead be listed as the last Key Finding.

Key Finding 3 needs to state a time frame for the soil carbon loss.

- *What other significant improvements, if any, might be made in the document?*

The writing is uneven across various subsections with some inconsistencies and duplications among sections. Also there are some inconsistencies in values used in different figures.

In the discussion of protection mechanisms, there is no mention of freezing and waterlogging as an important protection mechanism, especially in high latitude regions (boreal and Arctic).

Line-Specific Comments

P459, Line 14-20
Do increasing crop yields increase SOC?

P459, Line 22-24
Specify if this focuses on U.S. soils or North American soils. Specifically calling out Canada without calling out the U.S. creates confusion. The repeated presentation of discrete numbers for Canada, while a range is reported for the U.S., gives the impression that the Canadian data is more definite than the U.S. data.

P459, Line 37
Change to "between 16 Pg C and 78 …"

P460, Line 5-9
Here it seems that the terms "peatlands" and "permafrost" are used interchangeably. They are different despite some overlap (e.g., permafrost peatlands vs. non-permafrost peatlands vs. permafrost mineral soils).

P460, Line 11
It would be good to clearly state the scope and objectives of the chapter at the beginning.

P460, Line 32-36
Is this sentence useful? It could be deleted.

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[8] ABOVE (https://above.nasa.gov/cgi-bin/above_pubs_list.pl), SMAP (https://smap.jpl.nasa.gov/science/publications/); NGEE (https://ngee-arctic.ornl.gov/publications); SPRUCE (https://mnspruce.ornl.gov/content/project-publications).

P461, Line 32
Change to "The researchers found that the largest….".

P461, Line 2-4
"There is no possibility" is a strong phrase when it is known that better estimates could be made with better data. This makes it sound as if we will never have any better idea of North American carbon stocks.

P461, Line 42
Change "huge" to "large"? Delete "larger-scale" as ESMs are global scale, and thus "large-scale" is redundant.

P461-466, Subsection 12.2.
The subsection could be better organized, perhaps as follows:
12.2.1 Plant Litter Inputs
12.2.2. Soil Microbes
12.2.3 Macrofauna (foodweb)
12.2.4 Rhizosphere Interactions
12.2.5. Protection Mechanisms
12.2.6 Nitrogen Effects on SOM Dynamics

P462, Line 27
Need to discuss freezing and waterlogging as protection mechanisms.

P463, Line l8
Is better to use the phrase "parent materials" rather than "source materials", because in soil literature, "parent materials" refer to bedrock or other materials that soil develops on.

P463, Line 11
Change "outsized" to "important".

P463, Line 18-22
While this may be true, it is a logical leap that some readers may not be ready to take at face value. Yes, SOC stabilization by microbes affects the plant community, but the plant community also drives the microbial community (a chicken/egg scenario).

P463, Line 18-28
This appears to replicate subsection 12.2.2. Move/merge to that subsection?

P463, Line 31-33
Can 2001 be called a "recent" paper?

P464, Line 12-37
Fauna: This section reads more like a primer than an assessment. Need discussion of the direction and magnitude of effects, and how fauna can amplify or moderate other effects.

P464, Line 41 – P465, Line 3
What is the cause of this diverging trend in nitrogen deposition— fertilizer use changes? air pollution control measures? other?

P465, Line 12
This should be "23 grams of carbon per "gram" of nitrogen"

P465, Line 16 – P466, Line 28
In discussing gas fluxes, need to be more explicit about time periods and spatial domains, to provide context for the numbers.

P465, Line 19-21
State during what time period, or state "is released annually".

P465, Line 33-37
Could reference the Agriculture chapter here.

P465, Line 29-38
Need to use consistent units.

P466, Line 2-3
What about CH_4 oxidation/sink in upland soils?

P466, Line 12
Only one component "of" net SOC changes.

P466, Line 30 – P467, Line 14
The literature cited in this section is particularly light and limitedAlso, some terminology needs to be defined (priming, sorption, etc).

P466, Line 38
The "other ecosystem compartments" shouldn't include "atmosphere". Correct?

P467, Line 31-32
Change the statement to "…captures change in the carbon content of soils across CONUS over time."

P467, Line 37-38
Is density the correct term for a unit that does not include volume?

P468, Line 15 – P469, Line 5
Check on depths and context for the numbers cited.

P468, Line 17-20
Is 9.13 Pg C the 20 cm stock? Is it 73% of the 30 cm stock? Clarify to make the 18 Pg number (in line 19) make sense.

P469, Line 7
"153.7 Pg were in organic (peat) soils" is different from Chapter 13 (Terrestrial Wetlands), where peatland soil in Canada is stated to contain 130 PgC in Table 13.1.

P469, Line 7-37
This first paragraph presents conflicting data without smoothly transitioning between estimates: Tarnocai's total is 262.3 Pg C, Kurz's estimate places boreal forest alone at 208 Pg (which is ~80% of Tarnocai's total). If the boreal forest is 208 Pg, then Tarnocai's estimate is low for total Canadian soil carbon, because of significant contributions from other regions, therefore Tarnocai's estimated total will likely increase as further research on permafrost continues.

P469, Line 8-9
Reiterate that the remaining carbon stocks are those estimated by Tarnocai, as to not imply that all of Canada's soils are peat soils, tundra, forest, and agriculture.

P469, Line 9
Total soil carbon estimates for Canada likely will increase...

P470, Line 31-32
"Causes of soil loss in agricultural soils include..."
This list is true for all soils, except for the tillage part, which is specific to agricultural soils.

P470, Line 31-41
Quotes losses without specifying time periods? Over what period? Are these losses fast or slow?

P472, Line 24
Reword as "moisture disturbances"?

P473, Line 10
Remove the phrase "types of".

P473, Line 11-14
Could mention perennialism here.

P498, Table 12.1
The value given for "other" (11.2 PgC) is smaller than the value given in Table. 13.1 for wetlands in conterminous U.S. (13.5 PgC). Please check for consistency between these values.

P500, Table 12.3
Add a new row at the bottom of the table for "Total". Why is there no table for Canada?

P501, Figure 12.1.

- The letterings are too small to read
- What about CH_4 emissions, especially from "peatlands" (are they peatland near snow/ice? Is hard to tell).
- Label "tundra" right below "snow/ice", and label "land-use" at location between forest and agriculture?

- Cannot comment on other boxes and meanings of all the arrows, as it is difficult to read what the authors intend to show.

Chapter 13: Terrestrial Wetlands

Overview/Main Issues

This chapter focuses on carbon cycling in terrestrial wetlands (that is, non-tidal freshwater wetlands), providing information about area, carbon pool size, and fluxes of CO_2 and CH_4. It discusses carbon stocks and fluxes separately for peatlands (organic soil wetlands) and mineral soil wetlands. The chapter also discusses lateral carbon fluxes from terrestrial wetlands to aquatic/coastal systems. The main findings are that terrestrial wetlands continue to be a large carbon reservoir, and they have been a CO_2 sink and CH_4 source.

Some or most data used in the assessment were derived from the new compilation by the authors and are first presented in this chapter— a different approach from all other chapters, which mostly present and assess data and modeling syntheses in the peer-reviewed literature.

The Committee identifies several areas for improvement in this chapter, discussed below.

Key Findings issues. Four key findings focus on wetland area and carbon stocks, CO_2 sequestration and CH_4 emissions, wetland loss and carbon sequestration function, and future research needs. Some suggestions on improving/rephrasing the key findings include the following:

- Key findings 1-3 only present single values on wetland carbon stocks and CO_2 sink and CH_4 source, without any indication of uncertainties and range. Uncertainty statements are needed.
- The values presented in the Key Finding 2 (18 Tg CH_4/per year) are inconsistent with values presented in Executive Summary (21 Tg CH_4/yr). Likewise, the carbon sink value of 53 Tg/yr is not consistent with the value stated in Executive Summary (nonforested wetlands 36 + forested wetlands 28 = 64 TgC/yr), or with the value of presented in Chapter 2 (36 TgC, on p.78, line 7, and in Figure 2.3). Please update the values and make sure the values are consistent throughout the report.
- Findings 1 and 2 appear to be based on the new compilation by the chapter authors, as indicated in the Description of Evidence section, but without comparison to the estimates from top-down and bottom-up approaches (as presented in Saunois et al. (2016) for the period 2003-2012, among other papers. This chapter is supposed to provide an assessment of current knowledge on wetland CO_2 sink and CH_4 emissions. At minimum, the authors need to put the new estimate presented here in the context of what is available in the peer-reviewed literature. Another concern is that the values derived by the chapter authors do not correspond with a clear time period, as these values represent the mean of various individual measurements collected from different wetland sites over different time periods.
- Chapter 2 does not cite the CH_4 results from this chapter, but instead summarizes the results from both top-down and bottom-up approaches with appropriate uncertainty ranges as in Saunois et al. (2016).
- Key Finding1 of Chapter 9 (Forests) states that net carbon uptake by North American forests is 217 TgC/yr, with 80% in the U.S. This chapter (Wetlands) claims a carbon uptake by forested wetlands of 39 TgC/yr (Table 13.1). It is not clear if forested wetlands are included in the Chapter 9 uptake estimates. The authors need to coordinate with Chapter 9 authors and state clearly what is included in which chapter. Furthermore, it is not clear if CO_2 fluxes associated

with peatland fires (p.510, lines 31-35) are included in these estimates. Similarly, there could be a link with Chapter 5 (Agriculture) in the discussion about wetlands for agriculture.

Data compilation issues. Key data representation and data quality control issues related to this chapter, include the following:

- The Committee has concerns that 11 measurements of CH_4 emissions spanning three orders of magnitude, and two values on NEE from MN, WI, WV, MD and West Siberia (Table 13B.1), are averaged together to yield representative fluxes for forested peatlands in Canada and Alaska.
- In Table 13B.2, the 53 measurements on non-forested peatlands include wetlands with diverse hydrologic and biogeochemical conditions as well as sites from a coastal marsh, an estuary, and a tidal creek of Chesapeake Bay in VA (The Terrestrial Wetlands in this chapter should not cover tidal wetlands).
- At least two measurements appear to be from experimental study sites (poor fen – ammonium sulfate added in MN site, and poor fen with water table drawdown at Quebec, Canada site). The CH_4 measurements included in the table range over four orders of magnitude, from 0.0002 to 1.2 Mg C in CH_4/ha/yr. How would this range translate to uncertainties for scaled-up results for North America?
- It appears that the raw measurements/data haven't gone through quality control evaluation, and as a result, the robustness of the new data compilation results so heavily relied upon in this chapter should not be assessed in the context of SOCCR2 review. Such a new compilation would be better presented as a new study in a peer-reviewed venue, so that the site selection criteria and individual data sets used would be critically evaluated by peer reviewers.

