UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
AIR AND RADIATION

December 2012

Memorandum

SUBJECT: Peer Review of FASOM-GHG

FROM: Sara Ohrel
Climate Change Division

TO: EPA Council for Regulatory Environmental Modeling

The Climate Change Division (CCD) of the U.S. EPA Office of Air and Radiation has conducted analyses of greenhouse gas mitigation approaches for the Agency, the Administration, and Congress. This includes modeling and analysis to assess economically-efficient GHG mitigation potential and related land use and market changes in the agriculture and forestry sectors domestically. CCD has used the Forestry and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG), a sector-specific partial equilibrium model, to conduct such analyses. It should be noted that the version of the FASOM-GHG model utilized for this peer review is substantially different from the version used to analyze the Renewable Fuels Standard program (USEPA, 2010).

In accordance with the Office of Management and Budget Information Quality Bulletin for Peer Review and EPA's Peer Review Handbook, CCD has undertaken a peer review of the model by a panel of external experts (Panel).

The Peer Review (Review) was coordinated by Industrial Economics, Incorporated (IEc), through a subcontract with Stratus, Incorporated. IEc selected five experts in agricultural economics, forest economics, and/or land use modeling who conducted the Review. Please see the attached memo from IEc describing the process of the Review including Panel selection.

The Panel made a number of suggestions for improvement in the attached Review. The FASOM-GHG modeling team prepared a response to the Review report addressing the findings and discussing planned model improvements. This response is also attached.

Attachments:

1. IEc Peer Review Documentation Memorandum
2. Report of the Peer Review Panel: *"Forestry and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG) for Climate Change Analysis"*
3. Response to Peer Review Panel prepared by the FASOM-GHG Model Development Team

IEc

MEMORANDUM | December 20, 2011

TO Sara Ohrel, USEPA/CCD/CEB

FROM James Neumann

SUBJECT Documentation of Peer Review Process for the FASOM-GHG Model for Climate Change Analysis

1. OVERVIEW

Industrial Economics, Inc. (IEc) was contracted to manage the external peer review of an agriculture and forestry sector model currently being used by the Climate Economics Branch (CEB) of the Climate Change Division (CCD) of the Office of Atmospheric Programs, USEPA. The model is known as the Forestry and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG), developed initially by Drs. Bruce McCarl (Texas A&M University) and Darius Adams (Oregon State University) and currently maintained through the efforts of a large research consortium, which includes members from USEPA, USDA, USDA Forest Service, Duke University, RTI International, Oregon State University and the Electric Power Research Institute. This memorandum summarizes the results of the peer review. The first section provides a brief description of the process for selecting individuals to serve on the review panel. The second section provides a summary of information provided to reviewers to support their activities. The full text of the peer review panel's report is provided separately.

This independent, external peer review was conducted in compliance with EPA's Peer Review Guidelines. The peer review will assist CEB in supporting their analytical responsibilities to provide long-run economic and integrated assessment modeling support to CCD, EPA, and the US Government. These long-run analyses inform near-term policy development with feasible alternative projections that provide insights for policy making. For example, FASOM-GHG has been used by EPA for the purpose of analyzing the impacts of greenhouse gas legislative proposals on the agriculture and forestry sector, including analysis of carbon offsets from these sectors.

Results of the peer review will be used to help CEB evaluate the insights that can be gleaned from the model's results and its relative strengths and limitations. The review may also help to identify opportunities for improvements to the model and suggest research directions that strengthen the credibility of model results. Reviewers were asked to comment on the economic methodology and utility of model results. While the model may be deployed to support policy decision-making, no specific policy questions were asked of the reviewers.

2. PROCESS FOR SELECTING PEER REVIEW PANELISTS

The peer review process began in March 2010 and was completed in April 2011. IEc recruited five reviewers for the panel; one of these reviewers was recruited to serve as chairperson for the panel. The panel chair was engaged in June of 2010, and panel recruitment was complete in August 2010. A draft peer review report was complete by November 2010, and the report was finalized in April 2011. The reviewers were compensated for approximately six days of effort and provided with an honorarium sufficient to attract a high-quality review panel. The chair, who was also asked to oversee the review of the models and engage particularly in the technical and substantive nature of the economic model review, was compensated for approximately ten days of time.

IEc initially discussed a list of 46 candidate peer reviewers with EPA. While we consulted with EPA staff to clarify the expertise necessary to perform this review, and ensure that candidates met the stated requirements, IEc independently selected all of the reviewers, consistent with the guidelines of the *EPA Peer Review Handbook*.[1] IEc discussed conflict of interest and independence issues with each reviewer, and each signed a statement confirming that they had no financial or personal conflicts of interest. In addition four of the five reviewers signed a contract with IEc that included a requirement to immediately report any potential personal or organizational conflict of interest, should one arise during the course of completing the review. The fifth reviewer is a U.S Federal Government employee, who received no compensation for the review but did receive permission from his supervisor to participate in the review.

IEc selected peer reviewers for independence, economic expertise and knowledge, and modeling expertise, with a secondary concern to ensure that the panel as a whole was sufficiently broad to address the full range of charge questions. Each of the five peer reviewers ultimately selected are nationally recognized experts in the fields of agricultural economics, forest economics, and/or land use modeling – several cover more than one of these areas – and possess the specific knowledge, expertise and experience required to adequately and authoritatively respond to the charge for the review. Other areas of expertise for the collective panel include biofuels analysis, linear programming modeling techniques, and agricultural statistics.

Exhibit 1 below provides a brief description of the five reviewers and their relevant expertise.

[1] US Environmental Protection Agency, 2006, *Peer Review Handbook, 3rd Edition*, Science Policy Council, U.S. Environmental Protection Agency, Washington, DC, EPA/100/B-06/002, available at: http://www.epa.gov/peerreview/pdfs/Peer%20Review%20HandbookMay06.pdf .

EXHIBIT 1. SUMMARY OF QUALIFICATIONS OF PEER REVIEW PANEL

PEER REVIEWER	BRIEF DESCRIPTION OF QUALIFICATIONS
Dr. Kathleen Segerson, Panel Chair, University of Connecticut	Dr. Segerson is Philip E. Austin Professor of economics and former department head at the University of Connecticut. She is a fellow of the Association of Environmental and Resource Economists (AERE), where she currently serves as president, and of the American Agricultural Economics Association. Dr. Segerson's research focuses on the incentive effects of alternative environmental policy instruments, with particular emphasis on the application of legal rules and principles to environmental problems. Specific research areas include: the impact of legal liability for environmental damages in a variety of contexts, including groundwater contamination, hazardous waste management, and workplace accidents; land use regulation and the takings clause; voluntary approaches to environmental protection; the impacts of climate change on U.S. agriculture; and incentives to control nonpoint pollution from agriculture. In addition, she is a member of the Chartered Board of the U.S. Environmental Protection Agency's Science Advisory Board (SAB), and has served on several SAB committees, including as chair. Past service also includes several advisory committees for the National Academy of Sciences and the National Science Foundation.
Dr. Bruce Babcock, Iowa State University	Dr. Babcock is the Cargill Endowed Chair of Energy Economics, Director of the Biobased Industry Center, and professor of economics. His research interests include understanding energy and agricultural commodity markets, the impacts of biofuels on U.S. and world agriculture, the development of innovative risk management strategies for farmers, and the analysis of agricultural and trade policies.
Dr. Joseph Buongiorno, University of Wisconsin	Dr. Buongiorno is Professor Emeritus in the Department of Forest and Wildlife Ecology. His research interests include forestry economics and operations research, and the development and application of decision-making models, economic forecasting, international forestry, development planning, ecosystems management, and forest management techniques. His models have assessed the growth of multi-age, mixed-species shortleaf forests; the relation between productivity and ecological diversity in forests; the amenity value of forests; forest product markets; the world forest sector; the econometrics of international demand and supply of forest products; and international wood utilization accounts and technologies.
Dr. Scott Malcolm, US Department of Agriculture, Economic Research Service	Dr. Malcolm is an economist on the ERS staff and contributor to USDA's Regional Environment and Agriculture Programming (REAP) economic model of the agriculture sector. He is the lead or contributing author of several related USDA bulletins that apply the REAP model or explore issues in data to support similar quantitative analysis of the agriculture sector - for example, "Ethanol and a Changing Agricultural Landscape" November 2009

PEER REVIEWER	BRIEF DESCRIPTION OF QUALIFICATIONS
Dr. Andrew Plantinga, Oregon State University	Dr. Plantinga is professor of Agricultural and Resource Economics. In addition to his university experience, he has also held positions with the U.S. Forest Service and Resources for the Future. Dr. Plantinga's research focuses on the economics of land use, climate change, and forests. Particular emphasis is given to the development of methods for econometrically modeling land-use decisions, the application of land-use models to environmental and resource policy problems, and the modeling of land development pressures. Recently he has been working on applying techniques from macroeconomics to models of natural resource markets.

3. MATERIALS PROVIDED TO PEER REVIEW PANELISTS

Exhibit 2 provides a copy of the cover letter sent to the peer reviewers. As indicated in the letter, peer reviewers were provided a list of charge questions developed by the EPA sponsors; detailed documentation of the model; and summaries of quantitative results of a recent EPA effort to apply the model for policy evaluation. Note that some materials that became components of the review package were provided in response to questions of clarification from the panelists to the EPA sponsors.

The panel conducted several group conference calls, facilitated by IEc, in the period from August 2010, shortly after receipt of the review materials, and January 2011, including one call facilitated by IEc where panelists asked clarifying questions of the EPA sponsors. A draft of the review was completed and shared with EPA in early November 2010. An EPA review of the panel's draft review report was conducted to assess and suggest correction to any potential factual errors or clarifications. EPA formulated a response to the panel's draft review, which was received in mid-February, 2011, which provided certain technical clarifications of issues identified in the November 2010 draft report, and requested that the panel consider this input in finalizing their review. The panel considered all of EPA's clarifications, and adopted some changes to their draft report, which were incorporated in the final report delivered to EPA in late April 2011.

EXHIBIT 2. COVER LETTER FOR PEER REVIEWERS

IEc

INDUSTRIAL ECONOMICS, INCORPORATED

August 20, 2010

TO: Dr. Kathleen Segerson, Chair
Dr. Bruce Babcock
Dr. Joseph Buongiorno
Dr. Scott Malcolm
Dr. Andrew Plantinga,

Thank you for agreeing to serve as a peer reviewer of EPA's application of the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOM-GHG). The sponsor of this review is the US Environmental Protection Agency's Office of Air and Radiation, Office of Atmospheric Programs, Climate Change Division, Climate Economics Branch (CEB). One of CEB's specific responsibilities is to provide long-run economic and integrated assessment modeling support to EPA and the US Government. These long-run analyses inform near-term policy development with feasible alternative forecasts that provide insights for policy making.

CEB uses FASOM-GHG to perform selected analytical tasks related to their analyses of the costs and implications of alternative greenhouse gas control policies. CEB currently has a need for independent external peer review of this model. Results of the review will be used to help CEB evaluate the insights that can be gleaned from the model's results and its relative strengths and limitations. The review will also help to identify opportunities for improvements to the model and suggest research directions that strengthen the credibility of model results.

Today I have sent you via electronic mail a list of specific charge questions that we request you address in conducting your review, and use as a guide in organizing your response. You will also find the following items in your in-box:

- *Model Documentation for the Forest and Agricultural SectorOptimization Model with Greenhouse Gases (FASOMGHG), Draft Report prepared for Sara Bushey Ohrel, U.S. Environmental Protection Agency, prepared by Robert H. Beach, Darius Adams, Ralph Alig, Justin Baker, Gregory S. Latta, Bruce A. McCarl, Brian C. Murray, Steven K. Rose, and Eric White, August 2010.* This document should be the main focus of your review. Please review this draft documentation to determine if adequate information is provided to support your review. If the documentation is not adequate, please contact me immediately and we will attempt to augment it.

August 20, 2010
FASOM Peer Review Panel Members
Page 2

- *Selected Applications of FASOM-GHG.* EPA has also provided copies of reports or journal articles describing four applications of the model. These are provided to illustrate the capabilities of the model, provide a sample of selected results, and some model sensitivities and limitations.
- *Conflict of Interest Certification.* I have previously sent you this under separate cover. If you have not yet review, signed, and returned to me, you must do so before you begin your review. If you have any doubts about whether a current or past engagement represents a conflict of interest for this review, don't hesitate to contact me to discuss.
- *Your contract with Industrial Economics.* I have previously sent this to you under separate cover. If you have not yet returned a signed copy to me please do so before you commence your review.

EPA has also indicated that they will be providing an additional set of detailed sample results from the model. I expect to forward that to you no later than September 1.

If you would like to clarify further any aspect of the charge, the model, or the ultimate intended purpose of the model, please contact me and I can arrange a teleconference with the model developers, EPA, or both. Note that, in order to maintain the independence of the peer review, during your review I ask that you refrain from direct contact with the EPA sponsors of the review in the Office of Air and Radiation, Climate Change Division, Climate Economics Branch, or with other researchers s whom you know to be involved in the development of FASOM-GHG, except as arranged through me.

We request that you submit a draft written review to the panel chair no later than October 1, 2010, so that the panel may provide a full draft report to EPA no later than October 13, 2010. If this timeframe proves problematic for you, please contact me as soon as possible. You can e-mail the review to Dr. Segerson at kathleen.segerson@uconn.edu, and please copy me at jneumann@indecon.com. Please organize the review in the form of a memorandum or a short report (preferably in MS Word), beginning with your general impressions of the tool and then moving to your more specific comments in response to each charge question.

Thanks again for your participation. If you have any questions, please feel free to contact me via e-mail, jneumann@indecon.com, or by phone at (617) 354-0074.

Sincerely,

James Neumann
Principal
Industrial Economics, Inc.

