Lifecycle Greenhouse Gas Emissions due to Increased Biofuel Production

Methods and Approaches to Account for Lifecycle Greenhouse Gas Emissions from Biofuels Production Over Time

Peer Review Report

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Introduction

Background of Timing of Emissions Analysis

The United States Environmental Protection Agency (EPA) has undertaken a lifecycle assessment of the greenhouse gas (GHG) emissions associated with increased renewable fuels production as part of the proposed revisions to the National Renewable Fuel Standard (RFS) program. The Energy Independence and Security Act of 2007 (EISA) set the first-ever mandatory lifecycle GHG reduction thresholds for renewable fuel categories. The Act requires EPA to conduct a broad lifecycle analysis of expanded biofuel use, including emissions associated with indirect land use changes.

Several new pieces of analysis were developed to support this lifecycle assessment. A key component of the analysis is the issue of timing of GHG emissions and reductions. GHG emissions associated with gasoline or diesel are likely to be released over a short period of time, whereas GHG emissions from biofuels production may continue for a much longer period of time. The peer review detailed in this report looks at EPA's methods and approaches for discounting emissions over time to ensure comparability of biofuels to other fuels.

Evidence suggests that biofuel-induced land use change produces significant near-term GHG emissions, with displacement of petroleum by biofuels over subsequent years in effect "paying back" earlier land-conversion impacts. Therefore, it is critical to select an appropriate time horizon over which to analyze emissions and apply a proper discount rate to value near-term versus longer-term emissions. EPA highlights two options. Option one assumes a 30-year time period for assessing future GHG emission impacts and equally values all emission impacts regardless of time emitted (a 0% discount rate). Option two assesses emission impacts over a 100-year time period and discounts future emissions at 2% annually. Additional variations of the time period and discount rate are discussed in the proposed rule and peer review charge questions. This peer review focuses on time frames and discount rates proposed by EPA, appropriate criteria to select those parameters, and subsequent questions.

Background of Peer Review and Overview of Results

From May to July 2009, EPA arranged for several peer reviews to be conducted regarding aspects of its revisions to the RFS. Each of these reviews focused on the projection of emissions from indirect land use changes associated with increased fuel production as specified by EISA 2007. ICF International, an independent third-party contractor, coordinated the peer reviews and adhered to EPA's "Peer Review Handbook "(3rd Edition).

The peer review summarized here focuses in particular on the selection of a time frame and discount rate to calculate GHG emissions associated with the direct and indirect effects of biofuel production.

EPA's work assignment requesting the peer review required that peer reviewers be established and published experts with knowledge of the following topics:

- Development of GHG emissions estimates
- Estimation of benefits of emissions reductions over time (discounting)
- Lifecycle assessment

Using these criteria, the contractor developed a list of qualified candidates from the public, private, and academic sectors. The contractor compiled candidates from the following sources: (1) contractor experts in this field with knowledge of relevant professional society membership, academia, and other organizations; (2) Internet searches; and (3) suggestions from EPA.

Approximately 15 qualified individuals were initially identified as candidates to participate in the peer review. Each of these individuals was sent an introductory screening email to describe the needs of the peer review and to gauge the candidate's interest and availability. Also, candidates were asked to disclose any real or perceived conflicts of interest (COI) or other matters that would create the appearance of a conflict of impartiality. Candidates also were asked to provide an updated resume or curriculum vitae (CV). The contractor reviewed the responses and COI statements and evaluated the resume/CV of individuals who were interested for relevant experience and demonstrated expertise in the above areas, as demonstrated by educational degrees attained, research and work experience, publications, awards, and participation in relevant professional societies.

A number of candidate reviewers were unable to participate in the peer review due to previous commitments or real or perceived conflicts of interest. The contractor reviewed the remaining qualified candidates with the following concerns in mind. As stated in EPA's Peer Review Handbook, the group of selected peer reviewers should be "sufficiently broad and diverse to fairly represent the relevant scientific and technical perspectives and fields of knowledge; they should represent balanced range of technically legitimate points of view." As such, the contractor selected peer reviewers to provide a balance of complimentary economic, policy, and technical perspectives by including experts with expertise, knowledge, skills, and experience in each of those fields. In addition, balance was sought by including experts from both academic and non-profit backgrounds. The contractor submitted the proposed peer reviewers to EPA. In accordance with the EPA Peer Review Handbook, EPA reviewed the list of the selected reviewers with regard to conformance to the qualification criteria in the contractor's work assignment, which was established prior to the reviewer selection process. EPA concurred that all of the contractor's peer review selections met the qualification criteria.

The contractor contacted the following five peer reviewers who agreed to participate in the peer review:

1. Dr. Joseph Fargione, The Nature Conservancy
2. Mr. Ralph Heimlich, Agricultural Conservation Economics
3. Dr. Elizabeth Marshall, World Resources Institute
4. Dr. Jeremy Martin, Union of Concerned Scientists
5. Dr. Kenneth Richards, Indiana University

In addition to the initial COI screen mentioned above, the contractor asked the peer reviewers to complete a conflict of interest disclosure form that addressed in more depth topics such as employment, investments/assets, property interests, research funding, and various other ethical issues. The Peer Review Handbook acknowledges that "experts with a stake in the outcome – and therefore a conflict or an appearance issue – may be some of the most knowledgeable and up-to-date experts because they have concrete reasons to maintain their expertise," and that these experts may be used as peer reviewers if COI or the appearance of the lack of impartiality is disclosed. However, upon review of each form, the contractor and EPA determined that there were no direct and substantial COI or appearance of impartiality issues that would have prevented a peer reviewer's comments from being considered by EPA.

EPA provided reviewers with an excerpt from the May 5, 2009 proposed rule preamble, additional materials detailing EPA's lifecycle analysis, and charge questions to guide their evaluation. The charge questions were divided into four sections. The first set of questions concerned EPA's overall approach, the second set addressed time frames, the third set addressed the valuation of future GHG emissions, and the fourth set addressed other methodological considerations.

The main issues addressed in the peer review included (but were not limited to):

- EPA's approach to the GHG lifecycle analysis
- EPA's approach to accounting for lifecycle GHG emissions over time (e.g., applying "project" and "impact" time frames)
- EPA's approach to valuing future GHG emissions (e.g., choosing and using "discount rates")
- EPA's use of a snapshot approach versus a more dynamic year-by-year approach (e.g., "scenario analysis")

Most peer reviewers generally agreed that the approach taken by EPA was scientifically objective. However, Dr. Marshall commented that it was difficult to determine whether selection of the parameters followed a scientifically objective process because the discussion within the rulemaking documentation did not provide enough depth to justify the time accounting scenarios proposed. The reviewers' opinions of appropriate time frames varied considerably. Reviewers disagreed on whether EPA should use an impact time frame—the length over which to account for the changes in GHG emissions, in particular due to land-use changes, which result from biofuel production—or project time frame—how long production of a particular biofuel is expected to continue into the future. Reviewers also disagreed on what duration the various time frames should have. Some recommended that EPA use both a project and an impact time frame within the analysis, and some introduced the concept of a "rolling" time frame. Reviewers offered time frame lengths ranging from 13 to 100 years. More detail on the methodological approaches the reviewers felt were justifiable can be found in the summary of their preliminary remarks and their response to the specific charge questions below (as well as in their un-summarized responses provided in the Appendices).

Peer reviewers also had different opinions on the appropriateness of weighing emissions by applying a discount rate. All reviewers noted in some way that a discount rate should only be applied to a monetary unit, rather than a physical unit such as a carbon emission, although they acknowledged that since EPA was considering emissions to be a proxy for damages applying a discount rate was possible. Peer reviewers offered suggested discount rate values ranging from 0% to 7.9%.

Regarding other methodological considerations, reviewers tended to agree that EPA's snapshot approach was preferable to a dynamic, year-by-year approach. Some said that the year-by-year approach would significantly increase the complexity of the method, with questionable added clarity.

The following section includes summaries of the peer reviewer responses to the charge questions. The set of charge questions can be found in Appendix A. Some reviewers answered the questions at their broadest level, while others answered all or many of the sub-questions. Due to the varying format of the responses, responses are grouped as peer reviewers tended to address the issues rather than exactly how they were laid out in the original charge in cases where this seemed more intuitive.

The following section includes summaries of the peer reviewer responses to each charge question. The set of charge questions can be found in Appendix A and the full text of the peer reviewers' written responses can be found in Appendices B-F.[1] The peer reviewers' curricula vitae can be found in Appendix G. Peer reviewers were instructed to work independently and comments made by peer reviewers are individual opinions and do not represent the views of their affiliated organizations.

[1] Typographical errors in original peer review responses were corrected where noticed.

Peer Reviewer Responses to Charge Questions

Preliminary Remarks

Three of the five peer reviewers included preliminary remarks with their answers to the charge questions. A summary of those remarks is presented below.

Preliminary Remarks from Mr. Heimlich

Mr. Heimlich first described EPA's analytical problem and the purpose of the lifecycle analysis, and then laid out a conceptual framework. He explained that if EPA interprets EISA literally, then emissions are regarded as physical quantities with no relationship to valuation. In contrast, if EPA interprets EISA broadly, then emissions are a proxy for climate change damages. If this is the case, emissions "can be viewed in a valuation framework because the value of avoiding those damages sooner rather than later changes over time." Mr. Heimlich agreed with the broader interpretation, but emphasized that EPA's interpretation of the law was a matter for legal scholars.

If EPA assumes that emissions are a proxy for damages, Mr. Heimlich said that it was uncertain just how good a proxy those emissions would be. He clarified that some complexities were not fully accounted for by global warming potential (GWP) factors, such as the effects of carbon stock in the atmosphere and the decay rates of atmospheric GHGs on global warming.

Mr. Heimlich cited the Intergovernmental Panel on Climate Change (IPCC) formulation for a physical emission metric and went into considerable detail on calculating relative GWP (see Appendix C). He recommended that EPA "lay out which gases are emitted, in what year of the scenario, the cumulative effects of the decay of the emissions over the time path, and their impact on radiative forcing over their lifetimes." He said that the simplified process EPA used to calculate soil-carbon losses from land use change (averaging emissions over time and then distributing them along a time path in equal segments) was misleading and counterproductive. Instead he suggested using the revised Bern carbon cycle model, which accounts for the decay of CO_2 over time, and similar modeling for methane and nitrous oxide components of emissions.

Mr. Heimlich addressed selecting a time frame. Should EPA choose to consider emissions as a proxy for damages, he said the appropriate time frame should relate to the timing of those impacts rather than the timing of the project. He did not give a specific value for the time frame rather he commented that the damages should be adjusted to as closely mirror the damaging impact as possible. He advised against including speculations about the future of the renewable fuels industry, as this did not actually bear on the per-unit differences in impacts and would only add speculation to the analysis.

In conclusion, Mr. Heimlich wrote, "if EPA is using a time horizon long enough to encompass all the impacts from the 2022 level of production and resultant emissions from indirect land use change (including all emissions from land clearing and sequestration foregone), it should lay out those emissions as accurately as possible on their true time path, adjust them for their climate change potential using modeling like an improved version of fuel warming potential (FWP), and discount those adjusted emissions back to present terms using a non-zero discount rate that reflects the uncertainty in the estimate of the damages."

Preliminary Remarks from Dr. Martin

Dr. Martin stressed that EPA should distinguish between what is technically plausible and what is practical for the RFS regulation. He noted that the approach should minimize uncertainty and the use of speculative future scenarios as much as possible, but also be broad enough to capture a representative view of the impacts of fuel production.

Dr. Martin discussed selecting a time frame. Instead of selecting a long time frame with a high level of uncertainty, he approved using a short time frame confined to the foreseeable future. Specifically, he suggested using a time frame consistent with the expected lifetime of a fuel processing facility, and provided evidence supporting this suggestion.

Dr. Martin also discussed discounting. He argued that EPA had no basis to discount emissions in the RFS, because the language in EISA "clearly calls for a physical rather than an economic analysis." He did not believe that Congress intended to delegate significant decisions (such as the social cost of carbon and matters of intergenerational equity) to EPA within the context of defining a metric for RFS compliance. However, Dr. Martin did say that the use of GWP methodology to adjust simple mass values of emissions should be permissible.

Dr. Martin described the FWP methodology, which aggregates emissions over time into a metric for compliance with carbon intensity-based fuel regulations. He noted that the FWP methodology would still require selection of project and impact time frames. Regardless of the time frames selected, he maintained that fuel usage patterns and emissions from land use change should be limited to the project time frame to reduce uncertainty. However, biogeochemical processes, which are comparatively predictable, could be included in the time between the project and impact time frame.

Dr. Martin emphasized that adopting the FWP with equal impact and project time frames would ensure that "projects actually achieve reductions in cumulative radiative forcing (CRF) by the conclusion of the project." He urged EPA to recognize that "swift and deep reductions" of GHG gasses are essential to prevent catastrophic and irreversible climate change impacts. He cited peer-reviewed studies suggesting that global warming damage was happening faster than predicted by the IPCC. A complete discussion of those studies can be found in Appendix E.

Finally, Dr. Martin noted that while the FWP is a sensible approach, a 30-year time frame with a zero discount rate is also technically sound. Additionally, if EPA does choose to apply a discount rate, Dr. Martin argued that discounting radiative forcing is preferable to discounting emissions.

Preliminary Remarks from Dr. Richards

Dr. Richards stated that it was impossible to fulfill EISA's requirement to make a precise determination of the reduction in GHG emissions associated with each biofuel relative to petroleum, as there were too many unknowns in the process. However, he complimented EPA's understanding of the conceptual and practical issues involved.

Dr. Richards addressed selecting a time frame. He noted that the appropriate time frame is the period over which any affects might be felt, which in theory should be infinite. However, an infinite time frame presents practical issues. Instead, a discount rate can allow for a relatively shorter impact time period. He explained that "in evaluating the present value of a stream of annual benefits at a 10 percent discount rate, the difference between going out to 60 years versus 100 years is miniscule—less than 0.3 percent—virtual noise given the level of uncertainty. At a 2 percent discount rate the difference is quite a bit more."

Dr. Richards also addressed discounting. He stressed that the value of the carbon benefits, not the physical quantity itself, should be discounted. However, assessing the value of a unit of carbon emissions requires defining the damage function for a range of atmospheric concentrations of GHGs and defining the time path of concentrations, which is beyond the scope of the biofuels analysis exercise. He also encouraged EPA to keep separate the economic discount rate, the decay rate for the atmospheric residence time of gases, and the changing marginal damage function of emissions, to help both the analyst and the audience to remember the meaning of each operation.

Dr. Richards discussed the appropriate value of a discount rate. He said the discount rate should reflect society's positive and negative trade-offs between current and future impacts. The discount rate could address risk/uncertainty, the rate of time preference for consumption, as well as the rate of return on other available public endeavors. Dr. Richards demonstrated why a zero-value discount rate was incorrect, noting that "if [the emissions reductions project] doesn't matter when it is done, it doesn't matter whether it is done." He concurred with EPA's approach of using sensitivity analysis to determine the most appropriate discount rate.

Dr. Richards mentioned that analysts tend to assume constant marginal damages for emissions to simplify their analysis. However, constant marginal damages can give the appearance of discounting physical units, because all physical units have the same value under this assumption.

Dr. Richards summarized the prescribed approach, as noted below:

1. Choose a time horizon sufficiently long to accommodate all significant impacts. As a practical matter, the horizon can be shortened for higher discount rates.
2. Assume that the marginal damages associated with emissions will be constant over the horizon—not because this is accurate, but because it is easy and just as defensible as any other assumption.
3. Choose three discount rates that will allow testing of the sensitivity of the results to this necessarily controversial parameter. He would suggest, 2, 3, and 5 percent, but that is a matter of judgment.

After a consistent analytical approach is developed, Dr. Richards explained that EPA must complete a scenario analysis. To do so, EPA should choose of number of scenarios that seem plausible for each fuel/production approach and run all the scenarios over the full length of the time frame at the different discount rates. Dr. Richards acknowledged that the scenario analysis approach was "less precise than may seem to be called for by EISA," however he argued that it is the best approach, and that it "should stand up to both policy and legal challenges."

Dr. Richards described an oddity with EPA's sensitivity analysis. He noted that often sensitivity analyses concentrate on the extremes (the sets of parameters that are most and least favorable to a particular hypothesis). He was surprised that the EPA report combined a long frame with a higher discount rate and a shorter time frame with a lower discount rate. To examine the full range of outcomes, he suggested that this be reversed.

Dr. Richards concluded by reminding EPA that there is no such thing as a "scientifically objective" method for lifecycle analysis, because the work requires a great deal of judgment.

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[2]

A. Framing the Issues

Charge Questions 1 and 2
The preamble and RIA separates the discussion of how to account for the variable timing of transportation fuel lifecycle GHG emissions into different components: time frame, discount rate (or the relative treatment of current and future GHG emissions), and appropriate metrics. Is this a scientifically objective way to frame the analysis of lifecycle GHG impacts of different fuels in the context of what is needed for this rulemaking?

All peer reviewers agreed that EPA appropriately approached the GHG impacts lifecycle analysis of biofuels in the context of this rulemaking. However, Dr. Marshall commented that it was difficult to determine whether selection of the parameters followed a scientifically objective process because the discussion within the rulemaking documentation did not provide enough depth to justify the time accounting scenarios proposed. Dr. Martin and Mr. Heimlich urged EPA to show the interactions between time frame, discounting, and appropriate metrics. Mr. Heimlich further suggested that the discussion begin with appropriate metrics, as this factor narrows the choices for timing and discount rate. He emphasized that the framework would also be dependent on EPA's interpretation of EISA 2007. For example, a strict interpretation of EISA (one where emissions are purely physical units and not proxies for damages) would not support the economic concept of discounting. However, if EPA interprets EISA more broadly to consider emissions as a proxy for potential damages from warming, a discount rate could be appropriate.

Dr. Marshall responded that a proper approach is not based on the mere recognition of the time frame, discount rate, and metrics components, but the selection of values for those components. She claimed that the rulemaking documentation did not provide an in-depth analysis to justify the proposed time accounting scenarios, so it was difficult to determine if the selection of those perimeters followed a "scientifically objective" process.

[2] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

Charge Questions 1, 1a, 1b, and 2
As explained in the preamble and RIA, the time frame for analyzing lifecycle GHG emissions can be approached in different ways, such as:

a. ***Project time frame—how long we expect production of a particular biofuel to continue into the future***
b. ***Impact time frame—the length over which to account for the changes in GHG emissions, in particular due to land use changes, which result from biofuel production***

Do the preamble and RIA define these time frame concepts in a scientifically objective way for lifecycle analysis? What other concepts, if any should be considered?

Three of the five peer reviewers (Dr. Marshall, Dr. Fargione, and Dr. Martin) asserted that it was technically reasonable to consider the "project time frame" and the "impact time frame" separately in a comprehensive accounting methodology. Dr. Fargione elaborated that the most appropriate way to implement a lifecycle analysis is to "consider the change in emissions caused by actions taken over the time frame of a project, but consider the impact of these emissions over a longer 'impact time frame'."

A couple of peer reviewers agreed that the terms were clearly defined, but submitted additional clarification. Dr. Richards agreed that EPA clearly defined the terms "project time frame" and "impact time frame," but argued that these terms have no role in the analysis of the scenarios. He elaborated in his comments to subsequent charge questions that time frame and scenario building were being confused, and that the scenario design should address issues like when each fuel is likely to be priced out of the market. Mr. Heimlich stated that "project time frame" and "impact time frame" are more scientifically justifiable terms than "the fixed and arbitrary (but customary) 100- and 30- year periods" primarily discussed in the preamble. He believed that the idea of an "impact" time frame is inherently better defined, because reasonable assumptions could be made about the time frames under which those impacts would play out. In contrast, the "project time frame" was more difficult to define, because the RFS mandate extends to 2022 with no assurance of any market beyond that date. Mr. Heimlich cautioned against predicting the production of biofuels beyond 2022, noting that the regulation and related subsidy programs heavily influence renewable fuels markets in the United States.

Dr. Martin offered input on criteria to include within an impact time frame. He suggested that relatively predictable changes, such as biogeochemical considerations, be considered in an impact time frame. More unpredictable changes, such as land use and fuel emissions, should be considered for only the more foreseeable time frame.

Dr. Marshall introduced a new concept of a rolling impact horizon and compared it to EPA's impact horizon. The rolling impact horizon reflects "how long a unit of emissions, once it enters the atmospheric carbon stock, continues to significantly contribute to warming and the damages caused by that warming." In a rolling horizon, the impacts of a unit of emissions are measured over the same number of years, regardless of when that emission was released. In contrast, fixed horizons stop measuring the impacts of emissions at a fixed point, so the impacts of emissions in later years are analyzed over fewer years than the impacts of emissions in earlier years. Dr. Marshall explained the limitations of a fixed impact horizon (see Appendix D).

Dr. Marshall emphasized that the impact horizon she described is different from EPA's impact horizon, which is not an atmospheric impact horizon, but rather a "time horizon over which land use change emissions are measured that is distinct from the time horizon over which other project-related emissions (and emissions reductions are measured)." EPA's impact horizon captures the longer-term indirect land-use repercussions that can arise from disturbances in the market associated with the inception of biofuels production. She termed this the "secondary impact horizon" because its purpose is to capture the secondary (or indirect) emissions associated with land use change.

Dr. Marshall presented a figure of the impact horizon with the project horizon, and asserted that appropriate GHG accounting for biofuels must recognize the distinction between these time horizons (see Appendix D). Finally, she acknowledged the relevance of the "secondary impact horizon," but said it was likely that "the project horizon is long enough to accommodate the full impacts, including indirect impacts, of the original land use change decision, and that the specification of a separate secondary impacts horizon may be an unnecessary complication."

B. Determination of Project Time Frame(s)

Charge Question 1
What is a scientifically justifiable project time frame to consider for this analysis? Should the project time frames be different for each fuel?

Peer reviewers suggested project time frames ranging from 13 to 100 years. These time frames were based on the expiration of the EISA mandate, the life of a fuel production facility, the expected duration of fuel production, and the span of the project-related impacts.

Dr. Fargione and Mr. Heimlich asserted that considering a project time frame out to 2022 (the end of the EISA mandate) is the most reasonable. In Dr. Fargione's opinion, determining the project time frame is a policy question, not a science question, and he believed that extending the project time frame to include fuels produced after 2022 seems to violate the spirit and letter of the law. Mr. Heimlich argued that "EPA and others in Washington D.C. are making the market for renewable fuels" and doubted that any economic analysis could predict biofuels market futures beyond 2022.

Dr. Martin said a scientifically justifiable project time frame would be based on the expected life of the fuel production facility. Dr. Fargione supported this as an alternative option to the 2022 mandate. The peer reviewers agreed that the life of a fuel production facility is likely 20–30 years, but no more than 30 years.

Dr. Marshall stated that the project time frame should be determined based on an assessment of how long the fuel is expected to be produced, which could vary by fuel technology. In the absence of economic modeling, she said a 30-year time frame would be consistent with prior work based on estimates of refinery life spans. However, she pointed out that some groups have argued for a shorter project time frame based on predicted technological developments leading to displacement of biofuels in the marketplace.

Dr. Richards suggested that each scenario use a 100-year time frame for consistency, and emphasized that the time frame should cover all impacts from the outset of the project. He also noted that the time frame could be shortened when applying higher discount rates, because "the difference in present value between 60 years and 100 years of annual benefits is quite small at higher discount rates."

Peer reviewers also expressed differing opinions on whether time frames should vary by fuel. Dr. Marshall implied that different fuels could have different project time frames, while Drs. Martin and Richards maintained that the same project time frame should be used for each fuel. Dr. Martin added that different facility lifetimes across fuel types would add an unnecessary level of speculation and would make it difficult to compare the impacts of the fuels, which is a key reason to have a common metric. Other peer reviewers did not comment on this issue.

Charge Question 1a and 1a(i)
What are the proper criteria for determining the project time frame?
(i): Should the project time frame be based on when each fuel is likely to be priced out of the market? Should the project time frame be based on the EISA fuel mandates? What other criteria would you recommend, if any?

Peer reviewers recommended the following criteria for determining the project time frame: project time frames defined in the EISA fuel mandates; expected lifetime of a fuel production facility; expected length of biofuels production; time frames that cover all project impacts; and other factors that are expected to impact production, such as expected market conditions, projected advances in second-generation biofuels technology, projected advances in alternative automotive technologies, and additional fuel mandates. Dr. Martin emphasized that all criteria should be concrete and in the foreseeable future.

Two peer reviewers opposed selecting the project time frame based on the point when each fuel is likely to be priced out of the market. Dr. Fargione did not support this idea, noting that this point will be based largely on policy decisions and technological breakthroughs, making it essentially impossible to predict. Similarly, Mr. Heimlich advised EPA against assuming that renewable fuels will be produced beyond 2022, as this introduces "heroic assumptions, with even more heroic uncertainties, about the future of renewable fuels beyond 2022." He noted that EPA was tasked with comparing the relative emissions of renewable fuels and fossil fuels on a unit basis, so it should suffice to quantify the emissions associated with the 2022 volumes.

Dr. Richards claimed that EPA was confusing time frame with scenario building. He explained that the issue of exit from the market should be included in the scenario design. Specifically, he suggested that EPA run a scenario for the exit of corn ethanol from the market. He reiterated that the time frame should remain 100 years.

Charge Question 1b, 1b(i), and 1b(ii)
What is the best scientific method for determining the project time frame or frames?
(i): Is economic modeling the best method for determining the project time frame? If so, what specific models do you recommend for this analysis?
(ii): If you do not recommend economic modeling, what other methods do you suggest?

Four of five peer reviewers did not support the use of economic modeling to determine project time frame, offering various reasons for their opposition. Two peer reviewers explained other ways in which economic modeling could be useful.

The four peer reviewers who did not support the use of economic modeling cited various reasons for their opposition. Mr. Heimlich and Dr. Fargione did not believe economic modeling could reasonably conclude much about fuel market futures beyond 2022 because the market will be influenced largely by policy decisions on biofuels subsidies, tariffs, and import exclusions, as well as technological breakthroughs in alternative fuel pathways such as electric and hydrogen. Dr. Martin stressed that using economic modeling to predict the outcome of competition between different fuels, some of which are not yet commercialized, would add a considerable and avoidable level of speculation to the analysis. He emphasized this point by noting that the NEMS model produces significantly different results depending on the underlying technology assumptions and biomass supply curves. Dr. Richards said that economic modeling would not determine time frame.

Two peer reviewers offered alternative uses for economic modeling. Dr. Richards said economic modeling could help EPA determine scenarios that should be tested and assign likelihoods to those scenarios. He recommended running each scenario with a 100-year project time frame. Dr. Martin said that economic modeling could help to inform the decision about the lifetime of a fuel production facility, but stressed that ultimately a single duration should be applied across all fuel types.

Dr. Marshall, on the other hand, believed economic modeling is an appropriate way to estimate a project time frame. She said the model should take into account all factors that are expected to impact the production of first-generation biofuels, including expected market conditions, projected advances in second-generation biofuels technology, projected advances in alternative automotive technologies, and fuel mandates that are predicted to drive the market.

C. Determination of Impact Time Frame

Charge Question 1
What is a scientifically justifiable impact time frame to consider for this analysis? Should the impact time frame be different for each fuel?

Peer reviewers offered a variety of impact time frames from 20–30 years—to reflect the project time frame—to 100 years—to reflect the IPCC GWP time frame—with various qualifications. Some described criteria that should be taken into account, but did not offer specific time frames.

Dr. Martin responded that the impact time frame depended upon the metrics. If only emissions are being considered, then there is no need for an impact timeline to go beyond the project time frame of 20–30 years. If the FWP methodology were adopted, a longer impact time frame would be appropriate to maintain consistency with the IPCC-recommended 100-year GWP time frame. However, given the potential for irreversible impacts from climate change, Dr. Martin said it would be “reasonable and advisable” to use an impact time frame shorter than 100 years, to ensure that actual reductions are achieved by an earlier date.

Dr. Richards, Dr. Marshall, and Mr. Heimlich wrote that a scientifically justifiable impact time frame should be selected based on estimated climate impacts. Each elaborated on that notion in unique ways. Dr. Richards noted that the period capturing all significant impacts could be “quite long”, but did not provide a specific estimation. Dr. Marshall, citing Fearnside (2002),[3] wrote that climate scientists and thinkers have generally settled on a 100-year impact time frame, which is consistent with IPCC’s GWP 100-year impact time frame. However, she said the impact time frame used should be the one described in her peer review, rather than the

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[3] Fearnside, P.M. 2002. “Why a 100-year time horizon should be used for global warming mitigation calculations.” *Mitigation and Adaptation Strategies for Global Change* 7(1): 19-30.

“secondary impact horizon” described in EPA’s rule documentation. Mr. Heimlich specified that the impact time frame should encompass all significant impacts from emissions associated with the 2022 or 2010–2022 production of renewable fuels under the RFS mandate, since that is the “project” for which the impacts are being evaluated. However, he asserted that if the emissions time path is correctly specified, the impact time frame would be essentially irrelevant because including years with zero emission change would not affect the analysis. Finally, he noted that the correct impact time frame was dependent on the timing of production. He provided an example of such a time frame and explained what Dr. Marshall and other authors have referred to this as a “rolling time horizon” (see Appendix C).

Dr. Fargione said that a 100-year impact time frame is appropriate to consider impacts. However, he affirmed that the impact time frame is linked to discounting; if an appropriate discounting method is used, then the impact time frame becomes less crucial because future emissions would have less weight.

Dr. Richards questioned where EPA obtained the prediction that a reference case forest would continue accumulating carbon for 80 years.

Some peer reviewers also addressed whether the impact time frame should be different for each fuel. Mr. Heimlich supported applying different impact time frames to different biofuels. For example, he stated that comparing diesel to biodiesel from animal wastes would probably require only a single year, since there are no long-term sources of emissions to consider. On the other hand, production of corn ethanol would involve indirect land use change effects that may involve changes over many years. Dr. Marshall offered a contrasting opinion, asserting that the impact time frame is not likely to vary by fuel, because it is related to impacts of emissions.

Charge Question 2
What are the proper criteria for determining the impact time frame?

Peer reviewers recommended the following criteria for determining the impact time frame: inclusion of all significant climate impacts, timing of biofuel production, use (and value) of a discount rate, and reliability of the information used to determine metrics. Additional details of these criteria are discussed in the response to the preceding question.

Dr. Martin stressed that the impact time frame should only consider biogeochemical projections because these are less speculative. Any projected changes in land use should be confined to a period of no more than 30 years because they are too speculative to use as criteria beyond the project time frame.

Charge Question 3
What is the best method for determining the impact time frame or frames? What modeling or other information should inform the choice of an impact time frame?

Some peer reviewers offered methods or information that should be used to determine the impact time frame, while others listed methods or information that should not be used.

Dr. Martin said the impact time frame should be informed by the latest assessments of climate change, or should stay consistent with the impact time frame used for the GWP. Dr. Marshall referenced the IPCC GWPs and Fearnside (2002)[4] to inform her choice of impact horizon.

Dr. Fargione advised against calculating Net Present Value (NPV) over an infinite time frame because proper discounting needs to be conducted on a value, rather than a physical quantity. In the context of the RFS, he said it must be assumed that damages are proportional to a measurable physical quantity, such as radiative forcing. However, Dr. Fargione noted that the damages associated with radiative forcing become increasingly uncertain over longer time frames.

Mr. Heimlich advised against using Section 5.3.3.4 of the IPCC Agriculture, Forestry and Other Land Use (AFOLU) guidelines to inform the time path of emissions from land use conversion. He explained that this guideline averages the difference in soil carbon stocks before and after land use conversion over 20 years, when in reality, the loss of soil carbon from conversion is more rapid in initial years and tapers off in later years. Instead, Mr. Heimlich recommended that soil scientists familiar with the areas where land conversion is expected apply a general soil carbon loss curve that equals the total expected loss of soil carbon. Mr. Heimlich recommended the same method to better approximate the time pattern for foregone carbon sequestration as well.

Dr. Richards did not respond to this question.

Charge Question 4
Is it scientifically justifiable to select an impact time frame based on presumed climate impacts? For example, should we only be concerned with GHG reductions over the next 20–30 years, or is a different time frame justified?

Peer reviewers were split on the issue of selecting an impact time frame based on predicted climate impacts. Their responses are presented from most support to least support.

Dr. Martin asserted that it is scientifically reasonable to select a shorter impact time frame based on presumed climate impacts. He argued that “swift and deep reductions of heat-trapping gasses are needed to avoid catastrophic changes due to a warming climate.” Since post-threshold GHG reductions will not reverse damage, he wrote that it is reasonable to focus on avoiding the damage in the first place. Mr. Heimlich said that this is justifiable only if EPA interprets the law to consider emissions proxies for damages from climate change. Dr. Marshall acknowledged that the potential for irreversible change was a convincing reason to distinguish between current and future emissions; however, she argued that this should be addressed using an appropriate discount rate rather than altering the impact time frame. Dr. Richards did not believe it would be justifiable to select an impact time frame based on presumed climate impacts, writing, “assuming we care about all generations, then we should care about impacts at all times.” Dr. Fargione did not respond to this question.

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[4] Fearnside, P.M. 2002. “Why a 100-year time horizon should be used for global warming mitigation calculations.” *Mitigation and Adaptation Strategies for Global Change* 7(1): 19-30.

Charge Question 5 and 5a
How should the potential for "threshold" or irreversible climate change impacts influence our choice of an impact time frame?
(a): What evidence about these potential thresholds would be most appropriate for consideration when determining the impact time frame?

Peer reviewers responded with qualified support and opposition. Dr. Martin advised that, if there was significant evidence of potential threshold impacts by 2050, a 30-40 year impact time frame would be reasonable. If this were the case, Dr. Martin would also suggest adopting a shorter GWP impact time frame.

Dr. Marshall reiterated that the potential for irreversible change should be addressed through a discount rate, not the time frame. She said that discounting emissions effectively "buys time" for carbon capture and sequestration and other mitigation technologies to be developed and implemented. However, this method is dependent on technological improvements out-pacing increases in marginal damage that arise from increasing atmospheric stocks. In addition, irreversible change will play a critical role in defining a damage function associated with emissions over time. Dr. Marshall suggested that such a damage function have possible outcomes weighted by cumulative probability functions describing the expectation that such irreversible change will have already taken place in a given period or at a given stock or warming level. She also said that if this damage function were specified, it would not be relevant to the selection of an impact time frame over which that damage function operates.

Dr. Richards and Mr. Heimlich did not support the concept. Dr. Richards said that modeling the damages to predict a threshold for irreversible climate change impacts was beyond the scope of the current undertaking. Mr. Heimlich questioned how much specific knowledge was available to set a threshold date beyond which emissions reductions would be irrelevant. He described what a damage function predicting irreversibility would look like, and noted that the projections in the 2007 IPCC assessment report do not suggest such a damage function (see Appendix C). Two causes for a potential threshold effect would be the slowing or reversal of the Atlantic meridional overturning circulation (MOC) and the irreversible melting of either the Greenland or Antarctic ice sheets. Citing the 2007 IPCC report, Mr. Heimlich acknowledged that these effects are of concern, but opined that they "do not constitute threshold or irreversible phenomena of either sufficient certainty or temporal proximity to affect the time horizons for the RFS mandate." As an alternate strategy, Mr. Heimlich suggested incorporating the time-value of GHG reductions in the discount rate instead of limiting the time frame.

Dr. Fargione did not respond to the question.

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

Charge Question 1
If the impact time frame is longer than project time frame, how should GHG emissions in this longer time frame be accounted for as part of EPA's lifecycle GHG analysis?

Dr. Richards advised that GHG emissions in the longer impact time frame be accounted for the same way they are during the project time frame, while Dr. Martin suggested they be accounted for in a manner consistent with the GWP approach. Specifically, Dr. Martin wrote, "the atmospheric abundance of the GHG should be projected and the incremental cumulative radiative forcing calculated consistent with the GWP approach."

Mr. Heimlich indicated that emissions associated with biofuel production that are beyond the project time frame should only be considered if EPA interprets EISA to mean that emissions are proxies for climate change impacts. However, he cautioned against extending fuel production over the entire impact time frame, noting that “fuel produced in year t may have impacts (e.g., soil carbon loss, foregone carbon sequestration) that extend for 80 years even if fuel production ceases in year t+1.”

Drs. Fargione and Marshall did not respond to the question.

Charge Question 2
Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion?

Two peer reviewers gave conditional support, while three did not support considering sequestration from land reversion in EPA’s analysis.

Mr. Heimlich and Dr. Richards offered conditional support. Mr. Heimlich advised EPA to consider land reversion impacts only if it had reason to believe that croplands dedicated to biofuels would be reverted. He emphasized that sequestration from abandoned croplands could be greater or less than foregone sequestration from the original land clearing because sequestration depended on the location and character of the vegetative cover. He indicated that, in general, sequestration is greater for newly planted vegetation than mature vegetation. Dr. Richards stated that land reversion could be included if EPA finds the impacts from land reversion to be significant. He suggested trying different scenarios to test if land reversion has a significant effect on the GHG lifecycle analysis.

Drs. Fargione, Marshall, and Martin responded that land reversion should not be counted because there is no reason to assume that the land would revert. Instead, it is more likely that land would be kept in crop production for food or that the land would be developed. In addition, Dr. Marshall recommended that EPA consider post-project salvaged carbon as part of a second independent land use change that occurs once the biofuel project terminates. Dr. Fargione noted that even if land were reverted, the benefits of sequestration would be attributable to the grazing, forestry, or conservation payment activities associated with the new land use, not to biofuel production.

Dr. Fargione expanded on the reasons for his lack of support (see Appendix B). He interpreted EISA to mandate reduced emissions during the project time frame, and therefore concluded that emission reduction calculations should be based only on land use change and foregone sequestration that occur during the project time frame. He stated that the only policy-appropriate way to implement a lifecycle analysis was to consider GHG emissions independent of any speculated changes in land use after the end of the project time frame, and to account for emissions that were already released during the project time frame. According to Dr. Fargione, one potential exception to this would be if EPA were in to include long-lived forest products, as these emissions are not dependent on assumptions about future land use change.

Dr. Marshall introduced other issues to consider with land use and land reversion. She asserted that in cases where the initial conversion significantly affects the carbon potential of land on or off the site producing biofuels, then the biofuels driving that conversion should be credited or penalized with that change in carbon potential. She provided examples of deforestation and rehabilitation to illustrate the concept (see Appendix D). Dr. Marshall also suggested that land-use activity in the forest "increases risk of forest fire, causing additional carbon losses in neighboring forests, and that such fires increase the forest's susceptibility to further burning" and cited research by Nepstad et al. (2008)[5] on the issue. She added that such land-use changes also could fragment existing natural habitat, expand degraded "edge" habitat, and lose native species and biodiversity. Dr. Marshall concluded, "the potential for irreversible change along other social and environmental dimensions highlights the need for a more comprehensive definition of the sustainability of biofuel production than that captured by the GHG requirements alone."

Charge Question 3
Besides land reversion, what other factors following biofuel production should be considered in this analysis? What is the best way to estimate these GHG emissions changes?

Dr. Martin wrote that biogeochemical models could be considered if used in a way that is consistent with the GWP approach. Dr. Fargione did not suggest other factors that should be considered, but specifically advised against counting foregone sequestration beyond the project time frame. Dr. Richards, Mr. Heimlich, and Dr. Marshall did not suggest any additional factors to consider in the lifecycle analysis.

III. Valuation of Future GHG Emissions

A. Conceptual Issues

Charge Question 1 and 1a
Is it scientifically justifiable to treat future GHG emissions and reductions different than near term emissions/reductions?
(a): If so, what is the basis for such different treatment?

One peer reviewer offered strong support, while others in general offered conditional support based on interpretation of EISA and other factors.

Dr. Richards strongly supported weighing current GHG reductions more than future reductions. He commented that a zero discount rate would suggest that it would be equally valuable to continue postponing reductions, which is not the case. Dr. Richards directed EPA to look at the shadow price of emissions reductions from the large climate/energy/economy models.