The problems above on data representation and unsuitable sites were noted by simply looking at the tables. Other issues may exist in other sites/data sets. For the reasons discussed above, the Committee suggests that the authors do not present the new compilation results, but instead focus on the available information in the peer-reviewed literature (such as Saunois et al., 2016 on wetland CH_4 emissions).

Scientific clarity and accuracy. Some statements in this Chapter may not be scientifically accurate. Below are a few examples, with more details offered in the line-by-line comments.

- The statement on p.503, lines 30-31 ("*In undisturbed wetlands, carbon stocks are relatively stable over time…*") is wrong. Many published papers have documented that peatlands have continued to accumulate carbon since at least the end of last ice age, so the carbon stocks continue to grow over time (e.g., Gorham, 1991; Harden et al., 1992; Loisel et al., 2014; Yu et al., 2010, among others).
- On p.503 lines 37-38 the statement "*Similarly, both carbon stocks and fluxes are very sensitive to disturbance*" is redundant, as carbon stocks and fluxes are not independent of each other but closely related. A clear discussion and statement should be made earlier in the chapter that change in carbon stocks, or in any carbon reservoirs for that matter and wetlands included, would be induced by imbalance in carbon fluxes (uptake and release). A disturbance may increase carbon emissions, which in turn may affect carbon stocks, depending on other flux terms. Such a statement would guide reader to have clear understanding of the critical processes.
- At the beginning of subsection 13.3, the first sentence about "rooting zone" is problematic, as Sphagnum and all mosses have no roots, while these moss-dominated peatlands (Sphagnum-dominated bogs and brown moss-dominated rich fens) are widely distributed in Canada and

northern U.S. states. These moss-dominated peatlands are major carbon storage and sink, but they have no roots and rooting zone.

Global context. The chapter should provide a proper global context to discuss wetland carbon stocks and fluxes in North America. For example, regarding global or northern peatland carbon stocks, some seminal, recent synthesis papers (e.g., Gorham, 1991; Yu et al., 2010) are not discussed. Regarding global and North American wetland CH_4 emissions, many pertinent publications are not discussed (e.g., Bloom et al., 2017; Melton et al., 2013; Tian et al., 2015); Chapter 2 provides a more comprehensive synopsis of the topic (p.80).

Modeling discussion. The evidence for Key Finding 4 about the uncertainties appears to rely mostly on a 10-page USDA Forest Service report (Trettin et al., 2001) (p.525, lines 15-16). Also, the subsection 13.6.3 (*Are Current Models Adequate?*) barely mention many recent efforts on simulating wetland CH_4 emissions, such as models evaluated and compared in Melton et al. (2013) and Saunois et al. (2016).

Organization and writing. Some parts of the chapter could benefit from reorganization. For example, it may be more effective to divide sub-subsection 13.2.1 into several sub-subsections— including ones that focus on *Historical Regulation* and *Policies, Change in Wetland Area, and Carbon Stocks and Fluxes*. Within this chapter, the usage of words and technical terms is inconsistent and lacks clarity. For example, the uses of "carbon fluxes/emissions/update/release" and "annual accretion" sometimes lack clarity and at other times are used inaccurately. There is also some repetitive text within the chapter. It is clear that the chapter was written by a team of authors but hasn't been edited thoroughly. Numerous small editorial suggestions are listed in line comments below.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

The goals and objectives are not clearly described in the chapter. Presumably the goals are to provide an updated assessment of available literature on carbon cycling in terrestrial wetlands; yet it appears that the authors of this chapter instead conducted their own new data analysis and relied on these new results to reach conclusions.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

Some key findings/conclusions appear to derive from the authors' own new data analysis results, without proper assessments and comparison with abundant recent peer-reviewed literature. The chapter lacks a proper discussion of global context in terms of peatland carbon stocks and wetland CH_4 emissions. The model section is weak in discussing available models and simulations.

- *Are the findings documented in a consistent, transparent and credible way?*

Two main findings mostly rely on the new data compilation analysis by the authors of this chapter. As there are several issues related to the data representation and data quality control, the Committee cannot fully evaluate the credibility of the results/values and findings as commented on above. A more credible, transparent assessment would consider other peer-reviewed literature (e.g., Saunois et al., 2016 and Bloom et al., 2017 on wetland CH_4 emissions) and provide appropriate uncertainty statements.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Some Key Findings only present results from the chapter authors' own new data compilation and analysis. For example, the "description of evidence base" for Key Findings 1 and 2 only refer to Appendices 13A and B, and are not compared explicitly with the peer-reviewed literature. Also, there are many discrepancies with wetland carbon fluxes values cited in Executive Summary and Chapter 2. Many statements are inaccurate or confusing, and there is repetition of some material.

Tables 13.1 and 13.2 provide a useful summary of wetland data in each country and territory in North America. However, the values presented here should be consistent with the values discussed elsewhere in report (Chapter 13, other chapters, Executive Summary: see comments above). The scaling-up of results on NEE and CH_4 emissions presented in Table 13.1 have not been demonstrated to be credible due to the issues with data representation and data quality control of the individual measurements listed in Table Annex 13B (see general comments above). Also, Table 13.2 uses different units for CO_2 flux (Tg CO_2/yr here vs. Tg C/yr elsewhere) and CH_4 emissions (Tg CO_2e/yr here vs. Tg CH_4/yr mostly elsewhere).

Figure 13.1 is unclear and inappropriate. The ranges shown for CH_4 emissions are fundamentally unsupported by evidence. As noted above, the raw measurements of CH_4 emissions presented in table Annex 13B have a range spanning four orders of magnitude, and mean values were used for scaling up to the wetland-type specific total emissions shown in Table 13.1. The scaled-up values were divided by wetland areas to derive CH_4 emissions per unit area, and the CH_4 emission ranges apparently only show the ranges from various countries/territories per wetland type as in Figure 13.1, all within one order of magnitude. The presentation vastly underestimates the uncertainties.

In Figure 13.1, there is no unit specified for carbon pools, and the ranges indicated for four wetland types are large and do not seem to reflect the values presented in Table 13.1. The apparent vegetation carbon pools shown in the figure do not appear in Table 13.1. The units for carbon fluxes are Mg C/hectare/yr while Table 13.1 shows units as Tg C/yr for NEE and Tg CH_4/yr for CH_4. The graphic quality can be improved. For example, the blue wavy line near the top of soils appears to show the water table, but this is not explicitly indicated. Also, some trees appear to grow in air.

- *Are the research needs identified in the report appropriate?*

The stated research needs in Key Finding 4 appear to be based mostly on an old 10-page government report (Trettin et al., 2001).

The stated research need on model improvement is too general to be useful and does not appear to adequately consider much pertinent literature on wetland carbon models.

The stated research need on evaluating carbon sequestration and flux differences between restored and natural wetlands is a valid one but is too narrowly focused, without adequate justification why this stands out as a key finding. For example, how would the uncertainties in these differences impact the wetland carbon pool and flux assessments?

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

Some synthesis results and findings are presented here have not gone through normal peer review processes. More justification is needed to average CH_4 emission rates that vary over four orders of magnitude from individual measurements/studies for the scaling-up used in the chapter, in particular to assess how these very different values would impact the uncertainties of CH_4 emissions (see comments above).

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

The writing and organization can be much improved. There are many instances of scientifically inaccurate statements and lack of clarity in the use of terms and concepts. (Several examples are cited earlier in other sections of this chapter review).

- *Are the key findings well stated and supported by the detail provided in the chapter?*

Key Finding 1.

- The wetland carbon stock of 178 PgC is mostly from Canada at 130.5 PgC of wetland carbon stocks, including 116 PgC in peatlands (39.3 PgC in nonforested peatlands, plus 76.7 PgC in forested peatlands), as shown in Table 13.1. This peatland carbon stock in Canada is very different from the value used elsewhere—such as 153.7 PgC stated in Chapter 12 on P469 line 7 (cited Tarnocai, 1997). The chapter should consider all these estimates and come up with an assessment of likely range.
- Need to explain how the development of a U.S. soils database would improve greatly the assessment of carbon stocks in North America, including Canada and Mexico. Was the lack of a U.S. soils database a major uncertainty previously during SOCCR1 assessment?
- All figures/values stated here lack uncertainty statements.
- There is an uneven and inconsistent treatment of numerical values; for instance, why focus on the global proportion of wetland area in North America, but not global percentage of total wetland carbon stocks in North America?
- Why does the last sentence focus on wetland area?

Key Finding 2.

- This key finding relies only on the authors' own new data compilation and analysis. The chapter should consider and assess other estimates in the peer-reviewed literature, as discussed above.
- These figures and values on CO_2 sinks and CH_4 sources are inconsistent with the ones in Executive Summary and Chapter 2.

- Need some explanation of the significance of 43% and 40% mentioned here – why readers should consider this important?

Key Finding 3.

- It is unclear what rates were during historical times and what historical period this refers to.
- The evidence for this key finding appears to derive from a 2011 government report (USFWS 2011), at least for the United States. The URL cited for the report appears to link to more than 20 web pages or documents of approximately 100 MB.
- There is no traceable evidence presented in the Key Finding or Description of Evidence Base.

Key Finding 4.

- The stated research needs appear to be based mostly on an old 10-page government report (Trettin et al., 2001).
- This stated research need on model improvement is too general to be useful, and does not appear to adequately consider the pertinent literature on wetland carbon models (e.g., Melton et al., 2013; Saunois et al., 2016).

- *Are there other key findings missing? Any critical literature missing?*

It would be helpful for this chapter to include a key finding related to the impacts of climate change and natural disturbance (wildfires, permafrost thaw, drought and water-table drawdown) on wetland carbon fluxes (CO_2 sink and CH_4 emissions). That is, how could the flux rates stated in Finding #2 change in the future? There is abundant literature, at least on CH_4 emissions, that can help inform projections of future wetland carbon balance under a warming climate and changing disturbance regimes.

- *Are there any broader questions, such as the selection of the evidence and findings, weight of evidence, or the consistency of the application of uncertainty language?*

Evidence heavily relies on the authors' own new data compilation and analysis, and these new results have not been adequately evaluated in the context of available peer-reviewed literature. The quantitative statements in Key Findings lack uncertainty and range.

Line-Specific Comments

P503, Line 24-25
Perhaps state the wetland area first and then indicate the percentage of the global total. Why only indicate 42% of area, but not % of global total carbon stocks?

P503, Line 25
It is not clear if 178 PgC represents both soils and vegetation, as Figure 13.1 appears to show vegetation/forest carbon stocks as well? The value needs an uncertainty statement/range. There are two ways to distinguish wetlands: forested vs nonforested, and organic soil (peatlands) vs mineral soil wetlands. But this key finding only lists non-forested wetlands by area, and peatlands for both area and carbon stocks. There is no distinction made between soils and vegetation/biomass carbon stocks.