Final Report:

Peer Review of the Forestry and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG) for Climate Change Analysis

By:

Kathleen Segerson +
Bruce Babcock
Joseph Buongiorno
Scott Malcolm
Andrew Plantinga

Work performed under contract from the U.S. Environmental Protection Agency

through

Industrial Economics, Incorporated
James E. Neumann, Program Manager

+ Review Panel Chair

April 2011

I. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) uses a suite of models to provide analysis and predictions of the impacts of alternative policies designed to reduce emissions of greenhouse gases. One of these models is the *Forestry and Agricultural Sector Optimization Model with Greenhouse Gases* (*FASOM-GHG*). The agricultural components of FASOM-GHG are based primarily on the *Agricultural Sector Model* (*ASM*), while the forestry components draw from a number of forest sector models, most notably, the *Timber Assessment Market Model* (*TAMM*), the *North American Pulp and Paper Model* (*NAPAP*), the *Aggregate Timberland Assessment System* (*ATLAS*), and *AREACHANGE.* For use in evaluating climate change policies, the resulting combined agricultural-forestry model (*FASOM*) was expanded to include accounting for GHG emissions from both the agricultural and forestry sectors, thereby yielding the current model known as FASOM-GHG. In addition to including an accounting of GHG emissions, the model also includes detailed consideration of biofuels and the interaction between biofuel demand (for example, in response to renewable fuel standards) and outcomes in the agricultural and forestry sectors under different scenarios. A key feature of the model is the linkage between the agricultural and forestry sectors through land use shifts that are predicted to occur under alternative policy scenarios.

In accordance with its Peer Review Guidelines, EPA commissioned an independent, external review of *FASOM-GHG* to help EPA, the U.S. Department of Agriculture, and other agencies that use or rely on the model's results identify the model's strengths and weaknesses, evaluate its usefulness in assessing the impact of climate change policies, and recommend possible improvements. The primary materials provided to the review panel as input into the review were the following:

- Main model documentation: "Model Documentation for the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG)," prepared by Roger H. Beach, et al., RTI International, August 2010
- An HTML file and an Excel file with sample output of FASOM-GHG
- Several published papers presenting applications of FASOM-GHG to the study of the impacts of climate change policies (see list in Appendix A)

In addition, the panel held a conference call (October 5, 2010) with representatives of the model development team to clarify questions that the panel had at that time. This report is based on the panel's best effort to review the materials presented within the required timeframe. Because FASOM-GHG is a very large and detailed model, a complete evaluation of the model would require a detailed examination of all model equations, assumptions, and parameters (including the model code), which was beyond the scope of this review. Thus, the panel instead focused its attention on broader questions regarding (i) the model's structure, (ii) the reasonableness of some of the assumptions and parameters that appear to be critical in determining policy impacts, to the extent that these could be determined from the materials provided to the panel, and (iii) the reasonableness/credibility of the model's results.

The following is a summary of some of the major findings that emerge from the panel's review.

- FASOM-GHG is among the few models that are able to predict the impact of climate change policies on land use in the agricultural and forestry sectors. Since land use impacts are likely to be an important determinant of overall impacts on prices, quantities, and welfare, predicting these is critical for understanding and evaluating alternative policies. Thus, FASOM-GHG is a useful tool when used as part of a suite of models informing policy choices.
- FASOM-GHG provides a very detailed representation of the agricultural, bioenergy and forestry sectors. This is both a strength and a weakness. Overall, the panel believes that the current level of disaggregation in the model is hampering rather than enhancing the model's usefulness. It presents a false sense of precisions and limits both transparency and the extent to which sensitivity analyses can be run to better understand what is driving model predictions and to provide critical information about the impact of uncertainty about key parameters, relationships, and assumptions. A more aggregated model is likely to produce more defensible results and be more useful.
- Many of the predictions from FASOM-GHG, including the derived demand for agricultural land, are driven by assumptions about future productivity growth. However, the validity of some of these assumptions is highly questionable, especially when projections are extended out for very long time periods. For example, the model's assumptions about productivity increases and resulting livestock numbers are not supported by recent data and they do not result in reasonable projections of livestock numbers. This weakness leads to demands for feed that are too low, which is the primary source of agricultural demand for land. These assumptions should be critically evaluated for consistency with other data.

- The demand for agricultural land is also driven by assumptions about long run demand growth for individual commodities. However, long run predictions about future demand at the level of disaggregation included in the model are highly suspect, even if based on predictions that are reasonable over the next decade or so. Basing future demand for agricultural outputs on reasonable assumptions about income and population growth would provide more defensible predictions over the long run.
- To ensure public confidence in the model results and facilitate scholarly dialogue, FASOM-GHG needs to be carefully documented in a way that allows "outsiders" to understand and evaluate the model. In addition, the model needs to be validated against historical data, as well as subjected to rigorous peer review (of the model details, not just the results of applications). Model documentation, model validation, and peer review are particularly important for models used to provide input into important public policy decisions, such as those related to climate change policies.
- A number of the model's predictions do not seem consistent with expectations. For example, reported results indicate that corn ethanol plants are making a large amount of money in the baseline, and yet dry mill corn ethanol production does not expand, wet mill corn ethanol production contracts, and sweet sorghum ethanol production expands dramatically. Similarly, the projections of a significant contraction in agricultural land due to a $30 price of CO_2 despite a significant increase in returns to cropland indicate that the elasticity of supply of cropland is too high. The model's predictions need to be critically assessed to determine the source of these inconsistencies, and, if necessary, changes should be made to the model to ensure consistency with underlying economic principles.
- FASOM-GHG includes a number of constraints on choices. While some of these serve simply to reduce solution time, others have the potential to rule out choices that might be optimal under certain scenarios. The model documentation should clearly identify which constraints are potentially binding (change choices) and which are not. For those that are, the rationale for these constraints needs to be carefully explained and the sensitivity of the results to inclusion of the constraint should be provided.
- For several variables, the predicted levels fluctuate considerably across periods, with some activities coming in and out of solution in unexpected ways. If this is simply a lack of "smoothing", then it would perhaps be better to report

results with longer time intervals (e.g., 10 years rather than 5 years). On the other hand, if the predictions are to be taken literally, i.e., there is an expectation that in reality such switches would occur, then a careful explanation of this type of outcome is needed. Again, model validation would help determine the appropriate level of confidence in the model's 5-year predictions.

II. OVERVIEW OF KEY FEATURES OF THE MODEL

FASOM-GHG is a large, dynamic non-linear programming (simulation) model that maximizes the net present value of the sum of producer and consumer surplus across the U.S. agricultural and forestry sectors to solve for market equilibria over time. It is a comprehensive model that provides rich detail on land-using sectors in the U.S. The model incorporates the linkage between the agricultural and forestry sectors, endogenous prices for many commodities and inputs (especially land), and the capability to evaluate climate change policies in a comprehensive manner.

FASOM-GHG is run in 5-year time intervals, typically over a 60 to 100 year time horizon (p. 1-3).[1] The model solves endogenously for equilibrium input and output prices, domestic production and consumption, imports and exports, land and other resource use, management strategies, GHG accounts (emissions and sequestration), and economic welfare measures. The main focus is on domestic markets, with links to international markets included in a more aggregate way.

According to the model documentation, the parameter values for the model are drawn primarily from a variety of USDA and agricultural extension sources, other USDA and Forest Service data sources for current or historical data (e.g., the Major Land Use database, the Natural Resources Inventory, and the 2005 RPA Timber Assessment), as well as USDA future projections and historical trends.[2] In cases where data are not available, parameter values are assumed (see, for example, p. 6-7), presumably based on expert opinion, although the basis for these assumptions/opinions is not documented.

Perhaps the most notable and unique feature of FASOM-GHG is its ability to predict shifts in land use in response to policies that

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[1] Unless otherwise noted, all page references refer to the main documentation (Beach, et al. 2010).

[2] With the exception of the input elasticities with respect to changes in yields (p. 6-7), the model does not appear to draw on econometric estimates in the literature for elasticities related to the agricultural sector. This could reflect the fact that most elasticities in the literature are short run (annual) elasticities, rather than the medium or longer term elasticities that would be needed for FASOM-GHG. In addition, the model does not appear to make use of existing land use elasticities (e.g., Lubowski, Plantinga, Stavins, 2006). With regard to the forestry sector, the original forestry models upon which FASOM-GHG is based (e.g., TAMM) did use parameters that had been estimated econometrically, but the extent to which these parameters are used in FASOM-GHG is not clear from the documentation.

affect the returns to alternative land uses. Economic theory predicts that policies that, for example, would pay landowners to sequester carbon would increase the returns to forested land and hence be expected to shift land from other uses to forestry. While the direction of this effect is clear, its empirical magnitude, as well as its implications for other outcomes (e.g., input and output prices), are less clear. FASOM-GHG is able to provide empirical estimates of these policy impacts, by simulating optimal intertemporal land use decisions. This is a key strength of the model. However, because FASOM-GHG is a primary source of such predictions as used by EPA and others analyzing climate change policies, it is particularly important to assess whether the land use changes predicted by the model are credible and based on sound and best available information (see further comments below).

A second key and unique feature of FASOM-GHG is the level of detail in which it describes the agricultural and forestry sectors. For example, the model includes 40 primary crop products, 25 primary livestock products, 12 categories of forest and agricultural residues and 32 categories of public and private domestic and imported logs. In addition, there are 84 secondary commodities (27 crop products, 17 livestock products, 10 processing byproducts, and 40 forestry products). There are also disaggregated livestock feeds and production inputs. In addition, the model includes 63 sub-regions for agricultural production and 11 market regions. No other model being used to evaluate the impacts of climate change policies on the U.S. agricultural and forestry sectors has this level of detailed disaggregation. In the panel's view, this is both a strength and a weakness of the model (see further discussion below).

III. CROSS-CUTTING ISSUES

Before turning to specific responses to the charge questions posed to the review panel, we first discuss a number of cross-cutting or over-arching issues regarding the panel's evaluation of FASOM-GHG. These relate to the level of sectoral disaggregation in the model, model documentation, model validation, model constraints, and large fluctuations in outcomes. As will become clear below, these issues are inter-related and represent concerns that cut across the specific charge questions. More details supporting the identification of these cross-cutting issues are provided in the responses to those questions.

1. Level of Sectoral Disaggregation

As noted above, FASOM-GHG is a very detailed, disaggregated model. An advantage of using such a disaggregated model is that it allows for inclusion of parameter values and other model features that are specific to individual commodities, activities, land characteristics, environmental impacts and regions. Use of a detailed specification can provide more accurate predictions about aggregate impacts by using a "bottom-up" approach under which detailed impacts are summed to determine aggregate impacts. For example, if there are important GHG emission factors that differ widely across product categories or sub-regions, then a more aggregated analysis could miss important relationships and lead to incorrect aggregate predictions. In addition, detailed disaggregation allows for sub-sector and sub-regional impact analysis that might have important distributional and other implications and thus be of considerable interest both to specific user groups (e.g., commodity groups) and to policy makers. However, use of such a disaggregated model for evaluating future impacts of climate change policies 60 to 100 years into the future has a number of drawbacks as well.

a) False Precision.

One drawback is that providing such detailed impact analysis can lead to false confidence or belief in the precision of the results, especially when impacts are projected far into the future. The fact that the model is deterministic means that there are no confidence intervals given on any of the predictions and hence no information about the large uncertainties or potential errors that surround them. The potential errors that will likely be made at, for example, the individual commodity level are likely much greater than errors that would occur if commodities were aggregated to a much greater degree. This is particularly true for long-term projections, where technical change can be a critical factor in determining future market equilibria (and in some cases might even make some crops or forest products completely obsolete). It seems overly confident to claim that any model could reliably make predictions about the commodity "Orange, fresh (75 lb. box)" as distinct from the commodity "Orange, fresh (85 lb. box)" even 20 or 30 years from now, let alone 60 years from now. While such distinctions might be meaningful currently and important in the short run, it is not clear that they are meaningful for long run predictions. Similarly, the level of disaggregation in the forestry sector (both across products and regional) seems more than is necessary (and perhaps even desired) to capture important policy impacts (see further discussion below).

Because of the disaggregation in FASOM-GHG, the model "drivers" are very detailed projections over 30 to 100 years for individual variables, such as yields for durum wheat versus yields for hard red spring wheat or hard red winter wheat. As noted above, such detailed projections can give users a false confidence in the results. In addition, using a detailed model to make long-term projections makes it nearly impossible to extend the model to consider the role that international trade plays. Clearly a much greater portion of economic activity will be happening outside the United States over the next 50 years than occurred in the last 50 years. To the extent that international factors play a key role in driving U.S. markets, a modeling approach that treats the rest of the world on a less detailed basis than the U.S. is treated cannot capture the extent to which U.S. land resources will be in demand in the future.

An alternative approach would focus much more on the actual drivers of land use, which include population growth, income growth, and technical change, both in the U.S. and in all other countries. Given transparent assumptions about these driving forces, more aggregate production relationships (disaggregated regionally if needed) can be used to determine the demand for land and changes in GHG emissions. In the long-run, the two models might give similar answers, but the more aggregate model is a more humble approach, recognizing that it is impossible to project 40 years out what durum wheat yields are going to be so instead, making an assumption about aggregate growth in wheat or even grain yields in the U.S. and in other countries.

b) Data Requirements and Updating.

Clearly, the disaggregation in FASOM-GHG imposes a data requirement that is very onerous. While in some cases it might be easier to find disaggregated rather than aggregate data (for example, with regard to crop budgets), the *amount* of data required increases considerably with disaggregation. In some cases, there are little or no historical data or peer-reviewed estimates available on which to base parameter values, thus requiring parameters to be set at levels determined by the expert judgment of the modeling team. The sheer number of parameter values that are needed presents a serious challenge. It is not clear to what extent it is necessary to rely on expert judgment rather than available data.

In addition, to maintain credibility, the model must be continually updated. Because of the level of disaggregation, this requires that a huge amount of underlying technical data must be tracked down, verified, and updated on a continuing basis. FASOM-GHG is being continually updated and expanded, but the task of updating all of the presumably thousands of parameters in the model is a critical process that cannot be easily conducted (and documented) on a regular basis. Documenting changes to the model may be onerous, but it still must be done if the model is to be credible.

c) Transparency and Sensitivity Analysis.