Dr. Fargione and Mr. Heimlich asserted that discount rates are only justifiable when applied to monetary impacts, not physical impacts. However, both agreed that if EPA interpreted EISA as requiring emissions to be proxies for damages, then it was appropriate to adjust GHG emissions to fully reflect their impact on climate change. Dr. Fargione clarified that damages are more likely to be proportional to radiative forcing (as described in O'Hare et al.(2009)[6]), rather than GWP. He briefly explained the methodology and said, for the purposes of the RFS regulation, it would be reasonable to make the simplifying assumption that damages will scale directly to cumulative radiative forcing (see Appendix B).

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[5] Nepstad, D.C. C.M. Stickler, B. Soares-Filho, and F. Merry. 2008. "Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point." Phil. Trans. R. Soc. B, DOI: 10.1098/rstb.2007.0026.
[6] O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001.

Dr. Martin addressed all of the questions under section III.A in one space. He said it was reasonable to treat GHG emissions differently over time in a purely physical assessment, to the extent that the emissions have a different impact on radiative forcing or other climate impact due to changes in background level of GHGs or other biogeochemical factors. He stressed that these differences should be treated consistently with the models used in GWP approaches.

Dr. Marshall explained the purpose of discount rates and provided background on the debate over applying discounting principles to carbon units (see Appendix D). She concluded that a discount rate applied to carbon units can be scientifically justifiable if it captures more than just the "time value of money," and also reflects relationships that are assumed to drive the changing carbon value over time. Such relationships include the changing rate of damages produced by atmospheric GHG stocks, persistence of GHGs in the atmosphere, and initial GHG stock levels.

Dr. Marshall elaborated on how to properly discount emissions. She discussed the two relationships that define the path of damage expected from a unit of emissions. The first is the impact of that unit on atmospheric carbon stocks over time, and the second is the impact of those carbon stocks on damages from global warming over time. She then discussed steps for translating the physical impacts of a GHG unit into economic impacts. For each distinct time horizon (impact and project horizon), the impacts must be aggregated over time, and an appropriate discount rate must be applied to each aggregation. Once a path of emissions damages has been condensed into a single cost number associated with a unit of emissions in each time period, a second round of aggregating over time occurs. She walked through an example of aggregating impacts over time and discussed a figure that demonstrates how discounting emitted carbon tons is a short-cut for estimating two distinct rounds of carbon weighting (see Appendix D). Finally, Dr. Marshall summarized generalizations derived by Richards (1997)[7] in a theoretical exploration of the concept of discounting physical units (see Appendix D).

Within her discussion, Dr. Marshall made the following points about discount rates:

- It is likely that discount rates will differ between the project horizon and the impact horizon. For example, a discount rate for the impact horizon should take into account relevant biophysical variables, such as atmospheric carbon decay rate, as well as literature by Guo et al. (2006)[8] that describes the role of uncertainty in discounting over long time periods and declining discount rates. A discount rate for a shorter project horizon, however, should take into account market opportunity costs, which tend to have higher interest rates.
- If marginal damages increase rapidly over time, it is possible that the discount rate could be negative. Dr. Marshall explained that this could be caused by "a rapidly increasing atmospheric carbon stock, or by a marginal damage function with rapidly increasing damage as a function of stock." This would bias the analysis toward projects with later reductions over those with current reductions.
- If marginal damages increase at a non-constant rate, it is likely that an appropriate discount rate will also be non-constant. For example, Dr. Marshall explains that "in a

[7] Richards, K.R. 1997. "The Time Value of Carbon in Bottom-Up Studies." *Critical Reviews in Environmental Science and Technology* 27 (special): s279-s292.
[8] Guo, J., C. Hepburn, R.S.J. Tol, D. Anthoff. 2006. "Discounting and the social cost of carbon: a closer look at uncertainty." *Envir. Sci. & Pol*. 9(3): 205-216.

scenario where marginal damages from emissions are assumed to be increasing at an increasing rate with atmospheric carbon stock…an appropriate physical carbon discount rate structure is one with a discount rate that declines over time at a decreasing rate."

- A mis-estimated atmospheric carbon decay rate can significantly impact the discount rate because it impacts the path of marginal damages expected from a unit of emissions. While it might be tempting for EPA to characterize atmospheric carbon decline as a fixed proportion of stock, the actual path of decay is more complex and should be taken into account (see Appendix D).

Charge Question 2
Is it appropriate to apply a non-zero discount rate to physical GHG emissions (i.e., GWP weighted emissions) in some or all circumstances?

Two peer reviewers believed it was not appropriate to apply a non-zero discount rate to physical GHG emissions. Dr. Richards said it was never appropriate to apply a non-zero discount rate to physical GHG emissions, and Dr. Martin said it was not appropriate in the circumstances of the RFS. Dr. Martin stressed that the EISA called for physical emissions reductions rather than an economic analysis; he believed that Congress did not intend to delegate the decisions of strategy or intergenerational equity to EPA. Therefore, he argued that an economic assessment of social preferences should not be presented as a physical measurement.

The other three reviewers concurred that it was justifiable if physical emissions were being used as a proxy for economic damages associated with warming. Dr. Fargione and Mr. Heimlich responded that it was a matter of EPA interpretation of EISA. If EPA interprets the emissions comparison posed by Congress in EISA 2007 as an assessment of impacts on climate change, then using a non-zero discount rate would be legitimate because the physical measure is posed as a proxy for damages. If EPA is unwilling to make assumptions about the relationships between emissions and damages, however, then it should not apply discounting. In addition, Mr. Heimlich suggested that EPA trace the time path of emissions and sequestration from soil carbon and afforestation more carefully, because timing of these events matters in a discounting framework. Dr. Marshall agreed that applying a discount rate to physical carbon units could be scientifically justifiable if the procedure still assumes that various costs and benefits are driving the changing "carbon values" over time.

Charge Question 2a
Is it scientifically justifiable to apply a non-zero discount rate to physical GHG emissions under the assumption that GHG emissions have constant marginal damages regardless of when they occur (i.e., use GWP weighted emissions as a surrogate for monetary impacts)?

Peer reviewers tended to advise against applying a non-zero discount rate to GHG emissions under the assumption that GHG emissions have constant marginal damages. Dr. Martin said that the assumption of constant marginal damages is not justified, and therefore the GWP weighted emissions are a poor proxy for monetary impacts. Similarly, Dr. Marshall reported that a large body of scientific evidence suggests that GHG emissions will not have constant marginal damages. Dr. Richards said EPA was confusing discounting with the GWP issue. He clarified that the discount rate applies to trade-offs of damages occurring at different points in time, whereas GWP is a purely physical index of warming effects for comparison of different gases that does not give a measure of relative economic impacts.

Mr. Heimlich stated that adjustments between gases for GWP are not sufficient adjustments to proxy for constant marginal damages, because they do not fully account for the differing decay paths of different GHGs, and because they already incorporate a zero discount rate and 100-year time frame. He recommended that EPA use the revised Bern climate cycle model for CO2 and exponential decays for methane and nitrous oxide, since these models more fully account for the decay paths of the gases considered.

Dr. Fargione did not respond to the question.

Charge Question 2b
If discount rates are used when monetizing the impact of GHG emissions, is this scientifically justifiable for the purposes of lifecycle GHG assessment as defined by EISA?

The responses to this question varied. Mr. Heimlich found the question puzzling because he did not believe anyone was seriously discussing full monetization of the impact of GHG emissions. He noted that no current climate model can accurately predict the variables in sufficient detail to value them in monetary terms. Even if monetization were possible, he questioned if it would meet the Congressional intent of EISA. Dr. Martin reiterated that EISA called for physical emissions reductions rather than an economic analysis. Dr. Marshall wrote that the current EISA language did not explicitly require EPA to monetize impacts to determine an appropriate discount rate, but it also did not "preclude the application of a discount rate based on monetized impacts compared over time for the aggregation process." Drs. Fargione and Richards did not respond to the question.

Charge Question 3
Is it scientifically justifiable to apply a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts? Is this the only circumstance where a non-zero discount rate would be appropriate?

Peer reviewers agreed that this was a scientifically justifiable approach, but not all agreed that it should be used in EPA's analysis. Dr. Richards and Mr. Heimlich wrote that EPA would be justified in using a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts. Dr. Fargione did not answer the question directly but indicated that discounting was appropriate when emissions are assumed to be proportional to monetary impacts (see Appendix B).

Dr. Martin believed it would be justifiable to apply a non-zero discount rate to monetary impact over time, but he did not interpret EISA to call for an economic assessment. Therefore, he said discounting would not be appropriate. Dr. Marshall implied that the approach would be justifiable, but noted that discounting is only appropriate assuming constant marginal damages, and a large body of scientific evidence suggests that GHG emissions will not have constant marginal damages.

B. Choice of Discount Rate

Charge Question 1
What is the most scientifically justifiable discount rate (including the possibility of a zero discount rate) for this lifecycle analysis?

Peer reviewers suggested discount rates between zero and 7.9 percent. Peer reviewers tended to agree that this was a policy, rather than a science, question.

Dr. Fargione and Mr. Heimlich deferred to Office of Management and Budget (OMB) to select an appropriate discount rate. Dr. Fargione recommended a 3 percent discount rate based on his reading of OMB Circular A-4, noting that this rate was associated with social time preferences as recommended by OMB. Mr. Heimlich instead referred to Appendix C of OMB Circular A-94, which provides guidance on real interest rates for different maturities of Treasury notes and bonds and serves as a reasonable proxy for the social time preference for consumption. The OMB Circular A-94 rates varied from 2.7 to 7.9 percent, with the average rate over the 1979–2009 periods being 4.34 percent. Dr. Richards recommended a 5 percent discount rate. He suggested that EPA allow its clients and the public to assess the differences that different discount rates would produce. Dr. Martin recommended a zero discount rate coupled with a relatively short time frame, such as 20 years.

Dr. Marshall did not recommend a specific discount rate. She noted that discounting was only appropriate assuming constant marginal damages, and that a large body of scientific evidence suggests that GHG emissions will not have constant marginal damages. However, she did refer EPA to an analysis by Hellweg et al. (2003)[9] that discounts GHG emissions as a surrogate for discounting monetary impacts of emissions (under constant marginal damages).

Charge Question 2
What are the proper criteria for determining the discount rate?

Peer reviewers used or recommended the following criteria for determining the discount rate: OMB recommendations, preferences and opportunity costs, costs and benefits of emissions over time, and traditional economic discount factors (unspecified).

Dr. Martin reiterated that, because all the discounting approaches measure a fundamentally economic quantity and are not a means to compute the aggregate quantity of GHG emissions, he took the discussion of discount rates to be irrelevant to the RFS.

Charge Question 3
Should the choice of discount rate be related, or affected, by the selected time frames (i.e., project and impact) for lifecycle GHG analysis? If so, how?

Drs. Fargione and Richards said that the choice of discount rate should not be related to or affected by the selected time frame. In fact, Dr. Richards said that the opposite was true: the time frame should be affected by the choice of discount rate.

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[9] Hellweg, S., T.B. Hofstetter, and K. Hungerbuhler. 2003. "Discounting and the environment: Should current impacts be weighted differently than impacts harming future generations?" *Int. J. LCA* 8(1): 8-18.

Mr. Heimlich and Dr. Martin, on the other hand, believed that it was possible for the discount rate to be related to the time frame. Dr. Martin said that longer time frames make discount rates more relevant, but can also introduce complexities involving intergenerational equity and other matters. He stressed that EISA does not call for such considerations, and recommended that if EPA does select a long impact time frame, it adopt GWP methodology. Mr. Heimlich wrote that the discount rate should be "consonant with the time horizon." For example, a short-term discount rate should not be matched with a long-term time frame, or vice versa. He noted that if EPA selects a short time frame (about 20 years), then there is little to gain from a non-zero discount rate, because the effects of all emissions during such a short time frame could be considered equal. However, as the length of the time frame increases, more impacts are encompassed, and the increasing disparity between the value of present and future effects warrants the use of a non-zero discount rate. If EPA selects a longer time frame, Mr. Heimlich also recommended that EPA consider placing a risk premium on the discount rate to reflect uncertainties. However, he cautioned that there must be a clear rationale for increased uncertainty over the time frame, and the premium for increased uncertainty must be clearly identified; otherwise, the practice of discounting can merely compound the uncertainty.

Dr. Marshall did not respond to the question.

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

Charge Question 1
EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." How does this language impact or limit the approach taken by EPA to evaluate lifecycle GHG thresholds of biofuels?

Peer reviewers provided a number of interpretations of the EISA language. For instance, one believed EISA's language was decisively limiting, one believed it was potentially limiting, and one believed it did not limit EPA's approach.

Dr. Martin argued that the language in EISA limits the approach to what is consistent with either simple mass values or the GWP methodology as outlined by the IPCC. He maintained that a physical (rather than an economic) metric was required, because EISA does not mention intergenerational equity, cost benefit analysis, or other economic considerations. However, he thought it should be allowable to use methodologies that equalize emissions over time, as long as those methodologies were consistent with GWP methodology. Similarly, Dr. Richards responded that the language in EISA focuses on quantity and GWP rather than the value of impacts, which potentially may preclude EPA's more relevant policy analysis.

Dr. Marshall, on the other hand, said the language in EISA does not appear to limit the approach that EPA can take in evaluating lifecycle GHG thresholds. She argued that the language does not preclude applying a discount rate based on monetized impacts compared over time for the aggregation process. In addition, she said the language did not mandate the use of any particular adjustment factor or impact time frame.

Mr. Heimlich stressed that EPA's interpretation of the EISA language was a matter for legal scholars. However, in his opinion, the language on adjustments for relative GWP suggested that Congress intends to use the emissions as a proxy for damages from climate change.

Dr. Fargione did not respond to the question.

Charge Question 2

One alternative measure that has been proposed is the Fuel Warming Potential (FWP).[10] Would the FWP be an appropriate metric to use for this analysis? If so, how would it be applied in the context of determining comparative assessment of transportation fuel lifecycle GHG emissions?

Two peer reviewers agreed that the FWP could be an appropriate metric for EPA's analysis. Dr. Martin said that the FWP approach would be appropriate, as it is a purely physical measure of emissions and it accounts for time consistently with GWP methodology. His preliminary remarks provide more information on the application of the FWP. Dr. Fargione also agreed that the FWP approach meets the EISA requirements.

Mr. Heimlich indicated that the FWP would be appropriate after correcting some limitations. First and foremost, he said EPA should more explicitly trace both the emissions and their impact in their true time path using models such as the revised Bern carbon cycle model. He acknowledged that the FWP was a step in the right direction, but encouraged FWP model developers to correct the following limitations:

1. Decay rate for atmospheric CO2 assumes a constant background atmospheric concentration. In reality, radiative efficiency for a unit of CO2 decreases non-linearly as atmospheric CO2 concentration increases, and CO2 atmospheric residence time increases.
2. FWP assumes that GHG radiative efficiency is constant.
3. FWP only deals with CO2; it does not include methane or nitrous oxide.

Dr. Marshall outlined the advantages and disadvantages of the FWP metric (see Appendix D) but did not provide an opinion on the appropriateness of using FWP in EPA's analysis. Dr. Richards was not familiar with the FWP.

Charge Question 3

Are there other methods or metrics that would be more appropriate to account for GHG emissions over time?

Dr. Marshall noted that current efforts to monetize carbon emissions impacts could be used as a proxy for marginal damages. She suggested that this be incorporated into weighting metrics to account for stock dependence without requiring EPA to model concentration changes and stock-dependent damage impacts.

Dr. Martin and Mr. Heimlich were not aware of any other methods or metrics that would be more appropriate to account for GHG emissions over time.

Dr. Fargione and Dr. Richards did not respond to the question.

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[10] See for example O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001.

IV. Other Methodological Considerations

A. Scenario Analysis

Charge Question 1
EPA's proposed approach has been to look at a snapshot in time (biofuel volume change in 2022) and to project emissions and reductions forward based on this one time change in volume. A more detailed and perhaps more data intensive approach would be a year-by-year analysis comparing different volume scenarios of biofuels over time. Such a comparison would likely compare a base case and one or more expanded biofuel cases. A particular methodology for this approach would be to project different annual biofuel volumes and GHG emissions out into the future until the base case and policy case are equivalent (if ever).

- ***a. Would this approach present a clearer picture of the marginal impact of the RFS mandates?***
- ***b. Would this approach present a clearer picture of what the GHG impact is of a specific biofuel (i.e., what is needed for EISA requirements)?***
- ***c. Would this approach help to clarify the time frame discussion by tracking the GHG difference between scenarios over time until there are no more changes?***
- ***d. Would the base case ever provide the same amount of biofuel as the RFS policy case scenarios (e.g., this could include both cases having zero biofuels at some future date)?***
- ***e. Would the base case ever provide the same level of GHG emissions as the RFS policy case (i.e., at what point would you stop needing to consider differences between the two cases)?***
- ***f. Is there an alternative methodology for deciding the time frame over which we should project the yearly impacts of RFS?***

Four of the five peer reviewers (all except Mr. Heimlich) expressed some uncertainty over the question or said limited information was provided. These reviewers either declined to answer or further explained their current framing of the question before answering. Some peer reviewers advised against the proposed year-by-year approach, but others thought it might provide useful information.

Dr. Fargione did not support the proposed year-by-year analysis, noting that this could lead to incredibly long time frames that would be inconsistent with the intent of EISA. Mr. Heimlich responded that the year-by-year analysis would not offer additional information to determine the emission reductions for a specific biofuel. In addition, it would require a large number of assumptions made on an arbitrary basis, and it would be less transparent than the current approach. The year-by-year analysis would likely require additional Forest and Agricultural Sector Optimization Model (FASOM) and Food and Agricultural Policy Research Institute (FAPRI) model runs for longer time frames than those models are currently used, introducing more uncertainty. Mr. Heimlich concluded that "EPA has much to lose and little to gain by pursuing such an ambitious modeling assessment."

Dr. Marshall noted one advantage to the year-by-year analysis was that it would provide a clearer picture of the marginal impacts of the RFS mandates. However, it would also increase modeling complexity. Therefore, EPA would need to assess how the potential for added precision compared to the increased complexity of the year-by-year analysis. She explained that this would also depend on "whether per-gallon estimates of carbon impact are expected to change substantially by year and perhaps by scale of production in any given year." Dr. Marshall did not think that the year-by-year approach would help clarify the time frame discussion.

Dr. Richards thought that the year-by-year analysis might be informative. He stated that this approach would probably present a clearer picture of the GHG impacts of a specific biofuel, and might also help clarify the time frame discussion.

Dr. Martin said the proposed methodology was not clear and declined to respond in detail.

Two peer reviewers addressed the question of whether the base case would ever provide the same amount of biofuel as the RFS policy case scenarios. Dr. Richards believed it would be possible for the base case to provide the same amount of biofuel as the RFS policy case; for example, if more restrictive climate change legislation were implemented. Dr. Marshall agreed that due to changing technologies and other factors, biofuel production levels would likely decline to baseline levels and annual GHG emissions associated with the two fuels would equalize.

Charge Question 2
How could a yearly or cumulative impact approach be used to determine lifecycle GHG values for specific fuels or fuel pathways?

Four peer reviewers did not respond to the question, and the fifth peer reviewer (Dr. Richards) responded that he did not know.

Charge Question 3
What models, tools, and data sources are available that would enable this type of calculation?

Dr. Richards responded that EPA has already employed a number of models that should be helpful. He suggested EPA clarify its methods and separate the scenario building from the scenario analysis.

The remaining four peer reviewers did not respond to the question.

Additional Comments Associated with Section IV

Dr. Fargione recommended an improvement to EPA's current modeling approach. Instead of running the model separately for a scenario containing each fuel, he suggested that EPA use a model that includes the mandates for all the fuels, and then partition the effects amongst the fuels. He said this method will more accurately capture the total demand from all of the fuels in the mandate. He noted that if only one piece of the mandate was considered, it is possible that improvements in crop yields may free up enough land to avoid land use change, while the demand for new land from the full mandate might overwhelm the amount of land spared from yield improvements. Dr. Fargione further explained that once the model is run using all fuels, an appropriate way to partition the emissions is to base it on each fuel's relative GHG emissions from land use change. These relative emissions would be determined in separate model runs.

Mr. Heimlich described a potential discrepancy with the framing of the RFS. He explained that because the RFS requires a percentage change in emissions relative to fossil fuels, in theory, any volume of fuel could be used to calculate emissions. However, this assumes that the emissions associated with one gallon of fuel will be the same regardless of the total volume of fuel. He noted that this was not true for gasoline, which requires deeper drilling, different sources, and more processing at higher volumes, and therefore increases the energy inputs per gallon yielded. In the same manner, “the feedstock for renewable fuels is the product of an agronomic system using inherently limited natural resources that may be subject to even greater nonlinearities at different volumes.” Mr. Heimlich described in detail the data that EPA provides in the RFS RIA to check this assumption (see Appendix C), and concluded that the difference in emissions compared to gasoline were not invariant with volume, but instead increased with larger volumes. Mr. Heimlich noted that EPA could partially address this variance by assessing the impacts of all volumes of a renewable fuel required by the RFS in 2010–2022. He explained how to do this in more detail (see Appendix C). Mr. Heimlich reiterated that EPA should not extend fuel production over the entire impact time frame, and it should not project renewable fuel markets beyond 2022.

Dr. Marshall discussed implications for the time analysis scenarios presented by EPA. She noted that EPA proposes two different time frame scenarios (100-year time frame, 3% discount rate; and a 30-year time frame, 0% discount rate), neither of which makes a distinction between the project time frame and the impact time frame. Dr. Marshall argued that the most appropriate method would acknowledge and treat each time period separately within the same analysis. Dr. Marshall also noted that EPA’s envisioned impact time frame is significantly different from the impact time frame she describes (see Section II for full description).

If asked to select between EPA’s two time frame scenarios, Dr. Marshall would select the 30-year time frame with a zero percent discount rate. She believed that this time frame could be made consistent with the dual-horizon time frame if a number of simplifying assumptions were made (see Appendix D). Should EPA limit its scope or not consider it within its authority to calculate discount rates based on monetized assessments of economic damages of emissions, she noted that the 30-year/zero percent discount rate fixed project horizon was most logical and consistent with prior work. Dr. Marshall then explained why the 100-year/2 percent discount rate was less appropriate (see Appendix D).

Dr. Marshall summarized her general accounting recommendations as follows (see Appendix D for uncondensed version):

1. A GHG accounting method for land use change needs to analyze the expected damages associated with those flows over time. The corresponding monetary units associated with this damage can then be discounted to compare present and future flows. Discount rates need to be transparent and in keeping with standard economic arguments in support of discounting.
2. Discount rates used for physical carbon units are not analogous to monetary discount rates. They must reflect the relationship between emissions and costs as well as the relationships among costs over time.
3. The “project horizon” should be considered independently of the longer atmospheric “impact horizon.” In the context of biofuels production, “project horizon” refers to the period of time over which feedstock cultivation will occur (and benefits from displaced transport fossil fuel realized). “Impact horizon” refers to the period of time over which impacts of increased or decreased emissions are felt in the atmosphere. This approach does not align perfectly with either of the time analysis scenarios presented by EPA, but is roughly consistent with the “fixed project horizon/0% discounting” scenario.
4. In general, the impact horizon should be applied as a rolling target rather than a fixed target. If a truncated impact horizon is used, it acts as a form of discounting, and a justification for imposing that discounting structure must be provided.

5. Salvaged carbon from land reversion should not be considered as part of the GHG accounting protocol, because land reversion is not guaranteed. Instead, this should be considered a benefit associated with a future form of land use change should such conversion occur. However, permanent impacts to carbon potential due to land use change should be considered.

APPENDIX A

TIMING PEER REVIEW CHARGE QUESTIONS

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[11]

A. Framing the Issues

1. The preamble and RIA separates the discussion of how to account for the variable timing of transportation fuel lifecycle GHG emissions into different components:
   a. Time frame
   b. Discount rate, or the relative treatment of current and future GHG emissions
   c. Appropriate metrics
2. Is this a scientifically objective way to frame the analysis of lifecycle GHG impacts of different fuels in the context of what is needed for this rulemaking?

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

1. As explained in the preamble and RIA, the time frame for analyzing lifecycle GHG emissions can be approached in different ways, such as:
   a. Project time frame—how long we expect production of a particular biofuel to continue into the future
   b. Impact time frame—the length over which to account for the changes in GHG emissions, in particular due to land use changes, which result from biofuel production
2. Do the preamble and RIA define these time frame concepts in a scientifically objective way for lifecycle analysis? What other concepts, if any should be considered?

B. Determination of Project Time Frame(s)

1. What is a scientifically justifiable project time frame to consider for this analysis? Should the project time frames be different for each fuel?
   a. What are the proper criteria for determining the project time frame?
      i. Should the project time frame be based on when each fuel is likely to be priced out of the market? Should the project time frame be based on the EISA fuel mandates? What other criteria would you recommend, if any?
   b. What is the best scientific method for determining the project time frame or frames?
      ii. Is economic modeling the best method for determining the project time frame? If so, what specific models do you recommend for this analysis?
      iii. If you do not recommend economic modeling, what other methods do you suggest?

C. Determination of Impact Time Frame

1. What is a scientifically justifiable impact time frame to consider for this analysis? Should the impact time frame be the different for each fuel?
2. What are the proper criteria for determining the impact time frame?

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[11] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

3. What is the best method for determining the impact time frame or frames? What modeling or other information should inform the choice of an impact time frame?
4. Is it scientifically justifiable to select an impact time frame based on presumed climate impacts? For example, should we only be concerned with GHG reductions over the next 20–30 years, or is a different time frame justified?
5. How should the potential for “threshold” or irreversible climate change impacts influence our choice of an impact time frame?
   a. What evidence about these potential thresholds would be most appropriate for consideration when determining the impact time frame?

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

1. If the impact time frame is longer than project time frame, how should GHG emissions in this longer time frame be accounted for as part of EPA’s lifecycle GHG analysis?
2. Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion?
3. Besides land reversion, what other factors following biofuel production should be considered in this analysis? What is the best way to estimate these GHG emissions changes?

III. Valuation of Future GHG Emissions

A. Conceptual Issues

1. Is it scientifically justifiable to treat future GHG emissions and reductions different than near term emissions/reductions?
   a. If so, what is the basis for such different treatment?
2. Is it appropriate to apply a non-zero discount rate to physical GHG emissions (i.e., GWP weighted emissions) in some or all circumstances?
   b. Is it scientifically justifiable to apply a non-zero discount rate to physical GHG emissions under the assumption that GHG emissions have constant marginal damages regardless of when they occur (i.e., use GWP weighted emissions as a surrogate for monetary impacts)?
   c. If discount rates are used when monetizing the impact of GHG emissions, is this scientifically justifiable for the purposes of lifecycle GHG assessment as defined by EISA?
3. Is it scientifically justifiable to apply a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts? Is this the only circumstance where a non-zero discount rate would be appropriate?

B. Choice of Discount Rate

1. What is the most scientifically justifiable discount rate (including the possibility of a zero discount rate) for this lifecycle analysis?
2. What are the proper criteria for determining the discount rate?
3. Should the choice of discount rate be related, or affected, by the selected time frames (i.e. project and impact) for lifecycle GHG analysis? If so, how?

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

1. EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." How does this language impact or limit the approach taken by EPA to evaluate lifecycle GHG thresholds of biofuels?
2. One alternative measure that has been proposed is the Fuel Warming Potential (FWP)[12]. Would the FWP be an appropriate metric to use for this analysis? If so, how would it be applied in the context of determining comparative assessment of transportation fuel lifecycle GHG emissions?
3. Are there other methods or metrics that would be more appropriate to account for GHG emissions over time?

IV. Other Methodological Considerations

A. Scenario Analysis

1. EPA's proposed approach has been to look at snapshot in time (biofuel volume change in 2022) and to project emissions and reductions forward based on this one time change in volume. A more detailed and perhaps more data intensive approach would be a year-by-year analysis comparing different volume scenarios of biofuels over time. Such a comparison would likely compare a base case and one or more expanded biofuel cases. A particular methodology for this approach would be to project different annual biofuel volumes and GHG emissions out into the future until the base case and policy case are equivalent (if ever).
   a. Would this approach present a clearer picture of the marginal impact of the RFS mandates?
   b. Would this approach present a clearer picture of what the GHG impact is of a specific biofuel (i.e., what is needed for EISA requirements)?
   c. Would this approach help to clarify the timeframe discussion by tracking the GHG difference between scenarios over time until there are no more changes?
   d. Would the base case ever provide the same amount of biofuel as the RFS policy case scenarios (e.g., this could include both cases having zero biofuels at some future date)?
   e. Would the base case ever provide the same level of GHG emissions as the RFS policy case (i.e., at what point would you stop needing to consider differences between the two cases)?
   f. Is there an alternative methodology for deciding the time frame over which we should project the yearly impacts of RFS?
2. How could a yearly or cumulative impact approach be used to determine lifecycle GHG values for specific fuels or fuel pathways?
3. What models, tools, and data sources are available that would enable this type of calculation?

[12] See for example O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001

APPENDIX B

DR. JOSEPH FARGIONE RESPONSE TO CHARGE QUESTIONS

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[13]

A. Framing the Issues

1. **The preamble and RIA separates the discussion of how to account for the variable timing of transportation fuel lifecycle GHG emissions into different components:**
    a. **Time frame**
    b. **Discount rate, or the relative treatment of current and future GHG emissions**
    c. **Appropriate metrics**
2. **Is this a scientifically objective way to frame the analysis of lifecycle GHG impacts of different fuels in the context of what is needed for this rulemaking?**

Yes

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

2. **As explained in the preamble and RIA, the time frame for analyzing lifecycle GHG emissions can be approached in different ways, such as:**
    a. **Project time frame – how long we expect production of a particular biofuel to continue into the future**
    b. **Impact time frame – the length over which to account for the changes in GHG emissions, in particular due to land use changes, which result from biofuel production**
3. **Do the preamble and RIA define these time frame concepts in a scientifically objective way for lifecycle analysis? What other concepts, if any should be considered?**

Rather than describing the "project time frame" and the "impact time frame" as different approaches, these can be part of the same approach. The most appropriate way to implement a life cycle analysis is to consider the change in emissions caused by actions taken over the time frame of a project, but consider the impact of these emissions over a longer "impact time frame".

B. Determination of Project Time Frame(s)

1. **What is a scientifically justifiable project time frame to consider for this analysis? Should the project time frames be different for each fuel?**
    a. **What are the proper criteria for determining the project time frame?**
        i. **Should the project time frame be based on when each fuel is likely to be priced out of the market? Should the project time frame be based on the EISA fuel mandates? What other criteria would you recommend, if any?**
    b. **What is the best scientific method for determining the project time frame or frames?**

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[13] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

i. **Is economic modeling the best method for determining the project time frame? If so, what specific models do you recommend for this analysis?**
ii. **If you do not recommend economic modeling, what other methods do you suggest?**

It seems to me that the appropriate time frame is more of a policy question than a science question. In this context there are several reasonable and defensible positions regarding the time frame. The most reasonable position would be to consider a project time frame out to 2022, the end of the mandate. This is the only project time frame defined in the legislation. The GHG reduction mandates are intended to apply to fuels produced by that date, so extending the project horizon beyond that date to include fuels produced after that date would seem to violate the spirit and the letter of the law.

However, if you do not use this approach, it would make sense to use an estimated lifespan for an ethanol plant as the project time horizon, rather than using economic modeling. In the case of biofuels, the point at which the fuels will be priced out of the market is impossible to predict, as it will be based largely on policy decisions on biofuel subsidies and on technological breakthroughs in alternative fuel pathways such as electric and hydrogen. The average lifespan of an ethanol plant is not more than thirty years, so this would be a defensible project timeframe.

C. Determination of Impact Time Frame

1. **What is a scientifically justifiable impact time frame to consider for this analysis? Should the impact time frame be the different for each fuel?**
2. **What are the proper criteria for determining the impact time frame?**
3. **What is the best method for determining the impact time frame or frames? What modeling or other information should inform the choice of an impact time frame?**
4. **Is it scientifically justifiable to select an impact time frame based on presumed climate impacts? For example, should we only be concerned with GHG reductions over the next 20 – 30 years, or is a different time frame justified.**
5. **How should the potential for "threshold" or irreversible climate change impacts influence our choice of an impact time frame?**
    a. **What evidence about these potential thresholds would be most appropriate for consideration when determining the impact time frame?**

The determination of the time frame is linked to the question of discounting and how to weight future emissions. Assuming an appropriate discounting method is used, the question of the impact time frame becomes less crucial, because future emissions have less weight. A one hundred year time frame is an appropriate time frame over which to consider impacts. As EPA is aware, Net Present Value is most commonly calculated over an infinite time frame. Although one could make the argument in favor of this longer time frame, I would argue against it. This is because proper discounting (as discussed further below) can only be conducted on value (i.e. damages, not physical quantities such as emissions), so using proper discounting in this context is only possible by assuming that damages are proportional to some measurable physical quantity (e.g. proportional to radiative forcing). However, this assumption that damages are proportional to radiative forcing becomes more questionable over longer time horizons, given the uncertainties associated with climate change impacts, thresholds, and atmospheric CO_2 levels (e.g. because radiative efficiency of added CO_2 decreases non-linearly as background CO_2 concentrations increase).

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

1. **If the impact time frame is longer than project time frame, how should GHG emissions in this longer time frame be accounted for as part of EPA's lifecycle GHG analysis?**
2. **Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion?**
3. **Besides land reversion, what other factors following biofuel production should be considered in this analysis? What is the best way to estimate these GHG emissions changes?**

Land reversion should not be counted. There is no reason to assume that the land will revert. It is more likely that land will be kept in crop production, but will simply go toward food production than toward biofuel production, or that the land will be developed. Further, even if land were reverted, the benefits of sequestration would not be attributable to biofuel production. Rather, they would be attributable to the grazing, forestry, or conservation payment activities associated with the new land use. More generally, the calculation about emission reductions should be based on land use change that occurs during the project time frame. This can be justified on policy grounds: the intention was to mandate reduced emissions during the project horizon time frame, and emissions from land use change and emission savings from replaced fossil fuel use should both be counted over the same project time frame.

Similarly, one should not count foregone sequestration beyond the project time frame. In this way, the GHG emissions are independent of any assumed changes in land use after the end of the project horizon (which is the only policy-appropriate way to implement this lifecycle analysis). Thus, the only accounting required following the project time horizon is based on fate of the emissions already released (and their radiative forcing and residence time in the atmosphere). The only potential exception to this would be if you were in to include long-lived forest products. One should continue to include emissions from this source (if EPA decides to add it) even after the project time frame, as these emissions are not dependent on assumptions about future land use change.

III. Valuation of Future GHG Emissions

A. Conceptual Issues

1. **Is it scientifically justifiable to treat future GHG emissions and reductions different than near term emissions/reductions?**
    - d. **If so, what is the basis for such different treatment?**
2. **Is it appropriate to apply a non-zero discount rate to physical GHG emissions (i.e., GWP weighted emissions) in some or all circumstances?**
    - e. **Is it scientifically justifiable to apply a non-zero discount rate to physical GHG emissions under the assumption that GHG emissions have constant marginal damages regardless of when they occur (i.e. use GWP weighted emissions as a surrogate for monetary impacts)?**
    - f. **If discount rates are used when monetizing the impact of GHG emissions, is this scientifically justifiable for the purposes of lifecycle GHG assessment as defined by EISA?**
3. **Is it scientifically justifiable to apply a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts? Is this the only circumstance where a non-zero discount rate would be appropriate?**

Clearly, current reductions in GHG emissions are preferred to future reductions in emissions. However, a discount rate is only justifiable when applied to monetary impacts, because the economic justification for discounting hinges on the assumption that wealthier future generations will better be able to afford the costs of adaptation. Therefore, in order to discount GHG emissions, one must be able to assert that they are likely to be proportional to damages. However, GWP weighted emissions are not the most scientifically-defensible metric to use when estimating damages. Rather, damages are more likely to be proportional to radiative forcing, as described in O'Hare et al. (2009). Thus, discounting should be applied to estimates of radiative forcing, rather than GWP. It is reasonable, for the purposes of this regulation, to make the simplifying assumption that damages will scale directly to cumulative radiative forcing.

The method proposed in O'Hare et al (2009) that explicitly accounts for the residence time of emissions in the atmosphere and their radiative forcing, should be applied not just to CO2, but also to the other GHG emissions being considered by EPA. This will provide a more accurate estimate of the weighted GHG impact as requested under EISA.

If EPA is not willing to make assumptions about the relationship between emissions and damages, then they should not use any discounting. Economic discounting cannot logically be applied to physical quantities such as GHG emissions, only to economic quantities such as climate change damages.

O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001

B. Choice of Discount Rate

1. **What is the most scientifically justifiable discount rate (including the possibility of a zero discount rate) for this lifecycle analysis?**
2. **What are the proper criteria for determining the discount rate?**
3. **Should the choice of discount rate be related, or affected, by the selected time frames (i.e. project and impact) for lifecycle GHG analysis? If so, how?**

My reading of OMB circular A-4 (http://www.whitehouse.gov/omb/circulars_a004_a-4) is that a 3 percent discount rate is recommended for regulations such as EISA. Although a 7 percent discount rate is recommended for situations where private capital is diverted (based on the opportunity costs of diverted capital), that does not appear to be directly applicable here. Rather, discounting climate change damages over time is likely better reflected by the interest rate associated with social time preferences, for example if climate change damages increase the cost of private consumption. In cases dealing with social time preference, OMB circular A-4 recommends a discount rate of 3 percent.

The OMB recommendations provide objective criteria for selecting a discount rate. This is important because the selection of a discount rate is, by definition, a value judgment. Specifically it is an estimate of the time value preference that society puts on costs and benefits. Although some have argued that the empirically observed interest rates, upon which OMB has based its 3 percent estimate, do not necessarily reflect the true time preference of society associated with intergenerational climate change costs, these critics have not offered an objective alternative. Further, it is clear that society does prefer to cost reductions that occur sooner than later, so ignoring discounting does not seem justifiable. This is supported by OMB A-4, which states: "Benefits and costs do not always take place in the same time period. When they do not, it is incorrect simply to add all of the expected net benefits or costs without taking account of when the actually occur. If benefits or costs are delayed or otherwise separated in time from each other, the difference in timing should be reflected in your analysis."

The choice of discount rate should not be affected by the selected time frame. For example, there is no logical, scientific, or regulatory guidance justification for ignoring discount rates if a project horizon is "only" thirty years.

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

1. **EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." How does this language impact or limit the approach taken by EPA to evaluate lifecycle GHG thresholds of biofuels?**
2. **One alternative measure that has been proposed is the Fuel Warming Potential (FWP)[14]. Would the FWP be an appropriate metric to use for this analysis? If so, how would it be applied in the context of determining comparative assessment of transportation fuel lifecycle GHG emissions?**
3. **Are there other methods or metrics that would be more appropriate to account for GHG emissions over time?**

The FWP approach meets the language laid out in EISA. This is clear based on two lines of evidence First, note that EISA does not specify which mass values to use. IPCC itself calculates several values, based on the timeframe one chooses to consider. Thus, EISA cannot be interpreted as mandating the use of specific IPCC values. Second, the FWP approach actually does adjust the mass values for greenhouse gases to account for their global warming potential. The fact that FWP accomplishes this weighting in a way that is more accurate for any given timeframe than are the IPCC generalizations should count in favor of using FWP and cannot be used as an excuse for dismissing the FWP approach.