P503, Line30
All estimates need an uncertainty range. The stated CO_2 sink (53 Tg C/yr) is inconsistent with the value used in the Executive Summary (64 TgC/yr, (nonforested 36 + forested 28), p.37). Likewise, the CH_4 emissions value (18 Tg CH_4/yr) is inconsistent with the value in the in Executive Summary (21 Tg CH_4/yr, p.37). Also, Chapter 2 uses wetland CH_4 emission estimates with ranges in the peer-reviewed literature, rather than the values in Chapter 13.

P504, Line 1-6
Quantification is needed: What is the current wetland loss rate? What is the time period for "historical rates"? Has there been any change in wetland loss rates in the last 10 years since SOCCR1? It seems imbalanced to focus on wetland loss and wetland restoration/creation without commenting on impacts of natural disturbance on wetlands and their carbon dynamics.

P504, Line 7-10
This finding is too general to be useful. Either indicate the specifics/nature of improvements or delete.

P504, Line 13-36
Clarify wetlands definition (probably better to call the subsection "Terrestrial Wetlands").

P504, Line 13
Perhaps begin with a description of the chapter goals and objectives—to clarify if this is an assessment of available peer-reviewed literature or a presentation of a new data analyses.

P504, Line 16
A general scientific definition of wetlands seems more appropriate than "The United States defines…"? Would it be better to define wetlands as ecosystems that include soils and vegetation? Also, from this definition, how does one distinguish "peatlands" and "mineral soil wetlands"—based on water table/hydrology?

P504, Line 25
The sentences are confusing. "all peatlands are… classified as wetlands in Canada"? Why is Gorham et al., 2012 used as reference for definition of wetlands? Would "*Wetlands of Canada* (Canada Committee on Ecological Land Classification; National Wetland Working Group, 1988)" be a better reference?

P504, Line 31-32
Peatlands are ecosystems while Histosols are soil type. They should not be used interchangeably.

P504, Line 33
40 cm is repeated here, which may not be necessary.

P504, Line 41
Chapter 11 also discusses boreal carbon, so not only Arctic as stated. This subsection/paragraph should be rewritten in a clearer manner. Peer-reviewed scientific literature is available to cite in addition to government agency documents.

P505-507, Section 13.2
This subsection discusses historical views on wetlands and regulation/policy, carbon stocks and fluxes, and wetland area change; yet it has only one labeled heading [13.2.1 on change in Wetland Area]. It may help to instead re-organize the paragraphs under three sub-subsections as follows:

- 13.2.1. Regulations on wetlands (including lines 6-33, P506 and lines 17-26, P505).
- 13.2.2. Change in Wetland Area
- 13.2.3. Carbon Stock and Fluxes (the paragraph on P505-506)

This subsection does not adequately reflect the literature, especially the paragraph on wetland carbon stocks and fluxes.

P505, Line 30-31
The statement that "*In undisturbed wetlands, carbon stocks are relatively stable over time…*" is inaccurate. Many published papers document that peatlands have continued to accumulate carbon since at least the end of last ice age, and so carbon stocks continue to become larger over time (e.g., Gorham, 1991; Harden et al., 1992; Loisel et al., 2014; Yu et al., 2010, among others).

P505, Line 32-34
There are more data available that have been synthesized than just the single site in Roulet et al. (2007). For instance, Yu (2012) and Ratcliffe et al. (2018) both summarize net carbon balance data from several sites in Canada/North America.

P505, Line 34-36
It is confusing to describe CO_2 fluxes as "CO_2 emissions": do you mean C release/respiration? If so, what about C uptake/photosynthesis/GPP? Similar wording appears on line 42. Would be better to replace "emissions" with "fluxes" in this context.

P505, Line 37-38
"*Similarly, both carbon stocks and fluxes are very sensitive to disturbance*." This should clarify that carbon stocks and fluxes are not independent, as a change in carbon stocks would be caused by imbalance in carbon fluxes (uptake and release).

P505, Line 41
Among many references available, why cite here a study (Drexler et al., 2009) on California Delta about wetland drainage impacts on wetland decomposition?

P506, Line 1-5
References are needed here. Note this is Key Finding #3.

P507, Line 9-18
Provide discussion on oil sands exploration impact on wetlands/peatlands in Western Canada, especially since 2007.

P507, Line 39
The first sentence about "rooting zone" is problematic. What about Sphagnum or other moss-dominated peatlands in Canada and northern U.S. states? These moss-dominated peatlands are major C storage and sink, but they have no roots and rooting zone. This statement is not general enough as an opening sentence for the subsection; This paragraph overall is rather loose and lacks a single citation.

P508, Line 10
Change "Methane flux" to "Methane emission"?

P508, Line 19-21
The sentence is unclear. The sentence could mean large CO_2 flux dynamics, CO_2 uptake, or CO_2 release.

P508, Line 21
Change "from the perspective of " to "considering organic and mineral soils wetlands separately"

P508, Line 22
Delete "quite."

P508, Line 32
Change "reported literature" to "reported values in the literature."

P508, Line 40
The appropriate terms here should be "CO_2 uptake" and "CO_2 release", not "CO_2 sequestration and emissions."

P509, Line 4-9
The authors attempt to define the net ecosystem carbon balance (NECB) concept as defined by Chapin et al., 2006, but this paragraph lacks clarity. A distinction between respiratory carbon loss and non-respiratory loss (due to disturbance) is needed.

P509, Line 7
It should be clarified that carbon monoxide is due to fires.

P509, 13.3.1. Peatlands C stocks and fluxes
There are several improvements needs for this sub-subsection:
-Compare their "new" estimates of C stocks and fluxes with what is in the peer-reviewed literature
-Address the poor organization, lack of a reasonable global overview, and lack of proper references.
-Be more consistent use of CH_4 units (Tg C as CH_4/year on p.509, line 24 vs. Tg CH_4/yr in Key Finding #2)
-Address the lack of proper documentation of the value 20-30 gC/m^2/yr.

P509, Line 11-12
The distinction of fens and bogs as described here (based on water source and pH) is incomplete and inaccurate. As this chapter is about wetland carbon, it should state the difference in dominant plants in fens (sedges, and brown mosses mostly) and bogs (dominated by peat moss Sphagnum).

P509, Line 21-22
The 116 PgC in Canadian peatlands are inconsistent with the value of 153.7 PgC used in Chapter 12 and other literature. This difference needs to be discussed.

P509, Line 19-11
It would better (here and throughout the chapter) to present the values and then indicate the percentage.

P509, Line 24
The CH_4 unit is inconsistent with elsewhere in the chapter and report.

P509, Line 19-35
The values as presented in Table 13.1 should be discussed and compared with the peer-reviewed literature, such as Tian et al. (2015), Saunois et al. (2016), and Bloom et al. (2017) – all these references were cited and discussed in Chapter 2.

P509, Line 39
It is unclear what is meant by "mode of primary production".
The two references cited here appear to focus narrowly on specific macromolecules in peat, but this paragraph is supposed to talk about decomposition in general. Some more general discussion is needed to provide that unstated macromolecule examples.

P509, Line 40
The term "carbon density" is unclear. Does this mean carbon concentration (% carbon) or soil carbon density (kg C/m2) or bulk carbon density (g/cm3)?

P509, Line 41
The term "peat accretion" is not commonly used outside discussion of mineral soil wetlands, such as salt marsh, as in these mineral-rich systems mineral sediment transport and deposition are important part of peat and carbon accumulation process. "Peat accumulation" is a better term, as most or all materials are derived from dead plant litter.

P510, Line 2-4
The sentence is confusing. The term "carbon stocks" is unclear, as the subheading (Peatlands – Carbon Stocks and Fluxes) indicates it refers to the size of carbon pools in PgC. In this context, it may be better to refer as "soil carbon density" (kgC/m2). It is so obvious the values will depend on peat depths. Also, what is the range of 200-3000 MgC/hectare represented by peat depths? Finally, do these values represent North America or other geographic regions? Yu (2012) provides a range of peat carbon density values from the literature that were used in peatland carbon stock estimates.

P510, Line 4
Time frames need to be indicated for the carbon accumulation rates of 7-300 gC/m2/yr. Also, Loisel et al. (2014) presents the synthesis carbon accumulation data from a large database from northern peatlands that discuss the change in carbon accumulation rates over time.

P510, Line 5-6
The geographic region for the conclusion that bogs accumulate carbon faster than fens should be clearly indicated here to evaluate the relevance and applicability. Does this conclusion refer to peatlands in Finland (Tolonen and Turunen, 1996)? A recent study on several peatlands in western Canada show the opposite conclusion that fens accumulate the same or more peat than bogs (Yu et al., 2014).

P510, Line 9-22
The terms describing CH_4 fluxes are confusing in this paragraph. CH_4 emissions are the difference between CH_4 production and CH_4 oxidation in soil column. So their uses should be clear. CH_4 effluxes in line 14 should be replaced by "CH_4 emissions".

P511-512, Section 13.3.2
This subsection has the similar issues as for 13.3.2 on Peatlands.

P514, Line 11-13
The 52.5 Tg/yr carbon sinks are not consistent with the value stated in Executive Summary on page 37 (nonforested wetlands 36 + forested wetlands 28 = 64 TgC/yr) and with the value of 36 TgC as presented in Chapter 2 (page 78, line 7 and Figure 2.3). Also, it appears that all these individual values (NEE, CH4 and DOC) use different units (Tg C, Tg CH4, or Tg DOC, respectively).

P514, Line 16
The phase "carbon accretion in biomass" should be changed to "carbon accumulation".

P514, Line 16-18
This is a too simplistic an approach to estimate peatland carbon sequestration. First, the rates of 20-30 gC/m2/yr are likely apparent rates of peat carbon accumulation, rather than actual carbon accumulation rates (see Turunen et al., 2002 and Yu, 2011 for discussion). So these rates cannot be directly used to estimate contemporary peatland carbon sequestration rates. Second, it should be indicated for what time periods (for example over the last several thousand years) these rates were derived and applicable. The apparent rates (see Loisel et al., 2014) and modeled actual rates (Stocker et al., 2017) of peat carbon accumulation show highly variable values throughout the Holocene (the last 12,000 years). The Holocene means in two recent large-scale syntheses on northern peatlands are approximately 20 gC/m2/yr (Loisel et al., 2014; Yu et al., 2010).

P514, Line 21-24
This sentence is confusing. More discussion on vegetation/biomass is needed to make this simple calculation credible.

P514, Line 25
The authors realize that 120% value does not make sense, because the approach described here is not scientifically reasonable.

P514, Line 28
Is this (13.3.5) still under subsection 13.3?