The level of detail in FASOM-GHG also hampers the transparency of the model. Such a detailed model is difficult to document completely (see further discussion below). In addition, it is difficult to trace through and understand all of the interactions that are driving policy impacts. It apparently takes several days to run the model and solve for equilibrium outcomes. Since the basic structure of the model is conventional, it appears that the time required to run the model reflects mainly a combination of the level of disaggregation in the model and its dynamic structure. The long run time prevents one from "playing with" the model to get a better understanding of what is driving the results or testing the sensitivity of the results to, for example, alternative parameter specifications or the various constraints that are imposed on the model's solutions. This type of sensitivity analysis is essential not only for understanding the model, but also for reflecting uncertainties about critical parameters, assumptions, and predictions of exogenous factors. Because of FASOM-GHG's complexity, such analyses are prohibitively costly in terms of both time and resources. A more aggregated model would allow for more transparency and the ability to evaluate a wider set of assumptions about model inputs.

2. Model Documentation

With such a large model, thorough documentation is especially difficult but also especially critical. To judge the credibility of the model's results and have confidence in them, one must be able to see and understand fully the model's structure and inputs. The documentation that was provided to the review panel did not allow the panel to gain such an understanding. It provided general information about model structure and some details about model inputs and parameter values. However, much of the documentation provided simply alludes to general data sources from which information was drawn (e.g., MLU or NRI) rather than providing specific estimates (for example, of actual or implied elasticities) that can be judged based on other information. A comprehensive description of the mathematical model, data inputs, and derived parameters was not included. This undoubtedly reflects both the extensive scope of the model as well as its proprietary nature. Nonetheless, it makes it very difficult, if not impossible, for outsiders to fully comprehend and evaluate results from the model. In addition, it limits transparency, which is a critical part of engendering public confidence in model results used to support important public policy decisions. The lack of comprehensive documentation is in contrast to other models used for climate change analysis, such as the DICE model.

The panel believes that thorough, comprehensible documentation is critical for all models used by government agencies to support public policy decisions. This would allow other interested parties, especially other researchers, to replicate and check the results without extraordinary effort. Toward this end, it would be very useful for individuals to have access to a complete mathematical description of the model, including the dynamics, and to all the data, in the same document or website. Such documentation might be best maintained on-line to allow continuous updates as the model develops, new features are added, and old ones are modified. We recognize that such "openness" is difficult for a proprietary model (i.e., one that is not in the public domain), but that does not eliminate the importance of such openness in ensuring public confidence in the model and its predictions.

3. *Model Validation*

FASOM-GHG or earlier versions of the model have been used extensively in policy analysis, with applications dating back to the late 1970's. Many of these studies have been published in the peer-reviewed literature. In this sense, the model has been repeatedly "tested". However, while there are many FASOM-related publications, almost all of them focus on results and not on details of the model. At most, these papers present a brief and simplified representation of the underlying mathematical programming problem. As far as the review panel could tell, neither FASOM nor FASOM-GHG has been subjected to model validation exercises such as a test of whether it can reproduce historical outcomes. The credibility of the model would be enhanced by a thorough validation on historical data. Clearly, the model is meant to be predictive of future outcomes under a set of assumptions that might or might not turn out to be valid. However, it would still be useful to know how well the model can replicate things that did happen. Such a validation was done twenty years ago for the *Timber Assessment Market Model* (Adams and Haynes, 1980), which still serves, in revised form, as part of the FASOM-GHG model. It would be useful to do a similar validation for the complete model with current data. Such a validation is needed to enhance confidence in the model's predictions.

While model validation is a critical part of ensuring confidence in the usefulness of the model's results, it must be recognized that no model should be viewed as providing definitive information about what will happen if a particular policy is adopted. Like other similar models, FASOM-GHG is very useful to synthesize a large amount of information (both "hard" and "soft") about various relationships. However, the model should be recognized as one special representation of the U.S. agricultural and forestry sectors and the linkages between the two, and in the end it should be acknowledged that this and similar models are mostly useful for telling a coherent story, without obvious contradiction, for possible outcomes when a very complex system is subjected to a policy-induced perturbation. The ultimate test of any model's usefulness is whether it provides meaningful insight into possible policy-induced outcomes.

4. *Model Constraints*

FASOM-GHG includes a number of exogenous constraints that are imposed on various choices or outcomes. The purpose of these constraints apparently varies, but in all cases a more complete and thorough delineation and assessment of their role seems warranted. For example, some of the constraints are apparently imposed to facilitate solving the model by ruling out choices that the model developers have identified as never being optimal. When the eliminated options really are sub-optimal, constraints barring their selection will not affect the solution to the model and may simplify it. However, even in this case, if the model is used for the analysis of policies that go beyond historical experience, care must be taken to ensure that the sub-optimality assumption embodied in the constraint continues to be valid. For example, while historically forestland owned by industrial landowners might not have moved into agriculture, this does not imply that such a move would not occur under a climate change policy that changes prices sufficiently.

The model also includes constraints designed to produce "reasonable" projections by, for example, restricting regional crop mix or livestock mix to be a convex combination of historical mixes for that region. This is apparently necessary to account for some "missing" elements of the model that cause it to yield "unreasonable" predictions. Clearly, in contrast to the constraints that simply eliminate sub-optimal choices, these constraints are designed specifically to alter predicted outcomes. However, it is not clear how much they affect the model results, i.e., how sensitive the results are to the inclusion or relaxation of these constraints. Again, it would be useful to be able to run some sensitivity analyses to better understand the role or impact of these constraints. In addition, the documentation should discuss what missing model elements make the inclusion of these constraints necessary in order to generate credible predictions.

While the model includes several constraints that limit allowable equilibria, some of the biophysical constraints do not appear to incorporate potentially important considerations. For example, the constraint on water availability for the agricultural sector does not appear to change over time to reflect influences such as population growth and climate change.

5. *Large Fluctuations in Outcomes*

The model results exhibit considerable "lumpiness", with large fluctuations in outcomes from one 5-year period to the next (see further discussion below). This suggests that individual predictions within a five year period may not be very reliable. The FASOM team suggested that this lumpiness is essentially a reporting issue. The panel believes that it is a more fundamental result of the model structure, although it is often difficult to trace the source of the fluctuations. In addition, results for 2065 (the second to last period in the analysis horizon) should not be printed in the output, since considerable end effects are still apparent.

IV. RESPONSE TO SPECIFIC CHARGE QUESTIONS

1. *Please assess the quality of the data inputs to the model. Specifically, do the parameters of the model (e.g., demand growth, yield rates, prices, quantities, elasticities, emission coefficients, etc.) have an appropriate basis (e.g., econometric estimation, support from existing literature)?*

a. *Specifically for agriculture*

b. *Specifically for forestry*

c. *Specifically for bioenergy including biofuels and bioelectricity*

d. *Specifically for the reference data used to construct the baseline (e.g., emissions baselines of EIA's Annual Energy Outlook, EPA's U.S. GHG Inventory, USDA historic and baseline data on commodity production, acres, and inputs)*

As noted above, the documentation does not contain a full listing of parameter values for the model, with specific sources. General statements appear throughout the report indicating general data sources (e.g., MLU, NRI, USDA extension publications) but the specific numbers that have been taken from these sources are not provided in any comprehensive way. In addition, if any of the data were based on econometric estimations, this could not be determined from the documentation provided. In some cases, specific numbers are presented, while in other cases they are not. For example, although data are given for shifts in agricultural import supply, domestic demand and export demand curves (Table 6-4), no corresponding data are given for the forestry commodities that are listed in Table 2-2. The documentation mentions (p. 1-4 to 1-5) that the models that were used to develop the forestry sector of FASOM-GHG are described in more detail in Adams and Haynes (2007), but without going back to other sources and trying to determine the specific parameter values that were taken from these other models, it is nearly impossible to assess their quality (see further discussion below). More generally, it was difficult for the review panel to assess the quality of many of the data inputs. The data sources that are cited are appropriate sources, but without detailed parameter values, it is impossible to assess whether data from these sources have been used appropriately.

In addition, in some cases where specific parameter values were provided, the basis for them is unclear and appears to be inconsistent with other available information. For example, some of the demand and yield growth assumptions are unsupportable by existing data or common sense, especially when projected out far into the future, and the underlying assumptions driving the selection of specific biofuel feedstocks are unclear. The following provides detailed comments on some specific data inputs, and some of the difficulty the panel had in assessing their quality.

a) Agricultural Demand Growth

Food and fuel demand growth determines the demand for agricultural output. A large proportion of cropland is used to produce feed for animals, which in turn is utilized to produce eggs, meat, and dairy products for human consumption. Growth in the demand for these products depends on population growth and income growth. FASOM-GHG does not take projections of world population and income growth and translate these projections into growth in demand for food. Rather, it captures growth in the demand for agricultural products through shifts in domestic and export demand (see Table 6.4 of the 2010 model documentation). FASOM-GHG's approach to modeling demand growth is described in the model documentation (page 6-9) as FASOMGHG also incorporates exogenous shifts in the domestic and export demand curves for agricultural products as well as the import supply curve that take place over time. These values are based on USDA long-term commodity projections and historical trends. Table 6-4 summarizes the default assumed annual rates of change in these supply and demand curves.

For example, from Table 6-4 U.S. domestic demand for fed beef shifts out by 0.75% each year. Export demand for fed beef shifts out by 1% each year. The effect of an annual 0.75% increase in demand is that over 40 years, demand has increased by about 34%. However, the USDA long-term commodity projections that were apparently used to generate these projections only extend to 2019, and are not intended to be predictive of demand shift in 50 to 60 years.

In addition, much of the demand growth for U.S. commodities is likely to occur in other countries because it is highly unlikely that China, India, Vietnam and other fast-growing countries can increase their food production fast enough to keep up with increases in food demand. This means that the U.S. will either be exporting an increasing share of domestic production of livestock feed or products made from U.S. animal agriculture in the future. The approach taken by FASOM-GHG to model demand growth is ad hoc in that it is not based in a transparent way on assumptions about population and income growth in the U.S. and in the rest of the world. The land and GHG impacts of a policy that increases CO_2 prices are likely quite sensitive to how food demand is met in the baseline. Thus it would seem prudent that a better way of translating population and income growth into food demand growth is needed.

b) Animal Productivity Growth

Given a demand in the growth for animal agricultural products, the resulting change in demand for land depends on the rate of growth in productivity of the livestock sector. Table 6-3 shows the annual productivity gains that FASOM-GHG assumes will be met in the future. Productivity improvements range from a high of 2.33% and 2.25% for milk production and broiler production, to a low of 0.17% for beef. Maintaining these rates of productivity gain over 40 years would result in a 60% reduction in the amount of feed used per hundred pounds of milk or per pound of chicken.

As an alternative measure, corn fed to hogs is reported as is production of slaughter hogs. The result of dividing feed use (corn only) by production is shown in Figure 1. The implied productivity increases in Figure 1 are much larger than the model documentation suggests. In Table 6-3 of the documentation, it is stated that productivity increases for hogs for slaughter is 0.61% per year. The implied productivity increases in Figure 1 average more than 1% per year. Either other feed is being fed to hogs (which is not discoverable in the data provided) or there is a discrepancy between what the model documentation says and the what is actually in the model.

Figure 1. Pounds of Corn Fed per Pound of Hog Slaughtered

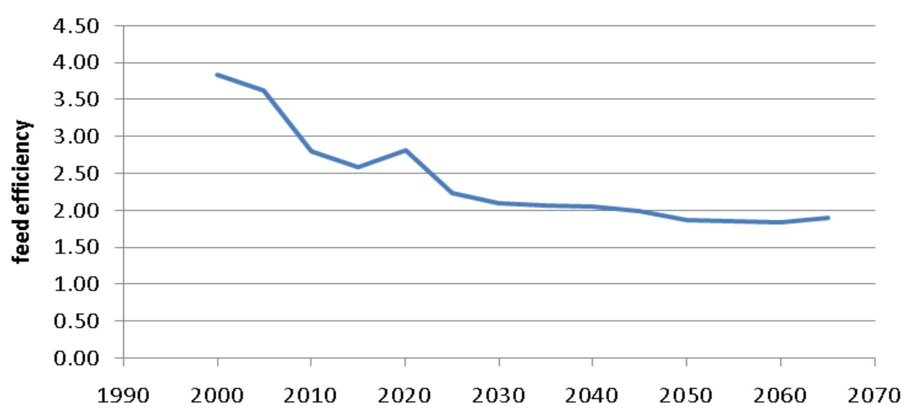
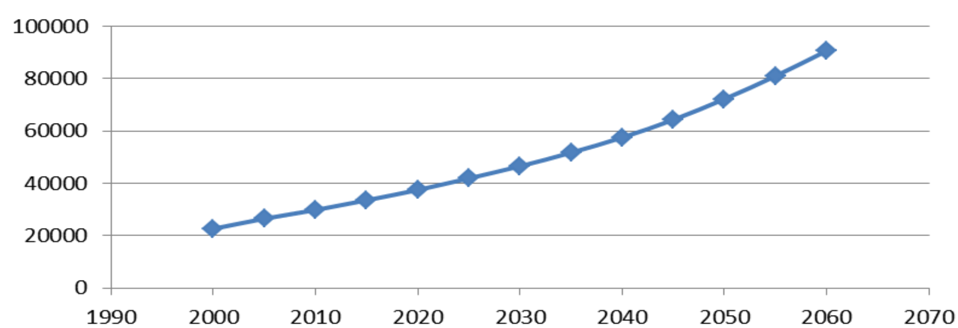


Table 6-3 of the documentation reports that FASOM-GHG assumes that milk productivity will increase by 2.33% per year.

From 1999 to 2009 the actual average annual change in "milk yield" was 1.48%.[3] But even this average annual change overstates productivity increases because it does not account for changes in feed use. An actual productivity increase should be measured holding feed use constant. So it seems that the assumed productivity increase for dairy cows is too high by at least a factor of two. To demonstrate how productive future cows would be under this assumption, the assumed milk production per cow (obtained from their html files) is shown in Figure 2. It just does not seem at all reasonable that milk production per cow will approach 40,000 pounds per year by 2020 when average production per cow is only now eclipsing 20,000 pounds per year per cow. The only possible way to accomplish this is a dramatic increase in feed efficiency and a dramatic increase in feed use per cow.