IV. Other Methodological Considerations

A. Scenario Analysis

1. **EPA's proposed approach has been to look at snapshot in time (biofuel volume change in 2022) and to project emissions and reductions forward based on this one time change in volume. A more detailed and perhaps more data intensive approach would be a year-by-year analysis comparing different volume scenarios of biofuels over time. Such a comparison would likely compare a base case and one or more expanded biofuel cases. A particular methodology for this approach would be to project different annual biofuel volumes and GHG emissions out into the future until the base case and policy case are equivalent (if ever).**
   a. **Would this approach present a clearer picture of the marginal impact of the RFS mandates?**
   b. **Would this approach present a clearer picture of what the GHG impact is of a specific biofuel (i.e., what is needed for EISA requirements)?**
   c. **Would this approach help to clarify the timeframe discussion by tracking the GHG difference between scenarios over time until there are no more changes?**

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[14] See for example O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001

   d. **Would the base case ever provide the same amount of biofuel as the RFS policy case scenarios (e.g., this could include both cases having zero biofuels at some future date)?**
   e. **Would the base case ever provide the same level of GHG emissions as the RFS policy case (i.e., at what point would you stop needing to consider differences between the two cases)?**
   f. **Is there an alternative methodology for deciding the time frame over which we should project the yearly impacts of RFS?**
2. **How could a yearly or cumulative impact approach be used to determine lifecycle GHG values for specific fuels or fuel pathways?**
3. **What models, tools, and data sources are available that would enable this type of calculation?**

The project time frame and the impact time frame are the two relevant parameters needed to determine the time frame of the analysis. If I understand the question, you suggest replacing the project and impact timeframes and instead determining the timeframe of the analysis based on when the base case and policy case end up with the same biofuel production (either by the base case rising to mandated levels or by both cases falling if mandates are removed after 2022). This would be inappropriate. Depending on the scenarios considered, this could lead to absurdly long project time horizons that would not be consistent with the intent of EISA. The mandated GHG emission reductions must occur within a reasonable timeframe in order to be consistent with the intent of the law as written and with the broader policy objective of helping to address climate change. The project time frame could reasonably be interpreted as ending in 2022 (see above), or could reasonably be interpreted as extending for the duration of an ethanol plant (~30 years).

However, I do recommend a different improvement to your modeling approach, having to do with your decision to run the model separately for a scenario containing each fuel. A better approach would be to use a model run that includes the mandates for all of the fuels, and then to partition the observed effects amongst the fuels. Because RFS2 mandates all of these fuels at the same time, land use change can only be accurately captured in a model that adds together the demand from all of the fuels in the mandate. This is because improvements in crop yields may free up enough land to avoid land use change when only one piece of the mandate is considered, but when the entire mandate is considered the demand for new land could overwhelm the amount of land spared from yield improvements. When using a model run that includes all the fuels, one must determine how to partition the emissions from land use to each fuel type. An appropriate way to do this would be based on their relative GHG emissions from land use change in separate model runs for each fuel. For example, if increased corn ethanol production by itself caused 90 tons of emissions from land use change, and increased soy biodiesel production by itself caused 10 tons emissions from land use change, one could attribute 90% of land use change emissions to corn ethanol and 10% to soy biodiesel in a model run that included increases in both fuel types.

APPENDIX C

MR. RALPH HEIMLICH RESPONSE TO CHARGE QUESTIONS

This document reviews the United States Environmental Protection Agency's (EPA's) methodology to account for lifecycle greenhouse gas (GHG) emissions of biofuel fuels over time. Based on documents from the proposed RFS2 rule published by EPA on May 5, 2009, EPA analyzed lifecycle greenhouse gas (GHG) emissions from increased renewable fuels use, taking into account the indirect effects, including emissions from land use changes, associated with biofuel production, as directed by the Energy Independence and Security Act of 2007 (EISA). A key component of the analysis is the issue of timing of GHG emissions and reductions. GHG emissions associated with gasoline or diesel are likely to be released over a short period of time, while GHG emissions from biofuels production may continue for a much longer period of time. The analysis looks at methods and approaches for discounting emissions over time to ensure comparability of biofuels to other fuels. This review is intended to inform the rulemaking process by providing an independent evaluation of EPA's methodology.

The review first lays out my understanding of EPA's analytical problem, a conceptual framework that is helpful in approaching the problem, and then addresses the specific questions posed in the charge to reviewers.

EPA's Analytical Problem

The purpose of the life cycle analysis undertaken by EPA is to estimate whether GHG emissions from renewable fuels meet the reduction limits established by Congress relative to fossil fuels in EISA 2007. For example, in the case of biomass-based diesel fuel, a renewable fuel can only meet that definition if it is a fuel that:

> " … has lifecycle greenhouse gas emissions, as determined by the Administrator, after notice and opportunity for comment, that are at least 50 percent less than the baseline lifecycle greenhouse gas emissions."

Inherently, EPA must compare the:

> "…aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their
> relative global warming potential."

The problem for EPA is compounded because the timing of life cycle GHG emissions from fossil fuels occurs over a short time period from well to wheels, while those from renewable fuels can occur over a much longer period of time, perhaps decades.

The framework for RFS2 is a timetable that ramps up production of renewable fuels in various categories from 2009 through 2022, and no further. Moreover, EPA is tasked with estimating the GHG emissions of a representative unit of renewable fuel rather than the total production of those fuels under the RFS2 mandate. EPA chose to base the analysis on a comparison of the amounts of fuels mandated for 2022, when each renewable fuel is produced at its maximum level.

Conceptual Framework

A key tenet in economics is that the value of something in the future is different than it is today. This concept takes account of two factors affecting value: the work of resources over time and the change in the value of money over time. The former is illustrated by the idea that if I had the resource (money) today, it could be employed in some productive way to earn even more by the future date. The latter is usually thought of in terms of inflation in nominal currency over time, which means that the purchasing power of a unit of currency generally declines over time due to long-term secular inflation in prices. More generally, the value of a nominal unit of currency changes (both increases under inflation and decreases under deflation) over time. The discount rate should account for both of these factors, unless the values laid out over the time path have already been deflated (inflated) based on assumptions about the expected rates of inflation (deflation).

How does economic valuation relate to EPA's problem? A literal reading of EISA 2007 and the GHG reductions that define renewable fuels implies that there is no relationship to valuation: emissions are physical quantities and the reduction standard is in terms of those quantities. A broader interpretation, however, is that Congress is concerned with the benefits of renewable fuels in reducing climate change associated with global warming. Congress' use of the term "relative global warming potential" suggests that this broader interpretation is correct.
If EPA's interpretation of the law is that GHG emissions are a proxy for reducing climate impacts (damages), they can be viewed in a valuation framework because the value of avoiding those damages sooner rather than later changes over time. If EPA believes a strict interpretation of the law is appropriate, emissions should not be treated as varying in importance over time. EPA's interpretation of the law is a matter for legal scholars, not economists.

If Congress meant to have EPA examine the relative climate change impacts of burning renewable fuels versus fossil fuels, how good a proxy for damages are emissions? Clearly, Congress recognized that not all GHGs are created equal because they specified that the "relative global warming potential" be calculated (more on this below). But global warming from the greenhouse gas effect is a function of the stock of GHGs in the atmosphere. That stock is affected by changes in emissions, but different GHGs have differing decay rates, so the impacts of differing time-paths of emissions are not equal, and are not fully accounted for by the GWP factors. [15]

If this is a correct interpretation of the law (an issue for legal scholars rather than economists), then GHG emissions can be viewed as a proxy for benefits of reducing the impacts of GHG emissions and Congress can be forgiven for not fully appreciating the complications of the behavior of these gases and their impact on warming. In the IPCC's latest report on the scientific basis for climate change, IPCC notes that the ideal formulation for a physical emission metric is given by:

$$AM_i = \int [(I(\Delta C_{(r+i)}(t)) - I(\Delta C_r(t))) \times g(t)]dt \qquad eq.(1)$$

where:

[15] CO2 declines in a non-linear fashion in accord with the Revised Bern Model, while methane (CH4) and nitrous oxide (N2O) decline exponentially with half lives of 12 and 114 years, respectively (Schimel *et al*., 1996; Forster et al.,2007 table 2.14 on p. 212)

$I(\Delta C_i(t))$ is a function describing the damage or benefit impacts of a change in climate (ΔC) at time t.
$g(t)$ is a discounting function over time, such as $g(t) = e^{-kt}$ the simple economic discount function, and
r is a time subscript referring to the emission time path.

To compare two emissions i and j , the absolute metric values AM_i and AM_j can be calculated to provide a quantitative comparison of the two emission scenarios. Only in the special case where the emission scenarios consist of only one component (as for the assumed pulse emissions in the definition of GWP), can the ratio between AM_i and AM_j be interpreted as a relative emission index for component i versus a reference component j (such as CO2 in the case of GWP) (Forster, et al., 2007, p. 210). The GWP is a simplified version of this formulation, which uses the global mean radiative forcing (RF) of each gas, integrated over a specific time horizon, specified as:

$$GWP_i = \frac{\int_0^{TH} RF_i(t)\,dt}{\int_0^{TH} RF_r(t)\,dt} = \frac{\int_0^{TH} a_i \cdot [C_i(t)]\,dt}{\int_0^{TH} a_r \cdot [C_r(t)]\,dt} \qquad \text{eq.(2)}$$

Where:

TH is the time horizon, effectively set at 100 years by assumptions below,
RF_i is the global mean RF of component i,
a_i is the RF per unit mass increase in atmospheric abundance of component i (radiative efficiency),
$C_i(t)$ is the time-dependent abundance of i,
and the corresponding quantities for the reference gas (r) in the denominator.

All GWPs given by the IPCC use CO2 as the reference gas.

The simplifications in going from equation (1) to the standard GWP index in equation (2) include:

(1) setting $g(t) = 1$ (i.e., no discounting) up until the 100-year time horizon (TH) and then $g(t) = 0$ thereafter,
(2) choosing a 1-kg pulse emission,
(3) defining the impact function, $I(\Delta C)$, to be the global mean RF,
(4) assuming that the climate response is equal for all RF mechanisms and
(5) evaluating the impact relative to a baseline equal to current concentrations (i.e., setting $I(\Delta Cr(t)) = 0$). (Forster, et al., 2007, pp. 210-11)

GWP indices are inadequate to account for the time effects of GHG emissions because of these assumptions, particularly the discounting assumption made in (1) and its implicit time horizon. If EPA is treating emissions as a proxy for damages, they should be adjusted to as closely mirror the damaging impact as possible, by calculating the direct global warming potential for each gas as it is emitted over time and accounting for its decay (Fearnside, et al., 2000).

That is, EPA should lay out which gases are emitted, in what year of the scenario, the cumulative effects of the decay of the emissions over the time path, and their impact on radiative forcing over their lifetimes. Averaging emissions over time and then laying them out on a time path in equal chunks, as EPA has done with soil carbon losses from indirect land use change, is misleading and unhelpful to this process. The revised Bern carbon cycle model accounts for the decay of CO2 over time, and similar modeling can account for methane and nitrous oxide components of emissions.

Regarding the time horizon that is appropriate, if EPA interprets the law as a comparison between proxies for damages, the appropriate time horizon should be related to the timing of those impacts. This is especially true since the "project" is only defined in terms of mandated amounts of renewable fuels until 2022. EPA should avoid unnecessarily complicating the analysis with considerations about the future of the renewable fuels industry (which is clearly affected by this very regulation) because they do not bear on the per-unit differences in impacts and simply add another layer of uncertainty to the analysis.

The difference in interpretation between a literal reading of the law and an interpretation of GHG emissions as proxies for damages from climate change conditions the framework in which the timing of emissions should be considered. If the former interpretation is correct, then a simple summation of emissions over as a short a period as possible (through 2022, or for 20 or 30 years, as examples) is appropriate. If the broader interpretation of damages is correct, then it behooves EPA to lay out the impacts in a way that as closely mirrors the timing and impact of emissions on warming as possible, short of a full-blown estimate of dollar damages avoided.

Conclusion

In short, if EPA is using a time horizon long enough to encompass all the impacts from the 2022 level of production and resultant emissions from indirect land use change (including all emissions from land clearing and sequestration foregone), it should lay out those emissions as accurately as possible on their true time path, adjust them for their climate change potential using modeling like an improved version of FWP, and discount those adjusted emissions back to present terms using a non-zero discount rate that reflects the uncertainty in the estimate of the damages.

Peer Review Charge Questions

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[16]

A. Framing the Issues

1. **The preamble and RIA separates the discussion of how to account for the variable timing of transportation fuel lifecycle GHG emissions into different components:**
    a. **Time frame**
    b. **Discount rate, or the relative treatment of current and future GHG emissions**
    c. **Appropriate metrics**
2. **Is this a scientifically objective way to frame the analysis of lifecycle GHG impacts of different fuels in the context of what is needed for this rulemaking?**

It is appropriate to discuss these three elements, but EPA needs to show that it is aware of the interactions between these three topics. I would suggest that the discussion begin with appropriate metrics because EPA's determination of the appropriate metric narrows the choices for timing and discount rate. As discussed above, if EPA chooses to make a strict interpretation of EISA 2007 and measure emissions strictly in GWP without further adjustment, it has implicitly rejected the idea that emissions are proxies for damages and should not use economic concepts of discounting. Given the problems of comparing emissions over long periods of time

[16] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

without some adjustment, the decision to use strict GWPs should lead EPA to use as short a time horizon as practical. On the other hand, if EPA interprets the law as requiring a comparison of emissions as a proxy for potential damages from warming, that implies a time horizon consonant with encompassing the impacts associated with each fuel's use.

The choice of discount rate is also related to the choice of metric. A strict use of emissions implies that discounting is inappropriate, while an interpretation of proxied damages would admit discounting. Using a proxy for damages implied that the damage function is not well understood, implying that the risk of having specified the damages correctly is high. If the risk that damages are incorrectly stated is high, it is not appropriate to use a risk-free discount rate.

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

1. **As explained in the preamble and RIA, the time frame for analyzing lifecycle GHG emissions can be approached in different ways, such as:**
    a. **Project time frame – how long we expect production of a particular biofuel to continue into the future**
    b. **Impact time frame – the length over which to account for the changes in GHG emissions, in particular due to land use changes, which result from biofuel production**
2. **Do the preamble and RIA define these time frame concepts in a scientifically objective way for lifecycle analysis? What other concepts, if any should be considered?**

Actually, the Preamble devotes the most space to discussing 100 year and 30 year time frames actually used in the analysis. The shorter discussion of "project" and "impact" time horizons is more scientifically justified than fixed and arbitrary (but customary) 100- and 30-year periods. I question, however, whether EPA is sufficiently clear on what constitutes the RFS2 "project". The RFS2 mandate only extends to 2022, with no assurance of any market at all beyond that date. Given that renewable fuels markets in the U.S. are essentially being created (or at least heavily influenced) by this regulation and related subsidy programs, estimating how long "…production of a particular biofuel …[will] continue into the future" seems like a particularly byzantine undertaking fraught with more uncertainty than EPA's main task of determining which meet the RFS2 standard. The idea of an "impact" horizon is inherently better defined, since the main impacts are those associated with indirect land use change, and reasonable assumptions can be made about time frames under which those impacts play out.

B. Determination of Project Time Frame(s)

1. **What is a scientifically justifiable project time frame to consider for this analysis? Should the project time frames be different for each fuel?**
    a. **What are the proper criteria for determining the project time frame?**
        i. **Should the project time frame be based on when each fuel is likely to be priced out of the market? Should the project time frame be based on the EISA fuel mandates? What other criteria would you recommend, if any?**
    b. **What is the best scientific method for determining the project time frame or frames?**
        ii. **Is economic modeling the best method for determining the project time frame? If so, what specific models do you recommend for this analysis?**

iii. **If you do not recommend economic modeling, what other methods do you suggest?**

In order to determine an appropriate "project" time frame, EPA must determine the "project" implied by the RFS2 mandate. Legislatively, the mandate only extends to 2022 and given how important this mandate is to markets for renewable fuels in the U.S. and the influence of various subsidies, tariffs and import exclusions on these markets, it seems problematic to me that any economic analysis can subjectively conclude much about market futures beyond 2022. That is, EPA and others in Washington DC are making the market for renewable fuels—a market that would bear little relationship to its current state without the policy support it has and continues to receive. So, the answer to b. i. is NO.

What is unarguable in the context of RFS2 is the mandate itself, and this offers the clearest basis for a project time horizon. Certainly, the emissions from mandated renewable fuels and from associated volumes of fossil fuels out to 2022 is within the purview of the regulation and does not require EPA to make heroic assumptions, with even more heroic uncertainties, about the future of renewable fuels beyond 2022. What does this course entail regarding emissions beyond 2022? It seems to me that EPA should NOT assume that renewable fuels will be produced beyond 2022, and it is not necessary for EPA to make that assumption. Because EPA is tasked with comparing the relative emissions of fossil fuels and renewable fuels on a unit basis, it should suffice to quantify the emissions associated with producing and using the 2022 volumes. An alternative (not necessary, but possible), is to quantify the emissions associated with producing the entire suite of volumes from 2010 to 2022, but not beyond.

This shades over to discussion of the impact time horizon because the time horizon is limited by when emissions from production in 2022 cease. These are mostly associated with emissions resulting from indirect land use change and should turn on when continued soil carbon emissions can be considered negligible. In the preamble, EPA states that soil carbon emissions continue for approximately 20 years. Carbon sequestration foregone because of the loss of forests and grasslands should be based on the nature of the forests and grasslands converted. That may mean that some would have sequestered significant carbon for many years, but more mature forests whose sequestration rate has slowed or stopped would cut off much sooner.

C. Determination of Impact Time Frame

1. **What is a scientifically justifiable impact time frame to consider for this analysis? Should the impact time frame be the different for each fuel?**
2. **What are the proper criteria for determining the impact time frame?**
3. **What is the best method for determining the impact time frame or frames? What modeling or other information should inform the choice of an impact time frame?**
4. **Is it scientifically justifiable to select an impact time frame based on presumed climate impacts? For example, should we only be concerned with GHG reductions over the next 20 – 30 years, or is a different time frame justified.**
5. **How should the potential for "threshold" or irreversible climate change impacts influence our choice of an impact time frame?**
   a. **What evidence about these potential thresholds would be most appropriate for consideration when determining the impact time frame?**

The impact time horizon should encompass all significant impacts of the emissions associated with the 2022 or 2010-2022 production of renewable fuels under the RFS2 mandate, since that is the “project” for which the impacts are being evaluated (see response to B. above). If different fuels have different impacts, they should be evaluated over the impacts that are implied by their production. For example, comparing diesel to biodiesel from animal wastes probably requires only a single year since there are no long-term sources of emissions to consider, while production of corn ethanol involves indirect land use change effects that may involve changes over many years. In effect, the time horizon is irrelevant if the emissions time path is correctly specified since including out years with zero emission change does not effect the analysis. That is NOT equivalent to continuing to burn the same quantity of fuel as mandated in 2022 on into the future, however, since the mandate says nothing about what will or will not be required beyond 2022.

Note that the correct impact time horizon is dependent on the timing of production. If EPA is evaluating the 2022 mandated level of a renewable fuel, the impacts lay out from that date forward in time until all impact are accounted for. The time horizon for assessing the 2010 mandated level would be approximately the same length in years, but would terminate 12 years sooner on the time path. Some authors have referred to this as a “rolling time horizon” versus a fixed time horizon (Marshall, 2009, p. 8).

In the preamble and RIA, EPA is currently using Section 5.3.3.4 of the IPCC AFOLU guidelines, in which the total difference in soil carbon stocks before and after land use conversion is averaged over 20 years. This is not an appropriate model for laying out the time path of emissions from land use conversion since the loss of soil carbon from conversion is observed to be quite rapid in initial years, then drop off in later years (Mann, 1986; Armentano and Menges, 1986; Davidson and Ackerman, 1993; Powers et al., 2004). According to the IPCC guidelines:

> “Changes in C stocks normally occur in a non-linear fashion, and it is possible to further develop the time dependence of stock change factors to reflect this pattern. For changes in land use or management that cause a decrease in soil C content, the rate of change is highest during the first few years, and progressively declines with time.” (IPPC, AFOLU, Chapter 2.3.3.1, p.2.38)

Short of developing detailed soil carbon loss curves for each area, EPA could use the judgment of soil scientists familiar with areas where conversion is expected to apply curves of a generally correct shape for soil carbon loss that equal the total soil carbon loss expected. A similar method could be used for to better approximate the time pattern of foregone carbon sequestration.

If EPA’s interpretation of the law is that emissions are proxies for damages from climate impacts, then it is justifiable to choose the time horizon based on relevant information regarding those impacts. The real question is: What is known about future climate impacts that limits the relevant time horizon? While it is likely true that reductions in emissions today are more critical in arresting climate change than emissions reductions many years from now, is there anything specific enough to set a cut-off date beyond which emission reductions are irrelevant? Is there any specific knowledge about the shape of the damage function over time that can be brought to bear?

It may be a better strategy to incorporate the time-value of emissions reductions in the discount factor, rather than limit the time horizon for emissions. If the time path of emissions is laid out correctly, a higher discount rate will put more emphasis on emissions that occur sooner in time than later.

The possible existence of threshold or irreversible climate impacts is significantly different than the more general issue of knowledge about future climate impacts. Thresholds or irreversibilities imply that the damage function is not only not linear with emissions, but is "kinked" or increases infinitely. However, there is little in the projections of the latest IPCC assessment report (IPCC, 2007) to suggest such a damage function. Two causes for such discontinuous effects are the slowing or reversal of the Atlantic meridional overturning circulation (MOC) and the irreversible melting of either the Greenland or Antarctic ice sheets. Regarding the former, the IPCC assessment concludes:

> "Based on current model simulations, it is *very likely*[17] that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence." (IPCC, 2007, p. 16).

With regard to ice sheet melting:

> "Contraction of the Greenland Ice Sheet is projected to continue to contribute to sea level rise after 2100. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland Ice Sheet and a resulting contribution to sea level rise of about 7 m." (IPCC, 2007, p. 17), and

> "Current global model studies project that the Antarctic Ice Sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance." (IPCC, 2007, p. 17)

While of concern, these results do not constitute threshold or irreversible phenomena of either sufficient certainty or temporal proximity to affect the time horizons for the RFS2 mandate, at least in my judgment.

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

1. **If the impact time frame is longer than project time frame, how should GHG emissions in this longer time frame be accounted for as part of EPA's lifecycle GHG analysis?**
2. **Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion?**
3. **Besides land reversion, what other factors following biofuel production should be considered in this analysis? What is the best way to estimate these GHG emissions changes?**

Within the framework that I suggest is appropriate above, the impact time horizon is definitely longer than the project time horizon because the project is either just the 2022 or the 2010-2022 RFS2 mandate for renewable fuels. If EPA interprets the law to mean emissions are proxies for impacts of climate change, then emissions from events associated with production of the renewable fuels beyond the project's life have to be considered. It is unnecessary (and

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[17] In IPCC standardized language, the following terms have been used to indicate the assessed likelihood, using expert judgment, of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%.

unhelpful) to extend fuel production which occurs during the project time horizon over the entire impact time horizon. Fuel produced in year t may have impacts (e.g., soil carbon loss, foregone carbon sequestration) that extend for 80 years even if fuel production ceases in year t+1. The emissions associated with those impacts need to be accounted for, but fuel production should not extend that long.

As a matter of symmetry, if EPA has reason to believe that croplands growing feedstock will be abandoned, then the subsequent sequestration of carbon in vegetation occurring on those lands should count as an indirect land use change as much as the conversion of forest or grassland to crops as renewable fuels ramps up. However, moving beyond the RFS2 mandates in 2022 once again puts EPA in the position of forecasting a market for renewable fuels that lacks any certainty, and compounds those uncertainties with additional ones about what would become of abandoned cropland (Marshall, 2009). However, since EPA is in no position to assume that renewable fuels will be produced and burned beyond the 2022 mandate, it could assume that U.S. exports of corn and soybeans diverted for biofuel production are released and available to replace local production in the consuming countries abroad. Whether this would happen depends on the relative cost of exported U.S. commodities versus local production, assuming that the costs of land conversion are sunk costs. Reversion of U.S. export supplies is not a foregone conclusion once the costs of converting land to crop production have been incurred and local agricultural economies strengthened, but simulations with the FAPRI models used to estimate indirect land use change should be capable of estimating how much the pre-biofuel export patterns would be resumed.

The sequestration from abandoned croplands will, in general, not be equal to the sequestration foregone from clearing the land originally. As before, what sequestration occurs depends on the location and character of cover established. In the absence of any program to actively replant vegetation for optimal sequestration, it is likely that natural revegetation would occur, with whatever sequestration that might have. In general, the rate of sequestration for newly planted vegetation is larger than that for mature vegetation, so the time path of sequestration should be as carefully constructed as that of foregone sequestration.

I am not aware of any other impacts on emissions that should be estimated in the absence of continued renewable fuel production beyond 2022.

III. Valuation of Future GHG Emissions

A. Conceptual Issues

1. Is it scientifically justifiable to treat future GHG emissions and reductions different than near term emissions/reductions?

a. If so, what is the basis for such different treatment?

As I laid out in the introduction to this review, I believe that giving different treatment to emissions and reductions depending on when they occur in time is legitimate if EPA interprets the Congressional requirement to compare emissions in EISA 2007 as requiring a comparison of damages from climate change. The basis for differential treatment is the same basis as that justifying treating benefits occurring at different times differently, as outlined above. When treating emissions as proxies for benefits, they should be adjusted as appropriate to fully reflect their impact on climate change.

4. **Is it appropriate to apply a non-zero discount rate to physical GHG emissions (i.e., GWP weighted emissions) in some or all circumstances?**
    1. **Is it scientifically justifiable to apply a non-zero discount rate to physical GHG emissions under the assumption that GHG emissions have constant marginal damages regardless of when they occur (i.e. use GWP weighted emissions as a surrogate for monetary impacts)?**
    2. **If discount rates are used when monetizing the impact of GHG emissions, is this scientifically justifiable for the purposes of lifecycle GHG assessment as defined by EISA?**

If EPA interprets the emissions comparison posed by Congress in EISA 2007 as an assessment of impacts on climate change, then using a non-zero discount rate is legitimate because the physical measure is posed as a proxy for damages. However, as noted above, the adjustments between gases for global warming potential (GWP) are not sufficient adjustments to proxy for constant marginal damages because they do not fully account for the differing decay paths of different GHGs, and because they already incorporate a zero discount rate and 100 year time horizon. An adjustment that fully accounts for the decay paths of the gases considered, such as the revised Bern climate cycle model for CO2 and exponential decays for methane and nitrous oxide, should be used. In addition, EPA needs to more carefully trace the time path of emissions and sequestration from soil carbon and afforestation than they have done because when these occur matters in a discounting framework.

Question 2.b. is puzzling because no one is seriously discussing full monetization of the impact of GHG emissions. By "monetization," I mean modeling the complete time path of dollar-denominated damages from climate change. This would be equivalent to the term $I(\Delta C_t)$ in eq. (1) above. To date, no climate model can accurately predict the time path of changes that will occur with increased GHG concentrations in the atmosphere, and the resulting physical damages that will accompany changes in sea level, precipitation and wind patterns, and damages to agricultural and forestry productivity and ecosystems in sufficient detail to value them in monetary terms.

There is no simple linear transformation between the time paths of this ordered set of proxies for damages from climate change associated with increasing GHG concentrations in the atmosphere:

1. GWP-adjusted emissions
2. Emissions adjusted for decay over time
3. Physical impacts of increasing GHG concentrations (e.g., floods, sea level change, hurricanes, crop failures, etc.)
4. Monetized value of damages.

Even if such a monetization could be estimated, would EPA be correct in interpreting this to meet the Congressional direction to compare GHG emissions from renewable fuels? I believe that if Congress thought such an assessment of monetized damages could be accurately estimated, they would have phrased the renewable fuels criteria in those terms: renewable fuels would have had to reduce the aggregate damages from climate change at least 20 percent compared with fossil fuels.

5. **Is it scientifically justifiable to apply a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts? Is this the only circumstance where a non-zero discount rate would be appropriate?**

Estimating climate impacts from GHG emissions, physical damages from climate impacts, and monetary values of physical damages would be a complete economic accounting (including any offsetting benefits of climate change) and EPA would be justified in using a non-zero discount rate to bring the time-path of such damages back to present value terms. However, if EPA interprets physical GHG emissions, with appropriate adjustments, as a proxy for physical damages and their economic value, it is appropriate to use a non-zero discount rate to compare two streams of these proxies in present value terms. Fearnside et al.(2000) refer to this as "immediate C emission equivalents" rather than the more customary net present value. If EPA is unwilling to assert that some adjustment of physical emissions is an accurate proxy for the stream of damages, discounting should not be used. However, the interaction with the time horizon becomes important in this case because the more remote in time emissions occur, the more unconvincing the argument that those emissions are just as important to us as ones that will occur more immediately.

B. Choice of Discount Rate

1. **What is the most scientifically justifiable discount rate (including the possibility of a zero discount rate) for this lifecycle analysis?**
2. **What are the proper criteria for determining the discount rate?**
3. **Should the choice of discount rate be related, or affected, by the selected time frames (i.e. project and impact) for lifecycle GHG analysis? If so, how?**

There are two competing schools of thought on discounting in cost-benefit analysis: a "positive" school that argues for a descriptive approach to setting discount rates based on observed behavior regarding time preferences, and a "normative" school that seeks to set discount rates that optimize the welfare of society over time (Scheraga and Sussman, 1999).

The positive school basically argues that cost-benefit analysis should efficiently allocate resources between projects and that the discount rate should therefore reflect the cost of capital and the consumption rate of interest, in a sense clearing the market between lenders with capital to invest, and borrowers' time preference for consumption. The rate of interest on private capital thus becomes one component of the discount rate because projects will likely divert some capital from private investment, raising the cost of capital to such investors. Another component in this view is the consumption rate of interest, at which society is observed to trade off present consumption for future consumption.

The normative school argues that the discount rate should be set to optimize social welfare over time. The solution to this mathematical optimization in terms of the discount rate, known as the social rate of time preference, consists of two components (Scheraga and Sussman, eq. 1.1 on p. 5). One is the pure rate of social time preference, expressing the simple idea that is better to consume today (when you are alive) than wait to consume tomorrow (when you may be dead). Second, is the rate at which the utility from consuming falls as consumption increases, expressing the perhaps naïve expectation that future generations will be wealthier than we are, and will appreciate each additional unit of consumption less than we do.

The normative and positive schools may come to some convergence in the notion of compensation, in that if those losing from a particular investment project can be compensated for their losses by those gaining from it, the project is Pareto optimal under at least the weak criterion that, after compensation, at least someone is better off than without the project (Randall, 1984 p. 56). They also converge around a concept known as the shadow price of capital, which argues that the cost of capital investments foregone can be expressed in terms of consumption foregone as well, an amount that is larger than the amount of capital. Translating all costs and benefits in terms of consumption foregone and discounting at a rate reflecting the social time preference for consumption is generally agreed as being both optimal and efficient.

None of this is particularly enlightening in the present case, since the adjusted emissions cannot be classified as either capital or consumption, *per se*. Capital will be employed to construct the renewable fuel refineries, but it is private capital. Damages from climate change (e.g., sea level rise, increased hurricanes) will not discriminate between vacation houses (consumption) and industrial facilities (capital stock). The best assumption that EPA can make in this case is that the time path of adjusted emissions from renewable fuel use versus fossil fuels proxies for real damages avoided by the RFS2 mandate in terms of consumption foregone (e.g., already reflecting the potential impact on consumption). The appropriate discount rate, therefore, is one that reflects the real social time preference for consumption. Appendix C of OMB Circular A-94 provides guidance on real interest rates for different maturities of Treasury notes and bonds, which are a reasonable proxy for the social time preference for consumption. The longest maturity (30 years) currently carries a rate of 2.7 percent, which is at the lowest it has been over the historic period since 1979. The highest real rate for 30 year bonds was 7.9 percent, in 1982, and the average rate over the 1979-2009 period is 4.34 percent.

With regard to interaction between the discount rate and the time horizon, the rate chosen should be consonant with the time horizon. It is not appropriate to match a short-term rate with a long time horizon, or the obverse. In general, there is more volatility in short-term interest rates than in long-term rates because short-term rates reflect all of the influences on credit markets on a day-to-day basis.

In the case of discounting emissions, if the time horizon EPA chooses is short enough (say 20 years) there is little to be gained by using a non-zero discount rate. In terms of their impact on the climate system, the effects of all emissions during such a short time horizon can be considered equal. As the length of the time horizon increases to encompass more of the impacts, the disparity between the value of present and future effects grows and non-zero discounting becomes necessary.

Another, more indirect potential interaction between the time horizon and the discount rate is the deliberate practice of using a higher discount rate with longer time horizons when the length of the time horizon encompasses greater uncertainty about the accuracy of future payment streams (Staehr, 2006; Mishan, 1976). Because the time path of emissions is a proxy for economic damages that may, or may not be very accurate, EPA should avoid using a “risk-free” discount rate and should consider placing a risk premium on the discount rate that reflects the uncertainty in accurately estimating damages using the emissions proxy. This practice can merely compound the uncertainty over the basis for setting discount rate unless there is a clear rationale for increased uncertainty in the out years of the time horizon and the premium for increased uncertainty is clearly identified.

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

1. **EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." How does this language impact or limit the approach taken by EPA to evaluate lifecycle GHG thresholds of biofuels?**
2. **One alternative measure that has been proposed is the Fuel Warming Potential (FWP). Would the FWP be an appropriate metric to use for this analysis? If so, how would it be applied in the context of determining comparative assessment of transportation fuel lifecycle GHG emissions?**
3. **Are there other methods or metrics that would be more appropriate to account for GHG emissions over time?**

How EPA interprets the EISA GHG emissions language is a matter for legal scholars, not economists. The addition of the language on adjustments for relative global warming potential suggest that Congress' intent is to use the emissions as a proxy for damages from climate change. If that is the case, EPA should consider further adjustments to more closely match the true time path of emissions and their effects on climate than the GWP.

As discussed above, GWP implicitly assumes a time horizon and no discounting, and ignores differences in the decay of gases over time. EPA should more explicitly trace both the emissions (e.g., emissions of soil carbon and carbon sequestration foregone from land clearing) and their impact (decay paths over time) in their true time path using models such as the revised Bern carbon cycle model. The Fuel Warming Potential (FWP) measure is an appropriate step in this direction, but it suffers from some limitations (O'Hare, et al., 2009, p. 4-5):

(1) The decay rate for atmospheric CO2 in FWP assumes a constant background concentration in the atmosphere, but radiative efficiency for a marginal unit of CO2 *decreases* non-linearly as the background concentration of CO2 in the atmosphere increases, and CO2's residence time in the atmosphere *increases* owing to a slowing of CO2 removal from the atmosphere.
(2) FWP assumes that the radiative efficiency of the GHG is constant.
(3) FWP only deals with CO2, excluding important impacts from methane and nitrous oxide.

The first limitation is not serious if emissions considered are small relative to the baseline CO2 atmospheric concentration, but the impact of RFS2 is likely large enough that the corrections to (1) and (2) should be incorporated into the model. Because land use change is a significant source of emissions in EPA's analysis, and agriculture and land use change emit large quantities of methane and nitrous oxides, these gases should be explicitly modeled in a FWP-like framework using decay models that are appropriate to their decay paths and parameters.

In short, if EPA is using a time horizon long enough to encompass all the impacts from the 2022 level of production and resultant emissions from indirect land use change (including all emissions from land clearing and sequestration foregone), it should lay out those emissions as accurately as possible on their true time path, adjust them for their climate change potential using modeling like an improved version of FWP, and discount those adjusted emissions back to present terms using a non-zero discount rate that reflects the uncertainty in the estimate of the damages.
I am not aware of any other metrics that would be more appropriate to use than those described above.

IV. Other Methodological Considerations

A. Scenario Analysis

1. **EPA's proposed approach has been to look at snapshot in time (biofuel volume change in 2022) and to project emissions and reductions forward based on this one time change in volume. A more detailed and perhaps more data intensive approach would be a year-by-year analysis comparing different volume scenarios of biofuels over time. Such a comparison would likely compare a base case and one or more expanded biofuel cases. A particular methodology for this approach would be to project different annual biofuel volumes and GHG emissions out into the future until the base case and policy case are equivalent (if ever).**
   - a. **Would this approach present a clearer picture of the marginal impact of the RFS mandates?**
   - b. **Would this approach present a clearer picture of what the GHG impact is of a specific biofuel (i.e., what is needed for EISA requirements)?**
   - c. **Would this approach help to clarify the timeframe discussion by tracking the GHG difference between scenarios over time until there are no more changes?**
   - d. **Would the base case ever provide the same amount of biofuel as the RFS policy case scenarios (e.g., this could include both cases having zero biofuels at some future date)?**
   - e. **Would the base case ever provide the same level of GHG emissions as the RFS policy case (i.e., at what point would you stop needing to consider differences between the two cases)?**
   - f. **Is there an alternative methodology for deciding the time frame over which we should project the yearly impacts of RFS?**
2. **How could a yearly or cumulative impact approach be used to determine lifecycle GHG values for specific fuels or fuel pathways?**
3. **What models, tools, and data sources are available that would enable this type of calculation?**

Because the renewable fuels criterion resolves to a simple percentage change in emissions relative to fossil fuels, any volume of fuels can be used, in theory, to make the calculation. However, this assumes that the percentage difference in emissions is scale neutral. That is, the emissions associated with one volume of renewable fuel are a linear function of any other volume of that fuel. While this is probably true for economically viable plant sizes of refineries, it isn't even true for gasoline (higher volumes require deeper drilling, different sources such as tar sands, more processing, etc., which increases the energy inputs per gallon yielded). The feedstock for renewable fuels is the product of an agronomic system using inherently limited natural resources that may be subject to even greater nonlinearities at different volumes.

EPA provides the data to check this assumption in the RFS2 RIA. The control case against which the RFS2 renewable fuel volumes will be compared is based on the 2007 IEA Annual Energy Outlook projection of 12.4 billion gallons of corn ethanol in 2022, versus the 15 billion gallon mandate. The effects from the 2.6 billion gallon difference are estimated in FASOM and FAPRI by running the models at the 2022 mandated levels for all fuels except corn ethanol, which is *reduced to* the reference level of 12.4 billion gallons. The results are then compared to the mandated case where all biofuels are at their mandated levels (15 billion gallons for corn ethanol; see Table 2.6-1 in the RIA). The differences between direct and indirect emissions are divided by 2.6 billion gallons to give the emissions per gallon, which are then compared to those for gasoline.   EPA's sensitivity analyses include a scenario where the reference level of corn ethanol without the RFS2 mandates is only 8.7 billion gallons, giving a 6.3 billion gallon increase in corn ethanol volume, 1.4 times as large as the primary analysis. The results are summarized in the RIA at p. 424, figure 2.8-17, which shows net emissions of 4 million grams of CO2 equivalents per mmBTUs, discounted over 100 years at 2%, or a 6% reduction compared to gasoline vs. 16% for the smaller volume. In the undiscounted 30 year time horizon, the difference is 9%, resulting in a 14% higher emission from ethanol compared to only 5% greater emissions from the lower volume. Therefore, the difference in emissions compared to gasoline is NOT invariant with volume, increasing as the scenario accounts for larger volumes.

EPA can address the nonlinearities associated with volume to some extent by assessing the impacts of *all* volumes of a renewable fuel required under the RFS2 mandate in 2010 through 2022. If EPA chooses to take this approach, the emissions associated with each years' volume should be identified and, after adjustments for impact on climate discussed above, laid out as accurately as possible on the time horizon, aggregated across all years of production (2010-2022), and discounted back to present terms. The impact horizon for any years' production of renewable fuels could extend 60 to 80 years to account for all foregone sequestration from indirect land use change, and the time horizons for different years will overlap, as in the "rolling time horizon" concept.

To clarify the impact time horizon in reference to point 1. c. above, it is unnecessary (and unhelpful) to extend fuel production over the entire impact time horizon. Fuel produced in year t may have impacts (e.g., soil carbon loss, foregone carbon sequestration) that extend for 80 years even if fuel production ceases in year t+1. The emissions associated with those impacts need to be accounted for, but fuel production should not extend that long.