P515, Line 6-7
"moist soil management": The wording is awkward. Is that wett soil management?

P517, Line 31 – P518, Line 32
The discussion in this subsection is inadequate.

P518, Line 34
This statement requires a reference citation.

P518, Line 35
This is inaccurate. Many models as discussed in Melton et al. (2013) use observational wetland areas, rather than simulate wetland extent directly.

P518, Line 36-37
Change to "between … and …."

P519, Line 2
It would be useful to provide a global context of peatland and mineral soil wetland areas separately.

P519, Line 12-13
The value of 21 Tg CH_4 /year is not consistent with other values used in the report (see general comments above). The top-down estimates for North America in Saunois et al. (2016) are 17-52 Tg CH_4/year. The 21 Tg CH_4/year value should be considered along with top-down and bottom-up estimates as presented in Saunois et al. (2016). These estimates focus a specific relevant time period from 2003-2012, almost identical to the decade between SOCCR1 and SOCCR2, so the values are most relevant to the SOCCR2 assessments. On the other hand, the value of 21 Tg CH_4/year as derived by the chapter authors have no specific time period that can be assigned.

P519, Section 13.6.3.
The section is very weak. See general comments above.

P536, Table 13.1. Line 2
Change "CH_4 flux" to "CH_4 emissions." Also, the table needs to provide a global context as well, including global wetland areas, carbon stocks, CH_4 emissions, etc.

P538, Table 13.2.
The units used here are inconsistent with ones in the text, such as Tg CO_2 per year, and Tg CO_2e per year for CH_4 flux.

P540-560, Appendix Tables
These tables and the appendix text are not necessarily useful or appropriate for this report. Considering all the issues with the approach, data representation, data quality control, and large range of individual measurements , the authors should consider take a different approach to assess the available peer-reviewed literature.

P541, Line 4-5
This statement is misleading, as both Dahl (2011) and this chapter use the same NWI database, so the tiny difference (of 0.09%) could be simply due to minor updates or rounding differences. Perhaps Chapter 13 can simply use the value by citing "Dahl (2011), with update NWI 2015)". Reproducing the content of the database here, even in a summarized form, may not be necessary. The level of details presented in this chapter is incomparable to other chapters in the SOCCR2 report.

P545, Line 13
Are these two estimates independent? If not, why the difference? Are they supposed to be the same?

P546-547, Tables 13A.7 and 13A.10
These tables use different units for area (km^2 vs. ha). Need more consistency.

P556-558
See the general comments on the data representation, data quality control and data variability/range. Similar issues may exit on mineral soil wetlands in Table 13B.4. Also, these tables use different units on CO_2 and CH_4 fluxes (Mg C/ha/year).

P504, Line 3
What does "23 times less" mean? Do you mean 1/24 here? This should be modified to avoid confusion.

P511, Line 14-30
You may want to consider citing Lu et al. (2017), which synthesizes the annual carbon fluxes (GPP, ER, and NEP) for a number of wetland sites globally.

P514, Line 11-13
"a net sink for atmospheric CO_2" should be changed to "a net carbon sink". The net ecosystem carbon balance here includes not only CO_2 but also CH_4.

P514, Line 16-18
It would be more reasonable and informative to use the range (20-30 g C/m^2/year) to derive a range for the peat soil carbon annual accretion rate in Tg C, rather than a single value.

P517, Line 30-32
Surprisingly this section does not quantitatively assess the historical and future trends of wetland carbon fluxes/stocks. Qualitatively assessing the potential effects of climate change on wetland carbon dynamics is certainly informative. But it would be much better if new or even existing model ensembles could be used to assess the trends of wetland fluxes/stocks.

P521, Line 34 – P522, Line 29
It is unclear whether the current models are adequate or not. If not, in what aspects of these models should be improved?

P522, Line 23-29
The one sentence on data issues does not seem sufficient. It is better to have a separate section on data needs. For example, it would be useful to have spatially and temporally explicit, high-resolution datasets that characterize the type, extent, and seasonal dynamics of wetlands.

P525, Line 11-12
"a significant carbon sink" should be changed to "a significant CO_2 sink" to avoid confusion because wetlands are a source of CH_4 (as indicated by the first half of the sentence).

P525, Line 17-19
The authors should mention another source of major uncertainty - the imperfect model structure and underlying processes (or model uncertainty).

P525, Line 27-29
It is certainly important to evaluate models, but the community needs to move forward by improving these models. Improving models should be explicitly mentioned here.

Chapter 14: Inland Waters

Overview/Main Issues

Inland waters are an important source of CO_2 to the atmosphere and a known but poorly quantified source of CH_4 to the atmosphere (Barros et al., 2011; Bastviken et al., 2004; St Louis et al., 2000). In SOCCR-1, rivers and lakes were considered a net carbon sink. A key message for this chapter is that much of the carbon that moves from terrestrial ecosystems into aquatic systems through lateral transfer is emitted to the atmosphere as CO_2. A fraction is either buried in lakes and reservoirs or transported to the coast. Significant biogeochemical processing of carbon happens in inland waters; there are significant data gaps that impede a more complete understanding of transformations under different physical, chemical, and biological conditions as well as a result of anthropogenic disturbance, both direct and indirect.

There are additional key messages about the potential impact of impoundments on carbon biogeochemistry, which are mainly to change the flow paths of carbon as well as the rates of CO_2 and CH_4 cycling. A final key message (which is not highlighted as such) is the statement that "*changes in aquatic carbon fluxes are directly linked to the residence time of water in both terrestrial and aquatic environments...*" and "*the half-life of organic carbon in inland waters is about 2.5 years, much shorter than the decades to millennia required for soil systems to completely turn over*." This has huge implications for carbon movement and processing in the face of changes in the frequency, timing, and intensity of precipitation events, for example.

Overall this chapter is mostly well written and clear. However, it could use a simple figure that illustrates the points made in section 14.1.2 about the many forms of carbon and their sources.

One general concern is how carbon fluxes are framed in this chapter. For instance, the chapter should make clear that Equation 14.1 (p.567, line 20) applies to the total (background + anthropogenic) carbon cycle—i.e., in the absence of anthropogenic perturbations, there would still be a net flux to (or from) the atmosphere, and the net flux would be balanced by lateral transports. Also, Key Finding1 suggests that the forest carbon sink is countered by CO_2 outgassing from inland waters. Indeed, this is reflected in Figure ES5. Taken at face value, Figure ES5 suggests that there is a very small net source/sink associated with non-fossil component of the North American carbon budget. One could easily come to the (wrong) conclusion that the North American sink is close to zero, contradicting top-down estimates that do not separate out inland waters. The authors need to figure out how the findings from this chapter could be integrated into the North American carbon budget, which is commonly thought of as that related to anthropogenic perturbations.

Statement of Task questions

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

One of the major new pieces of information for SOCCR2 is the emission contribution from inland waters.

Subsection 14.5 appears to need additional sub-subsection(s) on "North American and Regional Context". Needs reorganization.

- *Are the findings documented in a consistent, transparent and credible way?*

Yes although the report should be checked for consistency in reporting fluxes and pools within the chapter, and between text and figures presented in this chapter as well as in the first chapter.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Mostly, but see comments above about consistency. Also, the addition of a simple figure to illustrate section 14.1.2 would be helpful.

- *Are the research needs identified in the report appropriate?*

Yes, although it's a familiar tune: we need (high frequency) data on all aspects of the C cycle from a diversity of inland waters. It would be better for the authors to provide a more clearly prioritized list that could help advance the science for the next round of SOCCR assessment.

The authors could also discuss here methodological difficulties in understanding the carbon system in freshwater environments. For instance, Golub et al. (2017) illustrate that 30 years of data (DIC, alkalinity, pH) at the North Temperate Lakes LTER site are unable to yield consistent pCO2 estimates, nor are these estimates consistent with co-located direct pCO2 observations. The freshwater community needs to follow the approach of marine scientists in developing best practice laboratory techniques and inter-calibrated standards. The SOCCR2 authors could highlight these needed methodological improvements as an important part of the research agenda. Better spatial resolution is certainly important, but will be of no use if the data are unreliable.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

Yes, this is a well written chapter.

- *Are the key findings in your chapter well stated and supported by the detail provided in the chapter?*

The first key finding's statement that "This quantity is nearly identical to the estimated 223 Tg C…." is confusing in its comparison as well as the language ("almost identical?").

Line-Specific Comments

P565, Line 15
Perhaps change "The total flux" to "The total emission"?

P567, Line 12
Change "…suggest inland…" to "…suggest that inland …."

P571, Line 18
Change to "… suggests that…"

P573, Line7
Change to "assuming that 25%..."

P574, Line 10
It is not clear what "regional" refers to, in addition to "North America". There are no other sub-subsections, except 14.5.1 on global perspective.

P592, Figure 14.1.
This is a nice figure.

P565, Line 15-25
"flux … from inland waters across the coterminous U.S. …" could be interpreted as lateral flux. Also, it is not clear (until later) whether flux refers to a source or a sink here. Please restate the first sentence of both Key Findings 1 and 2.

P565, Line 28
Per $meter^2$ of what? Inland water? Or of continental area?

P572, Line 40
Regarding the increase in discharge: how about reduced precipitation or droughts?

P573, Line 16-18
"The rate of change" refers to the pCO_2 increases in 6 lakes or decreases in 3 lakes? Also, recovery from acid rain should increase pH, and hence decrease pCO_2?

Page 577, Line 16

Add reference to McKinley et al. (2011). This paper is referenced in Chapter 19 and should also be here, as this statement refers directly to this work.

Page 577, Line 33

Could add a reference to Baehr and DeGrandpre (2002) to illustrate that probes have been around for a while.

Chapter 15: Tidal Wetlands and Estuaries

Overview/Main Issues

This chapter synthesizes the latest scientific information on the carbon budget and dynamics of estuaries and tidal wetlands. The chapter provides an excellent summary of the state of knowledge in these coastal systems and the significant challenges posed by knowledge gaps. The Committee provides several ways that the chapter could be improved, including balancing the chapter with more estuarine information, including methane fluxes where possible, and expanding to include information from Hawaii, Pacific Islands, and Puerto Rico. The Committee also recommends expansion of Key Findings to reflect estuarine information and gaps in knowledge.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

This chapter is in alignment with the overall goals and objectives of the report as stated in the Executive Summary and Report Preface. This chapter is generally well written, is scientifically sound, and provides an excellent, thorough review of carbon cycling in tidal wetlands and estuaries.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

The chapter provides ample guidance on processes in tidal wetlands, but is in need of additional information on estuaries. For example,

- The majority of the "Findings" are focused on tidal wetlands, not estuaries
- Methane production is covered for tidal wetlands, but not estuaries – the chapter is in need of an introduction to processes that produce methane in estuaries and quantification of fluxes.
- Key Areas" on p. 612 (bulleted list) also focus primarily on tidal wetlands

The section on Pacific Coast estuaries needs a more thorough discussion of "low inflow" estuaries such as Tomales Bay, Elkhorn Slough, Newport Bay, that are very common on the West Coast of the U.S. The only really thorough treatment of methane source/sink is in the Pacific Coast Estuaries section; the Committee recommends the expansion of discussion of CH_4 in other sections where possible.