Figure 2. FASOM milk production per cow



With regards to broiler production, the model assumes an annual productivity gain of 2.25% per year. From 1989 to 1998, production of meat per slaughtered animal grew by 2.4% per year.[4] From 1998 to 2009, this growth rate declined to 1.2% per year. Applying the model's 2.25% rate of growth from 1998 for 30 years implies that meat production per broiler would exceed 9.6 pound by 2028. Current pounds of broiler meat per animal is 5.6. Thus, one can only conclude that the productivity gain assumed by the model is much too large by at least a factor of two.

Development of independent estimates of productivity gains for other livestock activities is beyond the scope of this review. However, the disparity between what the model assumes for dairy cattle and broilers with what the recent data show indicates that all

[3] Data for cow numbers and U.S. milk production obtained from FAPRI Outlook, available at http://www.fapri.iastate.edu/outlook/2010/.

[4] Data obtained from various issues of USDA reports titled "Poultry - Production and Value."

of these should be reviewed and feed use per pound of gain should be modeled explicitly.

c) Yield Growth

The model documentation reports a corn yield growth of 1.48% (Table 6-1). The html-reported production numbers result in a 1.56% annual yield increase, which again is higher than what the model documentation reports.

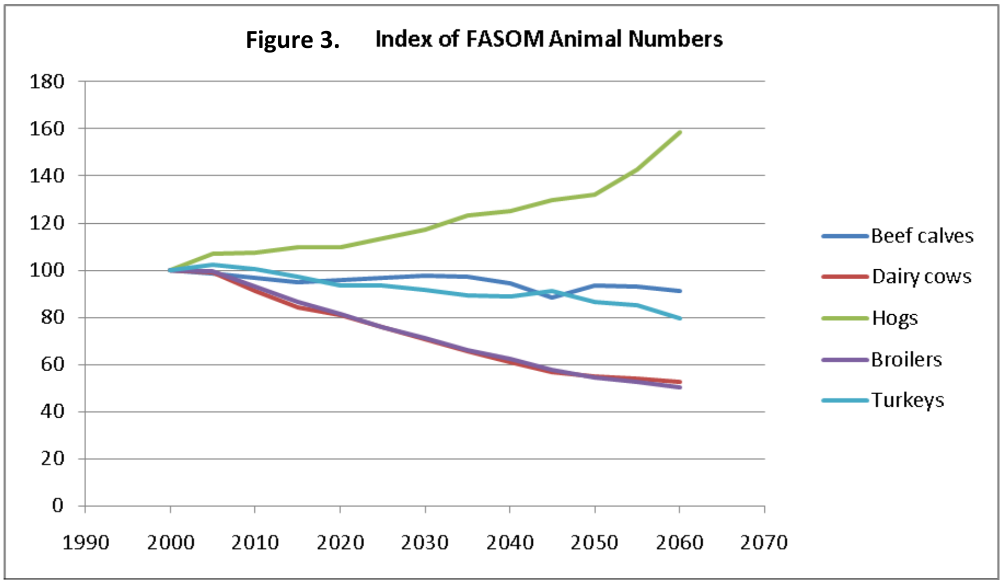
The actual average annual yield increase per harvested acre for U.S. corn production is 1.66% since 1980, 1.76% since 1990, and 1.74% since 2000. The documented corn yield increases in the model understate what has happened to U.S. corn yields. For U.S. soybean yields, FASOM-GHG assumes an annual growth rate of 0.43%. The actual annual yield growth rate from 1980 to 2010 is 1.43%, from 1990 it is 1.06% and from 2000 it is 1.59%. Thus it appears that the model is underestimating soybean yield growth rates substantially. The model documentation does not state on what data its yield growth rates are based. This should be made explicit.

d) Input Elasticities

Data presented in the previous paragraph implies that FASOM-GHG world projects corn yields will double in the next 40-60 years. The model assumes that this doubling in corn yields will require a 16% increase in N and P applications. This means that the ratio of yield to applied fertilizer will drop dramatically. Support for this assumption for at least N fertilizer comes from the dramatic drop in the ratio of corn yields to N applications in the last 30 or more years. This implies that less N is being lost to the environment and/or more N is being mined from soil organic material. The state of science on the question of whether these efficiency gains can be continued is in its infancy with little data or theory being generated to either refute or support the model's assumption. But this is a key assumption. One the one hand, if the efficiency N fertilizer use can be increased, this suggests that N_2O emissions from crop production will likely decrease in the future. However, if N applications have to increase, then perhaps N_2O emissions may begin to increase also. It is unclear how N_2O emissions are linked to applications of N fertilizer and resulting yield increases in the model.

e) U.S. Livestock Production

Because FASOM-GHG does not have an explicit link between world income and population growth and the demand for U.S. food, it is difficult to determine if the baseline livestock numbers are sensible. Because such a large portion of U.S. cropland is devoted to feeding animals, it is important to determine what U.S. feed demand is going to be. Figure 3 presents indices of livestock numbers taken from Table 114 in the html results for the sample model run. As can be seen, the baseline projections assume that U.S. populations of dairy cows, broilers, turkeys, and cattle for beef are all going to decline in the future. Only hog numbers are projected to increase.



The results in Figure 3 are a direct result of the strong productivity gains that the model assumes. However, as discussed above for broilers and dairy cows, the assumed level of productivity gains are much higher than can be supported by empirical data. Furthermore, no account is taken for feed use per pound of gain, which is what actually should be measured. The Figure 3 results indicates that the model's baseline projections imply much too low of demand for agricultural land because actual livestock numbers are likely to increase over the next 20 to 30 years.

f) Bioenergy Data

Developing and parameterizing a complex model that attempts to project future markets is a difficult task, and this is especially true for bioenergy. Not only must current costs and technological parameters be projected into the future, but costs and technological coefficients must be projected for technologies that do not yet exist, or are only in a nascent stage. In addition, the rate of technological growth must also be assumed. The "best available data" may be no data at all, but rather estimates based on expert opinion, best-guesses or proxies.

FASOM-GHG relies on a combination of actual data and expert opinion in parameterizing the bioenergy sector. The baseline technical data used to model bioenergy regarding conventional biofuels seems reasonable, and, in general, the model selects bioenergy parameters conservatively. The values for conventional grain-based ethanol conversion rates are in line with those used in other models. The conversion rates assumed for cellulosic ethanol (71.9 gallons per dry ton or 79.1 gallons per dry ton, depending on the feedstock), on the other hand, are at the lower end of the range of values that have been used. A recent Department of Energy study employed a range of 74 gallons per dry ton to 115 gallons per dry ton (West, et al 2009). Using rates of cellulosic feedstock conversion on the low end would tend to dampen the production of cellulosic biofuels, and reduce the value of producing cellulosic feedstocks.

Plant size and possible economies of scale play an important role in determining production decisions. In FASOM-GHG costs for biofuel production are derived by assuming a standard plant size - 75 million gallons per year for starch-or sugar-based ethanol and 100 million gallons per year for cellulosic ethanol. These sizes represent the prevailing structure of the industry with respect to grain-based systems. For cellulosic ethanol, there are no plants currently producing at anywhere near that scale, and it is not yet clear if cellulosic ethanol production will evolve similar to grain-based, or if it will evolve differently, with numerous small-scale plants. Evolution of costs and technology are among the many unknown elements surrounding cellulosic ethanol production. This could make a difference in the baseline results, since cellulosic ethanol production is observed to decline beyond 2025.

The baseline levels of bioelectricity production are low, although they do increase considerably in the carbon price scenarios. A recent study shows that bioelectricity outperforms ethanol across a range of feedstocks, conversion technologies, and vehicle classes (Campbell, et al. 2009). This suggests that the baseline benefits of bioelectricity may not be adequately captured in the model, although the offset potential is.

The main driver of expansion of biofuels production capacity is processing margins. Equilibrium margins should be equal to the cost of capital required to build a new plant. When margins exceed this level then new plants should be built. Based on an examination of the processing margins implied by the FASOM runs, this equilibrium relationship did not seem to hold. It appears that there needs to be a stronger zero-profit or long-run profit condition added to FASOM-GHG guiding expansion and contraction of the bioenergy sector.

One of the strengths of FASOM-GHG is that it contains a seemingly comprehensive list of bioenergy feedstocks that can meet the RFS. However, fairly small differences in technical assumptions concerning feedstock yields, conversion technologies, and production costs can lead to large changes in the amounts of various feedstocks that come into solution. The baseline solution that was provided to the panel reports that a large share of the cellulosic biofuel mandate will be produced from sweet sorghum pulp beginning in 2015. To make room for use of ethanol made from sweet sorghum, wet mill corn ethanol production dramatically declines and dry mill corn ethanol production never achieves today's production level until 2040.

The model's baseline projections suggest that we are going to limit the most cost effective way that the U.S. has of creating biofuels (corn ethanol from a dry mill plant), reduce ethanol production from existing wet mill ethanol plants, in favor or producing ethanol from a feedstock that does not yet exist. As pointed out above, these movements away from corn ethanol occur despite the fact that processing margins for corn ethanol plants appear to be quite high. There really is no way of knowing what underlying modeling process is driving these results without better knowledge of the model.

Given the large uncertainties about which, if any, cellulosic feedstocks will be used to produce cellulosic biofuels, and given the large differences in land competition between the different feedstocks (dedicated biomass crops use land whereas crop residues do not), and given the evidently large competition for land due to the $30 per ton CO_2 price in the scenario, low confidence should be given to a single model run that has chosen a particular feedstock to use. If too much confidence is given to any individual model run, then rather than being a strength, FASOM-GHG's comprehensive list of feedstocks is potentially a weakness. Nobody knows today which, if any, feedstocks will be competitive tomorrow. Model results that pick a single feedstock, sweet sorghum, and base all results on this single feedstock will reflect all assumptions made about this particular feedstock, when it is likely that some other feedstock (if any) will actually be the most competitive. An alternative approach would be to have a more aggregated representation of feedstocks – e.g., have two feedstocks designated as land using and non-land using – and then run the model forcing different proportions of each into solution to determine the land use consequences of alternative possible outcomes.

g) Forestry Data

As noted above, there are few data on the forestry sector in the most recent documentation. Rather, the documentation simply mentions (p. 1-4 to 1-5) that "the basic structure of the forest sector was based on the family of models developed to support the timber assessment component of the U.S. Forest Service's decennial Forest and Rangeland Renewable Resources Planning Act (RPA) assessment process". For the forestry sector, the data used in these models (TAMM, NAPAP, ATLAS, and AREACHANGE) are some of the best available regarding consumption, production, prices, and trade of forest products, and regarding forest inventory and forest area changes. However, it is difficult to assess how the data from these models have been used in FASOM-GHG without more detailed documentation.

In addition, it would be useful for the output of the model to show data prior to the base year (currently 2004, see p. 3-17) to detect whether the projected trends continue or diverge substantially from historical patterns. A base year of 2004 seems old by 2010. Although the model is appropriately designed for long-term projections (see p. 6-9), there have been substantial changes in trends in recent years. It would seem therefore useful to develop methods to quickly update the base year data, and to revise the projections as soon as new data become available.

For CO_2 accounting in FASOMGHG, according to the latest documentation (p. 1-5) the data were largely derived from the Forestry Carbon (FORCARB) model based on US Forest Service research (e.g. Joyce and Birdsey, 2000). Again, it would be useful to have these data in the documentation, like those provided for the agricultural sector in chapter 7 of the documentation, or to have them available in a central data base. Without the original sources and a more detailed description of how they were used in FASOM-GHG, it was impossible for the panel to assess more specifically the quality of the forestry data.

2. Please assess the theoretical and analytical quality (i.e., quality of assumptions, soundness of approach, appropriateness of approach, adequacy of representation, defensibility) of the following components of the modeling framework.

a) Agricultural Production

i) Sectoral disaggregation (representation of commodities and markets

ii) Production functions (functional form and parameters)

iii) Technological innovation (e.g., yield growth)

iv) Greenhouse gas emissions calculation (emissions/sequestration coefficients by source)

b) Forestry Production

i) Sectoral disaggregation (representation of commodities and markets)

ii) Production functions (functional form and parameters)

iii) Technological innovation (e.g., yield growth, forest management techniques)

iv) Greenhouse gas emissions calculation

c) Bioenergy Production

i) Production of alternative biofuels including corn-based and cellulosic-based ethanol

II) How Forestry and Agriculture sectors interact to project national land use change

iii) Quality of approach and usefulness of outputs

iv) National and regional scale resolutions (crop and livestock production, acres, input use particularly nitrogen fertilizer use, hard wood products production, acres afforested, management activities)

v) Sensitivity to alternative specifications or data

d) GHG Emissions and Carbon Sequestration

i) Are emissions from historical years consistent with the US EPA Inventory of US Greenhouse Gas Emissions and Sinks, and the USDA U.S. Agriculture and Forestry Greenhouse Gas Inventory?

ii) Are there technologies and practices that could significantly mitigate GHG emissions in agriculture and forestry that are not presently in the model? Are there complete datasets to provide an adequate basis for inclusion?

FASOM-GHG is a dynamic, non-linear programming model that solves for market equilibria by maximizing the net present value of the sum of producer and consumer surplus. This is a methodology that has precedents within the economics literature. The overall model structure provides a defensible basis for predicting the impacts of climate change policies on the agricultural and forestry sectors. As noted, the panel has not conducted a detailed review of the specific model equations or code, but, based on general model descriptions, the overall model structure appears appropriate given the assumptions made. It is a very powerful tool for agriculture/forestry sector analysis that has already been found useful in predicting the effects of GHG emissions.