It is neither necessary nor desirable to project renewable fuel markets beyond 2022. Because the RFS2 mandate, as well as other policy variables such as tax credits, blend requirements, and tariffs, essentially "make" the renewable fuels market in the U.S., any attempt to objectively model future volumes of renewable fuels beyond the 2022 mandate become hostage to assumptions about the levels of these policy variables. These issues are in addition to more fundamental uncertainties about future fossil fuel markets, transportation modes and policies, future technologies and a host of other variables that would largely influence the result.

The type of analysis discussed in IV. A. may be necessary for a cost-benefit analysis, but adds no useful information for determining the renewable fuel emissions reductions for a specific fuel. It would require a large number of assumptions which could only be made on an arbitrary basis and are not guided by the mandates in EISA 2007, and it would be considerably less transparent than the current approach. Accurate assessment of the emissions from agricultural feedstocks would presumably require many additional runs of the FASOM and FAPRI models, perhaps for time horizons that are far beyond the current time frames within which those models are generally used (20-30 years into the future). The uncertainties associated with extending these frameworks to those time frames are many orders of magnitude greater than those encountered in the usual time frames. My assessment is that EPA has much to lose and little to gain by pursuing such an ambitious modeling effort.

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APPENDIX D

DR. ELIZABETH MARSHALL RESPONSE TO CHARGE QUESTIONS

This review reflects the current thinking of the peer reviewer and not any official position of her current employer or affiliates. Portions of this review are excerpted from Marshall (2009). Due to the complexity of the subject matter and the short window available for the review period, the reviewer's thoughts on these matters are likely to continue to evolve.

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[18]

A. Framing the Issues

The preamble and RIA discuss how to account for the variable timing of transportation fuel lifecycle GHG emissions largely by addressing treatment of time frame and discount rate, and to a much lesser extent, appropriate metrics in the EPA's analysis. While these are the cornerstones of an appropriate approach to GHG accounting in the context of this rule-making, it is not the broad recognition of these components in framing the problem that can be judged as "scientifically objective," but the selection of their values. The selection of the values used for time frame, discount rate, and metric will reflect, either explicitly or implicitly, a number of factors and relationships not discussed in the rule documentation, including assumptions about expected damages arising from emissions, rates of change of those emissions, residence times and decay rates in the atmosphere, and assumptions about why different arguments for discounting apply given which of these factors have been included.

Because the discussion within the rulemaking documentation does not provide this depth of analysis in justifying the time accounting scenarios proposed, it is difficult to determine whether selection of the parameters followed a scientifically objective process, though it is entirely possible. Because the rule presents two significantly different scenarios for time accounting, it is clearly part of the objective of the peer review and comment period to determine which of these two scenarios is more consistent with respondents' own judgments about what scientific objectivity says about which of the above factors should be included within the scope of the EPA analysis, and what that implies about appropriate time frame and discounting. That will be my objective in this peer review.

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

The preamble and RIA define two time periods—the Project time frame and the Impact time frame—which they present as "different ways" of approaching the analysis of lifecycle GHG emissions. In fact, these are not different approaches to GHG accounting, but instead are two distinct time horizons that must be considered separately in a single comprehensive accounting methodology (Figure 1).

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[18] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

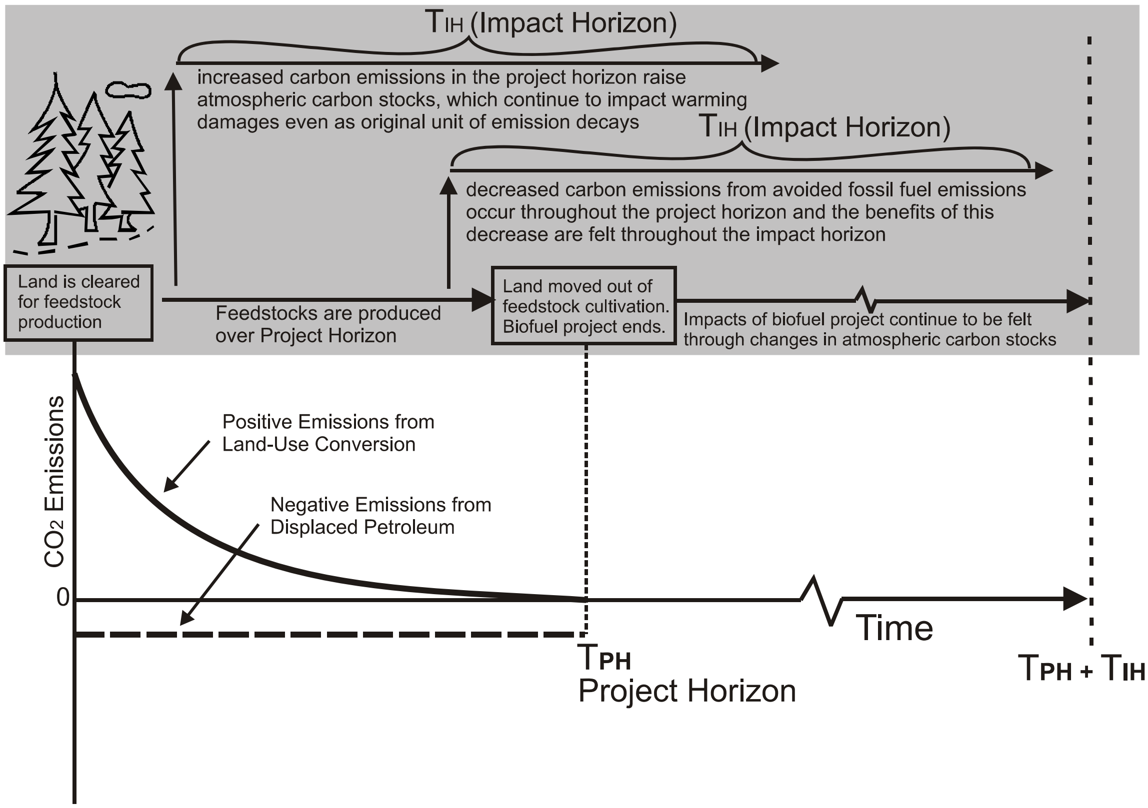

Figure 1: A stylized depiction of the time analysis structure that focuses on the emissions associated with land-use conversion (which includes both direct and indirect GHG impacts). Other emissions associated with production are not represented here.

There are two distinct time horizons illustrated in Figure 1: the "project horizon" and the "impact horizon." In the context of land-use conversion for biofeedstock production, the project horizon refers to the period of time over which biofeedstock production on that land will result in avoided petroleum fuel use. This is, in a sense, the "lifetime" of the biofuel project that is driving the initial land-use conversion to biofeedstock production, or the length of time that biofeedstocks will be produced on that land before the land moves into some other use.

The "project horizon" is a planning construct. It represents a prediction about how long converted land is likely to remain in feedstock production. That prediction captures the period of time over which benefits from reduced emissions due to biofuel production on that land will continue to be generated through avoided petroleum use. There are several factors that could shorten the expected cultivation time, including: the advent of alternative transport fuel technologies such as electricity, the commercialization of waste-sourced biofuels to replace crop-based biofuels, and policy changes such as reduction or elimination of subsidies to biofuels or biofeedstocks.

The "impact horizon" on the other hand, is largely a physical construct that reflects how long a unit of emissions, once it enters the atmospheric carbon stock, continues to significantly contribute to warming and the damages caused by that warming. Because greenhouse gases persist in the atmosphere and produce warming over time, the damage created by a unit of emissions in any time period includes a stream of warming potential into the future. The "impact horizon" is likely to be much longer than the "project horizon" because, although the emissions reductions associated with biofuel production will cease as soon as the land is moved out of feedstock production, the atmospheric benefits of those reductions continue. Similarly, the atmospheric impacts of the carbon dioxide emissions from the initial conversion will continue to be felt long after the land has moved into other uses. The distinction between these two time periods reflects the momentum of decisions made within the project horizon by acknowledging the persistence of emissions in the atmosphere and the cascading impacts of those emissions over time on the damages expected from global warming.[19]

Appropriate GHG accounting for biofuels, including those related to direct and indirect land-use change, must recognize the distinction between these time horizons. Designing a quantification scheme around a single time horizon that equates the impact horizon with the project horizon creates tension in the establishment of an appropriate length for that single horizon; extending the single horizon allows one to capture the implications of persistent carbon in the atmosphere, while shortening it makes it more reasonably reflective of how long land is likely to stay in cultivation. In fact, the time scales of the two horizons are completely different and should be treated as such in the GHG quantification methodology.

Note in the graphs above that the impact horizon is depicted as a rolling horizon. In other words, the impacts of a unit of emissions are measured over the same number of years, regardless of whether that emission takes place at the beginning of the project horizon or at the end. The alternative scenario would be a "fixed horizon." A fixed impact horizon is measured relative to year 0 in the accounting methodology, rather than relative to the year in which the emission occurs, so that the impacts of emissions in later years are measured over fewer years than the impacts of emission in earlier years. For a fixed, or "truncated", impact horizon, Figure 2 would be modified to appear as in Figure 3:

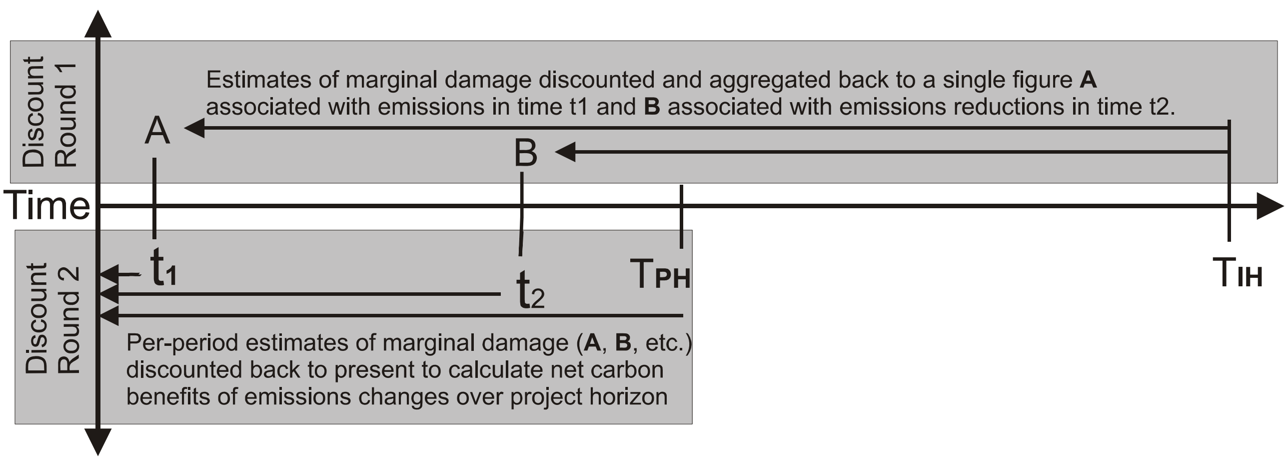

Figure 2: Discounting rounds with a fixed impact horizon.

The problem with establishing a fixed impact horizon is that this methodology will automatically favor projects whose emissions are deferred to the end of the project horizon.[20] This bias occurs because the impact of emissions occurring at the end of the project horizon is measured over fewer years than the impact of emissions occurring early in the project horizon; it is an artifact of the measurement truncation that does not reflect a legitimate difference in damage incurred between early and late emissions. In the context of emissions quantification for biofuel production projects, this bias means that the early carbon costs associated with the initial

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[19] O'Hare et al. (2009) refer to the project horizon as the "production period" and the impact horizon as the "analytic horizon."

[20] Analogously, the method will favor those projects whose displaced emissions occur early in the project horizon.

conversion will be weighted relatively more heavily than the later benefits associated with displaced carbon emissions from avoided gasoline use. Although such a result may emerge analytically from use of certain marginal damage functions or from use of a non-zero discount rate, there is often no theoretical justification for artificially exacerbating that effect through use of a fixed impact horizon.[21] For that reason, impact horizons should usually be measured on a rolling basis as shown in Figures 1 and 2.[22]

It is important to note that the definition of the impact horizon presented here differs significantly from the definition of the impact horizon that is presented in the Rule's documentation. The Rule's preamble states:

> "The second part would address the length over which to account for the changes in GHG emissions due to land use changes which result from biofuel production. We call this the "impact" time horizon".

EPA's "impact" horizon, therefore, is not an atmospheric impact horizon, but rather a time horizon over which land-use change emissions are measured that is distinct from the time horizon over which other project-related emissions (and emissions reductions are measured). EPA's impact horizon is broken out in order to capture the longer term land-use repercussions associated with biofuel production, in particular the indirect land use impacts that can arise over time from disturbances in the market associated with the onset of biofuels production.

EPA's definition of "impact horizon" is therefore a third relevant time horizon that is distinct from the project horizon and impact horizon described above. For the purposes of clarification, I will call this horizon a "secondary impact horizon" because its purpose is to capture the secondary (or indirect) emissions associated with land-use change. While recognizing the relevance of indirect land-use change emissions and the importance of including them in a comprehensive GHG accounting methodology, I question whether appropriately accounting for those emissions requires breaking out the secondary impact horizon separately in this particular context. Having a secondary impact horizon that is shorter than the project horizon is unnecessary, because all emissions, including those from indirect land-use change, should already be accounted for through the project horizon window. Having a secondary impact horizon that is longer than the project horizon, on the other hand, requires the regulator to objectively demonstrate that the original land-use change decision occurring in time period 0 continues to have impacts, reverberating through the marketplace, that influence land-use decisions beyond the project horizon and decades into the future (between 30 and 100 years, according to the proposed scenario in the documentation). Given the relatively long length of the project horizon proposed in this context, it seems likely that the project horizon is long enough to accommodate the full impacts, including indirect impacts, of the original land-use change decision, and that the specification of a separate secondary impacts horizon may be an unnecessary complication.

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21 Hellweg et al. (2003) describe "temporal cut-offs" such as truncation points as a special case of discounting. However while most justifications for discounting are more consistent with smooth functions of changing values over time, truncation is equivalent to a sudden, discontinuous imposition of an infinite discount rate, and as such is not justifiable using most of the common arguments in support of discounting.

22 There is a third way in which time can enter policy analyses for GHG reductions, and that is through the specification of target dates for achievement of an objective. California's Low Carbon Fuel Standard, for instance, calls for a 10 percent reduction in the average carbon intensity of California's transport fuels by 2020. While such formulations may imply that we are not concerned about impacts beyond 2020, and that a fixed impact horizon truncated at 2020 is therefore appropriate, a closer examination of the quantification methodology and purpose will usually show that is not the case.

B. Determination of Project Time Frame(s)

As mentioned above, the project time frame should be estimated based on an assessment of how long fuel using the fuel technology that is being assigned a carbon intensity figure is expected to be produced (this could vary by technology). That assessment should take into account all factors that are expected to impact production of, for instance, first-generation biofuels, such as expected market conditions; projected advances in alternative, second-generation biofuel technology; projected advances in alternative automotive technologies such as electric cars; etc. To the extent that fuel mandates such as EISA drive the market, these should also be considered. Economic modeling is an appropriate way to estimate a project time frame. In the absence of sophisticated modeling, selection of a 30-year horizon would be consistent with some prior work (based on estimates of refinery life spans), though some groups argue that a shorter project horizon would be more consistent with an economic analysis of technological development leading to displacement of biofuels in the marketplace.

C. Determination of Impact Time Frame

These comments refer to the impact horizon described in this review, not the impact horizon described in EPA's rule documentation.

The impact time horizon should be selected based on estimated climate impacts. Unlike the project time horizon, the relevant impact time horizon is related to impacts of emissions and not likely to vary by fuel. Due to differing residence times among GHGs in the atmosphere, the selection of an impact horizon will affect the relative contribution of different gases to the carbon equivalency intensity associated with a biofuel (as seen in the calculation of global warming potentials over different time frames).

A great deal of debate has already occurred in the climate arena regarding the appropriate time horizon to be used in measuring climate impacts of current emissions, and most large "users" of the concept seem to have settled down to a 100-year impact horizon. The IPCC uses global warming potentials calculated over a 100-year impact horizon as their standard measure of relative warming contributions. Fearnside (2002) provides several arguments for using a 100-year impact horizon in global warming mitigation calculations:

> "Here a case is made for using a time horizon of 100 years. This choice avoids distortions created by much longer time horizons that would lead to decisions inconsistent with societal behavior in other spheres; it also avoids a rapid increase in the implied value of time if horizons shorter than 100 years are used."[23]

How should the potential for "threshold" or irreversible climate change impacts influence our choice of an impact time frame?

One of the defining characteristics of the damage functions associated with atmospheric carbon stock system is the potential for irreversible change in the form of melting ice caps, changing ocean current patterns, etc. when certain atmospheric carbon stock and warming levels are

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[23] Fearnside (2002) is a proponent of ton-year accounting as a method of deriving relative impact weights for emissions over time. This method, however, relies on the use of a truncated impact horizon; its results are therefore sensitive to the time horizon chosen as well as to whatever implied discounting emerges from the truncation. As argued earlier, the implied discounting associated with truncation is a blunt instrument for addressing questions related to discounting and should usually be avoided unless justification can be provided otherwise.

reached. Although this risk is often ignored as a simplifying assumption in analyzing future costs of climate change, the existence of irreversible tipping points or "phase shifts" implies that GHG emissions from the present cannot be fully mitigated by a comparable level of sequestration once that phase shift has occurred. The potential for irreversible change is one of the significant determinants of the expected damage function for GHG emissions that must be considered in determining how to compare current to future emissions, and is one of the most convincing arguments for the need to make some sort of distinction between current and future, or pre-change and post-change, emissions.

In any scenario with an increasing risk of catastrophic system change, or phase shift, as atmospheric carbon stocks increase, the possibility that current emissions may expedite such a collapse must be considered in determining how current GHG emissions compare to future carbon emissions. The appropriate discount rate will depend on the assumptions made about this risk and about exogenous changes in technology that can help reduce that risk. This argument reflects the "buying time" justification for carbon discounting, which states that current emissions should be considered more important than future emissions because in the future there will be more technological options for mitigating carbon emissions. According to that argument, weighting current carbon emissions more heavily than future emissions therefore "buys time" for mitigation technology, such as carbon capture and storage, to be developed and implemented. This argument, however, is critically dependent on the premise that technological improvement will increase quickly enough to out-pace increases in marginal damage arising from increasing atmospheric stocks. That premise reflects embedded assumptions about the relationship between stocks and marginal damages and the rate of change in available mitigation technology.

Issues related to the threat of irreversible change are critically important in the determination of how to specify a damage function associated with emissions over time. Such specification could take the form of an "expected damage" function, with possible outcomes (with irreversible change and without) weighted by cumulative probability functions describing the expectation that such irreversible change will have already taken place in any given period or at any given stock or warming level.

While the potential for irreversible change is critical to the specification of a damage function, if damage functions are specified then it is not relevant to the selection of an impact horizon over which that damage function operates. Altering the time frame selected in an attempt to capture the risk of irreversible damages associated with atmospheric changes is a very blunt instrument with which to address that risk.

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

Several researchers have raised the possibility that revegetation of land after feedstock cultivation could lower the net carbon impact of land conversion for biofuel production by re-sequestering some of the carbon originally released (Delucchi, 2008). Some stakeholders argue that it is an error to neglect this possibility in GHG quantification for biofuels, as a failure to account for this "salvaged carbon effect" would result in an overly large carbon cost associated with initial land conversion.

It is certainly true that managed reforestation of retired feedstock acreage could recover a significant amount of lost carbon and that even unmanaged land abandonment might result in a slight recuperation of carbon losses. However, in the absence of post-project polices that guarantee that lands will be revegetated or rehabilitated, there is no assurance that "salvaged carbon" will be reclaimed. It is also possible that land would be converted to food production, grazing, or development, and additional losses could be incurred at that time. Because post-project land-use policies would be difficult, if not impossible, to implement and enforce, it is more appropriate to consider post-project salvaged carbon value as part of a second, independent land-use change that occurs when the biofuel project itself has terminated. I do not believe, therefore, that this "salvaged carbon" should be included in the quantification of the carbon associated with biofuels-related land-use change.

The focus on "salvaged carbon" highlights the concept of "carbon potential" with respect to a plot of land—that land that has been converted to one use still retains the potential for later reversion or restoration to a higher carbon use. For the reasons given above I do not believe that biofuels projects should be credited for the carbon potential remaining on the land they have converted in absence of a guarantee that the potential is realized. However, there is a residual element of land-use change that can persist post-project that *should* be considered where possible. In cases where the initial conversion significantly affects the carbon potential of land on or off the site producing biofuels, the biofuels driving that conversion should be credited with, or penalized with, that change in carbon potential. This dynamic can go in either direction. In cases of deforestation, the initial clearing of land and decades of production could create a scenario where even managed reforestation post-project is unlikely to restore soil carbon stocks in any reasonable time horizon; the biofuels driving the conversion should be penalized for this drop in carbon potential on that land. Conversely, in cases where biofuels production is used to rehabilitate marginal lands, making them more capable of supporting high-carbon uses post-project, the biofuels driving the conversion should be credited with this improvement in carbon restoration potential.

It is worth noting additional concerns about the argument that loss of biomass-based GHG sequestration is reversible and can therefore be "undone" at the end of the project horizon with revegetation of the land area used. Research in the Amazon suggests that land-use activity in the forest increases risk of forest fire, causing additional carbon losses in neighboring forests, and that such fires increase the forest's susceptibility to further burning (Nepstad et al., 2008). Such land-use changes are also associated with irreversible changes such as fragmentation of existing natural habitat, expansion of degraded "edge" habitat, and loss of native species and biodiversity. The potential for irreversible change along other social and environmental dimensions highlights the need for a more comprehensive definition of the sustainability of biofuel production than that captured by the GHG requirements alone.

III. Valuation of Future GHG Emissions

A. Conceptual Issues

It is common practice in cost/benefit analysis to treat current and future costs differently on the basis of one or more of the following factors: pure time preference, productivity of capital, diminishing marginal utility of consumption, and/or uncertainty (Hellweg et al., 2003). In project analysis with relatively short time frames of analysis, discount rates are generally used to capture observed decision-making behavior in capital markets. It is argued that in a world with scarce resources for investment, we should compare growth rates of other capital investments in deciding on optimal investment paths over time. The discount rate therefore captures some measure of the opportunity cost of *not* investing in other capital-improvement activities and instead investing in the project under consideration. That opportunity cost should also reflect a risk premium arising from the uncertainty associated with future outcomes of that investment decision (Howarth, 2005).

Because discount rates are generally used in the context of investment decision-making to reflect the “time value of money”, they are usually applied to monetary units, such as costs or benefits, rather than to physical units such as tons, million metric tons of carbon equivalent (MMTCE), or lbs per acre. Although the practice of using discounting to estimate the “time value of carbon” in assessing carbon mitigation options is becoming more common (Stavins and Richards, 2005), a great deal of disagreement exists about the validity of applying discounting principles to carbon units. In an early analysis of carbon discounting, Richards (1997) concludes: “(T)he choice of whether and how to treat the time value of carbon emissions reductions depends very much upon the policy context for which the analysis is designed.”

To understand the practical implications of incorporating a discount rate into GHG accounting methodologies, consider the question of temporary carbon storage. Put simply, is there any reason to invest in mitigation projects that will capture carbon today and then release an equivalent amount of carbon in 50 years? Ideally, this study would be conducted as a cost/benefit analysis, with explicit inclusion and comparison of emission cost and benefit functions over time. It would be common practice to include a discount rate in such an analysis, though interested parties may never agree on what that discount rate should be.

In practice, however, explicit cost and benefit functions for carbon emissions are often not available to analysts, nor are the resources to develop them.[24] GHG accounting methodologies therefore instead address whether a “net carbon benefit” exists by focusing on the physical carbon unit itself. In the temporary storage case described above, a discount rate of zero would yield a net carbon benefit of zero, suggesting that such a project would be neither beneficial nor harmful from a greenhouse gas perspective. A positive, non-zero discount rate, on the other hand, would yield a positive carbon benefit.[25]

When transferring the discounting practice over to physical units, it is important to recognize that, despite a failure to include explicit benefit and cost curves in the analysis, the estimation procedure still assumes that they exist and that they are driving changing “carbon values” over time. Application of a discount rate in such studies can be scientifically justifiable, but the discount rate must be chosen to capture more than just the “time value of money” dynamic generally associated with discounting practices. An appropriate physical carbon discount function form and rate must *also* reflect the very complicated relationships that are assumed to drive the changing carbon value over time, including the rate of change of the damages produced by atmospheric GHG stocks (which reflects changing assumptions about available mitigation technologies), the persistence rate of GHGs in the atmosphere, initial GHG stock levels, etc (Richards, 1997). Simple extrapolations from default monetary or market discount rates, or even the lower “social rates of time preference” often used in intergenerational analyses, are not appropriate except under very restrictive assumptions about the shape of the marginal damage curve from carbon emissions and its relationship to atmospheric stocks.

The purpose of comparing physical carbon emissions in the future to physical carbon emissions in the present through some sort of discounting procedure is essentially to evaluate how the

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[24] As in the quote from Richards (1997) above, the reviewer uses the term “carbon emissions” synonymously with “carbon dioxide emission.”

[25] The decision about whether the estimated carbon benefit would be “worth” the cost of the mitigation project then would depend on additional analyses about project cost and comparison to other mitigation options.

value of the damage caused by a unit of emissions in the future will compare to the value of the damage caused by a unit of emissions today. The process of applying a discount rate to carbon tonnage is a short cut to information about how the value of damages changes over time that skips a series of important steps related to translating physical impacts into economic impacts.

As illustrated in Figure 1, there are two distinct time horizons that must be considered in such analyses. Each of the distinct time horizons has its own associated stream of impacts and its own challenges for aggregating those impacts over time. Each separate aggregation procedure requires careful consideration of an appropriate discount rate for that aggregation (Figure 2).

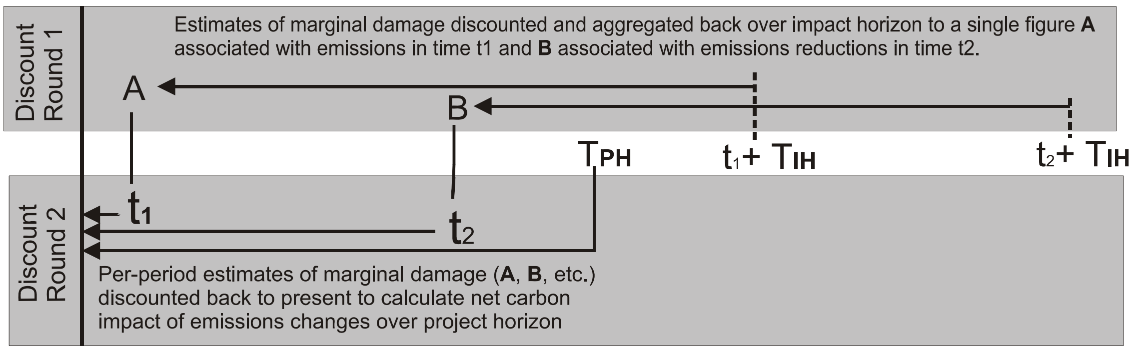

Figure 3: Discounting emitted carbon tons is a short cut for estimating two distinct rounds of "implicit" discounting, or carbon weighting.

Consider first the "impact horizon", which encompasses the path of warming impacts that result when a unit of carbon is emitted, regardless of when that emission occurs. The objective of aggregating over that time horizon is to associate a unit of carbon emissions in a given period with a single measure of damage that reflects the "cost" of that emission over time, or, conversely, the "benefit" of preventing that emission in that time period. There are several variables that affect the path of damage over time that is expected from a unit of emissions. One of these is the rate at which atmospheric carbon decays over time as carbon is re-absorbed into biotic sinks such as forests and oceans. The way in which this decay is represented varies, with some authors using a fixed decay rate applied to atmospheric stocks (Richards, 1997) and others using an exponential decay function that reflects a declining rate of carbon decay over time (Fearnside et al., 2000). In both cases, this variable reflects the purely physical dynamic of the persistence of carbon in the atmosphere over the impact horizon and translates a unit of emissions into an atmospheric carbon stock impact over time.

The second relationship defining the path of damage expected from a unit of emissions is the relationship between carbon stock and the damage expected from that stock. This relationship translates the physical stock dynamic described by the decay function into a measure of the cost implications of that stock response and moves the "impact horizon" into the realm of economics. Although there are many simplifying assumptions used in different analyses of carbon stock damage over time, such as the assumption that marginal damages are not stock-dependent at all or that they are linearly related to stock, the reality of this relationship is likely more complicated than such assumptions suggest. Although such simplifications improve the analytical tractability of the problem, they are difficult to justify for any other reason.

So in any time period, a unit of emissions is associated with a path of expected damages over time that reflects both the impact of that unit on atmospheric carbon stocks over time and the impact of those carbon stocks on damages from global warming over time. Integrating that damage path over the impact horizon produces a single value for the expected costs associated with a unit of emissions in a given time period. Because these impact figures are monetary, one might also include an economic discounting term in that aggregation procedure in order to reflect the “time value” of the cost and benefit numbers. (Failure to use a discount rate can be considered simply a special case of discounting where the discount rate chosen is equal to zero.)

Once a path of emission damages has been condensed into a single cost number associated with a unit of emissions (or a single benefit number associated with an avoided ton of emissions) in each time period, the second round of aggregating over time occurs. In the second round, the objective of the aggregation is to calculate a single total present value of all the carbon emission costs and avoided emission benefits that occur over the project horizon. Unlike the first round of aggregation, this is a fairly straightforward process of discounting cost and benefit figures over a finite time horizon using economic discounting.

It is quite likely that appropriate discount rates will differ between the project horizon and the impact horizon. Selection of an appropriate discount rate for the impact horizon should consider the relevant biophysical variables described above, and the emerging literature on declining discount rates and the role of uncertainty in discounting over long periods (Guo et al., 2006). The discount rate used over the shorter project horizon, on the other hand, may reflect the higher interest rates used to capture market opportunity costs over shorter investment horizons. The result of such an analysis could be very different discounting structures applied to the two distinct time horizons.

Complications in the application of monetary discount rates to physical carbon units arise when “current value” estimates of marginal damages from a unit of carbon emissions are expected to change over time. “Current value” estimates are estimates of marginal damage expressed in terms of the value at the time of emission. In the scenario illustrated in Figure 2, these values correspond to the values A and B. These values have been calculated using a discount structure from the time of emission forward, but that value has not been discounted back to the present.[26] If A=B for all time periods in the project horizon, then regardless of the discount rate structure applied to the impact horizon, the appropriate discount rate to apply to carbon units is whatever discount rate is selected as theoretically appropriate for the project horizon discount procedure illustrated above.[27]

The assumption of constant marginal damages is a very limiting case, however. There are many possible causes of non-constant marginal damages over time. These possible causes include atmospheric carbon degradation rates that vary with atmospheric carbon stock and paths of marginal damage that vary non-linearly with atmospheric carbon stock. The former dynamic would exist, for instance, if greater atmospheric carbon levels result in faster dissipation of carbon from the atmosphere through carbon fertilization impacts, or impacts of increased carbon on absorptive capacity of terrestrial and ocean carbon pools. Non-linear marginal damages exist if the impact of an equivalent change in atmospheric stock is expected to vary depending on the original stock level. Catastrophic atmospheric carbon thresholds are an

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[26] Once “current values” are discounted, they are called “present values.” Current values are the values that would be current at the time of emission, while present values are those values discounted back to the present.

[27] The discount rate structure applied to the impact horizon, however, must be identical for all units of emissions over the project horizon. The structure itself can be quite sophisticated, involving declining discount rates over time for instance, but it must be identically applied to all units of emissions. If a non-identical discount structure is applied to the emissions, it will result in changing current value estimates of damages, and this conclusion no longer applies.

extreme example of non-linear impacts; damages that are assumed to be a quadratic function of atmospheric stocks are another.

In a theoretical exploration of the concept of discounting physical units, Richards (1997) arrives at the following generalizations (which have been reworded to fit the context described here):

- If the marginal damages from emissions are growing over time (i.e. if B > A in figure 2), then the discount rate chosen for the project horizon will be higher than appropriate for application to carbon units.
- If marginal damages are growing over time at a rate equal to the discount rate that has been chosen as appropriate for the project horizon, then the appropriate discount rate to apply to physical carbon units is zero.
- If marginal damages are growing very quickly over time, then emissions reductions later in time have higher value than earlier reductions, and the appropriate discount rate to apply to carbon units may even be negative.

The increasing marginal damages over time can be caused by a rapidly increasing atmospheric carbon stock, or by a marginal damage function with rapidly increasing damage as a function of stock. Either of those scenarios will cause marginal damages to increase rapidly over time, which causes the appropriate carbon discount rate to fall below the “project horizon” discount horizon, and possibly even fall below zero. A negative carbon discount rate will bias the analysis toward projects with current emissions over those with later emissions (or with later reductions over those with current reductions).

Note that if marginal damages are increasing at a non-constant rate, it is likely that an appropriate carbon discount rate will also be non-constant. In the scenario where marginal damages from emissions are assumed to be increasing at an increasing rate with atmospheric carbon stock, for instance, an appropriate physical carbon discount rate structure is one with a discount rate that declines over time at a decreasing rate.

It is worth noting that the path assumed for carbon decline in the atmosphere can significantly impact an “appropriate” carbon discount rate through its impacts on the path of marginal damages expected from a unit of emissions. Although for analytical ease it is tempting to characterize carbon decline as a fixed proportion of stock, as Richards (1997) does, in fact the precise path of decay is more complicated than that. The 1996 IPCC revisions, for instance, described an atmospheric carbon decay model with a more rapid decline in early-year atmospheric carbon than prior reports had. Fearnside et al. (2000) found that using the revised stock decline model significantly increased the value of temporary carbon sequestration, suggesting that a higher carbon discount rate would be appropriate with the revised expectations about stock decay.

B. Choice of Discount Rate

If it is assumed that GHG emissions have constant marginal damages regardless of when they occur, then discounting GHG emissions can be used as a surrogate for discounting the monetary impacts of emissions, and traditional justifications for discounting can be explored to determine whether it is appropriate to apply a non-zero discount rate to those emissions, and what that discount rate should be. An example of such an analysis is found in Hellweg et al. (2003). Assuming that GHG emissions have constant marginal damages regardless of when they occur is equivalent to assuming that emissions in different periods have equivalent residence times in the atmosphere (i.e. that there are no stock effects affecting residence times), that there is no atmospheric stock effect influencing the warming impacts of gases, and that marginal damages from warming are neither stock- nor path-dependent. However, there is a large volume of scientific evidence that suggests that GHG emissions will not have constant marginal damages regardless of when they occur, so this simplifying assumption, though perhaps required for tractability, is not scientifically justifiable. A comprehensive and scientifically justifiable assessment of the relative weights of carbon emissions over time, used to determine an appropriate discounting scheme, would require an assessment of the relative weights arising from comparisons of expected damage costs and benefits of emissions over time, supplemented by an assessment of the traditional economic discount factors used to represent changes in the value of the those relative costs and benefits over time.

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." This language does not appear to limit the approach that EPA can takes in evaluating lifecycle GHG thresholds. Flexibility remains in the definition of "aggregate quantity," for instance; that definition could otherwise have restricted how emissions could be measured and aggregated over time. The current language, while not explicitly requiring the EPA to monetize impacts in order to determine an appropriate discount rate, does not preclude the application of a discount rate calculated based on monetized impacts compared over time for the aggregation process. Similarly, the mandate that mass values be adjusted to account for relative differences in global warming potential does not mandate use of any particular adjustment factor or impact time horizon, it merely requires that differential warming potential be accounted for somehow.

O'Hare et al. (2009) recommend use of the Fuel Warming Potential (FWP) measure as one method of capturing some of the dynamics mentioned above in the estimation of an appropriate weighting mechanism for carbon impacts across time. The advantages of this metric in its most complicated form are:

- it can incorporate a consideration of the stock effect on warming for various gases (through the calculation of annual radiative forcing and how it changes over time with externally changing concentrations of the gas),[28]
- it can accommodate a stock-dependent damage function that translates the physical measurement into a monetary measure of damage, and
- it can be amended to include other factors that might affect relative weights over time, such as social rates of time preference.

The disadvantage of this approach, of course, is the computational complexity associated with calculating future concentrations of GHGs, the concentration-dependent radiative forcing that would result from emissions, and an appropriate concentration-dependent damage function.[29]

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[28] Common methods of calculating radiative forcing allow for the measure of instantaneous forcing to be a function of concentration and therefore stock-dependent. In equation 1 of their paper, it appears that O'Hare et al. (2009) assume a linear relationship between radiative forcing and gas concentration (i.e. no stock effect) for simplicity.

[29] In their paper, O'Hare et al. (2009) eliminate the complexity of the stock-dependence through their simplifying assumptions (for ease of calculation and illustration); their version of the metric therefore simplifies back into a measure that produces results very similar to those that would result from simply discounting a stream of emissions. Many of the differences that are illustrated in their paper therefore arise from their use of a truncated impact horizon (as noted by NERA, 2009). This result is simply an artifact of the simplifications imposed, however; as the authors state, the metric has the potential to reflect much more complex impacts if a more sophisticated consideration of stock-dependence is included.

In their paper, O'Hare et al. (2009) eliminate the complexity of the stock-dependence through their simplifying assumptions (for ease of calculation and illustration); their version of the metric therefore simplifies back into a measure that produces results very similar to those that would result from simply discounting a stream of emissions using the factors considered in the third bullet above. Many of the differences that are illustrated in their paper therefore arise from their use of a truncated impact horizon (as noted by NERA, 2009). This result is simply an artifact of the simplifications imposed, however; the metric has the potential to reflect much more complex impacts on relative weights if a more sophisticated consideration of stock-dependence is included, as the authors suggest for future work.

Pre-existing efforts to monetize the impacts of carbon emissions, through values such as the "social cost of carbon," could also provide the EPA with proxies for marginal damages from emissions that can be incorporated into weighting metrics to account for stock-dependence without requiring them to explicitly model concentration changes and stock-dependent damage impacts.

Implications for the EPA time analysis scenarios presented

EPA's proposed rule contains two time analysis scenarios for which results have been produced and on which comments are being solicited. The existing scenarios include one using a 100-year time horizon for analysis, together with a 2% discount rate over that period, and one using a 30-year time horizon for analysis and a zero discount rate over that period. Neither of these scenarios makes a distinction between the project horizon and the impact horizon, and the description of each reflects the tension that arises when the two horizons are conflated. The 30-year horizon is proposed because it is a more conservative estimate of the how long biofuels can actually be expected to be produced, given changing market conditions, while the 100-year horizon is proposed to better reflect the long-term nature of the climate impacts associated with near-term emissions. Both arguments are correct, and clearly the most appropriate treatment of time in the analysis would be a method that acknowledges and treats each time period separately within the same analysis.

The preamble contains a proposed time analysis scenario that does differentiate between project horizon and impact horizon, but as described earlier, the way in which the impact horizon is envisioned within that description is significantly different from the impact horizon concept presented in this review.

If I were asked which of the two time analysis scenarios presented in the rule is most consistent with an objective quantification of the GHGs associated with biofuels, I would argue that the 30-year time horizon with a zero discount rate is more justifiable, and in fact is consistent with the dual-horizon framework above if a number of simplifying assumptions are made. As mentioned above, the impact horizon is significant if the analysis explicitly integrates a consideration of the stock-dependent residence, warming, and damage effects associated with emissions in any time period. Otherwise, if identical discounting structures are applied to emissions from all time periods, the current value of the weight associated with a unit of emissions in each time period (A and B in Figure 2) will be identical, regardless of the discounting structure used. In that case, the analysis simplifies down to an aggregation exercise over the project horizon alone. As mentioned earlier, a 30-year project horizon is consistent with some of the prior work in this field. In the EPA's scenario, aggregation over that 30-year project horizon is accomplished using a 0% discount rate, and selection of a 0% discount rate is consistent with most life cycle assessment analysis.

Should EPA limit its scope, or interpret the legislation to limit its scope, in this analysis to the physical realm, and not consider it within its authority to calculate discount rates based on monetized assessments of economic damages and costs, the “fixed project horizon (30 years or less)/0% discount rate” scenario is a logical set of parameters that is consistent with prior work.