While this chapter focuses on the continental U.S., the Executive Summary of the report indicates that Hawaii, Pacific Islands, and Puerto Rico are part of the report's purview. If that is indeed the intended scope, the report should incorporate known information on tidal wetlands and estuaries from these locations in both the text and the figures.

The discussion on p. 597 about why estuaries are unique systems to understand carbon cycling and acidification provides the basis for why some scientists refer specifically to this problem as "estuarine acidification". The authors may want to specifically use this term and explain why these processes are distinct from open ocean acidification that is dictated purely by influx of anthropogenic CO_2.

- *Are the findings documented in a consistent, transparent and credible way?*

The Findings are generally appropriate and are in alignment with the supporting text. However, they are primarily focused on tidal wetlands.

Finding 4 could be expanded to two bullets, one for tidal wetlands and one for estuaries.

The chapter would benefit from an additional Key Finding focused on research needs/gaps (for example, as seen in Chapter16)

An additional finding could focus on the loss of these critical habitats and the importance that has for the magnitude of the coastal carbon sink.

It is unclear why the authors rate Key Finding 2 with "high confidence" but "likely".

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Tables are effective and clear, and figures are appropriate. The addition of one figure showing an example observational dataset would be helpful.

In Table 15.1 it seems possible that Pacific Coast seagrass and tidal marsh extent have been underestimated. As this value is not well-established in the literature, we urge the authors to carefully review relevant databases to assure this is as robust an estimate as possible.[9]

Figure 15.2 is not consistent with the figure in the Executive Summary that indicates that Hawaii, Pacific Islands, and Puerto Rico will be considered.

Figure 15.1 is very complex, but is a useful and important figure.

The tables in the Appendix are important and provide valuable information to support the findings in the report. Can Table 15A.4 be expanded to include Pacific estuaries? (see text below about further underscoring research gaps and needs if this is the case)

- *Are the research needs identified in the report appropriate?*

Research needs should be highlighted as a Finding if possible. In general, while the Synthesis, Knowledge Gaps & Outlook section is well written, these needs could be more significantly emphasized in the report.

Additional information is needed on how sea level rise will impact carbon storage in these environments, and/or a discussion of the fact that this is a gap/need in knowledge.

Also in Section 15.7: protection of habitats that provide carbon storage potential shows up in both Chapter 17 and the Executive Summary. The Committee recommends providing a discussion here of the value of conserving tidal wetlands and estuaries given their carbon storage potential.

In general, because some "gaps" have been discussed in previous sections (which is appropriate), the Synthesis/Knowledge Gaps section (15.7) is slightly redundant. One way to streamline this section would be to provide a brief synthesis section and then bullet points for "gaps".

[9] For example: http://portal.westcoastoceans.org/;
http://www.westcoast.fisheries.noaa.gov/habitat/fish_habitat/seagrass_2.html.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

The authors appropriately summarize and cite published analyses.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

The chapter is well written, very through, and a concise point of reference for the state of the science on Estuary/Tidal carbon cycle. The level of technicality is appropriate for an interested scientific audience (undergraduates, graduate students, or scientists from other fields).

Line-Specific Comments

P595, Line 1-3
This Key Finding could be split into two.

P601, Line 17-28
The "low inflow estuaries" that are commonly found on the U.S. West Coast are not described and discussed here.

P604, Line 18
This should be corrected to "organic rich" not "organics rich."

P612, Line 18
Key Areas should be broadened to reflect the full chapter.

P641 Line 2
The map should reflect / align with Executive Summary in including Hawaii, Pacific Islands and Puerto Rico.

P596, Line 12
Replace "dropped" to "slowed" - to avoid .."rise dropped.."

P596, Line 39-40
This topic - the loss of habitat that serves as carbon storage - could be quantified further and included as a key finding.

P597, Line 1-24
This discussion summarizes why some scientist specify "estuarine acidification" processes as unique and distinct from ocean acidification. Authors may want to incorporate and utilize that term into their explanation.

P597, Line 35
Also methane emissions could be discussed here?

P601, Line 3
All other sections in this part of the chapter use regional abbreviations (GMx, MAB, etc) but Pacific Coast does not.

P601, Line 17
What is a "large marine ecosystem"? Does large refer to area?

P602, Line 30-40
Thorough treatment of CH_4 here, could be expanded to other sections.

P611, Line 12-39
Could an example dataset be included as a figure here to provide a time series of observational data?

P613, Line 32
Some of this section is redundant with previous material; may be able to streamline by providing a summary of "gaps" in bullets.

Chapter 16: Coastal Oceans and Continental Shelves

Overview/Main Issues

This chapter is a thorough review of data available on carbon cycling and storage in ocean and coastal systems. In general, the summary is accurate and well supported by evidence presented here.

The Committee identified just a few ways that the chapter could potentially be strengthened. This chapter should make clear at the outset that the fluxes presented here are total (pre-industrial/background + anthropogenic) carbon cycle; i.e. in the absence of anthropogenic perturbations, there would still be a net flux to (or from) the atmosphere, and the net flux would be balanced by lateral transports. The authors need to figure out how the findings from this chapter should be integrated into the North American carbon budget (e.g. Figure ES5), which is commonly thought of as that related to anthropogenic perturbations.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

This chapter is in alignment with the overall goals and objectives of the report as stated in the Executive Summary and Report Preface. This chapter is generally well written and is scientifically sound.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

In general, the Chapter is accurate and is well supported by scientific literature. The Committee did find a few content areas that could be expanded or included further. For example:

- Hypoxia is a linked process to much of what is discussed here, can it be reviewed and discussed here?
- Methane from coastal / continental shelf sources is not discussed. Should be introduced, explained, discussed, quantified.
- In ocean systems, one can trace anthropogenic vs. natural carbon perturbation/ fluxes. Can a discussion of the parsing of these sources be added here?
- Hawaii & Pacific Islands are not discussed; nor is Caribbean (Puerto Rico should be included). These are included in the map in the Executive Summary, so should be incorporated here. Similarly, trends, fluxes and gaps in knowledge for the Arctic coastline should be further discussed.
- There could be a more specific connection to social science added here, as many of the economic impacts on people will be felt in coastal zones (recreation, fisheries, tourism).

- *Are the findings documented in a consistent, transparent and credible way?*

The Findings appear to be in alignment with the supporting text.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Tables are effective and clear, and figures are appropriate.

The addition of one figure showing an example observational dataset from the coastal ocean would be beneficial.

The map needs to align with the Executive Summary regarding Pacific Islands and the Carribean.

Key Finding 2: What does "high confidence" apply to? The fact that the number is not well constrained?

- *Are the research needs identified in the report appropriate?*

The research needs and gaps were appropriate. The Committee expressed some concern that these and other key findings were not appropriately covered in the Executive Summary, so the authors should consider aligning with Executive Summary text.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

The authors appropriately summarize and cite published analyses.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

The chapter is well written, very through, and a concise point of reference for the state of the science on coastal carbon cycling. The level of technicality is appropriate for an interested scientific audience (undergraduates, graduate students, or scientists from other fields).

- *What other significant improvements, if any, might be made in the document?*

While Chapter 1 (Key Finding 2) states that global average temperature increase is found to be 0.85 degrees C, Chapter 16 avoids mentioning ocean temperature observations, despite the fact that this is the prime driver of the observable poleward migration of marine species, and the fact that oceans take up ~95% of all anthropogenic heat generated. It would be best to add a note or disclaimer about these omissions.

There are ongoing efforts by industry to re-inject below the sea floor large amounts of CO_2 associated with oil and gas production (wells with 30% co-produced CO_2 are now common). Such efforts are on the upswing and today are the industry standard. The report should perhaps acknowledge this progress, although this is not specifically a North American phenomenon.

Note that ocean CO_2 uptake and loss is not credited to any nation under IPCC CO_2 accounting. Ocean uptake is viewed as a "public good" — so that land-locked nations and small nations with large EEZs are treated equally in this matter. The chapter should make this distinction more clearly and avoid sending a confusing message by commingling these coastal ocean uptake terms with other North American sectors (industrial, agricultural, forestry) that can absorb carbon.

Line-Specific Comments

P653, Line 27-32
The sentence (photosynthesis in the spring, and respiration in summer and fall) could easily lead a reader to conclude (wrongly) that the biological carbon cycle is seasonal. The biological pump is much faster—with continuous grazing the residence time of phytoplankton is two weeks or less.

Chapter 17: Consequences of Rising Atmospheric CO_2

Overview/Main Issues

This chapter examines some of the impacts of rising atmospheric CO_2 levels, in particular on ocean acidification and on dynamics of terrestrial vegetation. The limitations in the focus of this chapter are striking, as it is hard to discuss these particular consequences without considering the concomitant impacts of rising CO_2 levels on factors such as temperature and precipitation changes, hypoxia, sea level, and changes in terrestrial biosphere. The Committee understands the limitations that the SOCCR2 authors faced when writing this chapter (i.e., they did not want to impinge upon topics that fall squarely within the domain of other National Climate Assessment reports). Yet for the chapter to be useful, it needs to be more well-rounded in terms of considering the full impacts of rising atmospheric CO_2 emissions. One possible solution would be to summarize key insights from the *Climate Science Special Report* more significantly at the beginning of this chapter, and to build the discussions from there. The authors may also consider changing the title of this chapter to "Direct Consequences of Rising Atmospheric CO_2 on the Biosphere", to contain the expectations of the reader.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

This chapter is in alignment with the overall goals and objectives of the report as stated in the Executive Summary and Report Preface. This chapter is generally well written and is scientifically sound. However, as stated above, the Committee finds a chapter solely on CO_2 consequences for ocean chemistry and terrestrial vegetation—without considering the inevitable broader consequences of climate change, sea level rise, changes in ecosystem structure etc.—to be not very useful for policy makers.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

In general, the report is accurate and is well supported by scientific literature. The Committee did find a few content areas that could be expanded or included further. For example:

- The section labelled "Limits in Ocean CO_2 uptake" does not actually address that topic (this is further addressed in another chapter, but should be summarized here).
- The chapter needs an expanded view of biological impacts of ocean acidification and CO_2 increase (not limited to calcification).
- Section discussing Geologic History is oversimplified to the point of potentially being confusing. Also, the paragraph at the bottom of this page is misleading—the multi-stressor context of the geologic record is a strength, not a weakness. Report should reflect this important role that the geologic record may play in understanding impacts of future change. Also, this section does not result in a Finding, which is inconsistent with the rest of the chapter.