Nevertheless, like all models its predictions depend on the underlying theory, data, and parameters on which it is based. For example, FASOM-GHG is a deterministic, dynamic simulation model. A fundamental premise of this modeling approach is that, at any given point in time, each agent making a decision knows with certainty all relevant information (including parameter values and functional relationships) for all future years and uses this information to compare and choose among alternative options. The long timeframe for the model and the difficulty of predicting technologies and other drivers far into the future raise concerns about the real-world validity of this premise, and highlight the need for both model validation and some recognition of the inherent uncertainties associated with model predictions.

In addition, the implementation of the modeling approach requires the specification of parameter values, functional forms, assumptions about future trends, etc. We have already provided some comments on these aspects of the model in the discussion above. Here we reiterate, summarize, and extend some of those comments.

a) Agricultural Production

i) Sectoral disaggregation. As discussed in detail above, the level of sectoral disaggregation in FASOM-GHG has advantages but also disadvantages. In the panel's view, the level of disaggregation in the model exceeds what is required, and perhaps even what is wise, for analyses extending 60 to 100 years into the future. Ultimately, the appropriate level of aggregation (disaggregation) should balance the ability to reliably predict exogenous factors affecting markets in the long run with the need for accuracy in describing production, consumption and environmental relationships. It is certainly not true that more disaggregation is always better. It is important to keep in mind the type of questions that the model is being asked to answer and the confidence that one can have in its predictions far out into the future. In future developments, the model developers might consider whether there are places where sectors within the model can be collapsed without serious loss of critical information or relationships. A more aggregated version of the model might be more transparent, be easier to run under multiple sets of assumptions (and hence do sensitivity analysis), and produce more credible results.

ii) Production Functions. There is very little discussion in the documentation about specific functional forms used in the model. Section 3 of the documentation describes the model structure using general functional forms. Specific equations embodying specific functional forms are not included. Thus, it was not possible for the panel to provide any comment on this aspect of the model.

With regard to parameters used in the production functions, again the panel found it difficult to assess these because of the discrepancies noted above.

iii) Technological Innovation. The model includes numerous assumptions about growth rates over time for, for example, yields for crops and livestock products, as well as shifts in import supply, domestic demand, and export demand curves (see Section 6 of documentation). Growth rates are assumed not just for aggregate categories but for very specific commodities, such as different types of wheat. In addition, the growth rates are assumed to be constant over the entire timeframe of a model run (e.g., up to 60 or 100 years). Some of the concerns that the panel has about the assumed growth rates were discussed in detail above.

iv) Greenhouse Gas Emissions Calculations. The GHG calculations are based on available data on inputs from crop budgets coupled with estimates from EPA, the IPCC, and the DAYCENT model developed by Colorado State University. These methodologies and data sources are appropriate.

b) Forestry Production

i) Sectoral Disaggregation. The number of forestry primary commodities (Table 2-1) is very large. As with the agricultural sectors, this has some advantages but also some disadvantages. The panel believes that there is possible scope for reducing the number of forestry commodities. The species (hardwood, softwood) and ownership (private, public) categories are reasonable. However, the distinction between pulplog and fuellog seems unneeded, as does the distinction between commodities in the woods and at the mill. Similarly, the number of wood products (secondary commodities, Table 2-2) is appropriate for lumber, plywood, and other panels, but may be excessive for pulp and paper products. Two pulp commodities (mechanical, chemical) and three paper commodities (newsprint, printing and writing paper, other paper and board) might be sufficient and simplify the model.

In terms of regional disaggregation, the model distinguishes 9 regions for forestry (Fig. 2-1 and p. 2-13), giving attention in particular to the Pacific Northwest, west and east of the Cascades Mountains. Again, this may be more than needed. The domestic forestry part of the model could be simplified by using three production regions (north, west, south). This seems to have already been done in the GHG part of the model (see p. 2-15).

One single domestic demand region, namely the entire U.S., may be enough to describe the demand for forest products.

Finally, the meaning of “imported softwood sawlog in the woods” is not clear. The documentation should contain a clear definition of all the commodities.

ii) Production functions. The model documentation mentions functions, as in “The hired labor is supplied according to a supply function”(p. 3-8), but there is rarely a documentation of the form of the functions. Sometimes, a reference is given such as in: “Softwood lumber imports into the United States from non-Canadian sources are based on a linear import supply function drawn from the 2005 RPA Timber Assessment Update (Haynes et al., 2007), which shifts over time to correspond to the base scenario in the Update” (p. 2-28), but an explicit formulation of these functions is missing. One exception is the explicit equation for transport cost [5.2] on p.5.-19.

Also lacking is a full formulation of the dynamics of the model. The latest documentation gives only the formulation of the static equilibrium at any point in time (p. 3-4). A sketch of the intertemporal objective function, maximizing welfare over the entire time period, is on p. 6-3. However, there is no mention of intertemporal constraints linking the state of the sector at a particular point in time to the previous states. These constraints seem especially important for the forestry sector. The state of the forest stock at any point in time should be a function of the previous state, of the harvest, of the reforestation, and the growth of the remaining stock during the inter-state interval. Apart from the brief reference to Johnson and Scheurman (1977), this formulation is not clearly given in the documentation. Constraints of this kind appear, for example, in Alig et al. (1998), but not in Beach et al. (2010) nor in Adams et al. (1999). Similarly, the level of timber stock (inventory) is usually taken as an important determinant of timber supply, in addition to price and interest rate. However, this functional relationship is not specified explicitly in the FASOM-GHG documentation (although it appears in Chapter 3 of Adams and Haynes(2007)). Instead, FASOM-GHG represents optimal harvest choices implicitly through first-order conditions, but this makes it difficult to evaluate, for example, the implied relationship between harvests and stocks. It seems important that an up-to-date and complete formulation of the model be incorporated in the documentation. Without this, it was impossible for the panel to review specific functional forms or relationships within either the agricultural or the forestry sector.

iii) Technological Innovation. According to the documentation (p. 6-11), “there are no exogenous increases in timber yields incorporated into the model”. However, as the reforestation activities can move land to managed forest types of higher productivity (Table 2-9), changes in silvicultural techniques seem to be captured adequately in the model. The documentation may need to acknowledge that so-called “soft data”, or “expert opinion” must inevitably, and legitimately, be used in this type of model. This is true for practically every aspect of the model (including demand, supply, cost, etc.), but especially for technical change, to represent developments that have yet to occur.

iv) Greenhouse Gas Emissions Calculations. FASOM-GHG models the dynamics of carbon in forests and forest products using the methodology in the FORCARB model developed by the U.S. Forest Service. This approach reflects current practice in the field and, notwithstanding the comment above regarding the need for better documentation, the FASOM team appears to be using the most recently available data (e.g, carbon tables from Smith et al. 2006 and products flows from Skog and Nicholson 2000). One issue that is not clarified in the model documentation is whether the carbon flows are consistent with the timber management practices chosen by the model. The Smith et al. data provide little information about how carbon flows vary with timber management practices. Yet, within FASOM-GHG there is detailed modeling of timber management (Table 2-9). Ideally, there would be consistency between carbon flows and timber management practices, especially if the model is used to investigate policy scenarios involving carbon payments.

c) Bioenergy Production

Modeling bioenergy production represents one of the biggest challenges in FASOM-GHG because it requires predictions of both future technologies and market conditions that are not currently part of observable market equilibria. Thus, the uncertainty in modeling this sector is far greater than the uncertainty in the modeling of the agricultural and forestry sectors, which have historical data that can at least in principle be used to validate these sectors of the model. For this reason, it is particularly important that the model be sufficiently flexible and tractable to run under alternative scenarios about future biofuels production, in terms of both quantity and feedstocks. As discussed in detail above, the panel sees some apparent inconsistencies in the modeling of biofuels production that raise concerns about the model’s predictions. In addition, the modeling and documentation suggest a level of confidence in future biofuels production-related choices that may not be warranted.

Despite the uncertainties about the modeling of bioenergy, which would exist for any model that would be used to predict the impact of climate change policies, clearly it is critical that bioenergy be modeled in a way that is as reasonable as possible. Bioenergy production is an important component of FASOM-GHG, with biofuels and bioelectricity receiving a comprehensive treatment.

Grain-based and cellulosic ethanol feedstocks are modeled with appropriate handling and storage costs. Demand for biofuels is exogenously specified, and held constant beyond 2025 at levels specified by RFS2. This is a reasonable approach, since there does not appear to be any better basis for modeling demand. In addition, within the model, while the total amount of ethanol produced is fixed, the share of ethanol coming from grain-based and cellulosic feedstocks can vary, depending on the price and availability of feedstocks. Thus, choices regarding specific biofuels alternatives are assumed to respond appropriately to economic incentives. Analytically, the model handles biofuels quite conventionally. Crop- and forest-based biomass are converted to biofuel by applying a biofuel per unit of biomass factor that varies among crops. Since total biofuel quantity is exogenous, biomass will come from the least expensive source; that is, land with the lowest opportunity cost. As noted above, the large array of biomass feedstocks available in the model increases the sensitivity to variations in parameter values for each individual feedstock.

FASOM-GHG makes assumptions about future cellulosic production costs that are reasonable based on estimates in the existing literature. Cellulosic production is in its infancy, and there is not yet consensus on the costs (or cost trajectory) producers will face. Thus, it is impossible to forecast which specific cellulosic conversion processes will emerge as commercially dominant. However, it seems prudent to assume that over time and certainly within the time horizon of FASOM-GHG, costs of cellulosic production on a per-ton basis will tend to decline over time as the technology matures. FASOM-GHG assumes that cellulosic feedstock conversion rates increase from a base level to a maximum feasible level by 2020. Given the uncertainty about future conversion rates, it would be helpful to know the sensitivity of model results to this assumption.

Although the basis cost assumptions about cellulosic biofuels are consistent with other estimates, the model's predictions regarding cellulosic production of ethanol are somewhat suspect. According to the model predictions, there is no "stickiness" of cellulosic production, i.e., in the predicted equilibria some sources appear and then disappear in later periods. Economic production of cellulosic biofuels is highly dependent on the proximity of the feedstock source to the biofuel plant. Sources that are economical in one period may indeed become uneconomical in later periods, but it is not clear whether they are to be replaced by feedstocks with the same proximity, and therefore the same logistics costs. This is particularly true if the cellulosic plants cannot utilize multiple feedstocks. Also, the cellulosic results would indicate that plants built to meet the RFS by 2020-2025 would gradually operate at considerably less than capacity over time.

The predicted time paths for different feedstocks also raise questions about the way the model incorporates biofuels. For example, ethanol's share of corn production in the baseline increases to 45% in 2055, while cellulosic ethanol production declines. While there very well may be economic reasons for such a trend to occur, the current political will seems to be to manage corn's share in ethanol production and foster growth of cellulosic feedstock production. The precise mechanism for managing cellulosic growth is as yet unknown. However, a cap on grain ethanol production would not be unwarranted, since growth would require incremental expansion of capacity (particularly of dry-mill plants).

In addition, some of the underlying assumptions and resulting predictions do not seem consistent with other empirical evidence. For example, whereas zero-tillage in corn remains fairly constant over the time horizon in FASOM-GHG's sample run, conservation tillage and conventional tillage do not progress smoothly, increasing and decreasing over time. Conservation tillage in particular shows a general decline from historical (2000 and 2005) levels. This does not seem to appropriately reflect the increased value from crop residue that can be removed from non-conventional tillage operations. Table 5-7 shows the harvestable residue rates for each crop/tillage combination. No residue harvest is allowed from conventionally-tilled land for any crop. Yet, there is evidence that some residue may be sustainably harvested from conventionally-tilled land (Nelson, et al. 2004). While it may be uneconomical to do so given the overhead and nutrient replacement, the yield penalty from switching to reduced tillage may make up for it. It could be a factor in high density corn producing regions.

In addition, it is difficult to ascertain from the results whether and when "constraints on agricultural production" (section 3.2.2), which have implications for the bioenergy sector, are binding. When projecting behavior of agricultural producer far into the future, it does not seem that it should be necessary to restrict future behavior to past patterns. For instance, footnote 17 on page 5-14 states that energy crop penetration is limited to 12.5%. However, if the U.S. is truly moving to a more significant role for agriculture in energy, it does not seem unreasonable to assume some regions may indeed become majority energy crop producers. Perhaps a progressive relaxation of these types of constraints over time can be managed. Another alternative might be to consider constant elasticity of transformation (CET) relationships between production activities to preclude the need for hard limits on activity bounds. Employing CET functions eliminates binding of arbitrary production constraints while maintaining the ability to increase production activities if it is economical to do so.

Finally, Table 7 shows many cellulosic ethanol activities to be producing at considerably less than the 75 million gallon minimum plant size (section 5.1.1) for many regions. This is true even if cellulosic feedstocks are aggregated (i.e., multiple feedstocks are allowed in a plant). Yet, no explanation for producing at less than full capacity in equilibrium is provided. In addition, significant biofuel production from switchgrass (in fact, from any of the agricultural land based cellulosic feedstocks) occurs only in 2030. Some explanation of these aspects of the model is needed to fully understand the model's drivers.

d) Modeling Land Use Allocations

FASOM-GHG represents major land uses and models land exchanges between the forest and agricultural sectors. This is a major strength of the modeling approach. The mechanism for land-use change in the model is relative profitability measured by the net present value (NPV) of rents from the land. According to the documentation (page 4-3):

The economic conditions for land movement are that when land moves into forestry, the net present value of the returns from one rotation in forestry plus the future value of forestland beyond the first rotation must be greater than the net present value of the land remaining in agriculture by at least the hurdle cost. For land moving from forest to agriculture, the net present value of land in agriculture must exceed returns to a rotation in forestry plus the future value of forested land by the investment cost to transfer land.

This description gives the impression that changes in land use are based on a comparison of the NPV from putting land into forestry until the end of the planning horizon to the NPV from agriculture to the end of the planning horizon, net of any conversion costs. In discussions with the FASOM team, the panel was told that the model actually evaluates all possible paths, including ones that involve subsequent land-use change in later periods,[5] and selects the one with the highest NPV. The second approach is consistent with optimal dynamic decision-making. The documentation should clearly explain this important feature of the model.