The 100-year horizon with a 2% discount rate, on the other hand, is predicated on the highly questionable assumption that biofuel technology will stay constant enough that land converted for biofuels use will stay in that use for 100 years. The 100 year time-frame is much more consistent with the portion of the analysis concerned with impacts (the impact horizon), but the use of a non-zero discount rate then thrusts EPA into the business of trying to estimate monetized cost impacts, which can be appropriately discounted. It is unclear how the 2% discount rate was selected, but it is unlikely to have emerged from an assessment of the stock-dependent residence, warming, and damage effects associated with emissions in any time period that would be required to appropriately weight carbon emission impacts by time period over the impact horizon. A direct application of the low discount rates often suggested for intergenerational analysis of costs and benefits is not appropriate in this setting, where the discount rate applied to emissions to aggregate them over time must reflect the relationship between emissions and costs as well as the relationship among costs over time.

IV. Other Methodological Considerations

Given the limited information provided on this question, I will answer as I currently understand it. If I have missed some of the complexities that the author of the question hoped to tease out, I apologize.

This question proposes an alternative scenario for how the carbon intensity of a gallon of biofuel could be calculated. This carbon intensity figure will necessarily represent an average emission associated with biofuel production, and the question addresses the issue of whether emissions should be averaged over the results calculated from a snapshot of a single year’s production (i.e. 2022, as currently formulated in the rule) or whether the average should be calculated by projecting the full impact of the RFS over time (with actual volumes as they are expected to ramp up) and taking an average over that set of emissions and production.

The advantage of the latter approach is that it would provide a much clearer picture of the marginal impacts of the RFS mandates (because they are explicitly modeled, rather than projected from an average calculated from a single year). The disadvantage of that approach is that it also requires a great deal more modeling complexity in calculating the average. Whether the improved precision is worth the increased up-front complexity depends on whether per-gallon estimates of carbon impact are expected to change substantially by year and perhaps by scale of production in any given year. Attempting to calculate an average based on production changes over time also adds another time dimension that complicates the question of how time is handled, and differences between the results of these two averaging approaches will be sensitive to decisions made about how to handle aggregate carbon impacts over time. Therefore, I do not think this approach will help to clarify the timeframe discussion. Under the proposed alternative, there will still be emissions occurring at different times that will need to be weighted by a consideration of damages in order to aggregate and determine an average.

It is possible to clearly define the timeframes of interest using production from a single year, but the existing EPA scenarios do not do that. In fact, if those time frames are clearly and correctly defined, the additional dimension added when overlapping project horizons are introduced in the proposed alternative average formulation should be straightforward to accommodate. However, the first step toward a correct time formulation should be to transparently select and define those time horizons for projects commencing in a single year.

It is important to reiterate that most of the complexity arising from the consideration of time comes from the recognition that it is not technically emissions that are the problem, but the path of damages that will result from them and the fact that these damages may differ over time due to various forms of stock-dependence. As discussed earlier, if the possibility of differential impacts is ignored due to various assumptions simplifying away considerations of stock-dependence, then time and time-frames are not particularly complicated to handle in either of these average formulations; in the case that marginal damages from emissions in any period are assumed to be identical, then the only factors influencing the relative weights of carbon emissions over time will be the traditional discounting factors applied at the point of emissions. Emissions themselves are discounted on the assumption that they are a proxy for the damages that they will create. These assumptions are not scientifically justifiable, so such simplifications would have to be justified on other policy grounds.

The alternative methodology suggests that total differences in emissions between the two biofuels development paths (with the RFS and without the RFS) will be calculated by identifying the point in the future at which the biofuels-related GHG emissions in the RFS policy case decline back down to those found in the base case and measuring differences up until that point. I agree that eventually, due to changing technologies, etc., biofuel production levels are likely to decline back to baseline levels, and that annual greenhouse gas emissions associated with the two fuels will equalize; in fact an understanding of those processes would be required to come up with estimates of an appropriate project horizon, etc. However, the usefulness of the alternative approach will depend on how precisely the modeling exercise can capture differences in the GHG intensity associated with biofuel production in different years over the life of the RFS, if such differences exist. Because I don't have a thorough understanding of where those differences are likely to arise, I am not able to assess how the potential for added precision compares to the complexity of having to account for them in the modeling and computational effort.

V. Summary of General Accounting Recommendations:

1. Ideally, a GHG accounting method for land use change associated with biofeedstock production should explicitly analyze the expected damages associated with those flows over time. The corresponding monetary units associated with this damage can then be discounted to determine how the impacts of future flows compare to those of the present. Discount rates must be transparently selected and justified in accordance with standard economic arguments in support of discounting (as appropriate): time preference; productivity of capital; diminishing marginal utility of consumption, and various forms of uncertainty.
2. Discount rates used for physical carbon units are not analogous to monetary discount rates such as interest rates or the social rate of time preference. They therefore should not be selected based solely on an extrapolation of how those financial discount rates are usually applied. Discount rates applied to emissions to aggregate them over time must reflect the relationship between emissions and costs as well as the relationships among costs over time.
3. The "project horizon" should be considered independently of the longer atmospheric "impact horizon" when selecting appropriate discounting horizons. In the context of biofuels production, the "project horizon" refers to the period of time over which feedstock cultivation will occur (and benefits from displaced transport fossil fuel

realized). The "impact horizon" refers to the period of time over which impacts of increased or decreased emissions are felt in the atmosphere. This approach is not strictly consistent with either of the time analysis scenarios presented by EPA, though under a series of simplifying assumptions it can be argued to be roughly consistent with the "fixed project horizon/0% discounting" scenario.

4. In general, the impact horizon should be applied as a rolling target that is measured relative to the year of emissions, which can occur at any point over the project horizon, rather than as a fixed target that is measured relative to year 0 of the project. Atmospheric impacts are therefore fully accounted for, whether the emissions or emissions savings occur at the end of the project or at the beginning. If a truncated impact horizon is used, it acts as a form of discounting, and a justification for imposing that discounting structure must be provided.
5. Salvaged carbon from acreage reversion or revegetation should not be considered as part of the GHG accounting protocol for land-use conversion for feedstock production. Carbon benefits associated with revegetation are not guaranteed when acreage is initially converted to biofuels production, and should more appropriately be considered a benefit associated with a future form of land-use change should such conversion occur. Permanent impacts to carbon potential that occur in association with initial land-use change and production over the project horizon should be attributed to the biofuels that drive that land-use change, however.

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APPENDIX E

DR. JEREMY MARTIN RESPONSE TO CHARGE QUESTIONS

Preliminary Remarks

In considering scientific principles for measuring GHG emissions over time, we should distinguish between what is technically plausible, and what is practical and reasonable in a metric for a regulation.

The RFS2 requires consideration of indirect emissions, including emissions from indirect land use change (ILUC). The consequential lifecycle analysis the EPA has proposed is an appropriate way to capture these ILUC emissions in the lifecycle analysis that is part of the RFS. This consequential approach is more complex, and does increase the uncertainty of the analysis, but without consideration of emissions from ILUC that are the consequence of increased use of biomass feedstocks for fuel production, the lifecycle analysis would produce results that were clearly incomplete, an artifact of the constraints of the accounting system rather than a realistic assessment of the effect of fuel production on overall GHG emissions. The same standard should be applied to the consideration of complexity in the accounting for time. The approach should minimize uncertainty and the use of speculative future scenarios insofar as possible, but be broad enough to capture a realistic view of the consequences of fuel production.

For a consequential lifecycle analysis to be meaningful, it must consider a timeframe sufficient for the consequences of the modeled activity to play out. In theory, each consequence of the initial activity has consequences of its own, and the chain of consequences can be carried forward indefinitely to avoid truncating the consequences at an arbitrary point. In practice, however, the boundaries of the consequential analysis must be set somewhere, and the farther into the future the analysis goes, the more uncertain the results and the more speculative the overall analysis becomes. Setting the truncation point far in the future and weighting near-term consequences more highly is a technically plausible way to avoid an abrupt truncation of consequences, but in practice it creates more problems than it addresses, since it still requires the speculative and uncertain predictions about the distant future, and also requires settling on the appropriate weighting over time. For these reasons, we think the truncation error is easily the lesser of two evils, and the analysis should be confined insofar as possible to the foreseeable future, specifically to a timeframe consistent with the expected lifetime of a fuel processing facility.

It is reasonable to distribute the emissions associated with expanding production of a given biofuel across the expected lifetime of a facility, and the 30 year timeframe proposal is consistent with that approach (although 20 years would also be reasonable). A timeframe of a few decades is also consistent with our ability to predict with reasonable confidence what the dominant production methods and technologies will be in agriculture, transportation and biofuel production. Because there is considerable inertia in the system, for instance the low turnover rate of the vehicle fleet, technological changes take decades to penetrate the marketplace. Beyond 30 years, however, the inertia of the existing vehicle fleet, fueling infrastructure and agricultural practice and technology become less significant. Projections about land use patterns and technology 50-100 years in the future are highly speculative and add a great deal of unnecessary uncertainty to the regulation.

While discounting is an essential part of financial and economic analysis, there is no basis to include it in the metric for emissions under the RFS. The language of EISA clearly calls for a physical rather than an economic analysis, and does not support the EPA making judgments on the social cost of carbon, matters of intergenerational equity, and etc. EISA states:

> "The term 'lifecycle greenhouse gas emissions' means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential."

The one allowable adjustment to simple mass values of emissions is the use of the IPCC Global Warming Potential (GWP) methodology. This methodology, developed to account for the different lifetimes and radiative efficiencies of the different GHG species, can also be used to compare scenarios that have different emissions profiles over time, as is described below. The preamble cites references that discuss discounting carbon, but these are in the context of finding the social cost of carbon or other economic quantities, and this is not consistent with the requirements in EISA. I see no indication that Congress intended to delegate these important decisions to the EPA within the context of defining a metric for RFS compliance.

I am part of a group that developed a methodology called the Fuel Warming Potential (FWP) to aggregate emissions over time into a metric for compliance with carbon intensity based fuel regulations.[30] This metric begins with a straightforward application of the GWP methodology to the projected emissions sequence from biofuels production that are the output of the consequential LCA analysis EPA is conducting. We also described how this methodology could be extended to develop an economic fuel warming potential metric that uses radiative forcing as a plausible proxy for economic damages, and discounts this to calculate the ratio of the net present values for a modeled scenario versus a reference scenario. As was previously stated, the RFS calls for a physical rather than an economic metric, so the economic FWP is not an appropriate metric for RFS compliance.

The use of the FWP methodology in the RFS still requires the choice of project and impact timeframes. The two timeframes could be equal, the impact timeframe could be tied to a key external date (such as a policy target date like 2030 or 2050 or the date at which irreversible damage is expected) or the impact timeframe could be chosen to coincide with the GWP timeframe (100 years is mentioned in the preamble). In any case, projections of fuel usage patterns and land use emissions should be limited to the project timeframe. In the period between the project timeframe and the analytic timeframe, the atmospheric concentrations of CO2 and other GHGs would change through biogeochemical processes, consistent with the models used in computing the GWP, but other emissions either positive or negative would not be considered. Projecting atmospheric changes for 100 years maintains consistency with GWP and adds no additional uncertainty beyond what is already part of the GWP. The FWP methodology is capable of evaluating speculative scenarios that include regrowth of forest

[30] O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001

following the end of the fuel production, but to do so would dramatically increase the uncertainty and speculative nature of the results and would be inappropriate for the purposes of the RFS.

Adopting the FWP with the equal impact and project timelines will ensure that projects actually achieve reductions in cumulative radiative forcing (CRF) by the conclusion of the project. This could be considered the most relevant for meeting near-term targets for reducing global warming pollution. Benefits in reduced radiative forcing (RF) would likely continue to accrue beyond the target date, based on the favorable balance of atmospheric GHGs, but would be truncated from the analysis. Alternative impact timeframes based on policy goals, such as a target of 2050, would ensure that the actual benefits in reduced CRF were delivered by the target policy date.

A near-term impact horizon is consistent with the latest climate science that indicates that swift and deep reductions of heat-trapping gasses are needed to avoid catastrophic changes due to a warming climate. The higher the peak of atmospheric concentrations of CO_2, the greater the level of irreversible consequences, such as species loss, melting of the polar ice caps, and sea level rise.[31,32,33] Peer-reviewed studies published since the release of the IPCC (AR4) provide compelling evidence that major impacts from human-induced climate change, including sea level rise and a reduction in the ability of the planet to absorb CO_2, are happening faster and at a greater magnitude than the IPCC report anticipated.[34]

Increased sea level rise: Increased contributions from melting mountain glaciers and ice sheets on land, as well as thermal expansion due to continued ocean warming, are resulting in higher sea level rise than projected by the IPCC. The IPCC estimated global average sea level rise for the end of this century (2090–2099) compared with the end of the last century (1980–1999) at between ~0.6–1.9 feet (~0.2–0.6 meter).[35] New analysis indicates that meltwater from land ice could lead to sea level rise of ~2.6 feet (0.8 meter) by the end of the century; and although ~6.6 feet (2.0 meters) is less likely, it is still physically possible.[36,37]

Reduction in CO_2 absorption: As temperatures rise and the ocean becomes more saturated in CO_2 (and hence acidic), the ability of the planet to absorb CO_2 diminishes. As a result, more CO_2 stays in the atmosphere. In 1960, a metric ton (1,000 kilograms; ~2,205 pounds) of CO_2 emissions resulted in around 400 kilograms (~881 pounds) of CO2 remaining in the

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[31] Solomon, S., G-K Plattner, R. Knutti, and P. Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions, Proceedings of the National Academy of Sciences, 106: 1704–1709.

[32] Archer, D, M. Eby, V. Brovkin, A. Ridgwell, L. Cao, U. Mikolajewicz, K. Caldeira, K. Matsumoto, G. Munhoven, A. Montenegro, and K. Tokos. 2009. Atmospheric Lifetime of Fossil Fuel Carbon Dioxide. Annual Review of Earth and Planetary Sciences, 37:117–34, doi: 10.1146/annurev.earth.031208.100206

[33] Meinshausen, M., N. Meinshausen, W. Hare, S. C. B. Raper, K. Frieler, R. Knutti, D. J. Frame, and M. R. Allen. 2009. Greenhouse-gas emission targets for limiting global warming to 2 ºC, Nature 458:1158-1162. doi:10.1038/nature08017.

[34] Canadell, J.G., C. Le Quéré, M. R. Raupach, C. B. Field, E. T. Buitenhuis, P. Ciais, T. J. Conway, N. P. Gillett, R. A. Houghton, and G. Marland. 2007. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks, Proceedings of the National Academy of Sciences.

[35] Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[36] Rahmstorf, S., A. Cazenave, J.A. Church, J. E. Hansen, R. F. Keeling, D. E. Parker, R. C. J. Somerville 2007. Recent Climate Observations Compared to Projections, Science, 316:709

[37] W. T. Pfeffer, J. T. Harper, S. O'Neel. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. Science 321:1340-1343.

atmosphere. In 2006, a metric ton of CO_2 emissions results in around 450 kilograms (~992 pounds) remaining in the atmosphere.[38]

While EPA has suggested they will adopt a 100 year impact timeframe, which would ensure maximum consistency with the GWP calculations used for national greenhouse gas inventories, a shorter impact timeframe of the 20 year GWP listed in the IPCC may be more appropriate. A shorter time horizon recognizes that deep and swift reductions in heat-trapping gasses are needed in the near-term to avoid potentially catastrophic and irreversible impacts from climate change.

Adopting the FWP with a 100 year analytic time-frame and a 30 year project time-line (and no post project land use or fuel emissions) gives results quite similar to the 30 year 0% discount rate proposed by in the preamble. This is because all of the emissions occur relatively close together (within 30 years) relative to the duration of the impact horizon. For this reason, while the FWP approach is consistent with the GWP, and should be allowable, using the proposed 30 year 0% discount rate is also technically defensible. If emissions occur over a period longer than 30 years, or the impact horizon is shorter than 100 years, the corrections in the FWP become increasingly significant and the use of the FWP becomes more necessary.

While an economic metric for is not appropriate for the RFS compliance, if discounting is used, it should be applied to economic costs rather than emissions themselves. In a paper I co-wrote, we argued that radiative forcing was a more reasonable proxy for damages than emissions themselves, and so discounting radiative forcing is preferable to discounting emissions[i]. This approach is also closer to the GWP methodology than alternative schemes, and therefore it is closer to the requirements of EISA. However, radiative forcing is still an incomplete proxy for damages, and if an economic analysis is to be performed, a more thoughtful consideration of damages over time is desirable.

Peer Review Charge Questions

5/19/2009

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[39]

A. Framing the Issues

1. **The preamble and RIA separates the discussion of how to account for the variable timing of transportation fuel lifecycle GHG emissions into different components:**
   a. **Time frame**
   b. **Discount rate, or the relative treatment of current and future GHG emissions**
   c. **Appropriate metrics**
2. **Is this a scientifically objective way to frame the analysis of lifecycle GHG impacts of different fuels in the context of what is needed for this rulemaking?**

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[38] Canadell, J.G., C. Le Quéré, M. R. Raupach, C. B. Field, E. T. Buitenhuis, P. Ciais, T. J. Conway, N. P. Gillett, R. A. Houghton, and G. Marland. 2007. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks, Proceedings of the National Academy of Sciences.

[39] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

The framing is reasonable. But the time frame, discounting, and appropriate metrics do bear on one another, as discussed below.

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

1. **As explained in the preamble and RIA, the time frame for analyzing lifecycle GHG emissions can be approached in different ways, such as:**
    a. **Project time frame – how long we expect production of a particular biofuel to continue into the future**
    b. **Impact time frame – the length over which to account for the changes in GHG emissions, in particular due to land use changes, which result from biofuel production**
2. **Do the preamble and RIA define these time frame concepts in a scientifically objective way for lifecycle analysis? What other concepts, if any should be considered?**

It is technically reasonable to consider separate project and impact timeframes, especially if the GWP metric is used. If an impact horizon, distinct from the project horizon is used, the impact time horizon should be applied only to the relatively predictable changes related to biogeochemical considerations. Relatively unpredictable changes in land use and fuel emissions related to direct human activity should be considered for only the more foreseeable timeframe of the project horizon. In particular, while it may be reasonable and consistent with the GWP to model the carbon cycle and biogeochemical considerations for 100 years, it is much more speculative to include consideration of postproduction land use decisions related to natural regeneration or other speculative post production land uses.

B. Determination of Project Time Frame(s)

1. **What is a scientifically justifiable project time frame to consider for this analysis? Should the project time frames be different for each fuel?**

There is no unassailable basis for choosing a very specific timeframe, and any choice will be, in some measure, arbitrary. That said, a timeframe of 20-30 years seems a reasonable balance between the need to allow initial emissions to be spread over several years of production and the need to anchor the analysis in the foreseeable future. To make even-handed comparisons between fuels, the timescale should be consistent across all fuels. The most sensible anchor for the project timeframe is the expected life of the fuel production facility.

a. **What are the proper criteria for determining the project time frame?**

The timeframe should be based on concrete factors in the foreseeable future such as the expected lifetime of a fuel production facility.

i. **Should the project time frame be based on when each fuel is likely to be priced out of the market? Should the project time frame be based on the EISA fuel mandates? What other criteria would you recommend, if any?**

Analysis of the probable duration of fuel production can help to inform the decision about the lifetime of a fuel production facility, within the range of 20-30 years, but in the end a single duration should be applied across all fuel types. Having different facility lifetimes across fuel types adds an unnecessary level of speculation and makes it difficult to compare the different fuels on an even basis, which is a key reason to have a common metric.

b. What is the best scientific method for determining the project time frame or frames?

ii. Is economic modeling the best method for determining the project time frame? If so, what specific models do you recommend for this analysis?

Economic modeling can help to inform the decision about the lifetime of a fuel production facility, within the range of 20-30 years, but in the end a single duration should be applied across all fuel types. Using modeling to predict the outcome of competition between different fuels, some of them not yet commercialized adds a considerable and avoidable level of speculation to the analysis. The economic modeling of not yet commercialized fuels is likely to reflect primarily the input assumptions about crops and technologies that are not yet developed. As an example, the NEMS model, used by EIA and others can produce significantly different results depending on the underlying technology assumptions and biomass supply curves and etc [cite Blueprint versus EIA]. This model can provide useful insight into how quickly different scenarios based on different assumptions will diverge, and this informs my suggestion that projections further than 20-30 years in the future are highly speculative.

iii. If you do not recommend economic modeling, what other methods do you suggest?

The project timeframe should be based on the typical lifetime of a facility and limited by our ability to make reliable predictions of the future. Because of the lifetime of our vehicle fleet, and the time to develop and commercialize new technologies we can predict that something like the status quo will prevail for a decade or so, but as we look more than 20-30 years in the future the ability to predict crops, yields, fuel usage etc, diminishes considerably.

C. Determination of Impact Time Frame

1. What is a scientifically justifiable impact time frame to consider for this analysis? Should the impact time frame be the different for each fuel?

The impact timeframe depends upon the metrics. If only emissions are being considered, then there is no need for an impact timeline that goes beyond the project timeframe of 20-30 years. If the FWP methodology is adopted, a longer impact timeframe would be appropriate to maintain consistency with the IPCC-recommended GWP timeframe of 100 years. However, given the potential for irreversible impacts from climate change, such as the melting of polar ice caps, sea level rise, species extinction, and the reduced ability of the planet to absorb CO_2, it would also be reasonable and indeed advisable to use a shorter impact horizon than 100 years, to ensure that actual reductions in cumulative radiative forcing from this fuel program result are achieved by an earlier date. Insofar as biofuels are an early action to address climate change, it would be reasonable to set an earlier target date for achieving results.

2. What are the proper criteria for determining the impact time frame?

The most important criteria is to choose an impact timeframe that allows the resulting metric to be based on concrete information and as little speculation as possible. Our ability to accurately predict fuel production patterns and land use patterns is limited to decades, but our ability to predict biogeochemical changes may be longer. Consistency with other parts of the regulation (such as GWP) is also an important criterion in developing timeframes and all the other parameters that influence the metric.

3. **What is the best method for determining the impact time frame or frames? What modeling or other information should inform the choice of an impact time frame?**

The impact timeframe should be consistent the urgency of making reductions emissions of heat trapping gasses, which should be informed by the latest assessments of climate change. A second consideration would be consistency with the impact timeframe used for the GWP. There is no justification for using an impact timeframe longer than 100 years. As mentioned previously, the impact horizon should only be used for biogeochemical projections, since projecting future patterns of land uses out further than the project timeline is excessively speculative. If the impact timeframe is used to project changes in land use, a shorter period of no more than 30 years should be used.

4. **Is it scientifically justifiable to select an impact time frame based on presumed climate impacts? For example, should we only be concerned with GHG reductions over the next 20 – 30 years, or is a different time frame justified.**

A shorter impact timeframe is scientifically reasonable and is consistent with the latest climate science that indicates that swift and deep reductions of heat-trapping gasses are needed to avoid catastrophic changes due to a warming climate. GHG reductions after these changes have occurred will not reverse the damage, and so it is reasonable to focus on avoiding the damage in the first place.

5. **How should the potential for “threshold” or irreversible climate change impacts influence our choice of an impact time frame?**

The possibility of threshold impacts suggests using a shorter impact horizon, all other things being equal. If there is significant evidence of potential threshold impacts by 2050, it would be reasonable to adopt a 30-40 year impact timeframe. In this case it might also be appropriate to adopt a shorter impact horizon for the GWP, giving a higher weight to shorter lived GHGs like methane than under the 100 year GWPs.

   a. **What evidence about these potential thresholds would be most appropriate for consideration when determining the impact time frame?**

See earlier discussion and references.

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

1. **If the impact time frame is longer than project time frame, how should GHG emissions in this longer time frame be accounted for as part of EPA’s lifecycle GHG analysis?**

For the time between the end of the project and the end of the impact timeframes the atmospheric abundance of the GHG should be projected and the incremental cumulative radiative forcing calculated consistent with the GWP approach.

2. **Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion?**

Because the timing of and land uses in the post project time period almost entirely speculative, neither carbon sequestration nor foregone sequestration in this period should not be included in the analysis of emissions.

3. **Besides land reversion, what other factors following biofuel production should be considered in this analysis? What is the best way to estimate these GHG emissions changes?**

Few if any projected GHG flows should be assigned to the post production time period with the possible exception of what is projected to occur by biogeochemical models, and these should be used in a way that consistent with the GWP approach adopted elsewhere in the regulation.

III. Valuation of Future GHG Emissions

A. Conceptual Issues

1. **Is it scientifically justifiable to treat future GHG emissions and reductions different than near term emissions/reductions?**
   a. **If so, what is the basis for such different treatment?**

It is reasonable to treat emissions GHG emissions differently over time in a purely physical assessment, insofar as the emissions may have a different impact on radiative forcing or other climate impacts due to changes in the background level of GHGs, or other biogeochemical factors. In practice these differences should be treated in a manner that is consistent with the models used in GWP.
In the FWP approach emissions are treated the same across time, but their impact on the overall FWP metric is lower if they occur further in the future because their impact on cumulative radiative forcing over the analytic horizon differs. This is justifiable and consistent with the treatment of GHGs in the GWP.

2. **Is it appropriate to apply a non-zero discount rate to physical GHG emissions (i.e., GWP weighted emissions) in some or all circumstances?**

In the circumstances of the RFS it is not appropriate to discount physical GHG emissions, but I would not venture to speculate about all other circumstances.

   a. **Is it scientifically justifiable to apply a non-zero discount rate to physical GHG emissions under the assumption that GHG emissions have constant marginal damages regardless of when they occur (i.e. use GWP weighted emissions as a surrogate for monetary impacts)?**

The assumption of constant marginal damages is not justified, and therefore the GWP weighted emissions are a poor proxy for monetary impacts.

b. If discount rates are used when monetizing the impact of GHG emissions, is this scientifically justifiable for the purposes of lifecycle GHG assessment as defined by EISA?

EISA calls for physical emissions reductions rather than an economic analysis. Thus it seems clear that Congress did not intent do delegate to EPA the discretion to decide larger questions of strategy, intergenerational equity, etc. There is a fundamental difference between an economic assessments and physical assessments, and economic assessment of social preferences should not be presented as a physical measurement.

3. Is it scientifically justifiable to apply a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts? Is this the only circumstance where a non-zero discount rate would be appropriate?

It is technically justifiable to apply a non-zero discount rate to monetary impact over time, although the details of the impact assessment and discounting procedures are non-trivial. However, such a metric would not be an appropriate for EISA, which does not call for an economic assessment.

B. Choice of Discount Rate

1. What is the most scientifically justifiable discount rate (including the possibility of a zero discount rate) for this lifecycle analysis?

A zero discount rate coupled with a relatively short time horizon (20 years or so) is the simplest and most scientifically justifiable approach.

2. What are the proper criteria for determining the discount rate?

There is an extensive and unsettled debate in the community of climate change researchers, and I do not endorse any specific approach. However, these discount approaches are all methods to measure some fundamentally economic quantity, and are not a means to compute the aggregate quantity of GHG emissions. Thus I take this debate to be largely irrelevant to RFS.

3. Should the choice of discount rate be related, or affected, by the selected time frames (i.e. project and impact) for lifecycle GHG analysis? If so, how?

Longer time horizons render decisions about discount rates more relevant and also more complex. Time horizons of more than few decades become especially complex and controversial, invoking debates about intergenerational equity and other complex matters. In the context of the RFS, however, there is no need to delve into these controversies, as EISA does not call for such considerations. If a long impact horizon is chosen, the EPA would do well to follow the lead of the IPCC and adopt the GWP methodology. This method is not without critics, but it is the commonly accepted approach and is already specified in EISA.

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

1. EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." How does this language impact or limit the approach taken by EPA to evaluate lifecycle GHG thresholds of biofuels?

This limits the approach to what is consistent with either simple mass values or the global warming potential methodology as outlined by the IPCC. EISA says nothing about adjustments for intergenerational equity, costs benefit analysis or other economic considerations. Clearly a physical rather than an economic metric is required. However, methodologies that equalize emissions over time following a methodology that is consistent with the methodology of the GWP should be allowable.

2. One alternative measure that has been proposed is the Fuel Warming Potential (FWP)[40]. Would the FWP be an appropriate metric to use for this analysis? If so, how would it be applied in the context of determining comparative assessment of transportation fuel lifecycle GHG emissions?

The application of this method would be appropriate, as it is a purely physical measure of emissions that takes account of time in the same manner as the GWP methodology. More information on the application of this method is included in my introductory remarks above.

3. Are there other methods or metrics that would be more appropriate to account for GHG emissions over time?

None that I am aware of.

IV. Other Methodological Considerations

A. Scenario Analysis

1. EPA's proposed approach has been to look at snapshot in time (biofuel volume change in 2022) and to project emissions and reductions forward based on this one time change in volume. A more detailed and perhaps more data intensive approach would be a year-by-year analysis comparing different volume scenarios of biofuels over time. Such a comparison would likely compare a base case and one or more expanded biofuel cases. A particular methodology for this approach would be to project different annual biofuel volumes and GHG emissions out into the future until the base case and policy case are equivalent (if ever).

This proposed methodology is not at all clear to me, and, since I don't find any description of it in the other documentation, I can not respond in detail to the proposal. In general any benefits from more detailed analysis should be weighed against any additional uncertainties that would come along with it. Additional uncertainty should only be tolerated to the extent it is necessary to meet the requirements of EISA.

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[40] See for example O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001

a. Would this approach present a clearer picture of the marginal impact of the RFS mandates?
b. Would this approach present a clearer picture of what the GHG impact is of a specific biofuel (i.e., what is needed for EISA requirements)?
c. Would this approach help to clarify the timeframe discussion by tracking the GHG difference between scenarios over time until there are no more changes?
d. Would the base case ever provide the same amount of biofuel as the RFS policy case scenarios (e.g., this could include both cases having zero biofuels at some future date)?
e. Would the base case ever provide the same level of GHG emissions as the RFS policy case (i.e., at what point would you stop needing to consider differences between the two cases)?
f. Is there an alternative methodology for deciding the time frame over which we should project the yearly impacts of RFS?

2. **How could a yearly or cumulative impact approach be used to determine lifecycle GHG values for specific fuels or fuel pathways?**
3. **What models, tools, and data sources are available that would enable this type of calculation?**

APPENDIX F

DR. KENNETH R. RICHARDS RESPONSE TO CHARGE QUESTIONS

General Comments

Thank you for the opportunity to review EPA's analysis of lifecycle greenhouse gas emissions associated with biofuels. It was a pleasure to read the materials related to the analysis. The timing and discount questions raised are challenging and complex. I was pleased to see the extent to which EPA's analysts had grasped both the conceptual and practical issues related to this type of work.

Overall, the problem with this type of analysis is that it is necessarily imprecise. When Congress, or more specifically the ESIA, requires EPA to make a precise determination of the reduction in GHG emissions associated with each biofuel/production method relative to petroleum, it is simply asking for the impossible. There are too many unknowns in the process.

In the face of this impossibility, EPA can dissemble and pretend to achieve the requisite comparison or it can be creative in how it approaches the task – substituting judgment for mathematical precision. The questions presented in this review and the methods used in the analysis, suggest that the agency has essentially opted for the former approach. But there is an undertone to the discussion, particularly when the topic turns to the uncertainty inherent in the analysis, suggesting that the analysts recognize the need for the latter.

I will attempt to respond to many of the specific questions posed, but it might be more constructive to outline an overall approach that would be constructive.

First, as to time horizon for the analysis, the appropriate time horizon is the period over which any affects might be felt. There is no theoretical "right" choice other than the infinite time horizon. Rather, the limits to time horizons are a practical matter – how far out do you have to go out before changes to the present value of any impacts will be insignificant? If you are using a zero discount rate, then the infinite time horizon is appropriate. If you use a higher discount rate, then a shorter time period is appropriate. For example, in evaluating the present value of a stream of annual benefits at a 10 percent discount rate, the difference between going out to 60 years versus 100 years is miniscule – less than 0.3 percent – virtual noise given the level of uncertainty. At a 2 percent discount rate the difference is quite a bit more.

Second, the appropriate "thing" to discount is the value of the carbon benefits, not the physical quantity itself (though see the follow up qualifying note). In a perfect analytical world, we would know the value of a ton of reduction of carbon-equivalent in each year; it would "simply" be the present value of all of the marginal damages of an extra ton in the atmosphere for the atmospheric residence time of carbon dioxide. That value, however, is elusive. Not only does it require an understanding of the damage function for a range of atmospheric concentrations of GHGs, it requires an understanding of the time path of concentrations. We can play with scenarios using the type of models that, say, Jae Edmonds of PNNL works with, but to define the damage function and to predict the time path of atmospheric concentrations, is beyond the scope of a simple biofuels analysis exercise.
It might be tempting to combine the economic discount rate, with a decay rate for the atmospheric residence time of gases and an additional function for the changing marginal damages of emissions, but you should resist that. Keep these as three separate steps in the

analysis, if possible. Keeping these effects separate helps both the analyst and the audience to remember the meaning of each operation. It facilitates discussion and debate.

That said, as a proxy for the complex analysis required to comport with theory, we tend to make the assumption that all emissions of carbon have the same marginal damages, regardless of their year of release. It is a concession to the limits of our knowledge, not a claim of theoretical rigor. This allows us to make calculations that are "good enough" for policy work. This gives the appearance of discounting physical units, only because all physical units have the same value under this assumption.

Third, the appropriate discount rate is the one that reflects society's tradeoffs between current and future impacts – both negative and positive. This choice is subject to much debate. The EPA materials suggest that the discount rate should reflect some combination of risk/uncertainty and pure rate of time preference for consumption. But it could also be argued that the discount rate should reflect the rate of return on other available public endeavors. If we didn't invest in reducing emissions of GHG's where would those resources go? What rate of return are we giving up?

It is pretty clear that zero is not the correct discount rate for the benefits of GHG emissions reductions. To understand this, consider a project to reduce emissions. The project can be started this year, next year, or the year after that, or in any future year. This project will involve an initial investment followed by a stream of benefits, say for 20 years. Assuming a zero percent discount rate, if we make the investment this year, the present value of the anticipated benefits will be the sum of the value of the reduction in each year it occurs. Now consider the alternative of waiting a year to start the project. The value of benefits is unchanged – same number of tons reduced, just delayed a year. In fact, we could keep delaying the project indefinitely with no change in the value of benefits. It really doesn't matter when the project is done; and if it doesn't matter when it is done, it doesn't matter whether it is done. This observation is even more true if you consider the robust assumption that we could be investing the capital for the project, getting it to grow. If we wait long enough for the capital to double, we might be able to do two emissions reductions projects. There is no convergence on this problem when you use a zero discount rate.

As a practical matter, it is challenging to choose the appropriate discount rate. For public investments, it is certainly greater than zero percent and almost certainly less than 10 percent. The best approach to dealing with this is going to be sensitivity analysis, which is what the EPA analysts have done.

So far, here is the practical approach prescribed:

1. Choose a time horizon sufficiently long to accommodate all significant impacts. As a practical matter, the horizon can be shortened for higher discount rates.
2. Assume that the marginal damages associated with emissions will be constant over the horizon – not because this is accurate, but because it is easy and just as defensible as any other assumption.
3. Choose three discount rates that will allow you to test the sensitivity of the results to this necessarily controversial parameter. I would suggest, 2, 3, and 5, but that is a matter of judgment.

Having now developed a consistent analytical approach, the exercise is reduced to one of scenario analysis. The challenge here is choosing scenarios that are indicative of how the future might unfold. The EPA analysts have already struggled with this some. The art is turning this analysis into a convincing argument that can be used to determine, as a legal matter, which biofuels/production methods will satisfy the ESIA thresholds. This cannot be done with mathematical/modeling brute force. It must be done with finesse – acknowledging the limits of the analysis but being clear that it is the best that can be done.

To do the scenario analysis, for each fuel/production approach choose a number of scenarios that seem plausible. For example, for corn based ethanol, choose one in which the production process starts at Year 0 (2022, perhaps) and continues indefinitely; a second in which the production starts in Year 0 and continues for N years, ceases, and is followed by natural regeneration; a third in which the production starts in Year 0, continues for M years and is then replaced by an advanced technology. Run all the scenarios over the full length of the time horizon, at the different discount rates. What story emerges? Is it generally above or below the 80 percent threshold?

Using this approach of scenario analysis and interpretation is less precise than may seem to be called for by ESIA. However, it is the best you can do and should stand up to both policy and legal challenges.

In the case of corn-based ethanol, the EPA analysis observed that there is an immediate release of carbon, followed by a long period of carbon benefits. The release of carbon is not well documented in the analysis, but let's assume it is true. If that is the case, two analytical conditions will favor corn ethanol – long time horizons and low discount rates. Often when we do sensitivity analysis we pay particular attention to the extremes – the set of parameters that most favors a particular hypothesis and the combination of parameters that is least favorable. The EPA report was odd in that it combined a long horizon with a higher discount rate and a shorter horizon with a lower discount rate. To examine the full range of outcomes these should be reversed. In fact, my suggestion, as indicated above, is to just do all analyses for 100 years or longer.

I would also note that the questions in the review charge consistently refer to a "scientifically objective" method for lifecycle analysis, belying an assumption that such a thing is possible. There is no such thing. This work requires the analyst to exercise a great deal of judgment. To move in the direction of objectivity, the best the analyst can do is to clearly state the assumptions that were used, carefully delineate the methods, and to invite interested parties to debate whether that approach is acceptable for the policy analysis purposes.

The discussion above has addressed many of the questions and concerns raised in the EPA materials. However, at the risk of being repetitive, on the following pages I will attempt to address some of the specifics form the Charge Questions.

Peer Review Charge Questions

I. Overall Approach to Treatment of Lifecycle GHG Emissions over Time[41]

The preamble and RIA separates the discussion of how to account for the variable timing of transportation fuel lifecycle GHG emissions into different components: (a) Time frame; (b)

[41] In this document the term "GHG emissions" refers to any change in GHG emissions, including emissions reductions or sequestrations.

discount rate, or the relative treatment of current and future GHG emissions, and (c) Appropriate metrics

Q1: Is this a scientifically objective way to frame the analysis of lifecycle GHG impacts of different fuels in the context of what is needed for this rulemaking?

This is largely the correct approach. By "Appropriate metric" I assume you mean choice of discount rate.

II. Time Frame(s) for Accounting

A. Conceptual Description of Time Frame(s) for Lifecycle GHG Analysis

As explained in the preamble and RIA, the time frame for analyzing lifecycle GHG emissions can be approached in different ways, such as:

- Project time frame – how long we expect production of a particular biofuel to continue into the future
- Impact time frame – the length over which to account for the changes in GHG emissions, in particular due to land use changes, which result from biofuel production

Q2: Do the preamble and RIA define these time frame concepts in a scientifically objective way for lifecycle analysis? What other concepts, if any should be considered?

The preamble defines the terms clearly. Note that these definitions are useful for discussion and scenario building, but they really have no role in the analysis of the scenarios.

B. Determination of Project Time Frame(s)

Q3: What is a scientifically justifiable project time frame to consider for this analysis? From Preamble: "For the determination of whether biofuels meet the GHG emissions reduction required by EISA, we present the results for a range of time periods, including both 100 years and 30 years in Section VI.C and specifically invite comment on whether use of a 100 year time frame, a 30 year time frame, or some other time frame, would be most appropriate."

See comments above. The timeframe should cover all impacts from the outset of the project/practice. As a practical matter you might shorten the timeframe when using higher discount rates, but only because the difference in present value between 60 years and 100 years of annual benefits is quite small at higher discount rates. That said, running each scenario out to 100 years seems simple enough and leads to consistency across analysis.