- Sea level is discussed in terms of "coastal protection" but not impacts on carbon sinks—please expand this section to discuss impacts on future carbon sinks/sources.
- The Chapter should address acidification in freshwater (not only in oceans). Though the data are insufficient to offer conclusive proof of acidification trends, the basic chemistry clearly indicates the potential for acidification is the same as in the oceans (Phillips et al., 2015). There is growing evidence of likely ecosystem impacts (Hasler et al., 2015; Weiss et al., 2018). Data are very sparse, and long timeseries are needed to understand these trends. Thus it is important to discuss this emerging evidence in SOCCR2.

- *Are the findings documented in a consistent, transparent and credible way?*

The Findings are generally appropriate and are in alignment with the supporting text. However, there are some ways the Findings could be improved:

- The discussion of fisheries/aquaculture impacts appears as a Finding but not extensively discussed in text.
- Finding 4 needs rewording for accuracy.
- Finding 2 is so generic as to be meaningless.
- Findings, generally, are not very quantitative here compared to other chapters (could use some quantification and statement of uncertainties).
- The Key Findings could be re-ordered: Finding 1 and 3 on the oceans, Finding 2 on land, and Finding 4 on carbon-climate feedbacks.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Figures are appropriate.

- *Are the research needs identified in the report appropriate?*

The research needs and gaps were appropriate.

- *Are the data and analyses handled in a competent manner? Are statistical methods applied appropriately?*

The authors appropriately summarize and cite published analyses.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

The level of technicality is appropriate for an interested scientific audience (undergraduates, graduate students, or scientists from other fields). The main problem is that the chapter does not directly refer to or summarize other impacts of rising CO_2, so as written the information is hard to interpret.

Line-Specific Comments

P695, Line 28-32
We suggest using “would increase”, “would likely change” … Without climate change and anthropogenic disturbances, “will” conveys too much confidence.

P696, Line 13-20
Need to bring in downstream effects— increased litter and greater decomposition/respiration.

P696, Line 22-23
Need to add brief statement/paragraph on the impact of CO_2 on ocean biota.

P697, Line 2
Have *at times* been well in excess of …

P697, Line 3
Add something like “Human civilization (which developed approximately X thousand years ago) during a time...”

P697, Line 34
Replace “rapid rise …” with “Solution of atmospheric CO_2 in sea water forms carbon acid...”

P697, Line 1-5
The decrease in atmospheric oxygen confirms the combustion.

P700, Line 28
Define residual land sink

P701, Line 15
Add reference to Swann et al. (2016).

P701, Line 19-28
Need to mention water here.

P702, Line 1
Suggest title change to “Indirect thermal effects of rising CO_2 on ecosystems.”

P702, Line 23
Taken up or released by ecosystems *and the oceans*.

P705, Line 14-27
Burke et al. (2015b) shows nonlinear dependence of agriculture on temperature.

P706, Line 6-8
The carbon sink varies with climate change as well.

P706, Line 18
Coastal wetlands as well?

P707, Line 1-3
Add references to Burke et al. (2015a); Hsiang et al. (2011, 2013).

Chapter 18: Carbon Cycle Science in the Support of Decision-making

Overview/Main Issues

This chapter examines how scientific knowledge about carbon cycle dynamics is currently used, and can be more effectively used, to inform different types of decision making needs. The chapter is focused mainly on decision-making in agriculture, forestry and other land use (AFOLU); it does not consider decisions made in many other sectors and activities that affect the carbon cycle. The chapter would be strengthened by more coverage of ways that AFOLU components of the carbon cycle are integrated into broader considerations, such as models and analysis of national GHG mitigation policy that balance AFOLU measures with other types of mitigation measures.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

The chapter would best open with a clear statement about the decision domain it addresses (drawing from P740, lines 39-41), followed by a statement about the goals of this chapter (drawing on P741, lines 6-9). The reader should be informed that the discussion mainly concerns AFOLU. And it should be made clearer at the outset what attention is given to issues such as climate change impacts, vulnerability and adaptation, in addition to the focus on carbon fluxes, stocks, and emissions mitigation.

It would be helpful in the examples used to provide some sort of explicit framework that clarifies questions such as: What information, how is it presented, and to whom? Who are the decision makers? What aspects of the carbon cycle do these decisions affect (sinks, sources, stocks, flows)? What information do decision-makers get, need, act upon?

- *Does the report accurately reflect the scientific literature? Are there any critical areas missing from the report?*

Noted below are some particular areas where additional discussion would be helpful:

Full Carbon Cycle. The text does not devote sufficient attention to ways that AFOLU (the main focus of the chapter) is integrated into carbon-cycle decisions, particularly those concerning mitigation of CO_2 emissions. For example:

- Section 18.2.1 (*Science Support for Decision Making*) reads as if only the natural sciences are relevant to the carbon cycle–not economics and other social sciences.
- Sections 18.3.1, 18.3.2 and 18.3.3 focus on data, models and accounting for the land use components of decision—even for decisions about land use that involve the energy sector and its emissions. The long list of tools (P748-749) ignores the integration of AFOLU into the overall carbon cycle, even for the decisions mentioned (e.g., P748, line 23)

- It is not sufficient to say that decision tools with cycle-wide coverage are dealt with in other reports (see P747, lines 12-20). The text should give the reader some insight into the ways that integrated assessment methods and models are used to explore the interaction of land use with other components of the carbon cycle. These issues could be addressed by adding text/references that point to the mention of integrated assessment models in Box 18.2.

Biofuels. The discussion of biofuels (P745)—a key U.S. national decision area—could do a much better job of explaining the interactions and feedbacks in biofuels development, and the multiple disciplines that are relevant to decision support. For example, this could include:

- more explicit mention of biofuels production effects on agriculture, grasslands and forestry, and influence on food prices;
- technology issues (e.g., cost of cellulosic ethanol; non-AFOLU fuels such as algae; use of direct air capture to produce synthetic hydrocarbon fuels)
- consideration of the fossil fuels used in biofuel conversion, and their emissions
- international trade in biofuel products (e.g., forest products, Brazilian ethanol) which are integrated into national models of energy and emissions (see comment above).

Also, given that this section (18.2.3) is on "Examples . . . for Decision Making", the discussion could be cast in the context of decisions about U.S. ethanol policy.

Ozone Damage. Mention should be made of feedbacks of carbon emissions (i.e., the resulting air pollution and climate effects) on ozone damage to agriculture and natural vegetation. Detailed discussion is not needed, but the effect deserves to be mentioned.

Communication. Section 18.2.2 (Science of Communicating Science) is incomplete in that it fails to call attention to the challenge posed by intentional dissemination of misinformation about climate change and efforts to undermine the public's trust in scientific institutions. Examples of appropriate references for such a discussion might include, for instance, Anderegg et al. (2010); Farrell (2016); Supran and Oreskes (2017). The authors might also want to consider that the challenge is not only understanding how the public interprets available science, but also understanding how carbon-cycle (and climate) science can be more accessible and relevant to individual and collective decision making. If it is not possible to deal with these important issues in this report, it might be worth considering dropping this "communication" section from the chapter altogether.

Culture. The discussion of knowledge co-production could be better linked to the discussions in Chapter 7 (Tribal Lands) about different forms of decision making, and different information and communication needs, in different communities. The chapter should also acknowledge the importance of factors such as cultural and economic diversity in decision making. An example is the South Florida Regional Climate Change Compact (P743, L26-38), which works because the counties "are tightly linked socially and economically". This aspect of the chapter could be enhanced by links to the earlier chapters on *Tribal Lands* and on *Social Science*.

- *Are the findings documented in a consistent, transparent and credible way?*

Because this chapter does not present new learning from research or empirical results, it does not lend itself well to findings akin to those of other chapters. Presumably however, the authors were required to come up with at least 4 or 5 key findings, and as a result, some of these findings seem forced or weak. Some specific notes below.

Key Finding 1 (Co-produced Knowledge). This finding should be edited to provide a more coherent message. (e.g., More relevant than what?) It is not the case that all information relevant to decisions *must* be co-produced by the scientific community and stakeholders. The language in P743, lines 20-21 is more helpful: "*continued communication among different shareholder communities and the scientific community . . .*" Perhaps also state that collaboration can help ensure the science is relevant to decision-maker needs. The confidence statement seems odd, given that the "finding" is just a sensible proposition, not a finding based on empirical evidence of decisions made with and without co-production of the science inputs.

Key Finding 2 (Integrating Human Knowledge). The obvious point that human drivers are the main reason for study of the carbon cycle does not merit elevation to a key finding.

Key Finding 3 (Attribution, Accounting & Projection). The point is also obvious and does not seem to merit elevation to a key finding. Without information on carbon-cycle fluxes and their origin, there is no carbon-cycle science, much less science to support decision making.

Key Finding 4 (Strong Links among Research). Reasonable, but it is not clear what "medium likelihood" means in this context.

Key Finding 5 (Improved Understanding). This finding should take account of the problem of intentional programs of misinformation (see above). Also, the evidence base refers to improving communications, whereas the finding involves understanding the public: these two different parts of the problem are not clearly explained.

- *Are the report's Key messages and graphics clear and appropriate? Specifically, to they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Messages and graphics are generally clear. The terminology in Figure 18.2 (Mode 1 and Postnormal) needs explanation, either in the text at P741 line 31 or in the caption.

- *Are the Research needs identified in the report appropriate?*

Yes, but many "needs" are listed with no sense of priority. Some rough ranking in importance would be useful. Additional effort is needed to provide guidance on research related to decision making. The main references to research needs are in short phrases in Boxes 18.2 and 18.3. The authors' view of research tasks should be elaborated in the text, with discussion of how the work would contribute to particular decision-making challenges.

- *What other significant improvements, if any, might be made in the document?*

The chapter would be improved by illustrating the use of carbon-cycle data and analysis for support of one or more specific decisions at the national level.

It would be useful for the text to give more attention to issues that are particularly important in informing decision making; for instance, discussion of the "fat" upper tail of climate response and threatened damage, and the implied urgency for action.

Line-Specific Comments

P739, Line 36
This should state "different from, although complementary to."

P740, Line 13-15
To say "optimal is most effective" is a tautology. Rewording is suggested.

P740, Line 5-12
The point being made in this paragraph is not clear. How is it that definitions enable eliminating gaps between science and decision making? What are the gaps? And why are the Management and Technology Drivers in Figure 18.1 mostly about agriculture, when something more general is called for? Why is renewable energy or nuclear energy not mentioned (and energy transition)?