Because FASOM-GHG is large and complex, exogenous constraints are introduced in the model to facilitate the search for a solution. As explained by the FASOM team, one role of these constraints is to limit the scope of the problem by ruling out behavior that would clearly be sub-optimal. The constraint on forest land conversion prior to trees reaching a commercial harvest age is an example.

[5] For example, a path that selects forestry for 4 periods, then 2 periods of cropland, then forestry again, etc.

For a number of other constraints on land use, however, the rationale is much less clear. These constraints include: 1) no pasture to cropland conversions (see statement at the bottom of p. 2-21, although this seems to be contradicted by the statement on p. 1-3); 2) no range to forest conversions; 3) private grazed forest area is fixed; and 4) no conversions out of industrial forest. In the first three cases, there is evidence in the historical record that contradicts the assumed behavior. According to NRI statistics, between 1982 and 1997, 25 million acres of pasture converted to cropland. Of all the land leaving pasture, the largest share went to cropland. A smaller amount, 15 million acres, was converted to forest, a transition that is permitted within the model. Range-to-forest transitions, while limited by moisture availability in some areas, have been significant in parts of the western U.S. in recent decades. Finally, recent increases in forest area in the upper Midwest, particularly in Wisconsin, have been due to efforts by farmers to prevent cattle from grazing forested areas.

In the documentation, it is argued that the fourth constraint is consistent with historical data. This may be true, but surely industrial forest owners would sell their land (which many have been doing recently) if offered a sufficiently high price and the new owners would allocate it to whatever uses—including non-forest uses—generate the greatest rents. This is, in fact, the assumption that underlies the land allocation mechanism in the model. While one can safely rule out behavior that is clearly sub-optimal, placing restrictions on potentially optimal behavior could have serious consequences. In these cases, it is better to let the model determine whether the behavior is optimal. This is especially true when the model is used to evaluate policy scenarios that go beyond historical experience.

A key issue in land reallocation is conversion costs. The documentation mentions efforts to include hurdle costs to “reflect the fact that it may require an income differential above and beyond the opportunity cost in agriculture to get agricultural producers to switch to forestry” (p. 4-2). While every effort should be made to accurately measure the benefits and costs of alternative land uses, it is important that land-use decisions be consistent with the fundamental premise in the FASOM-GHG methodology that individuals know with certainty (given the deterministic nature of the model) the values of all parameters in all future years. In standard models of hurdle costs (e.g., Dixit and Pindyck, 1994), uncertainty about the future value of an investment is a critical ingredient. Table 4-1 reports per-acre conversion costs for each region and three cost categories: low, medium, and high. According to earlier documentation, these conversion cost schedules were largely based on expert opinion. Given the important influence that conversion costs are likely to have on land-use allocations predicted by the model, they should, at a minimum, be subjected to sensitivity analysis. Since none of the results provided to the panel contain sensitivity analyses, it was not possible for the panel to assess the sensitivity of the land reallocation to alternative specifications or data.

With regard to the scale of national/regional resolution, as noted above, it seems that the number of forest production regions could be reduced from 9 to 3. More generally, though, for land use the regional resolution seems reasonable. It is important to model separately areas that are rainfed v. dry, temperate v. cold, and mountainous v. flat because the possibilities for land use can be quite different.

Finally, the available acreage estimates for forests in Table 4-1 come from Moulton and Richards (1990). This information is outdated and subsequent studies of carbon sequestration costs (see Dempsey, Plantinga, and Alig 2010) have found that Moulton and Richards were overly optimistic about prospects for afforestation.

e) Greenhouse Gas Emissions and Carbon Sequestration

The documentation that the panel received did not include a time path for historical emissions that could be compared to data from existing inventories. As noted previously, this type of validation appears not to have been done, at least for the current version of FASOM-GHG (including the GHG accounting components of the model). However, the calculations of CO_2 emissions are based on direct and indirect energy use data from crop budgets, which should be the best available information of this type. In addition, according to the documentation, the estimates of methane emissions are based on the EPA GHG inventory for 1990-2003, although the panel did not independently verify consistency of the model parameters with this inventory.

Similarly, for the forestry sector, FASOM-GHG's carbon accounting method and data are based largely on the US Forest Service FORCAR model (see Joyce and Birdsey 2007), which should ensure that forest carbon estimates from the model are consistent with the U.S. Forest Service estimation and projections of forest carbon sequestration (though, see the comment above regarding the Smith et al. 2006 data). As for CO_2 sequestration, the forestry sector of the model allows for sequestration through afforestation, reforestation, timberland management, and harvest of wood products (Table 7-14, p. 7-39). This is consistent with the main potential role of forests as carbon sinks. As the model also describes the potential role of wood in bioenery production, it allows useful assessments of the trade-off between CO_2 sequestration and bioenergy production.

More generally, the model is comprehensive and very detailed in its inclusion of GHG mitigation technologies and practices. In fact, as with other aspects of the model, the level of detail and disaggregation here might even be "overkill." The panel does not see any additional mitigation strategies that should be added, except possibly the ability to increase the carbon pool in solid wood products.

3. *Please assess the usefulness of the model for evaluating the effectiveness of GHG-mitigation policy instruments, and for forecasting the impacts on the forestry and agricultural sector.*

a) Are the model results reasonable and credible?

FASOM-GHG incorporates a very detailed and credible description of current market conditions, relationships, and parameters in the U.S. agricultural and forestry sectors. As such, it can produce credible results and predictions within a timeframe over which these basic dimensions of the model continue to reasonably represent reality. This implies that relatively short run predictions are likely to be reasonable and credible (although, as noted above, model validation would increase confidence in even those predictions). However, when the model is used to predict impacts far into the future that involve large uncertainties regarding, for example, bioenergy technologies and demand (both domestic and international), it no longer produces predictions that seem reasonable to the review panel. Thus, without explanation of apparent discrepancies, model validation, and sensitivity analysis, the model results are lack credibility.

For example, according to the results files provided to the review team (see rfs_waxz_3_regagresults.html and rfs_waxz_6_regforresults.html), in the contiguous U.S. there were 346.5 million acres of private timberland in 2000, in addition to 320.2 million acres of cropland and 519.8 million acres of pasture. The figures for forest and cropland are close to NRI statistics on non-federal land for 2001 (404.8 million acres of forest and 369.5 million acres of cropland), but way off for pasture (119.2 million acres). Under the baseline scenario, cropland is projected to decline nationwide by 1% by 2065 and private timberland is projected to decline by 12%. These results are similar to those developed for the U.S. Forest Service RPA assessment, which project 3% and 7% declines by 2062, respectively, in cropland and forest area. As well, the forest to urban and forest to agriculture projections by FASOM are similar to those in the RPA assessment.

However, the RPA projects a decline in pasture area of 31 million acres, compared to a 207 million acre increase under the FASOM-GHG baseline scenario (see rfs_waxz_3_regagresults.html). This increase in pasture is implausibly large since it would require land to be drawn from urban uses, the Conservation Reserve Program, and public lands. Further, almost the entire change happens in the 5-year period between 2000 and 2005. While not as extreme, there are other instances of abrupt land-use changes under the baseline that do not comport with how land-use changes have happened historically. For example, afforestation in the Southern region is 2.0 million acres in 2000, 4.1 million acres in 2015, 12.2 million acres in 2045, and 0 acres in every other period. The FASOM team explained that these lumpy changes are a reflection of the way the model is solved. While that may be true, it raises questions about the reliability of projections made at a 5-year time step.

As another example, under the \$30 CO_2 scenario (or, roughly, \$100 ton C), forest area increases by about 88 million acres, or about 25%, relative to the base scenario. This is a very small response relative to other studies of afforestation policies, including the Adams et al. 1993 *Contemporary Economic Policy* study that used a precursor to FASOM-GHG. The difference is explained by competition for land by other activities, such as biofuels. A strength of FASOM-GHG is its ability to account for the full range of responses to carbon incentives. FASOM-GHG projects that a \$30 per ton price for CO_2 will lead to fairly significant reductions in cropland as landowners plant trees to obtain sequestration payments. For example, in the Excel table T58.NationalLandSummary, U.S. cropland decreases by 7.2% in response to a \$30 per ton CO_2 payment. However, this decrease in cropland leads to fairly large increases in crop prices, with corn, soybean and wheat prices all turning higher.

It is not credible that cropland would be reduced by this magnitude given such a large increase in agricultural returns. There has been a very inelastic four-year response of aggregate U.S. cropland to much higher returns beginning with the 2007 crop. The acreage elasticity with respect to own returns over this time period is about 0.03 (Barr, et al. 2010). This suggests that cropland supply is much more inelastic than assumed by FASOM-GHG. That cropland gives up 7.2% of acreage in response to a \$30 CO_2 price despite a resulting increase in crop returns suggests a much more elastic response than is consistent with the data.

Indeed the five years of high prices that U.S. farmers have received since 2006 provides an excellent opportunity for model validation. Through 2010, U.S. farmers have no responded to these high prices with any significant expansion of cropland. This is despite widespread knowledge that expansion of the biofuel sector and the subsequent tying of crop prices to crude oil prices has resulted in as permanent of change in crop returns as anybody could hope to capture. A comparison of FASOM-GHG model results from a doubling in modeled crop returns with what we have actually experienced in terms of conversion of cropland would be a valuable validation exercise. At a minimum one would hope to see a sensitivity run showing how a CO_2 price of $30 per ton would affect afforestation rates if cropland conversion elasticities are more in line with what we have seen over the last five years than with what FASOM-GHG currently assumes will happen.

For example, FASOM-GHG projects that a $30 CO_2 price would reduce cropland by 23 million acres between 2010 and 2020. The one time when the U.S. experienced a greater than 20 million acre movement in cropland (land that was cropped plus cropland that was idled) in a 10 year period was between 1974 and 1984, a period of high prices and large coupled government subsidies. The question that needs to be answered, but could not be answered by the panel because of a lack of readily accessible results data, is whether the change in relative returns to cropland vs alternative uses of land in the FASOM-simulated 2010-2020 period are comparable to the change in relative returns to land that the U.S. experienced during the commodity boom in the 1970s. It is clear that the current crop commodity boom has not led to widespread expansion in acreage. Thus to give the model projections some historical validity and credibility, they should be compared to the change in relative returns in the 1970s.

One observes at times that the results can change sharply from period to period, rising to high values and then crashing to zero and later rising again. This happens for example in the predictions of afforestation in the South. In the baseline scenario the output file rfs_waxz_6_regforresults.htm reports 2 million acres in 2000, 4.1 million acres in 2015, 12.2 million acres in 2045, and 0 acres in all other periods. These periodic spikes and crashes of reforested areas seem improbable.

In addition to the above concerns about specific model predictions, the responses to Charge Questions 2 and 3 highlight other features of the model that raise concerns about the credibility of long run predictions. For example, the modeling of domestic sectors is very detailed, in terms of products and regions, at times perhaps too detailed, leading to complexity, high maintenance cost and very long run times (one to two days)), diminishing the ability to conduct experiments and do sensitivity analysis. On the other hand, the international dimensions may be too sketchy. This seems to reflect a view that the future of U.S. agriculture and forestry are determined mostly by what happens within the country, the rest of the world being an after-thought. However, it is possible that the future of U.S. agriculture and forestry will be determined in large part by developments in the rest of the world. To the extent that this is true, the usefulness of FASOM-GHG will be diminished because of its limited ability to capture critical international influences and feedbacks (see, for example, Sohngen, Sedjo, and Mendelsohn (1999).

Likewise, as noted above, the panel believes that the credibility of the model would be enhanced by a thorough validation based on historical data, particularly given some of the features of the model One critical feature of the model is the ability of agents to calculate with certainty optimal intertemporal choices. While often invoked in economic analysis and modeling, this is a strong assumption, and there is painful evidence of crises due to the fact that people (producers, consumers, investors) did not foresee the consequences of their actions, or chose to ignore them. One possible strategy is to begin by assuming that the economy behaves "as if" agents had perfect knowledge about future conditions, but then check that the model predictions do fit the observations, at least in general trend. Again, this is a call for validation of the basic model structure. At a minimum, the model documentation should clearly discuss the information assumptions upon which the model is based and their implications. To the extent possible, some information about the sensitivity of the results to this assumption would also be very useful.

b) Does the model have enough flexibility to support the analysis of multiple types of regulatory and incentive-based regimes and input data sources?

It is clear from the variety of contexts in which FASOM-GHG has been used that it is a flexible model that is capable of analyzing a wide range of policy options. As indicated in Table 7-14 of the documentation, the model allows for the investigation of a wide range of mitigation strategies, affecting multiple greenhouse gases. That the model has been used many times in the past to investigate such strategies can be taken as an indication of its usefulness and its ability to analyze multiple regulatory options.

c) The model assumes a price for emissions and conversely an incentive for reducing emissions, as this is how the model facilitates a dynamic solution without 'churning', or cycling between activities. In terms of economic modeling with a dynamic perfect-foresight model, are there alternative methods or recommendations for attaining solutions without churning?

It seems possible that the cycling between activities is due to the model structure and solution technique. Mathematical programming can often give corner solutions, especially when it includes linear relationships. In addition, switching between activities in dynamic models is not uncommon and can be a result of several factors. For example, often there are multiple optimal, or near optimal, solutions. Although they lead to the same value of the objective function, they may be physically quite different. In addition, churning can occur when the costs of switching are not adequately captured. It might be advisable to introduce more structure, such as sunk costs or non-linear relationships, to avoid unrealistic fluctuations of activities.

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APPENDIX A:

SELECTED LIST OF PAPERS USING FASOM-GHG

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Response to "Final Report: Peer Review of the Forestry and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG) for Climate Change Analysis" by Kathleen Segerson, Bruce Babcock, Joseph Buongiorno, Scott Malcolm, and Andrew Planting, April 2011

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Table of Contents

I. Executive Summary

The U.S. Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG)[1] is an economic simulation tool used to evaluate the potential implications of proposed policy designs and alternative future economic, biophysical, and climatic conditions on the U.S. forestry and agriculture sectors, land use, and greenhouse gas (GHG) emissions. For over 15 years, the model has been applied for a wide range of forestry, agricultural, renewable energy, and climate policy analyses, as well as climate change impact analyses over both the short/medium-run (defined here as up to 30 years) and long-run (more than 30 years) time horizons.