Q4: Should the project time frames be different for each fuel? <u>From Preamble</u>: "EPA intends to more carefully model these transitions in particular to better account for future land use impacts and we invite comments on methodology, sources of data, factors that should be considered in assessing whether and when a particular biofuel such as ethanol from corn starch, for example, will no longer be produced and recommendations on how to improve on our assessment of the likely stream of GHG emissions after 2022 that will result from the EISA mandates."

No, use the same timeframe for each fuel. There is no harm in adding extra years. Something will happen in those years and you might as well apply your best guess than to pretend there are no effects.

Q5: What are the proper criteria for determining the project time frame?

Response: See above.

Q6: Should the project time frame be based on when each fuel is likely to be priced out of the market? <u>From Preamble:</u> "We specifically seek comments on the 100 year and 30 year time frames discussed in this proposal. We also seek general comments on the most appropriate time periods for analysis of biofuels, and whether we should use different time periods for different types of renewable fuels."

You are confusing timeframe with scenario building. Use the same timeframe – I suggest 100 years – for each analysis. Address the issue of exit from the market with the design of the scenario. This should probably be one of the scenarios, particularly for corn ethanol.

Q7: Should the project time frame be based on the EISA fuel mandates?

I am not sure what you mean.

Q8: What other criteria would you recommend, if any?

See above.

Q9: What is the best scientific method for determining the project time frame or frames?

See above.

Q10: Is economic modeling the best method for determining the project time frame? If so, what specific models do you recommend for this analysis?

Economic modeling may help you (1) determine scenarios that should be tested and (2) assign likelihoods to the scenarios; but it will not determine the timeframe.

Q11: If you do not recommend economic modeling, what other methods do you suggest?

See above.

C. Determination of Impact Time Frame

Q12: What is a scientifically justifiable impact time frame to consider for this analysis? Should the impact time frame be the different for each fuel? <u>From Preamble:</u> "We seek comment on our estimate of the average length of annual foregone forest sequestration for consideration in biofuel lifecycle GHG analysis."

Be careful of cloaking your analysis in “scientifically justifiable” terms. As stated above, the time horizon should be chosen such that you capture all significant impacts. In the case of biofuels crowding out existing forests, that could be quite a long term if the forests would have continued growing for some time. In your analysis you keep referring to forests that, in the reference case, would have continued accumulating carbon for 80 years. I did not see any particular justification for that assumption – perhaps it emerged from the modeling.

Q13: What are the proper criteria for determining the impact time frame?

See above. The key is to capture all significant impacts. Use a shorter time horizon is equivalent to saying we are going to assume there no impacts after this point.

Q14: What is the best method for determining the impact time frame or frames? What modeling or other information should inform the choice of an impact time frame?

Q15: Is it scientifically justifiable to select an impact time frame based on presumed climate impacts? For example, should we only be concerned with GHG reductions over the next 20 – 30 years, or is a different time frame justified.

No this would not be justifiable. Assuming we care about all generations, then we should care about impacts at all times.

Q16: How should the potential for “threshold” or irreversible climate change impacts influence our choice of an impact time frame?

This goes to the issue of modeling damages. It is simply beyond the scope of this undertaking. Presumably it would increase the damages of near-term versus long-term emissions, but you simply do not have the information to support that conclusion.

Q17: What evidence about these potential thresholds would be most appropriate for consideration when determining the impact time frame?

D. Accounting for Lifecycle GHG Emissions after the Project Time Frame

Q18: If the impact time frame is longer than project time frame, how should GHG emissions in this longer time frame be accounted for as part of EPA’s lifecycle GHG analysis?

The same way they are during the project time horizon.

Q19: Should sequestration from land reversion be considered in this analysis? If so, what is the best way to estimate the impacts of land reversion? <u>From preamble:</u> “For this proposal, we have not projected the GHG emissions associated with land reversion, but we plan to consider land reversion in our final rule analysis and we seek comments on methodologies and approaches for doing this. We also seek comment on the related issue of how best to estimate how long each type of biofuel is most likely to continue to be produced, and whether production of these biofuels is likely to end abruptly or phase out gradually.”

This is part of your scenario building. Try different scenarios. Given the gradual rate of natural regeneration, the fact that it will occur at a time quite distant in the future, it will probably have little effect on the GHG lifecycle, but test it out. If it is significant, incorporate it in your discussion of GHG threshold findings.

Q20: Besides land reversion, what other factors following biofuel production should be considered in this analysis? What is the best way to estimate these GHG emissions changes?

NA.

III. Valuation of Future GHG Emissions

A. Conceptual Issues

Q21: Is it scientifically justifiable to treat future GHG emissions and reductions different than near term emissions/reductions? If so, what is the basis for such different treatment?

Absolutely. See discussion above. Bottom line…a sero discount rate suggests that it doesn't matter when reductions occur. If it doesn't matter when reductions occur, let's keep postponing reductions, because that is the cheapest alternative. You can find implicit discount rates by looking at the shadow price of emissions reductions from the large climate/energy/economy models. Obviously timing of emissions reductions matters.

Q22: Is it appropriate to apply a non-zero discount rate to physical GHG emissions (i.e., GWP weighted emissions) in some or all circumstances?

Never, though the outcome in some cases may look like you are discounting physical units when marginal damages are constant over time.

Q23: Is it scientifically justifiable to apply a non-zero discount rate to physical GHG emissions under the assumption that GHG emissions have constant marginal damages regardless of when they occur (i.e. use GWP weighted emissions as a surrogate for monetary impacts)?

Be careful. You are confusing the issue of discounting and GWP use. The discount rate applies to tradeoffs of damages occurring at different points in time. The GWP is a purely physical index of warming effects for comparison of different gases. It does not give a good measure of relative economic impacts. To get that we need a GWP adjusted for the difference in economic impacts (see Reilly and Richards, 1994, on greenhouse gas indexing).

Q24: If discount rates are used when monetizing the impact of GHG emissions, is this scientifically justifiable for the purposes of lifecycle GHG assessment as defined by EISA?

Not sure I understand the question.

Q25: Is it scientifically justifiable to apply a non-zero discount rate to GHG emissions that have been converted to climate impacts and then to monetary impacts? Is this the only circumstance where a non-zero discount rate would be appropriate?

Ultimately this is what you should be doing, as outlined above.

B. Choice of Discount Rate

Q26: What is the most scientifically justifiable discount rate (including the possibility of a zero discount rate) for this lifecycle analysis?

There is little or no science to this issue. It is a reflection of preferences and opportunity costs. 2 to 5 percent seem most reasonable. Zero discount rate is not justifiable. Use sensitivity analysis to allow your client/public to assess the differences that different discount rates would make.

Q27: What are the proper criteria for determining the discount rate?

See above.

Q28: Should the choice of discount rate be related, or affected, by the selected time frames (i.e. project and impact) for lifecycle GHG analysis? If so, how?

No. Just the opposite – the time horizon should be affected by the choice of discount rate.

C. Appropriate Metrics for Evaluation of Lifecycle GHG Emissions Over Time

EISA states that lifecycle GHG emissions are "the aggregate quantity of greenhouse gas emissions…where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential."

Q28: How does this language impact or limit the approach taken by EPA to evaluate lifecycle GHG thresholds of biofuels?

On first blush, it appears that by focusing on quantity and GWP rather than values of impacts, the ESIA may have precluded your more policy relevant analysis.

Q29: One alternative measure that has been proposed is the Fuel Warming Potential (FWP)[42]. Would the FWP be an appropriate metric to use for this analysis? If so, how would it be applied in the context of determining comparative assessment of transportation fuel lifecycle GHG emissions?

I am not familiar with this measure, but it is either consistent with the analysis outlined above or it is not. If not, then it would not be an improvement.

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[42] See for example O'Hare, Plevin, Martin, Jones, Kendal and Hopson; "Proper accounting for time increases crop-based biofuel's greenhouse gas deficit versus petroleum"; Environmental Research Letters, 4 (2009) 024001

Q30: Are there other methods or metrics that would be more appropriate to account for GHG emissions over time?

NA

IV. Other Methodological Considerations

A. Scenario Analysis

EPA's proposed approach has been to look at snapshot in time (biofuel volume change in 2022) and to project emissions and reductions forward based on this one time change in volume. A more detailed and perhaps more data intensive approach would be a year-by-year analysis comparing different volume scenarios of biofuels over time. Such a comparison would likely compare a base case and one or more expanded biofuel cases. A particular methodology for this approach would be to project different annual biofuel volumes and GHG emissions out into the future until the base case and policy case are equivalent (if ever).

Q31: Would this approach present a clearer picture of the marginal impact of the RFS mandates?

The underlying supposition here appears to be that because lifecycle impacts are a function of the interplay of a number of market and physical forces, the results will vary over time. For example, early action may not crowd out forests, but eventually it will. To some extent, then the lifecycle impacts of biofuels will depend upon how much of the biofuels have already been done. If this is the case, then a dynamic analysis might be quite informative. You might be able to justify a result said corn ethanol hits the 80 percent mark for 10 years and then doesn't.

Q32: Would this approach present a clearer picture of what the GHG impact is of a specific biofuel (i.e., what is needed for EISA requirements)?

Probably yes. I would try it to see what it reveals.

Q33: Would this approach help to clarify the timeframe discussion by tracking the GHG difference between scenarios over time until there are no more changes?

Perhaps, though it is not entirely clear based on this presentation.

Q34: Would the base case ever provide the same amount of biofuel as the RFS policy case scenarios (e.g., this could include both cases having zero biofuels at some future date)?

Possibly, though I am not sure I get the question. It seems that another case where the two lead to the same level of biofuels is when the RFS policy is not binding because other legislation, e.g., climate change legislation, puts an even greater constraint on the use of fossil fuels.

Q35: Would the base case ever provide the same level of GHG emissions as the RFS policy case (i.e., at what point would you stop needing to consider differences between the two cases)?

Not sure.

Q36: Is there an alternative methodology for deciding the time frame over which we should project the yearly impacts of RFS?

See above.

Q37: How could a yearly or cumulative impact approach be used to determine lifecycle GHG values for specific fuels or fuel pathways?

Not sure.

Q38: What models, tools, and data sources are available that would enable this type of calculation?

You seem to have already employed a number of models that should be helpful. However, you need to clarify your methods to separate out the scenario building from the scenario analysis.

APPENDIX G

CURRICULA VITAE OF SELECTED PEER REVIEWERS

Joseph Edward Fargione

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The Nature Conservancy
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CURRENT POSITION
2007-Present Regional Science Director, The Nature Conservancy, Central United States Region

PAST POSITIONS
2007-2007 Research Associate, Departments of Applied Economics & Ecology, Evolution, Behavior, University of Minnesota (With Drs. Steve Polasky and David Tilman)
2006-2007 Assistant Professor, Departments of Forestry and Natural Resources & Biology, Purdue University
2004-2006 Research Faculty, University of New Mexico (with Dr. Scott Collins)

EDUCATION
Ph.D. Ecology; University of Minnesota, St. Paul, MN, 2004
Advisor: Dr. David Tilman
Thesis: *Biodiversity and community structure in a tallgrass prairie: consequences of resource competition in space and time.*
B.A. Ecology; Hampshire College, Amherst, MA, 1996

HONORS AND FELLOWSHIPS
University of Minnesota, Doctoral Dissertation Fellowship, 2003-2004
Charles J. Brand Fellowship, 2001-2002
University of Minnesota, Graduate Student Fellowship, Fall 2000
University of Minnesota, Graduate Student Fellowship, 1998-1999
National Science Foundation, Pre-Doctoral Fellowship Honorable Mention, 1998, 1999
Johnson Scholar, Hampshire College, 1992-1996

GRANTS
"Energy by Design: Science-Based Wind Energy Siting," American Wind and Wildlife Institute ($193,000), 2009
"Energy by Design: Wind Siting for the Northern Great Plains" World Wildlife Fund, ($25,000), 2009
"Conservation for a Changing Climate: Protecting Nature in the Great Lakes Region", Donnelley Foundation ($120,000), 2008
Research Experience for Undergraduates, NSF ($6,000), 2007
"Spatial predictions of species loss due to nitrogen deposition in the United States," Agricultural Research Program graduate research fellowship, Purdue University ($36,000; award declined), 2007
"Effects of N-fixing plants on diversity and species interactions," LTER Network Office, Co-PI: Jenn Shah ($5,760), 2006
Research Experience for Undergraduates, NSF ($6,000), 2006
"Global change effects on grass-shrub interactions in an arid ecosystem," NSF Ecology Panel, Co-PIs: Scott Collins and William Pockman ($297,494), 2005
Dayton-Wilke Research Grant, Dept. of Ecology, Evolution, and Behavior ($1,000), 1999-2002

PUBLICATIONS

McDonald RI, J Fargione, J Kiesecker, WM Miller, and J Powell. *Submitted*. Energy sprawl of energy efficiency: Impacts of U.S. climate policy on natural habitats. *PLoS One*

Collins SL, JE Fargione, CL Crenshaw, E Nonaka, JT Elliott, and WT Pockman. *Submitted* Rapid plant community responses during the summer monsoon to nighttime warming in a Northern Chihuahuan Desert grassland. *Journal of Arid Environments*

Ravindranath NH, R Manuvie, J Fargione, JG Canadell, G Berndes, J Woods, H Watson, and J Sathaye. *In Review*. Green House Gas Implications of Land Use and Land Conversion to Biofuel Crops, In Scope Biofuels Report (B. Howarth, editor)

Fargione J, TR Cooper, DJ Flaspohler, J Hill, C Lehman, T McCoy, S McLeod, EJ Nelson, KS Oberhauser, and D Tilman. *Accepted*. Bioenergy and Wildlife: Threats and Opportunities for Grassland Conservation. *BioScience*

Wiens J, J Fargione, and J Hill. *In Review*. Biofuels and biodiversity. *Ecological Applications*

Dybzinski R, J Fargione, DR Zak, D Fornara, and D Tilman. 2008. The fertility effect: resource supply increases across an experimental plant species diversity gradient. *Oecologia*

Collins SL, KN Suding, EE Cleland, M Batty, SC Pennings, KL Gross, JB Grace, L Gough, JE Fargione, and CM Clark. 2008. Rank clocks and plant community dynamics. *Ecology* 89: 3534-3541

Fargione JE, J Hill, D Tilman, S Polasky, P Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Science* 319: 1235-1238

Cleland EE, CM Clark, SL Collins, JE Fargione, L Gough, KL Gross, DG Milchunas, SC Pennings, WD Bowman, IC Burke, WK Lauenroth, GP Robertson, JC Simpson, D Tilman, and KN Suding. 2008. Data paper: Species responses to nitrogen fertilization in herbaceous plant communities, and associated species traits. *Ecology* 89: 1175

Clark CM, EE Cleland, SL Collins, JE Fargione, L Gough, KL Gross, SC Pennings, KN Suding, and JB Grace. 2007. Environmental and plant community determinants of species loss following nitrogen enrichment. *Ecology Letters* 10: 596-607

Fargione J, D Tilman, R Dybzinski, J Hille Ris Lambers, C Clark, WS Harpole, JMH Knops PB Reich, and M Loreau. 2007. From selection to complementarity: Shifts in the causes of biodiversity-productivity relationships in a long-term biodiversity experiment. *Proceedings of the Royal Society B: Biological Sciences* 274: 871-876

Baez S, J Fargione, DI Moore, SL Collins, JR Gosz. 2007. Nitrogen deposition in the northern Chihuahuan desert: Temporal trends and potential consequences. *Journal of Arid Environments* 68: *640-651*

Diaz S, J Fargione, FS Chapin III, D Tilman. 2006. Biodiversity loss threatens human well-being. *PLoS Biology* 4: 1300-1305

Fargione J, and D Tilman. 2006. Predicting relative yield and abundance in competition with plant species traits. *Functional Ecology* 20: 533-540

Diaz S, D Tilman, J Fargione, et al. 2005. Biodiversity and the regulation of ecosystem services. *In* Millennium Ecosystem Assessment editors. Ecosystems and Human Well Being: Current State and Trends. Island Press, DC, USA

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Fargione J, and D Tilman. 2005. Diversity decreases invasion via both sampling and complementarity effects. *Ecology Letters*, 8: 604-611

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Tilman D, C Lehman, J Hille Ris Lambers, WS Harpole, R Dybzinski, J Fargione, and C Clark. 2004. Does metabolic theory apply to community ecology? It's a matter of scale. *Ecology*, 85: 1797-1799

Neuhauser C, and J Fargione. 2004. A mutualism-parasitism continuum model and its application to plant-mycorrhizae interactions. *Ecological Modeling*, 177: 337-352

PUBLICATIONS (continued)

Fargione J, CS Brown, and D Tilman. 2003. Community assembly and invasion: An experimental test of neutral versus niche processes. *Proceeding of the National Academy of Sciences*, 100: 8916-8920 (Highlighted on *Minnesota Public Radio* and in *BioScience*)

Craine JM, PB Reich, GD Tilman, D Ellsworth, J Fargione, and J Knops. 2003. The role of plant species in biomass production and response to elevated CO_2 and N. *Ecology Letters*, 6: 623-630

Fargione J, and D Tilman. 2002. Competition and coexistence in terrestrial plants. Pages 156-206 *In* U. Sommer and B Worm editors. Competition and Coexistence. Springer-Verlag, Berlin, Germany

Tilman D, J Fargione, B Wolff, C D'Antonio, A Dobson, R Howarth, D Schindler, W Schlesinger, D Simberloff, and D Swackhamer. 2001. Forecasting agriculturally driven global environmental change. *Science* 292: 281-284 (Highlighted in *Trends in Ecology & Evolution*)

PUBLISHED CORRESPONDENCE

Fargione JE, J Hill, D Tilman, S Polasky, P Hawthorne. 2008. Biofuels: Effects on land and fire - Response. *Science* 321: 199-200

Fargione JE, J Hill, D Tilman, S Polasky, P Hawthorne. 2008. Putting current practices in perspective - Response. *Science* 320: 1420-1422

PAPERS IN PREPARATION

Fargione J, SC Pennings, CM Clark, EE Cleland, SL Collins, L Gough, JB Grace, KL Gross, KN Suding, and D Tilman. No general relationship between species richness and productivity response to N addition in a synthesis of N fertilization studies

Invited Fargione J. The Ecological Impact of Biofuels. *Annual Review of Ecology, Evolution and Systematics*

PAPERS PRESENTED

Fargione JE, and D Tilman. 2006. Functional groups and community assembly: Assumptions, predictions, and empirical tests. Invited presentation in the symposium "Niche, neutrality, and community assembly". *Ecological Society of America Annual Meeting*, Memphis, Tennessee.

Fargione JE, S Pennings, C Clark, KN Suding, L Gough, JB Grace, EL Cleland, SL Collins, and KL Gross. 2005. A negative relationship between species richness and productivity response to N addition in a synthesis of N fertilization studies. *Ecological Society of America Annual Meeting*, Montreal, Canada.

Fargione J, and D Tilman. 2004. Plant invader abundance increases with differences in invaders and residents seasonal and spatial nitrogen uptake patterns. *Ecological Society of America Annual Meeting*, Portland, Oregon.

Fargione J, R Dybzinski, C Clark, J Hill Ris Lambers, S Harpole, D Tilman, and M Loreau. 2003. From selection to complementarity: Temporal trends in a long-term biodiversity experiment. *Ecological Society of America Annual Meeting*, Savannah, Georgia.

Brown CS, JE Fargione, and GD Tilman. 2001. Species diversity, resource competition and community invasibility: a Minnesota grassland experiment. Invited presentation in the symposium "Current status of knowledge on invasive species: Theory and practice". *Ecological Society of America Annual Meeting*, Madison, Wisconsin.

Hadley JL, J Schedlbauer, J Fargione. 2001. Diffuse illumination in an eastern hemlock (*Tsuga canadensis*) stand: Effects on photosynthesis and carbon storage. *Ecological Society of America Annual Meeting*, Madison, Wisconsin.

Fargione J, and D Tilman. 2000. Plant invasions are reduced by abundance of native perennial bunchgrass. *Ecological Society of America Annual Meeting*, Snowbird, Utah.

Fargione JE, CA Klausmeier, and CL Lehman. 1999. Community invasibility is increased by habitat destruction. *Ecological Society of America Annual Meeting*, Spokane, Washington.

Tilman D, J Fargione, and B Wolff. 1999. Forecasting the long-term effects of human-caused global change. *Ecological Society of America Annual Meeting*, Spokane, Washington.

INVITED SEMINARS

Fargione J. 2009. Biofuels and biodiversity. Biology Department, Kansas Sate University (planned)

Fargione J. 2008. Biofuels: Threats and opportunities for conservation. Minnesota chapter donor meeting, The Nature Conservancy

Fargione J. 2008. Biofuels: Threats and opportunities for conservation. Conservation Exchange (ConEx), Vancouver, Canada

Fargione J. 2008. Renewable Energy and Birds: Threats and Opportunities from Biofuels and Wind. Missouri Bird Conservation Initiative Annual Conference.

Fargione J. 2008. Modeling impacts of land clearing. Webinar for Midwestern Governors Association Low Carbon Fuel Standard Working Group.

Fargione J. 2008. Modeling impacts of land clearing. Fuel Lifecycle Modeling Workshop, Berkeley, CA

Fargione J. 2008. Mapping Wind and Wildlife. American Wind and Wildlife Institute, Minneapolis, MN

Fargione J. 2008. Renewable Energy: Threats and opportunities from biofuel and wind. Central and Mesoamerican regions staff enrichment training, The Nature Conservancy, Nebraska City, NE

Fargione J. 2008. Biofuels: Threats and opportunities. Eastern Region, All staff conference, The Nature Conservancy

Fargione J. 2008. Land Clearing and the Biofuel Carbon Debt. Capital Hill Briefing, American Meteorological Society, DC

Fargione J. 2008. Biofuels: Threats and opportunities. Metropolitan Energy Policy Coalition

Fargione J. 2008. Biofuels: Threats and opportunities. Wesleyan University

Fargione J. 2008. Land Clearing and the Biofuel Carbon Debt. Press Release, German Marshall Fund, DC

Fargione J. 2008. Biofuels: Threats and opportunities. Nebraska Board of Trustees, The Nature Conservancy

Fargione J. 2008. Biofuels: Threats and opportunities. Iowa Board of Trustees, The Nature Conservancy

Wiens J, and J Fargione. 2008. Biofuels and biodiversity. Ecological consequences of biofuels, Ecological Society of America, Washington DC

Fargione J. 2007. Biofuels: Threats and opportunities. Next Gen Energy Task Force, MN legislature

Fargione J. 2007. Biofuels: Threats and opportunities. WI Chapter, The Nature Conservancy

Fargione J. 2007. Biofuels: Threats and opportunities. MO Chapter, The Nature Conservancy

Fargione J. 2007. Biofuels: Threats and opportunities. MI Chapter, The Nature Conservancy

Fargione J. 2007. Biofuels: Threats and opportunities. MN Chapter, The Nature Conservancy

Fargione J. 2007. Biofuels: Threats and opportunities. Illinois Board of Trustees, The Nature Conservancy

Fargione J. 2007. Biofuel's footprint: Current and future land use for biofuel production. Biofuel and Wildlife Conference, University of Minnesota

Fargione J. 2007. Biofuel production and conversion of natural areas: Consequences for greenhouse gas emissions. Visit by the Japan Ecosystem Conservation Society, University of Minnesota

Fargione J. 2007. Global change, biodiversity, and invasion. Department of Wildland Resources, Utah State University

Fargione J. 2007. New insights from long term biodiversity experiments. Biology Department, Purdue University

Fargione J. 2007. Global change, biodiversity, and invasion. Department of Agronomy, Purdue University

Fargione J. 2006. Global change, biodiversity, and invasion. Department of Plant Biology, Michigan State University

Fargione J. 2006. Global change, biodiversity, and invasion. Kellogg Biological Station, Michigan State University

Fargione J. 2006. Global change, biodiversity, and invasion. Purdue Climate Change Research Center, Purdue University

Fargione J. 2005. New insights from long term biodiversity experiments. Institute of Environmental Sciences, University of Zurich

INVITED SEMINARS (Continued)

Fargione J. 2005. New insights from long term biodiversity experiments. Institute of Ecology, University of Jena

Fargione J. 2005. Biodiversity and resource competition in a tallgrass prairie. Department of Botany, University of Toronto

Fargione J. 2005. Plant species coexistence and global change: current and future research. Department of Botany, University of Toronto

Fargione J. 2005. New root productivity and global change experiments at the Sevilleta. *Sevilleta Symposium*, Sevilleta National Wildlife Refuge, Socorro, New Mexico

Fargione J. 2003. Interspecific niche differentiation: Consequences for invasion, coexistence, and biodiversity effects in a prairie plant community. Department of Biology, University of New Mexico

Fargione J, and D Tilman. 2003. Plant traits and resource competition: Controls on prairie plant abundances. Annual Cedar Creek Symposium, Cedar Creek Natural History Area, University of Minnesota

Fargione J, C Lehman, and S Polasky. 2003. Capitalism and the concentration of wealth. Environmental Resource Economics Seminar Series, Department of Applied Economics, University of Minnesota

Fargione J, R Dybzinski, C Clark, J Hill Ris Lambers, S Harpole, D Tilman, and M Loreau. 2003. Species effects and temporal trends in a long-term biodiversity experiment. Cedar Creek Science Seminar Series, Department of Ecology, Evolution, and Behavior, University of Minnesota

POSTERS PRESENTED

Hill J, J Fargione, D Tilman, S Polasky, P Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Ecological Consequences of Biofuels*, *Ecological Society of America*, Washington, DC.

Fargione JE, and D Tilman. 2006. Plant traits and resource competition: Controls on prairie plant abundances. *Long Term Ecological Research network All-Scientists Meeting*, Estes Park, Colorado.

Suding K, S Collins, E Cleland, L Gough, C Clark, J Fargione, J Grace, K Gross, S Pennings. 2006. The influence of primary productivity, community structure, and the abiotic environment on diversity loss due to nitrogen fertilization. *Long Term Ecological Research network All-Scientists Meeting*, Estes Park, Colorado.

Dybzinski R, J Fargione, D Tilman. 2006. The fertility effect: resource supply increases across an experimental plant species diversity gradient. *Long Term Ecological Research network All-Scientists Meeting*, Estes Park, Colorado

Baez S, J Fargione, D Moore, S Collins, J Gosz. 2006. N deposition in the northern Chihuahuan Desert: Temporal trends and potential consequences. *Annual Sevilleta Symposium*, San Acacia, New Mexico.

Fargione J, S Collins, and W Pockman. 2005. A proposed experiment: Global change effects on grass-shrub interactions. *Global Change and Biodiversity Meeting*, Dourdan, France.

Fargione J, and D Tilman. 2003. Plant traits and resource competition: Controls on prairie plant abundances. *Long Term Ecological Research network All-Scientists Meeting*, Seattle, Washington.

Brown CS, GD Tilman, and J Fargione. 2000. The effect of plant species diversity and identity on success of invading plants. *Long Term Ecological Research network All-Scientists Meeting*, Snowbird Utah.

Fargione JE, and TR Huggins. 1997. Species coexistence and community structure in epiphytic orchids in a citrus orchard on the island of Dominica. *Ecological Society of America Annual Meeting*, Albuquerque, New Mexico.

COURSES TAUGHT

Introduction to Environmental Conservation (Fall 2006, enrollment 440)

TEACHING PUBLICATIONS

Fargione J, and D Tilman. 2004. How does plant species biodiversity affect ecosystem productivity? Teaching Issues and Experiments in Ecology, Vol. 2: Data Set #1. [Online] **http://tiee.ecoed.net/vol/v2/issues/data_sets/cedar_creek/abstract.html**

REVIEWS

Fargione, J. 2005. Book Review: Models in Ecosystem Science, CD Canham, JJ Cole, and WK Lauenroth editors. *Journal of Vegetation Science* 16: 143-144

EXPERT CONSULTATIONS

UK government Biofuels Research Scoping Study, 2009
Government Accounting Office, Lifecycle energy balances and greenhouse gas emissions of biofuels, 2008
Government Accounting Office, Environmental impacts of increased biofuels production in the U.S., 2008
Union of Concerned Scientists, Biofuels research program development study, 2008
McKnight, Biofuels program development study, 2008

ACADEMIC SERVICE

Aquatic Community Ecology Search Committee, Department of Forestry and Natural Resources, Purdue University 2006
Buell Award Judge, Ecological Society of American Annual Meeting, Montreal, Canada, 2005
College of Biological Sciences Consultative Committee, University of Minnesota 2002-2003
Friday Noon Seminar Committee, University of Minnesota 2000-2001
Co-President Ecology, Evolution and Behavior Graduate Student Association, University of Minnesota 1999-2000
Ecology, Evolution and Behavior Written Preliminary Examination Committee, University of Minnesota 1999-2000
College of Biological Sciences Consultative Committee, University of Minnesota 1998-1999

JOURNAL REVIEWS

Acta Oecologia; American Naturalist; Biological Conservation; Biological Invasions; Crop Science; Ecological Applications; Ecology; Ecology Letters; Environmental Modeling and Assessment; Functional Ecology; Global Change Biology; International Forestry Review; Journal of Ecology; Journal of Applied Ecology; Journal of Vegetation Science; Mountain Research; Natural Areas Journal; Oecologia; Oikos; Perspectives in Plant Ecology, Evolution, and Systematics; Plant Ecology; Proceedings of the National Academy of Sciences, Science

PROPOSAL REVIEWS

US National Science Foundation
Swiss National Science Foundation

DISSERTATION AND THESIS REVIEWS

Eva Vojtech, Dissertation, University of Zurich

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EMPLOYMENT HISTORY:

May 2003-present—Principal Agricultural Conservation Economics (ACE)

Clients (principal contact):

- Environmental Defense Fund, Center for Conservation Incentives (CCI) (Robert Bonnie), 2003-present
- German Marshall Fund/Princeton University (Timothy Searchinger), 2007-present
- Environmental Working Group, (Craig Cox), 2009
- World Wildlife Fund, Washington Office (Sarah Lynch), 2005, 2008
- American Enterprise Institute (Bruce Gardner/Dan Sumner), 2006-2007
- Clean Air Task Force (Jonathan Lewis), 2007-2008
- Cambridge University, Department of Land Economy (Ian Hodge) 2006-2007
- Cornell University, Applied Economics and Management (Andrew Novakovic) , 2006
- Organization for European Cooperation and Development
    - Policies and Environment Division (Kevin Parris), 2007
    - Food, Agriculture and Fisheries Directorate (Catherine Moreddu), 2004-2005
- Rivers Institute, Hanover College, Indiana (Dennis Wichelins) 2006
- Bren School of Environmental Science and Management (David Stoms) 2005-2008

April 1999-May 2003—Deputy Director for Staff Analysis
Resource Economics Division, Economic Research Service, U.S. Department of Agriculture

September 1992-April 1999—Geographic Information System Coordinator
Resource Economics Division, ERS, USDA

December 1991-September 1992—Economist
Agriculture Policy Branch, Office of Policy and Planning Evaluation
Environmental Protection Agency

June 1990-December 1991—Section Leader
Land Use and Capital Investment Section, Resources and Technology Division, ERS, USDA

October 1983-June 1990—Agricultural Economist
Land Use Section, Resources and Technology Division, ERS, USDA

December 1977-October 1983—Economist/Resource Planner
Northeast Resources Group, River Basin Planning Branch, Natural Resource Economics Div., ERS, USDA

March 1974-September 1976—Research Assistant, Gladstone Associates, Newport, Rhode Island
December 1970-December 1973—Supply Officer, U.S. Navy, Newport, Rhode Island

EDUCATION:

MA Regional Science, University of Pennsylvania 1977
MCP City Planning, University of Pennsylvania 1977
BA Economics, Stanford University 1970

AWARDS AND HONORS:

American Agricultural Economics Association, 2000 Distinguished Policy Contribution
USDA Economists Group, 2001 Fred Woods Public Policy Award
National Partnership for Reinventing Government, 1999 Hammer Award, Conservation Reserve Enhancement Team
Soil and Water Conservation Society

- 2000 Honor Award
- 1995 Outstanding Reviewer, Journal of Soil and Water Conservation
- 1992 Berg Fellow, Soil and Water Conservation Society

USDA Awards (citations in parentheses)

- 2003 Group Honor Award for Excellence, Farm Bill Analysis Team (For developing a comprehensive, widely used, and highly acclaimed web-based synthesis and analysis of the 2002 Farm Bill, anchoring the United States Departments of Agriculture's coverage within 9 days of the bill's passage)
- 1997 Group Honor Award for Excellence, Conservation Reserve Program Team (Exemplary teamwork in deveoping and implementing a new nationwide policy creating a more environmentally sensitive and cost effective Conservation Reserve Program)
- 1991 Superior Service Award (Anticipatory research that contributes to economic understanding of the environmental and natural resource dimensions of farm policy)

COMMITTEE AND SERVICE ACTIVITY:

- RED *Amber Waves* Editor, 2001-2003
- RED Economics Editor for Web2000, 2000-2003
- RED representative on ERS\Purdue\Tennessee\NRCS New Generation of Farm Policy working group, 1999-2002
- ERS representative, USDA Conservation Reserve Working Group, 1999-2003
- Member, Soil and Water Conservation Society Farm Bill Conference Committee, 1998-99
- ERS representative, White House Working Group on Wetlands, Vice-President Gore's Clean Water Action Plan, 1997-98
- Member, Committee on Precision Farming: Site-Specific Management Information Systems, and Research Opportunities, Board on Agricultural, National Research Council, 1996-97
- ERS representative, USDA Agricultural Geographic Data Committee, 1992-2002
- ERS representative, Chesapeake Bay Decision Support System, 1993-95
- Program Chairman, AAEA Learning Workshop on GIS as a Research Tool for Economists, 1995
- Member, Soil and Water Conservation Society Annual Meeting Program Committee, 1994
- Officer, Grazing Lands Forum, 1987-94
- Member, Great Plains Agricultural Council, CRP Future Task Force, 1992-94
- EPA-OPPE representative, Domestic Policy Council Interagency Technical Committee on Wetlands Categorization and Mitigation Banking, 1991-92

Ralph E. Heimlich, Publications (listed by category in reverse chronological order)

Journals

58. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change" *Science* 319(5867):1238 – 1240, 29 February 2008 with Timothy Searchinger, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, Tun-Hsiang Yu and supporting material at http://www.sciencemag.org/cgi/data/1151861/DC1/1.

57. "Nitrogen sources and Gulf hypoxia: potential for environmental credit trading" Ecological Economics 52 (2005) 159– 168 (Ribaudo, Heimlich, Peters)

56. "Politics and Indices in the Conservation Reserve Program" Ecological Indicators, Vol. 1, No. 1, 2001, pp. 11-20. (Ribaudo, Hoag, Smith and Heimlich)

55. "Economic Analysis as a Basis for Large-Scale Nitrogen Control Decisions: Reducing Nitrogen Loads to the Gulf of Mexico" The Scientific World, Vol. 1, No. 2, 2001, pp. 968-975. (Doering, Ribaudo, Diaz-Hermelo, Heimlich, Hitzhusen, Howard, Kazmierczak, Lee, Libby, Milon, Peters, and Prato)

54. "Least-cost management of nonpoint source pollution: source reduction versus interception strategies for controlling nitrogen loss in the Mississippi Basin" Ecological Economics, Vol. 37, 2001, pp. 183-197.(Ribaudo, Heimlich, Claassen, and Peters).

53. "Development At and Beyond the Urban Fringe: Impacts on Agriculture" Agricultural Outlook AGO-283, August 2001. (Heimlich and Anderson).

52. "Genetically Engineered Crops: Has Adoption Reduced Pesticide Use?" Agricultural Outlook AO-273, August 2000. (Heimlich, Fernandez-Cornejo, McBride, Klotz-Ingram, Jans, and Brooks).

51. "Conservation Choices for a New Millenium" Choices 4th Quarter, 1999, pp. 43-46 (with Claassen).

50. "Estimating the Effects of Relaxing Agricultural Land Use Restrictions: Wetland Delineation in the Swampbuster Program" Review of Agricultural Economics, Vol. 20, No. 2, Fall/Winter 1998, pp. 390-405. (Claassen, Heimlich, House, and Wiebe)

49. "Agriculture and 'No Net Loss' of Wetlands" Choices 4th Quarter, 1998 (centerfold) (Heimlich, Wiebe, Claassen, Gadsby, and House)

48. "Paying for Wetlands: Benefits, Bribes, and Taxes" National Wetlands Newsletter, Vol. 20, No. 6, November-December 1998, pp. 1-15. (Heimlich and Claassen)

47. "Agriculture and Wetlands: Is 'No Net Loss' Achievable?" Agricultural Outlook AO-252, June-July 1998.

46. "Precision Agriculture: Information Technology for Improved Resource Use" Agricultural Outlook AO-250, April 1998.

45. "Agricultural Conservaton Policy at a Crossroads." Agricultural and Resource Economics Review Vol. 27, No. 1, April 1998, pp. 95-107. (Heimlich and Claassen).

44. "Estimating Cost Savings to Agriculture from Publicly Available Differential Global Positioning Systems." Modern Agriculture. Vol. 1, No. 4, October-November 1997, pp. 28-9, (Daberkow, Heimlich, and Breneman).

43. "Recent Evolution of Environmental Policy: Lessons From Wetlands," Journal of Soil and Water Conservation, Vol. 52, No. 3, May-Jun. 1997, pp157-161.(Heimlich, Wiebe, Claassen, and House).

42. "Sustaining Our Wetlands Gains," National Wetlands Newsletter, Vol. 19, No. 4, Jun.-Jul. 1997, pp 5-9. (Heimlich, Wiebe, and Claassen).

41. "Wetlands potentially exempted and converted under proposed delineation changes." Journal of Soil and Water Conservation. Vol. 51, No. 5, September-October, 1996, pp. 403-7, (Wiebe, Heimlich, and Claassen).

40. "Wetland Losses/Wetland Gains: Where is the Nation Headed?" National Wetlands Newsletter, Vol. 17, No.3May/June 1995, pp.1-25. (Heimlich and Melanson).

39. "The Evolution of Federal Wetlands Policy" Choices First Quarter, 1995. (Heimlich and Wiebe)

38. "Green Payments as a Policy Option" Agricultural Outlook AO-219 June 1995.

37. "Simulating Cost-Effective Wetlands Reserves: A Comparison of Positive and Normative Approaches" Natural Resources Modeling Vol. 9, No.1 Winter 1995, pp.81-96. (Parks, Kramer and Heimlich).

36. "Post-Flood Expansion of WRP" Agricultural Outlook. AO-211 September 1994. (Heimlich and Gadsby)

35. "Changes Ahead for Conservation Reserve Program" Agricultural Outlook. AO-209 July 1994. (Osborn and Heimlich)

34. "Changes in Land Quality Accompanying Urbanization in U.S. Fast-Growth Counties" Journal of Soil and Water Conservation. Vol. 49, No. 4, May 1994, pp. 367-374. (Heimlich and Krupa).

33. "Costs of an Agricultural Wetland Reserve" Land Economics. Vol. 70, No. 2. May 1994, pp. 234-46.

32. "Wetlands Policies in the Clean Water Act" Water Resources Update. special issue: The Clean Water Act Revisited. No. 94, Winter 1994, pp. 52-60.

31. "U.S. Conservation Policy--What's Ahead?" Agricultural Outlook. AO-202. November 1993. (Osborn, Anderson, Heimlich and Ribaudo).

30. "The Conservation Reserve Program: What Happens When Contracts Expire?" Choices. Third Quarter. 1993, pp. 9-14. (Heimlich and Osborn).

29. "Strategies for Wetlands Protection and Restoration." Agricultural Outlook AO-200. September 1993. (Heimlich and Gadsby).

28. "Farmland Loss to Urban Encroachment No Threat to U.S. Agriculture." Rural Development Perspectives. Vol. 8, No. 1, September 1992, pp. 2-7.(Heimlich and Vesterby).

27. "Agricultural Adaptation to Urbanization: Farm Types in Northeast Metropolitan Areas." Northeastern Journal of Agricultural and Resource Economics. Vol. 21, No.1, April 1992 (Heimlich and Barnard).