P741, Line 12
Explain what, in particular, has changed over the last decade. Is it the items on P752, lines 32-40?

P741, Line 13
Explain what is meant by "traditional science supply paradigm."

P741, Line 23
Does this mean communication with economics and the other social sciences, as well as among natural sciences? If so, specify.

P742, Line 22
Add a phrase to explain "attitudinal inoculation."

P743, Line 14-15
There is repetition of a citation.

P743, Line 4-18
For this section, need to add an example of a decision where NACP was involved or relevant.

P748, Line 12-13
It is not true that a robust process to develop projections is "relatively new". The work goes back a quarter century or more in the climate arena alone. If the authors believe this statement, the text should define "robust" and "new".

P755, Line 2-3
Fluxes not useful for decision making? Why not? This statement is inconsistent with the finding.

P755, Line 20-21
Statement about emissions estimates is not true.

P755, Line 12
Statement implies that carbon accounting is not done for forestry, agriculture, and fossil fuels, which is not true.

P757, Line 2-3
A good deal is known about this. What is needed is an understanding of how portions of the public are misled and what can be done to persuade those individuals and groups to trust scientists and scientific institutions.

Chapter 19: Future of the North American Carbon Cycle

Overview/Main Issues

This chapter nicely summarizes current understanding of future changes in carbon fluxes and stocks in North America and over the globe. The chapter also examines the various factors that will control future carbon fluxes/stocks such as climate, atmospheric composition, land use change, nutrient availability, and resource management. Critical carbon cycle vulnerabilities and key research needs are also identified. Finally, this chapter briefly describes the future methane cycle and the improvement of model projections. The Committee has some suggestions on how the chapter can be improved; in particular: the methane cycle deserves more attention; some tables and figures that do not seem fully relevant could be removed; the topic of research to improve terrestrial biosphere/earth system models should be included; and it would be helpful to add a summary/outlook section at the end of the chapter.

Statement of Task Questions

- *Are the goals, objectives and intended audience of the product clearly described in the document? Does the report meet its stated goals?*

The goals and objectives are implicitly referred to in the second paragraph of the Introduction, but it would be better to describe these more explicitly. The report meets the goals that were implicitly mentioned.

- *Does the report accurately reflect the scientific literature? Are there any critical content areas missing from the report?*

This chapter accurately reflects the scientific literature to a large extent. However, the methane cycle (sinks as well as sources) should receive more attention.

- *Are the report's key messages and graphics clear and appropriate? Specifically, do they reflect supporting evidence, include an assessment of likelihood, and communicate effectively?*

Table 19.2 is good. Tables 19.1 and 19.3 do not seem appropriate for this chapter; they might be a reasonable fit for Chapter 2.

Table 19.3 is incomplete particularly for the major drivers of change. The Table should include certainty bounds, and the timeframe for "future' should be specified.

Figures 19.1-19.4 are not necessary or relevant to this particular chapter. These figures may be appropriate for Chapter 1 or Chapter 2.

At first glance, Figure 19.5 suggests negligible trend in the different land cover categories. Could the figure be replotted to highlight the growth of urban areas?

Figures 19.8 and 19.9 are good. Perhaps even more useful to the reader however, would be additional analyses/figures related to projections of carbon stocks and trajectories of the percentage of fossil fuel emissions offset by carbon sinks (focusing on North America and stratifying by country and biome type).

- *Are the research needs identified in the report appropriate?*

The key research needs identified in Section 19.8 are appropriate. We suggest, however, that this section also address the topic of research to improve terrestrial biosphere/earth system models and coastal ocean biogeochemistry models. This is important given the large uncertainty in model simulations and large discrepancies among models.

- *Are the document's presentation, level of technicality, and organization effective? Are the questions outlined in the prospectus addressed and communicated in a manner that is appropriate and accessible for the intended audience?*

The Introduction section provides insufficient information on *why* we need to project the future of the North American carbon cycle. It would be good to have one paragraph focusing on the impacts of the carbon cycle on regional/global climate and one paragraph focusing on the effects of climate change (and other global change agents) on the carbon cycle.

The information presented on p.776 largely looks at the global scale, but given the focus of the SOCCR2 assessment, would it not help to also offer some discussion that focuses specifically on North America, including Canada and Mexico?

The chapter ends rather abruptly. Some sort of summary/outlook section could perhaps be added at the end of the chapter.

- *What other significant improvements, if any, might be made in the document?*

Section 19.2 (*Historical Carbon Cycle Changes*) is not needed, as this has been covered by Chapter 1 and/or Chapter 2. Removing this section will help shorten this chapter.

The methane cycle is only briefly described as a sidebar at the end of the chapter. More attention should be paid to the methane cycle, given that this chapter is about the future of the North American carbon cycle. It would also be nice to include one figure on the future projections of methane fluxes based on published data.

- *Are the key findings in your chapter well stated and supported by the detail provided in the chapter?*

The Key Findings are well stated and supported by the detail provided in the chapter. But it may be best to switch Key Findings 1 and 2, so that fossil fuel comes first, followed by sinks. And Key Finding 4 – Line 6 - need to mention hydrologic changes

Line-Specific Comments

P771, Line 22-25
The ";" should be replaced with ",".

P771, Line 27
The word "that" is needed after "meaning".

P773, Line 20-24
The discussion of CO_2 fertilization should be accompanied by mention of enhanced respiration.

P775, Line 4-15
These are the recent and current impacts of land use/land cover change, rather than changes for the future. Thus they are more appropriate for Chapter 1 and/or 2.

P776, Line 5-10
These results are for the global scale, not for North America. It would be helpful for the authors to also focus specifically on North America (by looking at Canada and/or Mexico).

P776, Line 20-27
Again, why not offer some focus on North America specifically (by touching Canada and/or Mexico), in addition to the global focus?

P777, Line 26
"In summary," should be removed, as the sentence is not a summary of the paragraphs above.

P778, Line 3-18
As above, would be helpful to put this in the context of North America specifically, in addition to the more general global-scale context.

P780, Line 1-38
Here too, this section (19.5.1) could focus on North America, in addition to the focus on the globe in general. It would also be better to use model ensembles to specifically examine the future responses of land carbon cycle to rising atmospheric CO_2 over North America.

P789, Line 15-37
The growing evidence that acidification may put ecological pressure on freshwaters could be cited here (Hasler et al., 2015; Phillips et al., 2015; Weiss et al., 2018).

P791, Line 23 – P792, Line 21
This section lists three sources of uncertainties in models: model structure, model parameterization, model evaluation. While model evaluation is important to discuss, it is confusing to characterize model evaluation itself as a "source of uncertainty". We suggest this list instead discuss 'model inputs' as a source of uncertainty. The SOCCR authors may wish to also consider recently published work that formally separates uncertainty into Model Structure, Internal Variability and Scenarios (Bonan and Doney, 2018; Hawkins and Sutton, 2009; Lovenduski and Bonan, 2017; Lovenduski et al., 2016). Scenarios could potentially be discussed as part of the "model input" category recommended above, and the authors may wish to add a paragraph on internal variability.

P791-792 , Section 19.2
This section should be revised to be more balanced between land and ocean perspectives. In the ocean, uncertainty in the projections of ocean circulation change, in addition to biogeochemical changes, should be mentioned.

P798, Lines 6-12
This section does not adequately explain the expected future slowing of the ocean sink. The current discussion of changing biology in the open ocean has minimal impact on carbon uptake. References such as Randerson et al. (2015) can provide an adequate global context.

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Appendix: Committee Biosketches

DR. INEZ Y. FUNG (NAS) (Chair) is a professor of atmospheric sciences at the University of California, Berkeley. She studies the interactions between climate change and biogeochemical cycles, particularly the processes that maintain and alter the composition of the atmosphere. Her research emphasis is on the global carbon cycle and how CO2 sources and sinks are changing. Dr. Fung is a recipient of the American Geophysical Union's Roger Revelle Medal, and appears in a NAS biography series for middle-school readers, Women's Adventures in Science. She is a fellow of the American Meteorological Society and the American Geophysical Union, as well as a member of the National Academy of Sciences, the American Academy of Arts and Sciences, the American Philosophical Society, and Academia Sinica (Taiwan). She received her SB in applied mathematics and her ScD in meteorology from Massachusetts Institute of Technology. Dr. Fung has served on over a dozen National Academies committees, and is the co-lead author of the 2014 NAS-Royal Society publication "Climate Change, Evidence and Causes".

DR. PETER G. BREWER is an ocean chemist, and senior scientist, at the Monterey Bay Aquarium Research Institute (MBARI). Prior to joining MBARI in 1991 he spent 24 years as a researcher at the Woods Hole Oceanographic Institution, rising to the rank of senior scientist. He served as program manager for Ocean Chemistry at the National Science Foundation (1981-1983), receiving the NSF Sustained Superior Performance Award. He has taken part in more than 40 deep-sea cruises and also has served as chief scientist on well over 100 ROV dives as well as major expeditions worldwide. He is a fellow, and the 2016 Maurice Ewing Medal awardee, of the American Geophysical Union, and of the American Association for the Advancement of Science. Internationally he has served as a lead author for the 2005 IPCC Special Report on CO2 Capture and Storage, as a member of SCOR, and as vice-chair of JGOFS. He has served as a member of the Vice-President Gore's Environmental Task Force, and was a member of MEDEA. He served as president of the Ocean Sciences Section of AGU from 1994-1996. Dr. Brewer holds a "By Courtesy" appointment in the Stanford University Dept. of Geological and Environmental Science. In 2010 he received the Zheng Zhong Distinguished Visiting Fellowship from Xiamen University, and a UK Royal Academy of Engineering Distinguished Visiting Fellowship. He is appointed as an independent scientist to the BP Gulf of Mexico Research Institute (GoMRI) Board overseeing the research devoted to the impacts of the Deepwater Horizon oil release. In 2012 he received an Einstein Visiting Professorship from the Chinese Academy of Sciences, and was made an Honorary Professor at Northwestern Polytechnical University, Xi'an. He serves also on the Major Projects Review Board of the Hong Kong University Grants Committee. Dr. Brewer's research interests are broad, and include the ocean geochemistry of the greenhouse gases. He has devised novel techniques both for measurement and for extracting the oceanic signatures of global change. At MBARI his current interests include the geochemistry of gas hydrates, the biogeochemical impacts of the growing oceanic fossil fuel CO2 signal and the multiple impacts of ocean acidification, and the development of in situ laser Raman spectrometry techniques for real-time measurement in the deep-sea. He served as co-Chair of the NSF Decadal Report Ocean Sciences at the New Millennium, on the US National Methane Hydrates Advisory Committee, and on the IPCC WG II Fifth Assessment Report. He is author, or co-author, of over 170 scientific papers, and the editor of several books. Dr. Brewer has served on several National Academies committees in the past.