ES.1 Peer Review Background

Given FASOM-GHG's important role in economic analyses of policies impacting the above sectors, the U.S. Environmental Protection Agency (EPA) sponsored an external peer review of the model. Stratus Consulting and its subcontractor Industrial Economics, Inc. (IEc) were contracted by EPA to manage an external peer review of FASOM-GHG. As stated in the charge provided to the Peer Review Panel (Panel) by the external contractors, the primary goals for initiating this peer review process were:

i. To help users evaluate the insights gleaned from FASOM-GHG results and the model's relative strengths and limitations,
ii. To comment on the economic methodology and utility of model results (in the general context of climate change analysis), and
iii. To identify opportunities for improvements to the model and suggest research directions that strengthen the credibility of model results.

In the end, the review was intended to generate a constructive assessment of the usefulness of FASOM-GHG to evaluate the effectiveness of GHG mitigation policy instruments through simulations of future land use changes and GHG mitigation opportunities in the U.S. forestry and agricultural sectors.

ES.2 Summary of Response to Peer Review

We, the FASOM-GHG development team, are grateful to the Panel for the time and effort they have devoted to conducting this peer review. The Panel's comments will serve as useful input as we define our priorities for future model development, documentation, and application. Ultimately, FASOM-GHG is a unique tool with broad applicability, as the Panel noted*: "It is clear from the variety of contexts in which FASOM-GHG has been used that it is a flexible model that is capable of analyzing a wide range of policy options … the model allows for the investigation of a wide range of mitigation strategies, affecting multiple greenhouse gases. That the model has been used many times in the past to investigate such strategies can be taken as an indication of its usefulness and its ability to analyze multiple regulatory options."* (page 33)

The peer review provides a number of constructive suggestions that will help to better communicate the model's strengths and weaknesses, and improve the model in the future (e.g., more regular and more detailed documentation updates, more international considerations, additional validation exercises). However, several key Panel comments about model shortcomings are inconsistent with the Panel's

[1] This model has also been referred to as "FASOMGHG" or "FASOM" in some recent applications.

statements regarding the model's function, role, and application. One particular inconsistency is the Panel's criticism of the model's predictive power, while elsewhere in the document the Panel recognized (correctly) that FASOM-GHG's main function is projected responses to policy change, not prediction. Large economic models are often used in the energy and climate policy community to gain valuable policy insight—not for predicting the future with strict accuracy (Huffington et al., 1982; Peace and Weyant, 2008). This misperception of FASOM-GHG as a predictive model leads the Panel to an evaluation of FASOM-GHG against criteria more applicable to other model types and functions and to recommendations that are not consistent with the typical use of the model and evaluation goals of this review process. As a result, we find that some Panel recommendations are not applicable or would not improve the usefulness of FASOM-GHG. We highlight some of those instances below.

ES.3 Response Highlights

First, we note a number of the Panel's comments regarding the overall strengths and utility of the model:

1. *"FASOM-GHG is among the few models that are able to [estimate] the impact of climate change policies on land use in the agricultural and forestry sectors. Since land use impacts are likely to be an important determinant of overall impacts on prices, quantities, and welfare, [estimat]ing these is critical for understanding and evaluating alternative policies. Thus, FASOM-GHG is a useful tool when used as part of a suite of models informing policy choices"* (page 2).
2. *"The overall model structure provides a defensible basis for [project]ing the impacts of climate change policies on the agricultural and forestry sectors"* and the model is a *"very powerful tool for agriculture/forestry sector analysis that has already been found useful in [project]ing the effects of GHG emissions"* (pages 20, 21).[2]
3. The model *"incorporates a very detailed and credible description of current market conditions, relationships, and parameters … can produce credible results and [projections] within a [time frame] over which current market conditions, relationships, and parameters in the U.S. agricultural and forestry sectors continue to reasonably represent reality"* (page 30).
4. The Panel stated that *"it is clear from the variety of contexts in which FASOM-GHG has been used that it is a flexible model that is capable of analyzing a wide range of policy options …. the model allows for the investigation of a wide range of mitigation strategies, affecting multiple greenhouse gases. That the model has been used many times in the past to investigate such strategies can be taken as an indication of its usefulness and its ability to analyze multiple regulatory options"* (page 33).
5. *"A strength of FASOM-GHG is its ability to account for the full range of responses to carbon incentives"* (page 31) and *"the model is comprehensive and very detailed in its inclusion of GHG mitigation technologies and practices"* (page 29).

Second, the FASOM-GHG team has already incorporated several constructive suggestions from the Panel and plans to address others in future model development. We highlight major updates here and describe them in more detail in Section II:

[2] Note that although we agree with these points overall, FASOM-GHG simulation output should be interpreted as "projections," not "predictions." This critical distinction is discussed in detail in subsequent sections.

1. Documentation updates (pages 3, 7, etc.): The Panel recommends more detailed and more regularly updated FASOM-GHG documentation. We prepared a version of the documentation focused on key model developments in recent years specifically for the peer review (Beach et al., 2010a) and plan to provide additional updates at multiple levels of detail suitable for different stakeholders on an ongoing basis (Section II.D).
2. Improved characterization of future agricultural commodity demand (pages 12, 13): We have econometrically estimated relationships between per capita commodity demand and commodity prices and incomes for commodities included within the model and have updated commodity projections based on exogenous projections of domestic and international populations and incomes (Sections II.H).
3. More detailed international linkages (pages 7, 32, 33): Although international trade is already reflected within the model, there is room for improved global integration. Members of the FASOM-GHG model development team have been involved in collaborative efforts with global modelers to further develop international components (Section II.G).
4. Conducting additional model validation (pages 3, 9, 30): In addition to the kind of sensitivity and comparative analyses typically done in studies applying FASOM-GHG (e.g., multiple scenarios, assumptions, and comparisons with existing literature), we have expanded our efforts to validate the model as appropriate for this type of model, as seen in Baker et al. (2011) (Section II.C).

Finally, one of the primary objectives of this review is to evaluate the model and its results for relevant applications, such as GHG mitigation policy analysis. The Panel considers a number of relevant issues; however, some important commentary and findings are based on mischaracterizations of the basic model functions and use. As a result, conclusions and recommendations based on the mischaracterizations are not relevant for FASOM-GHG, and therefore do not inform evaluation of the model or its future development. Specifically:

1. The Panel referred to and evaluated FASOM-GHG's ability to "predict" the future (pages 2, 5, 6, 7, etc.). However, although FASOM-GHG does project future scenarios based on variations in policy, technology, and other key factors, it is not a predictive model. Rather, it is a simulation model designed to examine possible future outcomes under various plausible scenarios for the purposes of evaluating potential implications of policy designs. For example, FASOM-GHG is often used to examine how the forest and agriculture sectors may respond to alternative future policy conditions relative to projections under business-as-usual conditions in the model. Simply put, FASOM-GHG output is a projection of what *could* occur given modeling assumptions and policy scenarios. Policy analysts and other clients often use FASOM-GHG to analyze the relative difference between two scenarios due to a change in a policy variable. This approach is particularly useful in understanding the potential market and environmental implications of policies for which there is *no or limited historical basis*. The fact that FASOM-GHG is a projections model is recognized in a few places in the peer review (page 4, the bottom of page 9, and top of page 10). However, a number of key peer review comments are based on the misperception that FASOM-GHG is used by developers and clients for making predictions with strict accuracy and should therefore be evaluated for its predictive ability. Because of this mischaracterization, several of the Panel's comments on the credibility of the model's results, model dynamics, aggregation, and validation based on predictive power do not apply.

2. FASOM-GHG is an intertemporal optimization model. This means that decisions in FASOM-GHG are modeled to explicitly recognize the role of expectations about future market conditions in today's decisions. This is frequently misunderstood to imply that intertemporal optimization models assume that decision makers have perfect knowledge about the future. Instead, it is an accepted modeling approach that recognizes and attempts to capture the fact that production and investment decisions today are influenced by expectations about future markets and returns on investments (i.e., expectations, rational or otherwise, drive today's decisions). The absence of expectations would be a much more significant shortcoming than the choice to model it as a full information problem from the outset.
3. The Panel assumed that sensitivity tests of model parameters and scenarios are not conducted because of model size, run time, and expense (pages 2, 8, 10, etc.). However, this is not the case. As numerous reports, journal articles, and other publications indicate, the FASOM-GHG modeling team regularly runs parameter sensitivities for model testing and policy analysis. Many FASOM-GHG research papers have been peer reviewed, indicating that those reviewers have been sufficiently satisfied with the selection and description of parameter assumptions and alternative scenarios to recommend publication.
4. The Panel found the detailed nature of FASOM-GHG both a strength and weakness. Regarding the latter point, the Panel commented that *"[a] more aggregated model is likely to produce more defensible results and be more useful"* (page 2). FASOM-GHG is built on a detailed data structure, which allows for direct use of commodity-level input data and estimated parameters from historical statistics and provides flexibility for exploring different issues. There is no reason a detailed structure in and of itself implies questionable results. The question is not whether the model is detailed or not, but whether the results are conceptually intuitive and scientifically acceptable. More aggregate reporting, however, is common with FASOM-GHG research because aggregate policy design insights are typically the focus. Reviewers for peer-reviewed publications and government reports have found these types of results intuitive, scientifically sound, and compelling enough for publication (e.g., Alig et al., 2010; Baker et al., 2010; USEPA, 2005). At the same time, valuable detailed FASOM-GHG insights have also been published. For instance, FASOM-GHG simulations have offered unique insights into the potential subregional distribution of policy impacts (e.g., Pattanayak et al., 2005). Such breadth of analyses is not possible with an aggregated version of the model.
5. Important clarifications pertaining to specific Panel concerns related to the credibility of FASOM-GHG's data inputs and simulation results, including land use categorization and simulated land use changes, fluctuations in output, time steps, yield growth rates, and international trade representation are provided in subsequent sections and the Appendix.

Despite the issues listed above, the Panel raised important points for consideration that will be helpful as we plan future model development and documentation to build on the important and unique role that FASOM-GHG plays in land use and climate-related policy analysis, including studies of GHG mitigation, renewable energy, and possible policy impacts on forestry and agriculture sector markets. In Section II we provide specific responses to key Panel comments and concerns. We discuss options for addressing these points, whether through additional documentation of features already in the model that may require clarification or through changes to the existing model data, parameters, or structure. The FASOM-GHG development team is engaged in revising and enhancing the model on an ongoing basis, and we expect to continue making use of the Panel's comments in prioritizing these efforts. Section III briefly summarizes and concludes our response.

In addition, we provide an Appendix that includes a number of more detailed responses clarifying how FASOM-GHG addresses specific points raised by the Panel, including references to model documentation and scientific literature, as well as supplemental information from the model development team. Specific clarifications are provided in the Appendix on topics such as model documentation, model structure, constraints, terminal conditions, disaggregation, demand growth, productivity change, timber supply, bioenergy, feed use, and other key issues.

II. Modeling Team Response and Plans for Addressing Comments

In this section, we respond to the Panel's main comments and discuss our plans for addressing specific comments. This section is organized around the major topics raised in the peer review document, as follows:

A. Credibility of Results
B. Model Structure, Dynamics, and Intertemporal Optimization
C. Model Validation
D. Model Documentation
E. Model Constraints
F. Level of Detail and Disaggregation
G. Characterization of International Markets
H. Role of Socio-Economic Drivers in Future Demand
I. Technical Change/Yield Growth in Agriculture

A. Credibility of Results

In response to the charge question "Are the model results reasonable and credible?" the Panel responded:

> *FASOM-GHG incorporates a very detailed and credible description of current market conditions, relationships, and parameters in the U.S. agricultural and forestry sectors. As such, it can produce credible results and predictions within a time frame over which these basic dimensions of the model continue to reasonably represent reality. This implies that relatively short run predictions are likely to be reasonable and credible (although, as noted above, model validation would increase confidence in even those predictions). However, when the model is used to predict impacts far into the future that involve large uncertainties regarding, for example, bioenergy technologies and demand (both domestic and international), it no longer produces predictions that seem reasonable to the review panel. Thus, without explanation of apparent discrepancies, model validation, and sensitivity analysis, the model results are lack[ing] credibility.* (page 30)

The Panel's evaluation of the credibility of FASOM-GHG's long-term results is based on several incorrect assumptions, including a mischaracterization of the model and its use, long-term precision of results and uncertainty, the use of sensitivities, and the role of expert judgment. All of these points are addressed below.

A.1 Model Mischaracterization

Most importantly, the Panel implied that FASOM-GHG is viewed as a predictive tool; thus, the criterion for evaluation is the model's ability to accurately "predict" future conditions (pages 1, 2, 3, 4, 5, 6, etc.). However, FASOM-GHG is a simulation model designed to simulate possible future conditions (given assumptions about the future) and evaluate the potential implications of proposed policy designs—not to produce exact predictions of technological progress and other conditions in the future global economy. Simulation models can provide unique insights into the potential effects of policy actions over time.

Specifically, FASOM-GHG is used for evaluating scenarios of potential future outcomes relative to a counterfactual future (e.g., with and without a policy), given a set of assumptions about technologies, markets, and biophysical conditions. In many cases, it is the magnitude of difference between these two futures that provides insights about potential policy impacts. It is primarily the Panel's mischaracterization of the model as being predictive that leads the Panel to conclude that *"the model results are lack[ing] credibility"* (page 30) (see Hendry and Mizon [2000a, b] for discussion of the differences in evaluation criteria between models used for forecasting vs. policy analysis). Unfortunately, this mischaracterization of the model meaningfully affects a significant share of the peer review. More specifically, the mischaracterization reduces the value of numerous Panel comments on model dynamics, aggregation, validation, and overall credibility of the model's long-term results.