26. "New Wetland Definition Debated." Agricultural Outlook AO-180. November 1991.

25. "Land Use and Demographic Change: Results from Fast Growth Counties." Land Economics. Vol. 67, No. 3. August 1991, pp. 279-91. (Heimlich and Vesterby).

24. "Agriculture Adapts to Urbanization." Food Review. Vol. 14, No. 1, Jan.-Mar. 1991, pp. 21-25.

23. "Wetlands and Agriculture: Defining a New Relationship." Forum for Applied Research and Public Policy. Vol. 6, No. 1, Winter 1990, pp. 78-83.

22. "A Wetland Reserve: What Cost?" Agricultural Outlook AO-166. August 1990.

21. "Grazing Lands: The Future of CRP Land After Contracts Expire." Journal of Production Agriculture. Vol. 3, No. 1, January 1990, pp. 7-12. (Heimlich and Kula)

20. "Grazing Lands: How Much CRP Land Will Remain in Grass?" Rangelands. Vol. 11, No. 6, December 1989, pp. 253-257. (Heimlich and Kula).

19. "Beyond Swampbuster: A Permanent Wetland Reserve." Journal of Soil and Water Conservation. Vol. 4, No. 5, September-October 1989, pp. 445-450 (Heimlich, Carey, and Brazee)

18. "Productivity of Highly Erodible Cropland." Journal of Agricultural Economics Research. Vol. 41, No. 3, Summer 1989, pp. 17-22.

17. "Metropolitan Agriculture: Farming in the City's Shadow." Journal of the American Planning Association. Vol. 55, No. 4, Autumn 1989, pp. 457-66.

16. "Economic and Physical Marginality of Highly Erodible Cropland." special article in Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report. AR-12. Economic Research Service, USDA, September 1988.

15. "Metropolitan Growth and High-Value Crop Production." special article in Vegetables and Specialties Situation and Outlook Report. TVS-244. Economic Research Service, USDA, February 1988.

14. "Rivers of Empire: Water, Aridity, and the Growth of the American West: Book Review." Agricultural Economics Research. Vol. 38, No. 4,Fall 1986, pp.31-33.

13. "Swampbusting in Perspective." Journal of Soil and Water Conservation. Vol. 41, No. 4,July-August 1986, pp. 219-24. (Heimlich and Langner).

12. "Economics of Wetland Conversion: Farm Programs and Income Tax." National Wetlands Newsletter. Vol. 8, No. 4, July-August 1986, pp.7-10.

11. "Agricultural Programs and Cropland Conversion, 1975-1981." Land Economics. Vol. 62, No. 2., May 1986, pp.174-81.

10. "Soil Erosion on New Cropland: A Sodbusting Perspective." Journal of Soil and Water Conservation. Vol. 40, No. 4, July-August 1985,pp.322-26.

9. "Landownership and the Adoption of Minimum Tillage: Comment." American Journal of Agricultural Economics. Vol. 67, No. 3, August 1985, pp. 679-81.

8. "An Improved Soil Erosion Classification for Conservation Policy." Journal of Soil and Water Conservation. Vol. 39, No. 4, July-August 1984, pp.261-66 (Heimlich and Bills).

7. "Participation in a Central Anaerobic Digester and Cogeneration Facility: Economic and Environmental Analysis for Farm Decision Making." Journal of the Northeastern Agricultural Economics Council. Vol. 12, No. 1,, Fall 1983, pp.59-68.

6. "A Linear Programming Economic Analysis of Lake Quality Improvements Using Phosphorus Buffer Curves." Water Resources Research. Vol. 19, No. 1, February 1983, pp.21-31. (Ogg, Pionke, and Heimlich).

5. "Evaluation of Soil-Erosion and Pesticide-Exposure Control Strategies." Journal of Environmental Economics and Management. Vol. 9, 1982, pp.279-88, (Heimlich and Ogg).

4. "Economics and Environmental Effects of Manure Handling Systems for Northeastern Dairy Farms." Journal of the Northeastern Agricultural Economics Council. Vol. 11, No. 1, Spring 1982, pp. 45-56.

3. "Efficiently Reducing Nonpoint Phosphorus Loads to Lakes and Reservoirs," Water Resources Bulletin. Vol. 16, No. 6, December 1980, pp. 967-70, (Ogg, Heimlich, and Pionke).

2. "A Modeling Approach to Watershed Conservation Planning." Journal of Soil and Water Conservation. Vol. 35, No. 6, November-December 1980, pp. 271-73 (Ogg, Heimlich, and Hostetler).

1. "Implementation of New Conservation Programs and the Need to Respond to Changing Market Conditions." Southern Journal of Agricultural Economics. July 1980, pp. 173-77 (Ogg and Heimlich).

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Published Proceedings and Book Chapters

33. "Land Retirement for Conservation: History, Analysis, and Alternatives" in Gardner, B.L. and D.A. Sumner (eds.) *The 2007 Farm Bill and Beyond*, AEI Agricultural Policy Series, The AEI Press, American Enterprise Institute, Washington, DC. and Policy Summary, May, 2007.

32."A Case Study of Policy-related Transaction Costs in Land Conservation Programmes in the Unites States," in *The Implementation Costs of Agricultural Policies*, Organization for Economic Co-operation and Development, 2007. pp. 161-195.

31."Green Payments Now—What's Missing?" *Building the Scientific Basis for Green Payments*, Sarah Lynch and Sandra S. Batie (eds.), World Wildlife Fund, Washington, DC, April 2005. pp.12-14

30. "The U.S. Experience with Land Retirement for Natural Resource Conservation," and "Evaluating Bids in the U.S. Conservation Reserve Program," Xu Jintao and Ulrich Schmitt (Eds.) Workshop on Payment Schemes for Environmental Services: Proceedings, CCICED Task Force on Forests and Grasslands, Beijing, April 22 - 23, 2002, China Forestry Publishing House, pp. 12-15 and 36-38. (full text on CD-ROM)

29. "Farmland Protection Programs: How Would We Know They Worked?" Presented at Protecting Farmland at the Fringe: Do Regulations Work?, A National Conference, Baltimore, MD, September 5-7, 2001. 29 pp. Precis in Protecting Farmland at the Fringe: Do Regulations Work? Strengthenting the Research Agenda, NERCRD Regional Rural Development Paper No. 7, Northeast Regional Center for Rural Development, Pennsylvania State University, December 2001.

28. "Implementation of Conservation Compliance Provisions: Experience in the U.S. with Highly Erodible Land and Wetland Conservation." In Baldock, D. (editor) Meeting Environmental Standards Under Agenda 2000. Proceedings of an international workshop, Madrid, Spain, October 3-7, 2000. Institute for European Environmental Policy and World Wildlife Fund. 25 pp. PowerPoint presentation

27. "Adoption of genetically engineered seed in U.S. agriculture: Implications for pesticide use." In Fairbairn, C., Scoles, G., and McHughen, A. (eds.) Proceedings of the 6th International Symposium on theBiosafety of Genetically Modified Organisms. July 2000, Saskatoon, Canada, pp. 56-63. (Heimlich, Fernandez-Cornejo, McBride, Klotz-Ingram, Jans, and Brooks)

26. "Measuring the Economic Consequences of Hypoxia and Its Mitigation: Gulf Fisheries and Nutrient Reduction Strategies" in Nancy N. Rabalais and R. Eugene Turner (eds.), The Effects of Hypoxia on Living Resources, with Emphasis on the Northern Gulf of Mexico, American Geophysical Union (Doering, Heimlich, Kazmierczak, Jr., Peters, Ribaudo, and Solow). 25 pp. (forthcoming)

25. "Agriculture Sector Resource and Environmental Policy Analysis: An Economic and Biophysical Approach" in Environmental Statistics: Analyzing Data for Environmental Policy, Novartis Foundation, London, 1998. (House, McDowell, Peters and Heimlich)

24. Chapters 3 and 4, Adoption Impacts and Policy Implications, Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management, report of the National Research Council committee on Assessing Crop Yield, Site-Specific Farming, Information Systems, and Research Opportunities, 1997.

23. "Agricultural Adaptation to Urbanization: Farm Types and Agricultural Sustainability in U.S. Metropolitan Areas" Chapter 14 in Ivonne Audirac (ed.) Rural Sustainable Development in America, John Wiley & Sons, New York, NY, 1997, pp. 283-304. (Heimlich and Barnard)

22. "Environmental Indicators for U.S. Agriculture" in S.Batie (ed.) Developing Indicators for Environmental Sustainability: The Nuts and Bolts, SR-89, Michigan State University, 1996, pp. 99-116.

21. "Targeting Green Support Payments: The Geographic Interface between Agriculture and the Environment" in Sarah Lynch (ed.) Designing Green Support Programs Policy Studies Program Report No. 4, Henry A. Wallace Institute for Alternative Agriculture, December 1994, pp. 11-54.

20. "Wetlands and Riparian Areas: Economics and Policy." in Encyclopedia of Agricultural Science, Volume 4. Academic Press. 1994, pp. 497-514.

19. "Buying More Environmental Protection with Limited Dollars." in When Conservation Reserve Program Contracts Expire: The Policy Options. Soil and Water Conservation Society. March, 1994, pp. 83-97. (Heimlich and Osborn)

18. "Using an Environmental Benefits Index in the Conservation Reserve Program." in Post Conservation Reserve Program Land Use conference proceedings, NCT-163 Post CRP Land Use Alternatives Project, Denver, CO, January 10-11, 1994, pp. 118-33. (Barbarika, Osborn, and Heimlich)

17. "After the Conservation Reserve Program: Macroeconomics and Post-Contract Program Design." in Proceedings of the Great Plains Agricultural Council. June, 1993, pp. 113-33. (Heimlich and Osborn)

16. "Integrating Land-Related Program, Survey, and Inventory Data." in Gene Wunderlich (ed.) Land Ownership and Taxation in American Agriculture. Westview Press, Boulder, CO, 1993, pp. 237-44.

15. "Environmental Set-Aside and Cross-Compliance Programmes: Preliminary Lessons From U.S. Experience." in The Implementation of Agri-Environmental Policies in the EC, proceedings of a workshop for the Commission of the European Communities and the Institute for European Environmental Policy. November 1991. (Ervin, Osborn, and Heimlich)

14. "Agricultural Adaptation to Urbanization: Farm Types in U.S. Metropolitan Areas." in Rural Planning and Development: Visions of the 21st Century, Volume 2, proceedings of a conference sponsored by the University of Florida and the American Planning Association. February, 1991. (Heimlich and Barnard)

13. "Soil Erosion and Conservation Policies in the United States" in Nick Hanley (ed.) Farming and the Countryside: An Economic Analysis of External Benefits and External Costs CAB International, London, 1991, pp. 59-90.

12. "Economics of Wetland Preservation: The Agricultural Connection." in R.R. Sharitz and J.W. Gibbons (eds.) Freshwater Wetlands and Wildlife DOE Symposium Series No. 61, USDOE, Oak Ridge, TN, 1989, pp. 877-88. (Langner and Heimlich)

11. Land Use Transition in Urbanizing Areas: Research and Information Needs, proceedings of an ERS/Farm Foundation workshop, Washington, DC, June 6-7, 1988, 217 pages. (editor)

10. "The Swampbuster Provision: An A Priori Evaluation of Effectiveness." in D. Fisk (ed.) Wetlands: Concerns and Successes. American Water Resources Association symposium September 1989, pp. 509-21.

9. "Conversion of Wetlands to Urban Uses: Evidence from Southeastern Counties." in D. Fisk (ed.) Wetlands: Concerns and Successes. American Water Resources Association symposium September 1989, pp. 161-73. (Heimlich and Vesterby)

8. "Changes in Wetlands Due to Urbanization: A Regional Perspective." in E.J. Luzar and S.A. Henning (eds.) Alternative Perspectives on Wetland Evaluation and Use. SNREC Publ. No. 27. Southern Rural Development Center and the Farm Foundation. December 1989.

7. "Land Use Change in Fast Growth Areas: ERS's Role in Urbanization Research." in Land Use Transition in Urbanizing Areas: Research and Information Needs, proceedings of an ERS/Farm Foundation workshop, Washington, DC, June 6-7, 1988, pp. 73-89. (Heimlich and Reining)

6. "The Swampbuster Provision: Implementation and Impact." in Proceedings of the National Symposium on Protection of Wetlands from Agricultural Impacts. Biological Report 88(16). U.S. Dept. of Interior, Fish and Wildlife Service, Ft. Collins, CO. Apr. 1988. pp. 87-94.

5. "Urban/Agricultural Land Use Trend Analyses." in P. Parks (ed.) Land Area Modeling and Its Use in Policy: A Workshop on Current Research. Proceedings of a symposium, School of Forestry and Environmental Studies, Duke University, Durham, NC, April 22, 1988. pp. 6-7.

4. "Dynamics of Land Use Change in Urbanizing Areas: Experience in the Economic Research Service, USDA." in W. Lockeretz (ed.) Sustaining Agriculture Near Cities. Soil and Water Conservation Society. 1987, pp. 135-54. (Heimlich and Anderson)

3. "An Improved Soil Erosion Classification Scheme: Update, Comparison, Extension." Invited paper presented to Convocation on Physical Dimensions of the Erosion Problem, National Research Council Board on Agriculture, Washington, D.C., December 6-7, 1984. Published in Soil Conservation: Assessing the National Resources Inventory. Volume 2, National Academy Press, Washington, D.C., 1986, pp. 1-17. (Heimlich and Bills)

2. "Modeling Dairy Farm Operator Response to Nonpoint Source Control Regulations." Selected paper presented to Nonpoint Pollution Control Tools and Techniques for the Future, a symposium sponsored by the Interstate Commission on the Potomac River, Gettysburg, PA, June 11-13, 1980. (Heimlich and Stachowski)

1. "Agricultural Runoff in Selected Vermont Watersheds: Economic Modeling." Selected paper presented to Natural Resources--How Can We Conserve Them?, 7th Annual Lake Champlain Basin Environmental Conference, Chazy, NY, June 10-11, 1980. (Heimlich and Stachowski)

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ERS and USDA Series

31. Agricultural Resources and Environmental Indicators, 2003, AH-722, December 2002, 227 pp. (Heimlich and William Anderson, editors).

30. Development at the Urban Fringe and Beyond: Impacts on Agriculture and Rural Land, AER-803, June 2001. 80 pp. (Heimlich and William D. Anderson).

29. Maintaining Farm and Forest Lands in Rapidly Growing Areas. Report to the Secretary of Agriculture, From the USDA Policy Advisory Committee on Farm and Forest Land Protection and Land Use. January 2001. 73 pp.

28. 6.5 Wetlands Programs. Agricultural Resources and Environmental Indicators, 2000. September 2000. 27 pp.

27. 6.1 Conservation and Environmental Programs Overview. Agricultural Resources and Environmental Indicators, 2000. September 2000. 28 pp.

26. Farm Resource Regions, AIB-760, July 1999.

25. Agricultural Impacts are Severe Locally, but Limited Nationally, AIB-755, September 1999 (Morehart, Gollehon, Dismukes, Heimlich, and Brenemen).

24. Wetlands and Agriculture: Private Interests and Public Benefits, AER-765, August 1998 (Heimlich, Wiebe, Claassen, Gadsby, and House)

23. Wetlands Reserve Programs. AREI Update no. 6, November 1997 (Gadsby, Wiebe, and Heimlich)

22. "Wetlands Programs." Module 6.5,in Anderson , M. and Magleby, R. (eds.) Agricultural Resources and Environmental Indicators, AHB-712, July 1997 (Heimlich, Claassen, Wiebe, and Gadsby)

21. Major Land Use Changes in the Contiguous 48 States, AREI Update no. 3, June 1997 (Vesterby, Daugherty, Heimlich, and Claassen)

20. "Wetlands: Data from the NRI." in Lee, L. (ed.) 1992 National Resources Inventory Environmental and Resource Assessment Symposium Proceedings. NRCS, USDA, September 1995

19. Economics of Agricultural Management Measures in the Coastal Zone, AER-689, February 1995 (Heimlich and Barnard)

18. "Wetlands Programs." Module 6.4,in Anderson , M. and Magleby, R. (eds.) Agricultural Resources and Environmental Indicators, AHB-705, December 1994 (Heimlich,Gadsby and Wiebe)

17. Urbanization of Rural Land in the United States, AER-673, March 1994 (Vesterby, Heimlich, and Krupa)

16. Expiration of Conservation Reserve Program Contracts, AIB-664-2, April 1993 (Osborn and Heimlich)

15. Urbanizing Farmland: Dynamics of Land Use Change in Fast-Growth Counties, AIB-629, September 1991 (Heimlich, Vesterby and Krupa)

14. A National Policy of 'No Net Loss' of Wetlands: What Do Agricultural Economists Have to Contribute?, Staff Report No. AGES9149, August 1991 (editor).

13. Conservation and Environmental Issues in Agriculture: An Economic Evaluation of Policy Options, Staff Report No. AGES9134, July 1991, (Ervin, Algozin, Carey, Doering, Frerichs, Heimlich, Hrubovcak, Konyar, McCormick, Osborn, Ribaudo, Shoemaker)

12. "Economics of Livestock and Crop Production on Post-CRP Lands." in Joyce, L., Mitchell, J. and Skold, M. (eds.) The Conservation Reserve--Yesterday, Today and Tomorrow. General Tech. Rpt. RM-203, Rocky Mountain Forest and Range Exp. Sta., May 1991. (Heimlich and Kula)

11. A Permanent Wetland Reserve: Analysis of a New Approach to Wetland Protection, AIB-610, August 1990 (Carey, Heimlich, and Brazee)

10. Metropolitan Growth and Agriculture: Farming in the City's Shadow, AER-619, September 1989 (Heimlich and Brooks)

9. Productivity and Erodibility of U.S. Cropland, AER-604, January 1989

8. The Land Improvement Tax Simulator (LITS): An Analytical Tool, ERS Staff Report AGES860919, October 1986 (Heimlich and Daugherty)

7. An Economic Analysis of USDA Erosion Control Programs: A New Perspective, AER-560, August 1986 (Strohbehn, Anderson, Barbarika, Colacicco, Heimlich, Lee, Osteen, Pavelis, Ribaudo, Schaller, Taylor, and Young)

6. Swampbusting: Wetland Conversion and Farm Programs, AER-551, August 1986. (Heimlich and Langner)

5. Sodbusting: Land Use Change and Farm Programs, AER-536, June 1985

4. Characteristics of Landowners Converting Land in the Western Great Plains, 1975-77, ERS Staff Report AGES850409, May 1985

3. Erodible Soils: Definition and Classification, Soil Conservation Service A and P Staff Report 85-2, March 1985 (McCormack and Heimlich)

2. Assessing Erosion on U.S. Cropland: Land Management and Physical Features, AER-513, July 1984 (Bills and Heimlich)

1. Economics of Water Quality in Agriculture-- A Literature Review, ESCS-58, July 1979 (Christiansen, Ogg, and Heimlich)

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Presented Papers

55. "Estimating Greenhouse Gas Emissions from Soy-Based U.S. Biodiesel When Factoring in Emissions from Land Use Change," paper prepared for workshop on the lifecycle carbon footprint of biofuels organized by the Farm Foundation and the U.S. Department of Agriculture, Jan. 29, 2008 (with Tim Searchinger)

54. "Agri-environmental Indicators and Policy Inventory Linkages: Integrating agri-environmental indicators and the OECD policy inventory," at OECD Workshop on Indicators for Developing, Monitoring and Analysing Agri-Enviromental Policies, Washington, DC, March 19-21, 2007.

53. "Local and National Priorities for Water Quality Goals:
Reconciling Watersheds and Estuaries" at Innovations in Reducing Nonpoint Source Pollution Conference, Indianapolis, Indiana, The Rivers Institute at Hanover College November 28-30, 2006.

52. "A Green 2007 Farm Bill: Paying farmers for water quality improvements as an alternative to traditional commodity programs" at Innovations in Reducing Nonpoint Source Pollution Conference, Indianapolis, Indiana, The Rivers Institute at Hanover College November 28-30, 2006.

51. "A Green 2007 Farm Bill: Paying Farmers for environmental improvement as an alternative to traditional commodity programs" at On The Dairy Horizon: Reflections about Trade, Environment and the Safety Net, 13th Annual Workshop for Dairy Economists and Policy Analysts organized by the Extension Education Committee of the Cornell Program on Dairy Markets and Policy and National Institute of Livestock and Dairy Policy, San Antonio, TX, March, 23-24, 2006.

50. "Green Payments Now—What's Missing?", Building the Scientific Basis for Green Payments, World Wildlife Fund and Michigan State University, Washington, DC, April 14-15, 2005.

49. "The Policy-Related Transactions Costs of Land Conservation in the United States: Evolution and Comparison Between Programs" OECD Workshop on Policy-Related Transaction Costs, Paris, 20-21 January 2005.

48. "Improving NRCS EQIP Allocation and Ranking: More Bang for the Buck", Soil and Water Conservation Society Meetings, St. Paul, MN, July 24-28, 2004.

47. "Is NRCS "EQIPed" to Get the Most from EQIP? State Allocation and Ranking Procedures", *Is NRCS EQIPped to Get the Most from EQIP? Analysis of State Allocation and Ranking Procedures*, organized symposium, Soil and Water Conservation Society Meetings, St. Paul, MN, July 24-28, 2004.

46. "The U.S. Experience with Land Retirement for Natural Resource Conservation" Workshop on Payment Schemes for Environmental Services, Western China CCICED Forest Grasslands Task Force and Chinese Center for Agricultural Policy, Beijing, PRC, April 22-23, 2002.

45. "Farmland Protection and Smart Growth: Saving Urban Influenced Farmland" Northeast/Midwest Institute Briefing, Senate Smart Growth Task Force and the Liveable Communities Task Force, Washington, DC, July 30, 2001.

44. "A Green Payments Analysis" New Generation of Farm Policy Meeting, Purdue University, West Lafayette, IN, March 1, 2001.

43. "Establishing Effective Incentives in Practice: The Role of Valuation and Influence of Other Factors" OECD/ERS Rural Amenities Workshop, Washington, DC, June 5-6, 2000. 47 pp.

42. "Wetlands and Agriculture: Restoration, Conservation and the Future of "No Net Loss", The State of North America's Private Land, Farm Bill Conservation Conference, Soil and Water Conservation Society, Chicago, IL, Jan. 19-21, 1999.

41. "Wetlands and Agriculture: Restoration, Conservation and No Net Loss", Resources for the Future, October 28, 1998 (Claassen and Heimlich)

40. "Agricultural Soil Quality" OECD Workshop on Agri-Environmental Indicators, COM/AGR/CA/ENV/EPOC(98)77, York, United Kingdom, September 22-25, 1998, 39 pp. (Arnold, Bomans, and Heimlich)

39. "On Using Agri-Environmental Indicators to Assess Environmental Performance" OECD Workshop on Agri-Environmental Indicators, York, United Kingdom, September 22-25, 1998

38. "Nitrogen Sources and Gulf Hypoxia: Potential for Point-Nonpoint Trading," American Agricultural Economics Association Meeting, Salt Lake City, Utah, Aug. 2-5, 1998, 19 pp. (Ribaudo, Heimlich and Peters)

37. "Public Policy Regarding Precision Agriculture" in Precision Agriculture in the 21st Century: The Report of the National Research Council, AAEA Annual Meeting, Salt Lake City, UT, August 2-5, 1998.

36. "Economic Forces Affecting United States Agriculture and Natural Resources," EPA-LGU-NASA-USDA Summit, SAES/USDA-CSREES National Environmental Initiative (SUNEI), Towson, MD, June 3, 1998.

35. "Wetland Valuation: Lessons from the Literature," OMB/CEA Steven's Amendment Seminar, Washington, D.C., May 4, 1998, 25 pp.

34. "Wetland Conversion for Agriculture After the FAIR Act," American Agricultural Economics Association Meeting, Toronto, Ontario, Jul. 27-30, 1997, 21 pp. (Claassen, Heimlich, and House)

33. "Soil and Landscape Limitations on the Supply of Land in Urbanizing Areas," American Agricultural Economics Association Meeting, Toronto, Ontario, Jul. 27-30, 1997, 16 pp. (Heimlich and Bills)

32. "Consequences of Exempting Wetlands from Swampbuster and Section 404" in "Wetland Futures: Can We Sustain 'No Net Loss'?", interactive session, Soil and Water Conservation Society Meeting, Toronto, Ontario, Jul. 22-25, 1997, 7 pp.

31. "A National Analysis of Changes in Watershed Factors Potentially Affecting Wetland Quality," Soil and Water Conservation Society Meeting, Toronto, Ontario, Jul. 22-25, 1997, 17 pp.

30. "Hypoxia in the Gulf of Mexico: Comparison of Sources of Nitrogen in the Mississippi Basin," Soil and Water Conservation Society Meeting, Toronto, Ontario, Jul. 22-25, 1997, 20 pp. (Ribaudo and Heimlich)

29. "Using GIS to Analyze the Economics of Swampbuster Exemptions" at Wetlands '96, Association of State Wetland Managers, Wetland, Floodplain, and River On-Line Services and GIS Applications, Arlington, July 9-12, 1996 (Claassen and Heimlich)

28. "Strategies for a More Sustainable Agriculture: Precision Farming", NRED Sustainability Workshop, Washington, D.C., Oct. 21-22, 1996. 35 pp.

27. "Background on Wetlands Issues" Agriculture and the Environment: Issues and Options for the 1995 Farm Bill, organized by the Soil and Water Conservation Society, Washington, DC, March 9-10, 1995

26. "Data Analysis with GIS" AAEA Learning Workshop on GIS as a Research Tool for Economists, Indianapolis, August 1995.

25. "Applying GIS to Resource Economics" 5th Annual National Capital Area ARC/INFO Users Group Conference, Baltimore, December 1995. (Heimlich and Breneman)

24. "Environmental Indicators for U.S. Agriculture" at Developing Indicators for Environmental Sustainability: The Nuts and Bolts, Resource Policy Consortium, Washington, DC, June 12-13, 1995.

23. "Developing a Geographic Information System For Resource Economic Analyses." selected paper, Soil and Water Conservation Society meetings, Norfolk, VA. August 4-7, 1994.

22. "Wetlands: Data from the NRI." 1992 National Resources Inventory Environmental and Resource Assessment Symposium. Washington, DC. July 19, 1994.

21. "Wetlands Policies in the Clean Water Act." National Symposium on New Directions in Clean Water Policy. University Council on Water Resources. Charlottesville, VA. July 28-30, 1992.

20. "Policy Directions for the Clean Water Act Reauthorization: Markets, Mandates, Planning and Science." National Symposium on New Directions in Clean Water Policy. University Council on Water Resources. Charlottesville, VA. July 28-30, 1992. (Painter and Heimlich).

19. "National Economic Perspective on Wetlands." Living with Wetlands: Policy and Politics, Nebraska Water Conference. Lincoln, NE. March 15-17, 1992.

18. "Costs and Benefits of an Agricultural Wetland Reserve: A Normative Approach." Association of American Geographers 88th Annual Meeting. San Diego, CA. April 18-22, 1992.

17. "Integrating Land-Related Program, Survey, and Inventory Data." Land Ownership and Taxation Seminar. Washington, DC. October 3-4, 1991.

16. "Wetlands and Agriculture: Recent Federal Policy and Emerging Issues." Southern Extension Public Affairs Committee, Clearwater, Florida. June 25, 1991.

15. "Agricultural Adaptation to Urbanization: Farm Types in U.S. Metropolitan Areas." special symposium on sustaining agriculture near cities. Sponsored by WRCC-71, Western Regional Science Association meetings, Monterey, California. February 25-28, 1991.

14. "Agricultural Adaptation to Urbanization: Farm Types in Northeastern Metro Areas." selected paper. Northeastern Ag. and Resource Econ. meetings, Truro, Nova Scotia. June 18-20, 1990.

13. "A National Policy of 'No Net Loss' of Wetlands: What do Agricultural Economists Have to Contribute?" org. symposium. AAEA meetings, Vancouver, BC. Aug. 1990.

12. "An Agricultural Wetland Reserve: Creating Wetlands from Drained Cropland." Selected paper presented to American Agricultural Economics Association summer meeting, Baton Rouge, LA, July 30-August 2, 1989.

11. "Grazing Lands and the Conservation Reserve Program." Invited paper presented at the 1989 Forage and Grasslands Conference, Guelph, Ontario. May 1989. (Heimlich and Vough)

10. "Adapting Agricultural Land Use to the New Settlement Pattern." Selected paper presented at the Population Association of America annual meetings, Baltimore, MD, March 30-31, 1989.

9. "Land Use and Demographic Change: Results from Fast Growth Counties." Selected paper presented at the Population Association of America annual meetings, Baltimore, MD, March 30-31, 1989. (Vesterby and Heimlich)

8. "Economic and Physical Marginality of Highly Erodible Cropland." Selected paper presented to American Agricultural Economics Association summer meeting, Knoxville, TN, July 31-August 3, 1988.

7. "Metropolitan Agriculture in the Northeast: New Settlement Patterns and Agricultural Adaptation." Selected paper presented to Northeastern Agricultural and Resource Economics Association meeting, Kingston, RI, June 22-24, 1987.

6. "Reducing Erosion and Agricultural Capacity: Our Cropland Base and the Conservation Reserve." Selected paper presented to American Agricultural Economics Association summer meeting, Reno, NV, July 28-August 2, 1986.

5. "Relationships Between Erosion Control Benefits and Land Use Change in Upstate New York." Poster paper presented to the National Symposium on Erosion and Soil Productivity, New Orleans, LA, December 10-11, 1984. Indexed as P84-ER16 by American Society of Agricultural Engineers. (Heimlich and Bills)

4. "Geographic Information Systems in Policy Research: Examples From an Evolving System." Selected paper presented to Soil Conservation Society of America Annual Meeting, Hartford, CT, July 31-August 3, 1983. (Ogg, Heimlich, and Bills)

3. "Economics of Size in Dairy Farm Adjustment to Water Quality Constraints." Selected paper presented to American Agricultural Economics Association summer meeting, Logan, UT, August 1-4, 1982.

2. "Local Impacts of Soil Conservation Strategies for a Large River Basin in the Southeast." Contributed paper presented to Southern Agricultural Economics Association meeting, New Orleans, LA, February 5-7, 1979. (Ogg , Heimlich and Hostetler).

1. "An Analysis of Land Clearing on Eastern North Carolina Wetlands." Contributed paper presented to Southern Agricultural Economics Association meetings, New Orleans, LA, February 5-7, 1979. (Heimlich, Ogg and Hostetler).

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Other Publications and Reports

27. Environmental Quality Incentives Program (EQIP) Program Assessment, A Report from the Soil and Water Conservaiton Society and Environmental Defense. March 2007, 30 pp.

26. Conservation Security Program (CSP) Program Assessment, A Report from the Soil and Water Conservaiton Society and Environmental Defense. February 2007, 34 pp.

25. Background Materials and Ideas for Farm Policy Reform Center for Agriculture in the Environment, American Farmland Trust, DeKalb, Illinois August 17, 2005

24. "Good Conservation Programs Are Specific to the Landowner's Situation", Conservation Incentives, Environmental Defense, Center for Conservation Incentives, pp. 7-8, Fall 2005

23. Getting a Bigger Bang for the Buck: Assessment of EQIP 2003 allocation and ranking systems and ideas for further improvements, Environmental Defense, Center for Conservation Incentives, Washington, DC, February 2004, 56 pp. (Friedman and Heimlich)

22. "U.S. Experiences with Incentive Measures to Promote the Conservation of Wetlands" ENV/EPOC/GEEI/BIO(97)9, Environment Directory, Environment Policy Committee, Organization for Economic Co-operation and Development, May 1999, 40 pp., (Wiebe, Claassen, and Gadsby).

21. "Evaluation of Economic Costs and Benefits of Methods for Reducing Nutrient Loads to the Gulf of Mexico," Chapter 6, Report to the Committee on Environment and Natural Resources, Office of Science and Technology Policy, November 1998, 173 pp. (Draft) (Doering, Diaz-Hermelo, Howard, Heimlich, Hitzhuzen, Kasmierczak, Libby, Milon, Prato, and Ribaudo)

20. Who Gets What: Program Payments to U.S. Farmers. Internal paper for NRED Farm Bill Team, 1995 (Erickson, Heimlich, and Kascak)

19. "A Farm Model for Evaluating Nonpoint Source Pollution Abatement Programs." SP-94-03. Dept. of Ag and Applied Econ., Virginia Polytechnic Institute, 1994 (Bosch and Heimlich)

18. An Explosion in Slow Motion: Noxious Weeds and Invasive Plants on Grazing Lands. Report of the Eighth Grazing Lands Forum, Washington, DC, December 2, 1993. (editor)

17. "America's Cropland: Where Does It Come From?" Agriculture: A Critical U.S. Industry, 1991 Yearbook of Agriculture, pp. 3-9 (Heimlich and Daugherty).

16. Strategic Planning for Grazing Lands Issues. Report of the Fourth Grazing Lands Forum, Harpers Ferry, WV, October 30-November 2, 1989. (editor)

15. Effects and Recommendations Regarding the Conservation Title of the 1985 Food Security Act on Great Plains Agriculture. Report of the Great Plains Agricultural Council 1985 Food Security Act Task Force, March 1989. (contributor).

14. Grazing Lands and the Conservation Reserve Program. Report of the Third Grazing Lands Forum, Harpers Ferry, WV, October 11-13, 1988. (editor)

13. Multiple Use Values of Grazing Lands. Report of the Second Grazing Lands Forum, Harpers Ferry, WV, October 5-7, 1987. (editor)

12. "Agriculture and Urban Areas in Perspective." The American Land: 1987 Yearbook of Agriculture, pp. 141-47.

11. Crop Yields and Net Income on Prime Farmland in New York. A.E. Research 84-21, Cornell University, November 1984. (Bills, Heimlich, and Stachowski).

10. Guidelines for Economic Analysis of Soil Erosion on Vermont Farms. Vermont Erosion Control and Runoff Management Study, July 1984.

9. Animal Waste and Water Pollution Potential in the SESAW Study Area, New Jersey. Technical Report to the New Jersey Statewide Erosion, Sediment, and Animal Waste Study, July 1983.

8. Sources and Control of Agricultural Soil Erosion--Tioughnioga Watershed, Cortland, Madison, and Onondaga Counties, New York. New York Special Cooperative River Basins Study, April 1983.

7. Sources and Control of Agricultural Groundwater Contamination in the Otter Creek-Dry Creek Watershed, Cortland, Madison, and Onondaga Counties, New York. New York Special Cooperative River Basins Study, April 1983.

6. Phosphorus Reduction and Farm Income: Modeling Efficient Responses to Phosphorus Loading Constraints on Vermont Dairy Farms. Vermont Agricultural Runoff Study, May 1982.

5. Water Quality Analysis: Normanskill Watershed. New York Special Cooperative River Basins Study, July 1981.

4. Reducing Erosion in Watersheds of the Tar-Neuse River Basin: Model Documentation, Analysis, and Utility. June 1981. (Heimlich and Ogg).

3. Projections of Land Use and Soil Loss in the Chowan-Pasquotank River Basin. June 1978. (Heimlich and Ogg).

2. Employment and Industry in the Chowan-Pasquotank River Basin. July 1976. (Heimlich and Ogg).

1. Agriculture in the Chowan-Pasquotank River Basins. July 1976. (Heimlich and Ogg).

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APPOINTMENTS

2005-Present Sr. Economist, Biofuels Production and Policy Project, World Resources Institute, Washington, DC

At WRI, I manage the biofuels production and policy project, which uses a national agro-environmental production model to explore the economic and environmental impacts of relying more heavily on agriculture to meet the nation's energy needs, as well as the potential for various forms of policy to mitigate those impacts. Current analysis is focusing on the projected impacts of cellulosic ethanol produced from distinct feedstocks such as corn stover and switchgrass. I am also involved in several other WRI projects exploring the international trade and environmental implications of scaling up biofuels and biomass production in South America and Southeast Asia and the potential for sustainable trade and procurement policies to address those impacts, and I serve as the WRI representative on the Council for Sustainable Biomass Production. Responsibilities include project budgeting, preparing research grant proposals, and participating in multiple public speaking and outreach engagements.

2000-2004 Assistant Professor, Agricultural Economics, Pennsylvania State University

While on the Penn State faculty, I taught both graduate and undergraduate classes in economic theory, natural resource economics, and mathematical programming. My research interests centered on the co-evolution of the environmental and social landscapes as reflected in changing land-use patterns and impacts. To explore the potential impacts of a wide array of programs and policy on those patterns, I employed a variety of simulation models designed to reflect the complex relationships between economic and biophysical processes and how those relationships respond to changing policy incentives. My responsibilities included managing graduate students, serving on departmental management committees, and preparing research grant proposals.

1994-1999 Research Assistant, Agricultural and Applied Economics, University of Minnesota
1992-1994 Graduate Assistant, Wildlife and Fisheries Management, Texas A&M University
1990-1992 Book Review Editor, *Science News*, Washington DC

PROFESSIONAL PREPARATION

2000 Ph.D., Agricultural and Applied Economics, University of Minnesota
1996 M.S., Agricultural and Applied Economics, University of Minnesota
1988 M.S., Biological Sciences, Stanford University
1988 B.S., Biological Sciences, Stanford University

PUBLICATIONS

Marshall, Liz. 2009. "Biofuels and the Time Value of Carbon." WRI Working Paper, World Resources Institute, Washington, DC, *in press*.

Marshall, Liz, and Zachary Sugg. 2009. "Corn Stover for Ethanol Production: Potential and Pitfalls." WRI Policy Note, World Resources Institute, Washington, DC. 10 pp.

David, Mark B., Stephen J. Del Grosso, Xuetao Hu, Elizabeth P. Marshall, Gregory F. McIsaac, William J. Parton, Cristina Tonitto, Mohamed A. Youssef. 2009. "Modeling denitrification in a tile-drained, corn and soybean agroecosystem of Illinois, USA". *Biogeochemistry.* Online publication date: 2-Jan-2009.

Saunders, Caroline, William Kaye-Blake, Liz Marshall, Suzie Greenhalgh and Mariana de Aragao Pereira. 2009. "Impacts of a United States' biofuel policy on New Zealand's agricultural sector." *Energy Policy*. Online publication date 18-January-2009.

Marshall, Liz, and Zachary Sugg. 2008. "Finding Balance: Agricultural Residues, Ethanol, and the Environment." WRI Policy Note, World Resources Institute, Washington, DC. 10 pp.

Marshall, Liz. 2007. "Carving out Policy Space for Sustainability in Biofuel Production." Agricultural and Resource Economics Review 36(2): 183-196.

Marshall, Liz. 2007. "Thirst for Corn: What 2007 Plantings Could Mean for the Environment." WRI Policy Note, World Resources Institute, Washington, DC. 10 pp.

Marshall, Liz, and Suzie Greenhalgh. 2006. "Beyond the RFS: The Environmental and Economic Impacts of Increased Grain Ethanol Production in the U.S." WRI Policy Note, World Resources Institute, Washington, DC. 6 pp.

Marshall, Elizabeth, and Frances R. Homans. 2006. "Juggling Land Retirement Objectives on an Agricultural Landscape: Coordination, Conflict or Compromise?" *Environmental Management* 38(1): 37-47.

Marshall, Elizabeth, and James Shortle. 2005. Urban development impacts on ecosystems. In S. Goetz, J. Shortle, and J. Bergstrom (eds.), Land Use Problems and Conflicts: Causes, Consequences and Solutions. Routledge Publishing, New York.

Marshall, Elizabeth, and James Shortle. 2005. "Using DEA and VEA to Evaluate Quality of Life in the Mid-Atlantic States." *Agricultural and Resource Economics Review* 34(2): 185-203.

Marshall, Elizabeth. 2004. "Open-Space Amenities, Interacting Agents, and Equilibrium Landscape Structure." *Land Economics* 80(2): 272-291.

Marshall, Elizabeth, and Frances R. Homans. 2004. "A Spatial Analysis of the Economic and Ecological Efficacy of Land Retirement." *Environmental Modeling and Assessment* 9: 65-75.