DR. EVAN H. DeLUCIA is the G. William Arends Professor of Biology and Baum Family Director at the University of Illinois at Urbana-Champaign. Dr. DeLucia served as the founding director of the Program in Ecology and Evolutionary Biology, the head of the Department of Plant Biology, and the director of the School of Integrative Biology. He was named director for the new Institute for Sustainability, Energy and Environment in 2013. After completing his BA at Bennington College and working as a teaching fellow at Phillips Andover Academy, DeLucia completed a MFS (1982) in forest ecology at Yale University and a PhD (1986) in plant ecology and physiology at Duke University. He joined the faculty at Illinois in 1986, where he was recognized as a University Scholar in 1997. In 1994, DeLucia was a Bullard Fellow at Harvard University and in 2002 he was a Fulbright Fellow at Landcare Research in New Zealand. DeLucia became a fellow of the American Association for the Advancement of Science in 2005 and of the Ecological Society of America in 2015. He is a member of the American Association of Plant Physiologists, the International Union of Forest Research Organizations, the Ecological Society of America, the American Geophysical Union and the American Association for the Advancement of Science. He was elected Chair of the Physiological Ecology Section of the Ecological Society (1996-98). He currently provides editorial services for several prominent journals, including Ecology, Oecologia, Tree Physiology, and Global Change Biology. How the use and management of land affects the climate system, and the responses of forest and agro-ecosystems to elevated carbon dioxide and other elements of global change are at the center of DeLucia's research interests. Using ecological, physiological and genomic approaches, DeLucia seeks to understand how global change affects the carbon cycle and the trophic dynamics between plants and insects. DeLucia previously served as a committee member for the review of the 2013 National Climate Assessment Report with the National Academies.

DR. DAVID L. GREENE is a senior fellow of the Howard H. Baker, Jr. Center for Public Policy and a research professor of Civil and Environmental Engineering at The University of Tennessee. In 2013 he retired from Oak Ridge National Laboratory as a corporate fellow after 36 years researching transportation and energy policy issues. Much of his research is concerned with the effectiveness and impacts of fuel economy and greenhouse gas emissions standards. He served on four National Research Council (NRC) committees evaluating the Corporate Average Fuel Economy Standards between 1990 and 2015. Other areas of research interest include alternative fuels, the costs of oil dependence and the transition to low carbon energy in transportation. From 2011 to 2012 he served on the NRC's Committee on Transitions to Alternative Vehicles and Fuels. In all, he has served on more than a dozen NRC and Transportation Research Board (TRB) special committees and is a member emeritus of the TRB's standing committees on Energy and Alternative Fuels. He has testified to the U.S. Congress concerning transportation and energy issues on a dozen occasions. Author of over 100 peer-reviewed journal articles and over 275 professional publications, he is a Lifetime National Associate of the National Academies and recipient of the Transportation Research Board's Roy W. Crum Award. He was recognized by the Intergovernmental Panel on Climate Change for contributing to the award of the 2007 Noble Peace Prize to the IPCC. He holds a PhD in geography and environmental engineering from The Johns Hopkins University as well as degrees in geography from the University of Oregon (MA) and Columbia University (BA).

DR. TESSA M. HILL is an associate professor and Chancellor's fellow at the University of California, Davis, in the Department of Earth & Planetary Sciences. She is resident at UC Davis Bodega Marine Laboratory, a research station on the northern California coast. Dr. Hill graduated with a BS in Marine Science from Eckerd College (1999) and a PhD in Marine Science from UC Santa Barbara (2004). She was then a UC President's postdoctoral fellow at UC Davis, prior to starting a faculty position. Her research interests include climate change, both past and present, and understanding the response of marine species to environmental perturbation. She is part of the Bodega Ocean Acidification Research (BOAR) group at Bodega Marine Laboratory, which aims to understand the impact of ocean acidification on marine species. Dr. Hill leads an NSF-supported program with future (pre-service) K-12 science teachers to infuse their classrooms with climate change science, and an industry-academic partnership to understand the consequences of ocean acidification on shellfish farmers. Her work has been featured in a variety of mass media outlets (e.g., NPR, The New York Times, Al Jazeera America, Science Friday). She has served as an associate director of the UC Davis Coastal & Marine Sciences Institute since 2013. She is a fellow of the California Academy of Sciences, a AAAS Leshner Public Engagement Fellow, and a recipient of the Presidential Early Career Award for Scientists & Engineers (PECASE). Dr. Hill has yet to serve on a National Academies committee.

DR. HENRY D. JACOBY is the William F. Pounds Professor of Management (emeritus) in the Sloan School of Management and former co-director of the Joint Program on the Science and Policy of Global Change, both at the Massachusetts Institute of Technology (MIT). His work has focused on the integration of the natural and social sciences and policy analysis in application to the threat of global climate change. Previously, he served on the faculties of the Department of Economics and the Kennedy School of Government, both at Harvard University. He has also served as director of the Harvard Environmental Systems Program, director of the MIT Center for Energy and Environmental Policy Research, associate director of the MIT Energy Laboratory, and chair of the MIT faculty. He has an undergraduate degree in mechanical engineering from the University of

Texas at Austin and a PhD in economics from Harvard University. Dr. Jacoby currently serves as a member of the National Academies' Committee to Advise the USGCRP and has served on several other committees in the past.

DR. GARY S. MORISHIMA is the natural resources technical advisor to the president of the Quinault Nation, an affiliate professor at the University of Washington, and CEO of MORI-ko, LLC, a natural resources consulting firm. With expertise in modeling, statistical analysis, natural resource management, and policy analysis, he has been called upon to participate in domestic and international legislative, administrative, judicial, and educational processes. He recently served on the Department of the Interior's Advisory Committee on Climate Change and Natural Resource Science. Dr. Morishima has authored numerous publications relating to natural resource manangement and holds a PhD in quantitative science and environmental management from the University of Washington. Among the honors he received are a Pride in Excellence Award from the Boeing Company and Outstanding National Forester from the Intertribal Timber Council. Dr. Morishima has yet to serve on a National Academies committee.

DR. J. WILLIAM MUNGER is a senior research fellow in atmospheric science at the Harvard University School of Engineering and Applied Sciences. His work focuses broadly on the carbon cycle and air pollution. Current projects include managing a long-term observatory for forest-carbon exchange at the Harvard Forest Long-term Ecological Research site, and collaborating with partners in China to observe CO2 emission and exchange with vegetation at a rural Chinese site. Additionally he is part of the Arctic-Boreal Vulnerability Experiment with a project to quantify how CO2 and CH4 exchange in the arctic is responding to climate change. Dr. Munger received his MS from University of Minnesota in 1981 studying environmental controls of acid precipitation. He received his PhD from California Institute of Technology in 1989 studying the chemical composition of fog and clouds. Dr. Munger has yet to serve on a National Academies committee.

DR. DAVID S. SCHIMEL is currently a senior research scientist at the Jet Propulsion Laboratory, leading research focused on carbon-cycle climate interactions, combining models and observations. For the previous five years, Schimel led the National Ecological Observatory Network project where he was responsible for the top-level science design, site selection, and observing system simulations. From 2001-2007, Schimel was at the National Center for Atmospheric Research as a senior scientist, with research focused on assimilation of carbon cycle data in land and atmospheric models. From 1998-2001, Schimel served as founding co-director and managing director of the Max Planck Institute for Biogeochemistry in Jena, Germany. Schimel served as convening lead author for the first IPCC assessment of the carbon cycle. He has served as an IPCC CLA four times, and as a lead author twice. From 1988-1989, Schimel was an NRC Fellow at NASA Ames. He received his PhD from Colorado State University in 1982 and has served on a number of NRC committees since 1992.

DR. KATHLEEN C. WEATHERS is the G. Evelyn Hutchinson Chair of Ecology at the Cary Institute of Ecosystem Studies. She received her master's degree from Yale University and Ph.D. from Rutgers University. Weathers carries out biogeochemical research in ecosystems around the world focusing on carbon, nitrogen, sulfur, and other elemental cycling in the context of how biology affects geochemistry and biogeochemical cycling across heterogeneous landscapes, and within and among multiple systems (air-land-water). Specific topics have included quantifying cross-boundary nutrient fluxes and their impact on ecosystem processes (e.g., nutrient and pollutant delivery and biogeochemistry from ocean to forest); how landscape and plant structure affect fog inputs and how fog affects the biotic and abiotic maintenance of ecosystems; the importance of tree species, and their pests and pathogens, in controlling landscape biogeochemistry; and the effect of cyanobacteria on oligotrophic lake resilience. Dr. Weathers is an elected a Fellow of the American Association for the Advancement of Science (AAAS) and the Ecological Society of America (ESA). She is co-chair of the grassroots Global Lakes Ecological Observatory Network (GLEON; www.gleon.org).

DR. JINGFENG XIAO is currently a research associate professor at the Earth Systems Research Center, University of New Hampshire. Dr. Xiao's research interests include terrestrial carbon cycle, remote sensing, ecological modeling, vegetation dynamics, land cover/land use change, disturbances, and human-environment interactions. He is particularly interested in understanding the impacts of climate variability and change, land cover/land use change, and disturbances on terrestrial carbon cycling as well as their feedbacks to the climate over various spatial and temporal scales. He combines remote sensing, ecological modeling, field measurements (e.g., eddy covariance measurements), model-data fusion, and statistical analysis to answer important carbon cycle and climate change related questions. Dr. Xiao earned his PhD in global ecology from the Department of Geography at the University of North Carolina at Chapel Hill in 2006, MS in remote sensing from the Institute of Remote Sensing & GIS at Peking University in 2000, and BS in physical geography at the Department of Geography, Lanzhou University. He was a post-doc at Purdue University from 2006 to 2008 and a research associate at the Pennsylvania State University from 2008 to 2009. Dr. Xiao has not yet served on a National Academies committee.

DR. ZICHENG YU is a professor in the Department of Earth and Environmental Sciences at Lehigh University. He is a paleoecologist and paleoclimatologist, with research interests in understanding past climate change, peatland carbon dynamics, and carbon cycle–climate connections, in particular in high latitude and high altitude regions. He has led field research in Alaska, the Tibetan Plateau, Kamchatka, western Canada, Patagonia and the Antarctic Peninsula, studying carbon accumulation and climate sensitivity of peat-forming ecosystems. He has served on proposal review panels in the National Science Foundation. Over the last decade, he has worked on global peatland carbon data synthesis, and he now serves as a leader of PAGES (Past Global Changes) C-PEAT (Carbon in Peat on Earth Through Time) Working Group. Dr. Yu received his PhD in Botany from University of Toronto (Canada) in 1997 and BS from Peking University (China). Dr. Yu has not yet served on a National Academies committee.