Marshall, Elizabeth, Frances R. Homans, and Robert Haight. 2000. "Exploring Strategies for Improving the Cost-Effectiveness of Endangered Species Management: The Kirtland's Warbler as a Case Study." *Land Economics* 76(3): 462-473.

Marshall, Elizabeth, Robert Haight, and Frances R. Homans. 1998. "Incorporating Environmental Uncertainty into Species Management Decisions: Kirtland's Warbler Habitat Management as a Case Study." *Conservation Biology* 12(5): 975-985.

Jeremy I. Martin, Ph. D.
Senior Scientist, Clean Vehicles Program
Union of Concerned Scientists
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Education

Ph. D. California Institute of Technology, Pasadena, California **September 1992 – September 1997**
Dept. of Chemistry and Chemical Engineering;
Major in Chemistry, Minor in Chemical Engineering
Dissertation: Statistical Mechanics of Polymers at Interfaces

B. A. Haverford College, Haverford, Pennsylvania **September 1986 – May 1990**
Chemistry and English Literature double major

Research Experience

Lifecycle Accounting for Biofuels **January 2008 to Present**
Studied lifecycle accounting methodology and related regulations pertaining to biofuels regulations in the US Federal government and California. Participated in California Air Resources Board workshops on California Low Carbon Fuel Standard regulations and a workshop at Purdue University on the GTAP economic model as it pertains to California's LCFS regulations. Developed a methodology to incorporate emissions over time into a single metric for regulatory use.

Microelectronic Process Integration and Reliability Research **January 2000 – May 2007**
Studied the mechanical reliability of low permittivity materials under stress, the chemical stability of these materials in oxidative environments and the effect of interfacial properties and plasma treatments on Copper elelctromigration behavior. Studied the integration of new materials into overall semiconductor manufacturing process and necessary adjustments in other processes to accommodate the new materials.

Electronic Materials Research **January 1999 to April 2005**
Developed and characterized new dielectric materials for use in semiconductor interconnects. In particular I worked on thin films deposited by plasma assisted chemical vapor deposition (PE-CVD) with reduced permittivity (or low k) compared with conventional silicon dioxide but adequate mechanical properties. Also investigated novel zeolyte based materials for use as low k dielectrics in conjunction with a research group at the University of California at Riverside.

Polymer Physics Research **June 1993 to September 1997**
Studied the physics of polymers at interfaces relevant to problems in colloidal stablization, thin films, and biological tethered ligand receptor interactions. Developed numerical approaches to the solution of problems of polymer thermodynamics.

Surface Science Research **January 1990 to May 1990**
Studied the surface mobility of Gold atoms on the 110 surface using Monte Carlo Simulations

Professional Experience

Senior Scientist at Union of Concerned Scientists (UCS) **January 2008 to present**
Washington, DC
Manage, design and carry out research to analyze and assess transportation issues; direct regulatory policy

campaigns; compile, write and edit reports to document and communicate research results; develop and recommend transportation policies; promote policies to media, government and public; provide technical assistance on transportation issues to the public, government, and others; serve as lead spokesperson on key technical and policy issues; represent UCS, its philosophy and positions at various public forums.

Unpaid Internship at National Resources Defense Council **November 2007 – December 2007**
Washington DC
Research and analysis at Climate Center working on Low Carbon Fuels, Coal to Chemicals and water issues.

Paid Consultant to Union of Concerned Scientists **August 2007 - September 2007**
Washington, DC
Researched the public literature and composed a short paper on the state of Cellulosic Ethanol research and development for Food and Environment Program, Union of Concerned Scientists.

Senior Member of Technical Staff: Interconnect Research **April 2007 to July 2007**
Advanced Micro Devices (AMD)
Stationed at Albany Nanotech Center as part of an advanced research alliance (AMD, IBM, Freescale) working on research related to future technology nodes (45nm, 32nm and beyond).

AMD: Senior Member of Technical Staff: External Manufacturing **April 2005 – April 2007**
Stationed at Chartered Semiconductor Manufacturing in Singapore. Responsible for technology transfer, qualification and supervision of manufacturing for AMD products manufactured at Chartered.

- Transferred technology from AMD manufacturing site in Germany to Chartered
- Supervised technology and reliability qualification
- Worked closely with Chartered to optimize yield, review and approve process changes
- Disposition noncompliant or potentially out of spec material

AMD: Senior Member of Technical Staff: Process Development **February 2003 – April 2005**
Stationed at IBM East Fishkill 300mm development/manufacturing site as part of 7 company technology alliance (AMD, IBM, Sony, Toshiba, Chartered, Infineon, Samsung) developing 90nm, 65nm and 45nm manufacturing technology for high performance Semiconductor Devices. Promoted to Senior Member of Technical Staff in December 2004.

- "Dielectric module owner" for 90nm and 65nm BEOL development teams.
- Collaboratively developed new CVD processes to enhance reliability and mechanical properties of dielectric films.
- Transferred knowledge of 90nm and 65nm process and integration to AMD manufacturing site
- Work with AMD global team addressing low k related chip packaging issues
- Participated in 300mm tool selection for AMD's new manufacturing site in Dresden, Germany

AMD: Member of Technical Staff and Interconnect Process Technology Manager
July 2002 – January 2003
Stationed at Central Research and Development Facility of United Microelectroncs Corporation (UMC) in Hsinchu, Taiwan

- Managed 4 AMD assignees to UMC alliance (metals, dielectrics and CMP)
- Led inter-group effort to address ultra low k process integration issues
- Coordinated interconnect process development between Taiwan, US and Germany

AMD: Member of Technical Staff: Low k Materials and Integration **March 1999 – July 2002**
Member of the AMD/Motorola Technology Alliance working at Motorola's Advanced Product Research and Development Laboratory in Austin, Texas

- Process/tool selection and process development of CVD low k ILD (SiCOH) and dielectric barrier (SICN) films (1999 – 2000)
- Integration of CVD Low k materials in 130nm and 90nm technology (2000 - 2002)
- Coordinated low k activities among AMD sites and transfer to manufacturing

- Managed 3 AMD dielectrics assignees to the Alliance

AMD: Senior Engineer, Dielectrics Process Development **October 1997 – March 1999**
AMD R&D Center in Sunnyvale, California
- Completed one-year rotation program through all process areas (thin films, etch, photolithography, diffusion/implant, and yield engineering) in an advanced development and pilot production factory manufacturing logic and flash memory
- Joined Advanced Process Development Organization Dielectric Thin Films group

US Patents

7,369,905	Method and apparatus for pressure and plasma control during transitions
6,989,601	Copper damascene with low-k capping layer and improved electromigration reliability
6,927,113	Semiconductor component and method of manufacture
6,797,652	Copper damascene with low-k capping layer and improved electromigration reliability
6,642,619	System and method for adhesion improvement at an interface between fluorine doped silicon oxide and tantalum
6,610,594	Locally increasing sidewall density by ion implantation
6,600,333	Method and test structure for characterizing sidewall damage in a semiconductor device
6,514,844	Sidewall treatment for low dielectric constant (low K) materials by ion implantation
6,500,755	Resist trim process to define small openings in dielectric layers
6,498,112	Graded oxide caps on low dielectric constant (low K) chemical vapor deposition (CVD) films
6,436,808	NH3/N2-plasma treatment to prevent organic ILD degradation
6,420,193	Repair of film having an SI-O backbone
6,406,993	Method of defining small openings in dielectric layers
6,294,472	Dual slurry particle sizes for reducing microscratching of wafers

Publications

O'Hare, M.; Plevin, R. J.; Martin, J. I.; Jones, A. D.; Kendall, A; Hopson, E. "Proper accounting for time increases crop-based biofuels' greenhouse gas deficit versus petroleum." Env. Res. Lett. 4, (2009)

Ryan, E. T.; Martin, J. I.; et al. "Line Resistance and Electromigration Variations Induced by Hydrogen-Based Plasma Modifications to the Silicon Carbonitride/Copper Interface." J. Electrochem. Soc. 154.7, H604-H610 (2007)

Li, Z.; ..., Martin, J. I.; et al. "Mechanical and dielectric properties of pure-silica-zeolite low-k materials," Angewandte Chemie - International Edition 45.38, 6329-6332 (2006)

Martin, J. I.; Zhang, C.-Z.; Wang, Z.-G. "Polymer-tethered ligand-receptor interactions between surfaces," J. of Polymer Sci., Part B: Polymer Physics 44.18, 2621-2637 (2006)

Edelstein, D.; ..., Martin, J.; et al. "Comprehensive reliability evaluation of a 90 nm CMOS technology with Cu/PECVD low-k BEOL," 2004 IEEE International Reliability Physics Symposium Proceedings p 316-319 (2004)

Edelstein, D.; ... Martin; et al. "Reliability, yield, and performance of a 90 nm SOI/Cu/SiCOH technology," Proceedings of the IEEE 2004 International Interconnect Technology Conference 214-216 (2004)

Yang, C.-C.; ... Martin, J.; et al. "Electrical and reliability evaluation of Cu/low-k integration: exploration of PVD barrier/seed and CVD SiC(N,H) cap depositions," Proceedings of the Advanced Metallization Conference 2004 213-220 (2004)

Rhee, S.-H.; ..., Martin, J.; et al. “Calculation of effective dielectric constants for advanced interconnect structures with low-k dielectrics” Applied Physics Letters 83.13 2644-2646 (2003)

Martin, J.; et al. “Integration of SiCN as a low kappa etch stop and Cu passivation in a high performance Cu/low kappa interconnect,” Proceedings of the IEEE 2002 International Interconnect Technology Conference 42-44 (2002)

Ryan, E.T.; Martin, J.; et al. “Integration damage in organosilicate glass films,” Proceedings of the IEEE 2002 International Interconnect Technology Conference 27-9 (2002)

Yu, K. C.; ..., Martin, J.; et al. “Integration challenges of 0.1 mu m CMOS Cu/low-k interconnects,” Proceedings of the IEEE 2002 International Interconnect Technology Conference 9-11 (2002)

Ryan, E. T.; Martin, J. I.; et al. “Effect of material properties on integration damage in organosilicate glass films,” J. Materials Research 16.12 3335-3338 (2001)

Tsui, T., J. I.; Martin, J. I.; et al. “The use of the four-point bending technique for determining the strength of Low K dielectric/barrier interface,” Materials Research Society Proceedings 612 D121-D125 (2000)

Martin, J. I., Wang, Z.-G.; Zuckerman, D.; Bruinsma, R.; Pincus, P. “Forces between Surfaces with Weakly End-Adsorbed Polymers,” Journal de Physique II France 7 1111-1121 (1997)

Martin, J. I.; Wang, Z.-G.; Schick, M. “Effects of polymer brush self-assembly on spreading and thin film stability,” Langmuir 12.20 4950-4959 (1996)

Martin, J. I.; Wang, Z.G. “Polymer brushes: scaling, compression forces, interbrush penetration, and solvent size effects,” J. Physical Chemistry 99.9 2833-2844 (1995)

Roelofs, L. D.; Martin, J. I.; Sheth, R. “Competition between direct and concerted movements in surface diffusion with application to the Au(110) surface,” Surface Science 250.1 17-26 (1991)

Kenneth R. Richards

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Indiana University
Bloomington, IN 47405
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Education

WHARTON SCHOOL, UNIVERSITY OF PENNSYLVANIA Philadelphia, PA
Ph.D., Public Policy and Management 1997

Emphasis in environmental, natural resource and regulatory economics and policy. Field examination in public finance. ***Dissertation title:*** "Integrating Science, Economics and Law into Policy: The Case of Carbon Sequestration in Climate Change Policy."

THE LAW SCHOOL, UNIVERSITY OF PENNSYLVANIA Philadelphia, PA
Juris Doctorate 1997

Emphasis in torts, administrative law, environmental law, regulatory law and law and economics.

TECHNOLOGICAL INSTITUTE, NORTHWESTERN UNIVERSITY Evanston, IL
Master of Science, Civil Engineering 1984

Emphasis in urban and regional planning, public decision-making processes and quantitative methods for natural resource planning**.**

TECHNOLOGICAL INSTITUTE, NORTHWESTERN UNIVERSITY Evanston, IL
Bachelor of Science, Civil Engineering 1983

Emphasis in environmental engineering.

DUKE UNIVERSITY Durham, NC
Bachelor of Arts, Botany and Chemistry 1979

Emphasis in ecology, marine biology and chemistry. Included semester of classes and research at the Duke Marine Laboratory in Beaufort, NC.

Professional Experience

SCHOOL OF PUBLIC AND ENVIRONMENTAL AFFAIRS, INDIANA UNIVERSITY Bloomington, IN
Associate Professor 2004-Present
Assistant Professor 1997-2004
Lecturer 1996-1997

Teaching Assignments: Public Management Economics; Financial and Cost-Benefit Analysis; Environmental Economics; Natural Resources Policy and Management; Climate Change Science and Policy; JumpStart Math Class; Case Studies for Policy Analysis; Law, Public Policy and Management; Law and Public Policy; Law and Public Affairs; Government Regulation in a Market Economy; Governance in Public and Private Contexts; Decision-Making in Public and Private Contexts; Public Management and Administration; SPEA Capstone Course; and SPEA Cohort Project.

INDIANA UNIVERSITY SCHOOL OF LAW Bloomington, IN
Adjunct Professor 2007-Present

Teaching Assignment: Energy Law and Policy, Climate Change Law and Policy

CENTER FOR RESEARCH ON ENERGY AND THE ENVIRONMENT Bloomington, IN
Associate Director for Policy 2008-Present

Helped propose and establish new center; Developing mission, marketing and funding strategies. Leading early research projects on carbon capture and sequestration policy and law, international forest carbon agreements, and spatial-econometric modeling of energy technology and environmental policy impacts on Indiana.

RICHARD G. LUGAR CENTER FOR RENEWABLE ENERGY Indianapolis, IN
Associate Director 2007-Present

Supporting Center Director with design and formalization of the Center's by-laws, development and execution of the strategic plan, identification of research projects, development of proposals and assembling research teams.

IU AT OXFORD PROGRAM Bloomington, IN
Director 2005-Present

Proposed, designed and continue to deliver biennial summer program to take public affairs and business students to Oxford for courses in decision-making and governance. Responsible for developing and delivering course content; organizing guest lecturers and complementary field trips and arranging logistics, lodging and meals.

ICF CONSULTING
Senior Consultant 2001-2002

Provided cost-effectiveness analysis and evaluation of carbon sequestration options for nation's largest investor-owned utility companies.

BLOOMINGTON ENVIRONMENTAL COMMISSION Bloomington, IN
Commissioner 1999-2004

Provided guidance to City Council and Mayor on local environmental issues. Managed development of the Bloomington Environmental Quality Indicators Report. Managed development and analysis of city greenspace GIS database. Supervised interns and managed analyses and reports.

U.S. DEPARTMENT OF JUSTICE/U.S. ENVIRONMENTAL PROTECTION AGENCY
Consultant 1998

Participated in planning and review of materials prepared in support of the federal government's argument in wetlands litigation case.

AMERICAN AUTOMOBILE MANUFACTURERS ASSOC. AND CHARLES RIVER ASSOC.
Consultant 1997

Commissioned to draft paper on the costs of controlling greenhouse gas emissions and potential role of carbon sequestration in U.S. greenhouse gas policy.

HERMISTON POWER PROJECT
Expert Witness 1996

Provided expert testimony on carbon offset projects in hearing conducted by the Oregon Department of Energy to determine award of permit for 500 MW power plant.

PACIFIC NORTHWEST LABORATORY Washington, DC
Senior Economist 1993-1996

Managed federal process for development of guidelines for voluntary reporting of greenhouse gas emissions, emissions reductions and carbon sequestration under Energy Policy Act of 1992, Section 1605(b) (see, 59 Fed. Reg. 52769 (1994)). Arranged and led public meetings on proposed voluntary reporting guidelines. Managed development of handbook for U.S. Initiative on Joint Implementation (USIJI), an international program created in accordance with the Framework Convention on Climate Change, 1992, art 4. Managed research to bring constitutional law, contract and public finance theory to bear on issues related to environmental policy instrument choice. Advised Clinton Administration on policy options for the Climate Change Action Plan. Organized conference on "Economics of Climate Change" with more than thirty presenters.

ECONOMIC RESEARCH SERVICE, U.S. DEPARTMENT OF AGRICULTURE Washington, DC
Economist 1991-1993

Conducted research on design of emissions offset and tradable allowance programs, economics of carbon sinks, renewable energy technology development and dynamic optimization of climate change policy. Advised White House staff on international climate change issues leading up to treaty negotiations in 1992.

PERKINS COIE Washington, DC
Summer Law Associate Summer 1991

Clerked with emphasis in environmental law and litigation.

COUNCIL OF ECONOMIC ADVISERS Washington, DC
Junior Staff Economist 1988-1989

Represented CEA at U.S. Federal Government interagency policy development meetings on global environmental issues. Provided economic guidance to the Response Strategies Working Group of the International Panel on Climate Change (IPCC). Wrote U.S. position paper, "Economic Measures," for the IPCC Response Strategies report. Drafted portions and assisted with the writing of the 1989 *Economic Report of the President*, Chapter 6, "Science, Technology and the U.S. Economy." Analyzed economic impacts of proposed Clean Air Act Amendments.

WHARTON CENTER FOR APPLIED RESEARCH Philadelphia, PA
Project Consultant 1987-1988

Developed and tested negotiation training tools for resolving multiple stakeholder public policy conflicts, including prisoners' rights and hazardous facility siting.

RISK AND DECISION PROCESSES CENTER Philadelphia, PA
Consultant to Nevada Nuclear Waste Repository Project 1986-1988

Conducted research on role of compensation in resolution of disputes related to siting hazardous facilities.

GOVERNMENT OF THE COOK ISLANDS AND U.S. PEACE CORPS Cook Islands
National Energy Planner 1984-1986

Headed Energy Planning Unit. Evaluated economic and engineering aspects of alternative energy technologies. Advised Minister of Energy on tariff policy. Designed specifications and negotiated contract for wood-fueled electricity generation plant. Conducted field trials on drying rates of wood fuels.

Professional Associations

Indiana State Bar Association
American Bar Association

Divisions/Sections: Government and Public Sector Lawyers Division; Environment, Energy, and Natural Resources Section; and Administrative Law and Regulatory Practice Section

American Economic Association
Association for Public Policy Analysis and Management
Midwest Law and Economics Association

Licenses

License to practice law: Indiana (inactive)

Publications

PAPERS, CHAPTERS, AND REPORTS

Plantinga, Andrew and Kenneth R. Richards. 2009. “International Forest Carbon Sequestration in a Post-Kyoto Agreement.” In Aldy, Joseph E. and Robert N. Stavins, eds. (2009). Post-Kyoto International Climate Policy: Implementing Architectures for Agreement. New York: Cambridge University Press.

Andersson, Krister, Andrew Plantinga, and Kenneth Richards. 2009. “The National Inventory Approach for International Forest Carbon Sequestration Management.” Forthcoming in Dieter Helm and Cameron Hepburn, eds. *The Economics and Politics of Climate Change.* Oxford University Press.

Andersson, Krister, Tom Evans, and Kenneth R. Richards. 2009. “National Forest Inventories: Policy Needs and Assessment Capacity.” Forthcoming in *Climatic Change.* Volume 93 (Nos. 1 -2): 69-101.

Plantinga, Andrew and Kenneth R. Richards. 2008. "International Forest Carbon Sequestration in a Post-Kyoto Agreement." Harvard Project on International Climate Agreements. Discussion Paper 08-11. Cambridge, Massachusetts.

Richards, Kenneth R. and Stephanie Hayes Richards. 2008. "Coal and the Environment, 2006-2008," Chapter 8 in *Indiana Coal Report 2008*. Indiana Center for Coal Technology Research. West Lafayette, Indiana.

Ringquist, Evan J., A. James Barnes, Mark Davis, Flynn Picardal, and Kenneth Richards. 2008. "Waste Tire Policy Recommendations for Indiana." Prepared for the Indiana Department of Environmental Management Office of Pollution Prevention and Technological Assistance. Indianapolis, Indiana.

Richards, K. and S. Richards. 2008. "An Analysis of the Leading Climate Change Bills in the U.S. Senate: S. 2191 America's Climate Security Act of 2007 (Warner-Lieberman) vs. S. 1766 Low Carbon Economy Act of 2007 (Bingaman-Specter)." *Environmental Law Reporter* 38: 10388-10417

Richards, K. 2007. "Environmental Taxes in the United States." *Critical Issues in International Environmental Taxation: International and Comparative Perspectives, Volume IV: 189-217.* Oxford University Press.

Arvai, J., G. Bridge, N. Dolsak, R. Franzese, T. Koontz, A. Luginbuhl, P. Robbins, K. Richards, K. Smith Korfmacher, B. Sohngen, J. Tansey and A. Thompson. 2006. "Adaptive Management of the Global Climate Problem: Bridging the Gap Between Climate Research and Climate Policy," *Climatic Change* 78 (1): 217-225.

Richards, K., N. Sampson, and S. Brown. 2006. "Agricultural and Forestlands: U.S. Carbon Policy Strategies." Report for the Pew Center on Global Climate Change.

Stavins, R. and K. Richards. 2005. "The Cost of U.S. Forest-based Carbon Sequestration." Report for the Pew Center on Global Climate Change.

Richards, K. 2005. "Forest Carbon Sequestration Costs in the United States and Louisiana." In Proceedings of Louisiana Natural Resources Symposium, July 18-20, 2005. Louisiana State University: Baton Rouge, Louisiana.

Richards, K. 2004. "A Brief Overview of Carbon Sequestration Economics and Policy," *Environmental Management* 33(4):545-558.

Richards K. and C. Stokes. 2004. "A Review of Forest Carbon Sequestration Cost Studies: A Dozen Years of Research," *Climatic Change* 63:1-48.

Richards, K. 2003. "The Instrument Choice Game: When Do Environmental Taxes Win?" Chapter 4 in *Critical Issues in International Environmental Taxation: International And Comparative Perspectives, Volume I.* Eds. J. Milne, K. Deketelaere, L. Kreiser and H. Ashiabor, 61-88.

Andersson, K. and K. Richards. 2001. "Implementing an International Carbon Sequestration Program: Can the Leaky Sink Be Fixed?" *Climate Policy* 1: 73-88.

Richards, K. 2000. "Framing Environmental Policy Instrument Choice," *Duke Environmental Law and Policy Forum*, 10:221-282.

Richards, K. 2000. "A Grateful Response to Comments on 'Framing Environmental Policy Instrument Choice,'" *Duke Environmental Law and Policy Forum* 10:425-443.

Richards, K. and K. Andersson. 2000. "The Leaky Sink: Persistent Obstacles to a Forest Carbon Sequestration Program Based on Individual Projects," *Climate Policy* 1: 41-54.

Rayner, S. and E. Malone (eds). 1998. *Human Choice and Climate Change, Volume 1: The Societal Framework*. Columbus, Ohio: Battelle, Lead Author on Chapter 5, O'Riordan et al., "Institutional Dimensions."

Richards, K., R. Alig, J Kinsman, M. Palo and B. Sohngen. 1997. “Consideration of Country and Forestry/Land-Use Characteristics in Choosing Forestry Instruments to Achieve Climate Mitigation Goals.” In *The Economics of Terrestrial Carbon Sequestration*. Eds. Sedjo, Sampson and Wisniewski. Boca Raton: CRC Press.

Richards, K. 1997.“Estimating Costs of Carbon Sequestration for a United States Greenhouse Gas Policy.” Report prepared for Charles River Associates, Inc.

Richards, K. 1997. “The Time Value of Carbon in Bottom-up Studies.” In *The Economics of Terrestrial Carbon Sequestration*. Eds. Sedjo, Sampson and Wisniewski. Boca Raton: CRC Press.

Richards, K. 1997. “Coercion and Enterprise in the Provision of Environmental Public Goods: The Case of Carbon Sequestration in the United States.” In *The Economics of Terrestrial Carbon Sequestration*. Eds. Sedjo, Sampson and Wisniewski. Boca Raton: CRC Press.

Richards, K. 1997. “Commentary on Edmonds et al., ‘Atmospheric Stabilization and the Role of Energy Technology’ ” In *Climate Change Policy, Risk Prioritization, and U.S. Economics Growth, Monograph Series on Tax, Regulatory, and Environmental Policies & U.S. Economic Growth*. American Council for Capital Formation Center for Policy Research, Washington DC, January 1997.

Intergovernmental Panel on Climate Change (IPCC). 1996. *Working Group III Second Assessment Report, Economics of Climate Change,* Lead Author on Chapter 8, "Key Determinants of Abatement Costs," and Chapter 9, "Estimates of Abatement Costs."

Richards, K. 1996. "Joint Implementation in the Framework Convention on Climate Change: Opportunities and Pitfalls." In *An Economic Perspective on Climate Change Policies, Monograph Series on Tax, Regulatory, and Environmental Policies & U.S. Economic Growth*. American Council for Capital Formation Center for Policy Research, Washington DC, January 1996.

Hahn, R. and K. Richards 1994. “Evaluating Economic Instruments for Controlling Greenhouse Gas Emissions,” U.S. Department of Energy.

Rayner, S., and K. Richards. 1994. "I Think that I Shall Never See...A Lovely Forestry Policy: Land Use Programs for Conservation of Forests," *Proceedings of IPCC Working Group III Workshop on Policy Instruments and Their Implications*. Tsukuba, Japan. January 1994.

Rosenthal, D., J. Edmonds, K. Richards, and M. Wise. 1993. "Stabilizing U.S. Net Carbon Emissions by Planting Trees," *Energy Conversion and Management* 34: 881-888.

Richards, K., R. Moulton and R. Birdsey. 1993. "Costs of Creation of Carbon Sinks in the U.S.," *Energy Conversion and Management* 34: 905-912.

Reilly, J. and K. Richards. 1993. "Climate Change Damage and the Trace Gas Index Issue," *Journal of Environmental and Resource Economics* 3: 41-61.

Richards, K.. 1992. "Policy and Research Implications of Recent Carbon Sequestering Analysis," in *Economic Issues in Global Climate Change: Agriculture, Forestry and Natural Resources*. Eds. J. Reilly and M. Anderson. Boulder, Colorado: Westview Press.

Gregory, R., H. Kunreuther, D. Easterling, and K. Richards. 1991. "Incentives Policies to Site Hazardous Waste Facilities," *Risk Analysis* Vol. 11, No.4: 667-675.

Richards, K. 1991. "U.S. Potential for Tree Planting and Forest Management to Sequester Carbon," Prepared for Pacific Northwest Laboratory, Washington D.C. Incorporated in Report to Congress, *Limiting Net Greenhouse Gas Emissions in the United States*, Department of Energy, DOE/PE-0101, 1990.

Moulton, R. and K. Richards. 1990. "Costs of Sequestering Carbon through Tree Planting and Forest Management in the United States," U.S. Department of Agriculture, Forest Service, General Technical Report WO-58, December 1990.

Richards, K. 1990 "Policy Options," In *Options for Reducing Greenhouse Gas Emissions*, Ed. D. Fisher, The Stockholm Environment Institute.

Hahn, R. and K. Richards. 1989. "The Internationalization of Environmental Regulation," *Harvard International Law Journal* 30:421-446. Reproduced in *The International Library of Essays in Law and Legal Theory: Environmental Law*. Ed. Michael C. Blumm. Hanover, NH: Dartmouth Press, 1992.

BOOK REVIEWS

Richards, K. 2007. "Book Review: *The State and the Global Ecological Crisis*, John Barry and Robyn Eckersley, editors." Forthcoming in *Perspectives on Politics*.

Richards, K. 1998. "Putting a Price Tag on Nature - *Nature's Services: Societal Dependence on Natural Ecosystems*, Ed. Gretchen C. Daily," *Issues in Science and Technology* XIV(2):88-90.

OPINION/EDITORIAL ARTICLES

Graham, J. and K. Richards 2009. "Better to Craft New Legislation" Invited contribution to New York Times online forum, "Who Should Regulate Greenhouse Gases?" February 19, 2009. at: http://roomfordebate.blogs.nytimes.com/2009/02/19/the-epa-puts-on-the-heat/#more-189

Richards, K. 2008. "Reframing the cap-and-trade dialogue" and "Don't forget about the role of politics" invited contributions to the Bulletin of Atomic Scientists round table discussion of Carbon Taxes vs. Cap-and-Trade.

Richards, K. 2008. "Forests in the U.S. Climate Program: Promising, but the Key is Implementation." Resources for the Future Weekly Policy Commentary.

Richards, K and Barnes, A.J.. 2008. "Carbon Capture Key to Coal," *The Journal Gazette* and *The Indianapolis Star*. November 18, 2008

Richards, K. 2008. Op-ed piece that appeared under alternative titles including "Further drilling won't ease pain at pump," "Hard Facts of Increased Global Consumption Argue against Ever-more Drilling," and "Renewables are the Only Path to Energy Independence." Published nationally in June and July 2008 by 31 newspapers.

Richards, S. and K. Richards. 2007. "Congress, Carbon and CCX – This Time it's Our Money." *The Times of Northwest Indiana*. December 27, 2007.

Richards, K. 2007. "McCain-Lieberman Bill is Backward; Bingaman Got it Right." *The Hill*. March 5, 2007.

IN DEVELOPMENT

Richards, K. and S. Richards. "The Evolution and Anatomy of Recent Climate Change Bills in the U.S. Senate: Critique and Recommendations", report commissioned by Senator Richard G. Lugar.

Giovanni, E. and K. Richards. "Determinants of the Costs of Carbon Capture and Sequestration for Expanding Generation Capacity."

Richards, K., J. Allerhand and J. Chang.. "Legal Considerations for Geological Sequestration."

Richards, K., D. Seesholtz, J. Grice, M. Auer, J. Barbour, B. Fischer, C. Freitag, and G. McCardle. "Internal Organization and External Contracting for the Forest Service's NEPA Process: Lessons from New Institutional Economics and Strategic Organizational Design." In Review.

Richards, K., D. Seesholtz, C. Freitag,, M. Auer, J. Barbour, B. Fischer, and G. McCardle,. "Contrasts in NEPA: Approaches by U.S. Forest Service Region 1 and Region 6 - A Pilot Study."

Richards, K., D. Good, and J. Chang. "The Rationality of State Level Fees for Hazardous Waste Management: The Case of the Midwest States."

Recent Invited Presentations

"Evolution and Anatomy of Recent Climate Change Bills in the U.S. Senate: Critique and Recommendations" National Association of Regulatory Utility Commissioners, Subcommittee on Clean Coal, NARUC Winter Meetings, Washington D.C. February 2008.

"Cost Model of Carbon Capture and Sequestration"; "Carbon Capture and Sequestration: Analyzing the Analogs"; "Property Law Theory for Carbon Capture and Sequestration"; and "Guidance for the State of Indiana on Carbon Capture and Sequestration." Briefing of Duke Energy. Indianapolis, Indiana. December 2008

"Global Warming." Senator Lugar's Symposium for Tomorrow's Leaders. Indianapolis, Indiana. December 2008.

"The Evolution and Anatomy of Recent Climate Change Bills in the U.S. Senate: Critique and Recommendations."Indiana Energy Conference. Indianapolis, Indiana. October 2008.

"CCS Regulation: The Implications of Property Rights and Tort Law." Indiana Governor's Carbon Capture and Storage Summit. Indianapolis, Indiana. September 2008.

"Climate Change and the Future of Indiana," Taped and distributed talk as part of virtual conference organized by Sierra Club and other environmental organizations. Bloomington, Indiana. October 2008.

"The Evolution and Anatomy of Recent Climate Change Bills in the U.S. Senate: Critique and Recommendations." Indiana Center for Coal Technology Research. Bloomington, Indiana. June 2008.

"Carbon Capture and Storage: Lessons from Energy Law and Policy." Seventh Annual Carbon Capture and Sequestration Conference. Pittsburg, Pennsylvania. May 2008.

"Preparing for Carbon Capture and Storage: Policy and Legal Considerations." Bard College. Avon upon Hudson, New York. April 2008.

"Preparing for Carbon Capture and Storage: Policy and Legal Considerations." Pennsylvania State University. University Park, Pennsylvania. March 2008.

"Forest Carbon in a Post Kyoto Agreement." Kennedy School of Government, Harvard University. Cambridge, Massachusetts. March 2008.

"Global Warming Policy," Senator Lugar's Symposium for Tomorrow's Leaders. Indianapolis, Indiana. December 2007.

"Applications of New Institutional Economics to the U.S. Forest Service NEPA Process." The Law School at the University of South Carolina at Columbia. Columbia, South Carolina. November 2007.

"Issues to Watch in Upcoming Climate Legislation" SPEA Alumni Meeting, Chicago IL. October 25, 2007.

"Global Warming Developments," Senator Lugar's Symposium for Tomorrow's Leaders. Indianapolis, IN. December 8, 2007.

"Contrasts in NEPA: Approaches by U.S. Forest Service Region 1 and Region 6 - A Pilot Study," NEPA in the 21st Century Forest Service Workshop. Skamania, WA. March 20-21, 2007.

"Internal Organization and External Contracting for the Forest Service's NEPA Process: Lessons from New Institutional Economics and Strategic Organizational Design," NEPA in the 21st Century Forest Service Workshop. Skamania, WA. March 20-21, 2007.

"What is Next for Terrestrial Carbon Sequestration?" Modeling Ag-Forest Offsets and Biofuels in U.S. and Canadian Regional and National Mitigation. March 5-8, 2007

"Global Warming Policy," Senator Lugar's Symposium for Tomorrow's Leaders. Indianapolis, IN. December 5, 2006.

"Launching a National Terrestrial Carbon Sequestration Program,**"** Keynote address at Carbon and the Minnesota Landscape: Setting the Agenda, Minnesota Terrestrial Carbon Sequestration Workshop. Minneapolis, MN. November 21, 2006.

"Agricultural and Forestlands: U.S. Carbon Policy Strategies," Congressional Briefing. Washington, DC. September 29, 2006.

"Environmental Taxes in the United States: A Harlequin Romance." Keynote address at 6th Annual Global Conference On Environmental Taxes. Leuven, Belgium. September 22 – 24, 2005.

"Forest Carbon Sequestration Costs in the United States and Louisiana," Louisiana Natural Resources Symposium, Louisiana State University. Baton Rouge, Louisiana. July 18-20, 2005.

"Developing a Greenhouse Gas Abatement Program: Recognizing Diversity." Keynote address at Greenhouse Gas Management Canada Policy Forum. Victoria, British Columbia. April 28-29, 2005.

"State Hazardous Waste Taxes and Small Firm Behavior." U.S Environmental Protection Agency, National Center for Environmental Economics Seminar Series. Washington, DC. February 17, 2005.

"Sequestration: What Elements Are Needed to Implement It, and Are They in Place?" Keynote address at EPA Forestry and Agriculture Greenhouse Gas Modeling Forum. Shepardstown, WV. October 13-15, 2004.

"Implementing a Carbon Sequestration Program: The Case for Adaptive Management," Adaptive Research and Governance in Climate Change Workshop. Ohio State University. Columbus, Ohio. December 15-17, 2002.

"A Brief Overview of Carbon Sequestration Economics and Policy," Plenary address at USDA Symposium on Natural Resource Management to Offset Greenhouse Gas Emissions. Raleigh, NC. November 19-21, 2002.

Recent Review Panels

Indiana Geological Survey, Review and Advisory Panel, Bloomington Indiana. November 8, 2007.

U.S. Department of Energy, Industrial Technologies Program Review. Arlington, VA. September 6-9, 2006.

National Energy Technology Laboratory, Carbon Sequestration Program Review. Pittsburgh, PA. September 26-29, 2005.

U.S. Department of Energy, Integrated Assessment Review. Washington, DC. May 26, 2004.

Grants, Fellowships and Awards

School of Public and Environmental Affairs, Indiana University. 2009. Sustainability Research Development Grant ($10,000) for "Third Party Sustainability Certification: Does the Forest Sustainability Certification (FSC) Program Deliver?" with Miranda Hutton and Steve Rayner.

Smith School for Enterprise and the Environment, Oxford University. 2009. Support **(~GBP 9,400)** for Senior Visiting Research Fellow position.

Indiana University. Office of Vice President for International Affairs. 2009 Support **($1,500)** for Support for Senior Visiting Research Fellow Position at Smith School for Enterprise and the Environment.

Duke Energy Foundation. 2008 – 2009. Research grant **($63,000)** for "Carbon Capture and Sequestration Law and Policy."

Indiana University. 2009 – 2011. President's grant **($50,000)** for "Modeling the Impact of Enhanced Renewable Energy Production and Utilization and the Consequences for Indiana" via Center for Research on Energy and the Environment Indiana University.

Kennedy School of Government, Harvard University. 2008. Commissioned paper **($3,000)** on Forests in a Post Kyoto Agreement. With Andrew Plantinga.

U.S. Forest Service. 2008 – 2009. Grant **($30,000)** for "Formalization in the NEPA Process" with Sergio Fernandez and Burnell Fischer.

U.S. Forest Service. 2008 – 2010. Grant through Society of American Foresters **($125,000)** for "Forest Service Decision Rationale in NEPA" with Michael Mortimer and Clare Ryan.

Indiana University. 2008 - 2010. IU President's grant with J.C. Randolph and John Rupp **($390,000)** for development of Center for Research on Energy and the Environment.

U.S. Forest Service. 2006-2007. Research grant with co-investigators Burnell Fischer and Matt Auer **(budget: $49,045)** for "Comparative Analysis of NEPA Process, Organization, and Personnel."

U.S. Forest Service. 2006-2007. Research grant with co-investigators Burnell Fischer and Matt Auer (**budget: $76,754**) for "New Institutional Economic Analysis of the Forest Service NEPA Responsibilities: A Business Approach."

Indiana Department of Environmental Management. 2006-2007. Research grant with PI Evan Ringquist, A James Barnes, and Flynn Picardl **(budget: $110,000)** for "A Waste Tire Management Program for Indiana."

Duke Energy. 2005. Grant for symposium and carbon grove planting **($10,000)** in honor of former U.S. Environmental Protection Agency Administrator William Ruckelshaus.

U.S. Environmental Protection Agency. 2001-2003. Research Grant with CoPI David Good **(budget: $180,000)** for "Looking Inside the Black Box: Microlevel Empirical Analyses of the Impact of State and Federal Policy Instruments on Hazardous Waste Generation and Management."

National Science Foundation. 1998. Conference grant **($18,250)** for conference held in 1999 on "A Comparison of Environmental Policy Implementation in the United States and Canada."

Canadian Embassy. 1998. Conference grant **($3,000)** for conference held in 1999 on "A Comparison of Environmental Policy Implementation in the United States and Canada."

Teaching Excellence Recognition Award, Summer Faculty Fellowship. 1998. Teaching fellowship **($6,000)** for "Developing Internet Support for Economics and Law Classes" to support early work on development of websites to support classroom pedagogy.

U.S Department of Energy. 1996-1998. Research grant **($107,297)** for "Beyond AEEI: Technical Changes in Integrated Assessment." Work conducted in cooperation with the Pacific Northwest National Laboratory, operating under separate grant.

Honors

International Panel on Climate Change certificate for "contributing to the award of the Nobel Peace Prize of 2007"	2008
Freshman Learning Program, Fellow	2007
Trustees Teaching Award, Indiana University	2002
Excellence in Teaching Award, School of Public and Environmental Affairs	2000
Outstanding Undergraduate Teaching Award, School of Public and Environmental Affairs	1999
Excellence in Teaching Award, School of Public and Environmental Affairs	1999
Director's Award for Excellence, Pacific Northwest National Laboratory	1993
Norman and Rosita Winston Law and Economics Fellow, University of Pennsylvania	1988, 1990-1991
Alfred F. Buehler Public Administration Fellow, Wharton School, University of Pennsylvania	1987-1988
Wharton Dean's Fellow in Public Policy, University of Pennsylvania	1986-1987
Walter P. Murphy Fellow in Civil Engineering, Northwestern University	1982-1983