Simulation models such as FASOM-GHG offer advantages for considering potential intermediate and distant futures where economic drivers may fall outside of historic ranges of data. This is especially true for simulating responses to potential policies that have not been introduced in past settings (for example, climate mitigation policies) or the development of new markets or technologies (e.g., new agricultural production technologies). Econometric forecasting models are often (though not necessarily) better suited for shorter-run predictions (e.g., 1 to 10 years) where deviations from historic trends are often expected to be modest, while simulation models are better suited for longer-run projections (e.g., 10 to 50+ years) where structural changes are more likely, deviations from history can be significant, and differences between potential alternative futures are informative.

It is necessary to simulate policy impacts at least as far into the future as the policies being evaluated dictate to inform related policy decisions (e.g., climate policy proposals can set targets for reductions through 2050). Also, in the case of forestry, longer-term analysis is often necessary to capture biophysical considerations (e.g., growth rates, rotation periods) as well as the related investment behavior. In general, analysis of the potential impacts of climate change or energy policy, or policies related to forestry, necessitates simulation of impacts decades into the future to provide policy relevant insights.

A.2 Long-Term Precision of Results

The Panel is correct when it stated that:

> *It must be recognized that no model should be viewed as providing definitive information about what will happen if a particular policy is adopted … [FASOM-GHG] should be recognized as one special representation of the U.S. agricultural and forestry sectors and the linkages between the two, and in the end it should be acknowledged that this and similar*

models are mostly useful for telling a coherent story, without obvious contradiction, for possible outcomes when a very complex system is subjected to a policy-induced perturbation. The ultimate test of any model's usefulness is whether it provides meaningful insight into possible policy-induced outcomes. (pages 9, 10)

Unfortunately, the review often deviates from this central principle.

The Panel found that *"one drawback [of FASOM-GHG] is that providing such detailed impact analysis can lead to false confidence or belief in the precision of the results, especially when impacts are projected far into the future"* (page 6). It is true that uncertainty increases the further one looks into the future, which is one reason why a simulation model like FASOM-GHG that provides a great deal of flexibility to introduce new technologies and evolving market relationships, conditions, and parameters can be an appropriate tool when medium- to long-run insights are needed.[3]

FASOM-GHG was not designed, nor is it used, to predict the exact long-run path of the U.S. agriculture and forestry sectors and related commodity markets. Rather, FASOM-GHG output is an estimation of what could occur given the modeling assumptions and policy scenarios. Thus, the model results should be viewed as insights as to what may happen under scenarios of plausible potential futures, where the primary focus is often on the simulated changes in outcomes under a policy case relative to the projected baseline. This includes circumstances for which there is limited or no historical data or experience from which to draw inferences (e.g., futures with significant GHG incentives or bioenergy production goals or the use of currently noncommercial technologies such as new agricultural production technologies). When the policies of interest introduce an entirely new market or price signal, as they do for some types of climate policy, the ability of the model to explain behavior in some historic period is not necessarily a useful indicator of the model's value for assessing impacts under conditions outside historical experience. Ultimately, it is the overall pattern of change (in land use, GHG emissions, etc.) in response to alternative scenarios that is most important to many FASOM-GHG users.

A.3 Clarifications and Responses for Specific Comments on Credibility of Long-Term Results

Although many of the claims regarding credibility are broad, the Panel did give some specific examples of why they found the long-run results lacking credibility (pages 30–33). To directly address these specific concerns, brief clarifications are provided here, with more detail in the following sections and in the Appendix.

- ***Land use categorization and shifts:*** On page 30, the Panel noted how *"the RPA projects a decline in pasture area of 31 million acres, compared to a 207 million acre increase under the FASOM-GHG baseline scenario … This increase in pasture is implausibly large …"* The Panel obtained this result from a regional production table that combines all pasture, cropland pasture, and rangeland into a single category called "pasture" for the purposes of that particular table. This is not one of the tables typically used in reporting land use and inadvertently included

[3] The Panel is correct that longer-run modeling, especially in the context of emerging markets, comes with greater uncertainty, regardless of the model type (page 24). A common approach for addressing long-run uncertainty with simulation models is to consider scenarios of alternative plausible and informative assumptions (e.g., higher/lower commodity demand, faster/slower technological improvement, or different policy conditions). This is the approach taken with FASOM-GHG, as discussed in more detail in Section II.B below. There are many uncertainties involved in any long-term analysis with any model, but a key strength of simulation models is the ability to examine numerous scenarios and scenarios that fall outside historical experience.

a reporting error in acreage calculations. In results highlighted for the Panel as those used by FASOM-GHG users for national acreage results, the combined U.S. pasture and cropland pasture area have the correct acreage allocation from the model solution—a decline of 41 million pasture acres from 2000 to 2050. This decrease is similar to the RPA projections cited by the Panel. In addition, there appears to be a misinterpretation of how land use is classified in FASOM-GHG.[4] Additional detail is provided in Appendix response number 32.

- ***Cropland response:*** On page 31, the Panel stated that under a \$30 CO_2 price, in the results they were given, FASOM-GHG found a 25% increase in forest land and 7.2% decrease in cropland. The Panel then finds that *"[i]t is not credible that cropland would be reduced by this magnitude given such a large increase in agricultural returns."* It is not clear what criteria the Panel used to conclude that the simulated contraction in agricultural land is too large or how that is consistent with their statement that afforestation is relatively small. Most of the Panel's comments on cropland response appear to disregard the increased returns available for forestry, competition for land, and the implications for landowner decision making. More details are in Appendix response number 2.
- ***Fluctuations in results*:** The Panel pointed out fluctuations in afforestation results (page 31) and questioned the reliability of projections made at a 5-year time step. Such fluctuations are not uncommon in multiperiod models of this type. In the absence of constraints on changes in activities between periods, there may be oscillatory shifts in elements of the projection from period to period as relative returns to alternative activities change. In these cases, one or more activities verge on optimality and may move in and out of the solution until some threshold is passed, at which point they are permanently included or excluded. This behavior can arise, in part, because of the "lumpy" nature of inputs or step-wise changes in costs or returns. Although model output can be smoothed out by averaging over multiple periods, the fundamental cause of the cycling should be recognized. It is not a deficiency of the model, but a result of inputs that reflect the best estimates of the user for the particular scenario under examination. We are in the process of exploring additional limits on changes in capital-intensive and other processes likely to have adjustment lags that potentially lead to solution cycles. More information is provided in Appendix response number 3.
- ***International details:*** As part of its finding on credibility, the Panel found that the international details are *"*sketchy*"* (page 32). As discussed in the model documentation (Section 2.6, Beach et al., 2010a), FASOM-GHG does include endogenous international trade effects. In addition, the model has been linked with detailed international models to better reflect international circumstances. FASOM-GHG's international details are discussed further in Section G below.
- ***Validation against historical data:*** Though we plan to conduct more validation exercises, some of the Panel's suggestions are not feasible (pages 9, 33). This is discussed further in Section C.
- ***Forward-looking model function:*** The Panel found the *"ability of agents to calculate with certainty optimal intertemporal choices"* (page 33), which is commonly called forward-looking behavior, a strong assumption and questions the implications of this assumption for model results. Intertemporal optimization is based on well-established economic theories on agent

[4] To develop the initial allocation of land across land uses, FASOM-GHG developers rely on the Major Land Use (MLU) database and the Natural Resources Inventory (NRI), both published by the U.S. Department of Agriculture (USDA). The area of land in "pasture" is developed to be consistent with the NRI classification of "grassland pasture" but to avoid overlap with some other land use classes reported in the MLU database. Thus, direct comparisons of these databases with FASOM-GHG outputs are not appropriate.

behavior and expectations and efficient capital markets. It is commonly employed in dynamic models where investment behavior is an important aspect of the potential policy response. This clarification is further discussed in Section B.1.

A.4 Sensitivity Analysis of Long-Run Model Results

Some comments on credibility reflect the Panel's assumption that FASOM-GHG users rely on future estimates without testing findings through sensitivity analyses (pages 7, 32): *"the modeling of domestic sectors is very detailed … leading to complexity, high maintenance cost and very long run times … [thus] diminishing the ability to conduct experiments and do sensitivity analysis."* Sensitivity analyses have been, and will continue to be, a major application of FASOM-GHG. One of the key aspects of most studies using the model has been comparison of results across alternative assumptions and scenarios. McCarl and Schneider (2001), Alig et al. (2010), and Baker et al. (2010) are specific examples, though the vast majority of published FASOM-GHG papers and reports perform sensitivity analyses.

Analysis of the potential impacts of climate change policies necessitates simulation of impacts several decades into the future to answer policy-relevant questions and is done routinely in models used for these purposes. Many uncertainties are involved in long-term projections with any model, but a key strength of simulation models is the ability to conduct analyses of numerous scenarios, including those that are plausible but fall outside historical experience. As with any model simulating the potential impacts of policies into the future, the uncertainties surrounding the results increase as one moves further into the future. The impacts of the underlying assumptions and parameters have consistently been and will continue to be thoroughly examined through sensitivity analyses.

Partly because of ample testing through sensitivities, FASOM-GHG has been, and is, a useful tool for policy makers, stakeholders, and the general public for providing meaningful insight into possible policy-induced outcomes in the forestry and agriculture sectors. Going forward, we will continue conducting sensitivity analyses on key parameters and assumptions, such as the work on future demand and alternative agricultural yield growth discussed in Sections II.H and II.I, respectively. In addition, we plan to conduct more model comparison and validation exercises to the extent feasible, both of which will entail sensitivity analysis.

A.6 Use of Expert Judgment

On page 7, the Panel stated that *"[i]n some cases, there are little or no historical data or peer-reviewed estimates available on which to base parameter values, thus requiring parameters to be set at levels determined by the expert judgment of the modeling team. The sheer number of parameter values that are needed presents a serious challenge. It is not clear to what extent it is necessary to rely on expert judgment rather than available data."*

In regard to input data, we endeavor to use the best data that are available, and FASOM-GHG's parameters are updated when additional or revised data become available. However, given data limitations, especially in many of the emerging or anticipated sectors and markets where FASOM-GHG is being applied, the best data available may need to be supplemented by expert judgment and best estimates about the future (e.g., technological change). The Panel did state that *"'expert opinion' must inevitably, and legitimately, be used in this type of model. This is true for practically every aspect of the model (including demand, supply, cost, etc.), but especially for technical change, to represent* *developments that have yet to occur"* (page 24). It is important to note that this is not a practice unique to FASOM-GHG, as other large optimization models in the agricultural science and economics literature use parameters drawn from expert opinion (Lonsdorf et al., 2009; Walsh et al., 2003).

Over more than 15 years since FASOM-GHG has been introduced, its developers and users have published a large variety of papers (including examples given to the Panel) in peer-reviewed/refereed journals based on FASOM-GHG results, most relating to some aspect of climate change impacts or climate change policy. The publication record suggests that a wide range of reviewers have been convinced that the model structure was appropriate and credible for applications used in published papers. Although the Panel's comments downplay the significance and meaning of this publication record, we believe it gives strong support for the credibility of the model. It is true, as the Panel noted on page 9, that journal articles do not include comprehensive descriptions of methodology and model structure but instead present features relevant to the application. Nonetheless, it is the role of the expert journal peer reviewers to judge model adequacy, the sensibility of outcomes, and the logic of the linkages between policy changes and shifts in simulation results. Recognizing that more in-depth discussion of model methodology is still desirable, we propose to make current and forthcoming documentation efforts described in Section II.D readily accessible via other publication outlets, including updates posted regularly on development team member websites.

B. Model Structure, Dynamics, and Intertemporal Optimization

The Panel offered suggestions regarding changes to model dynamics and function such as intertemporal optimization (pages 5, 21, 23, 33), confidence intervals (pages 6, 21, 33), fluctuations in results (pages 10, 11, 31), and the use of alternative functional forms (page 34). However, some of these suggestions cannot be readily incorporated because they are inconsistent with FASOM-GHG's basic model structure and the model's purpose. In this section, we discuss these specific suggestions.

B.1 Intertemporal Optimization

The Panel expressed concern that the modeling approach used for FASOM-GHG relies on the assumption that agents have perfect knowledge about future conditions or, in other words, have perfect foresight (page 33). Intertemporal optimization models, sometimes referred to as perfect foresight models, do not, however, portend that agents have perfect knowledge of the future. Instead, such models acknowledge that people make decisions based on expectations about the future. Incorporating expectations is an accepted modeling approach that recognizes and accounts for the fact that present production and investment decisions are influenced by expectations about future prices and returns on investments (see Section B.1.2 for examples of other models using this approach). For applications to forestry and other sectors making long-term investments, the absence of expectations would be a much more significant shortcoming than modeling expectations based on agents having full information.

The ability to react to changes in expected future market conditions resulting from current decisions is a basic characteristic of intertemporal optimization models. Optimization results are consistent with the supposition that agents are rational and respond with the best information available at the time, including changed expectations about future markets. This function of the model is based on well-established economic theories about rational expectations (Muth, 1961) and intertemporally efficient capital markets (Fama, 1970).

B.1.1 Comparing Intertemporal Optimization and Recursive Dynamic Models

One approach to implementing rational expectations in a modeling context is to assume that decision-making agents have at least as much information about the markets being modeled as is contained in the market model itself. In developing expectations of the future, agents in effect use the model to make projections of future periods. In this way, the influence of decisions being considered in the current period will be reflected in expectations of future market characteristics. This can be implemented in a model in many ways. For example, Adams and Haynes (1980, pp. 22–23), in a submodel of investment decision, assume agents use the demand and supply equations of their model to project future prices but with lagged (past) values of all shifters except the investment variable being adjusted. In the intertemporal optimization context of FASOM-GHG, agents use the model's demand and supply relations and future expected values of all shifters.

Conversely, there are myopic models (which can be static models or can be structured as recursive dynamic models). For a discussion on such model types in relation to forest modeling, see Sohngen and Sedjo (1998). In myopic models, expectations of future values of a variable are sometimes developed using processes completely independent of the model's structure, often through some form of econometrically estimated distributed lag in past values of the variable and correlates or simply as a fixed investment component. Other information contained in the model, such as parameters of behavioral relations, is ignored. Importantly, in this and related approaches, expectations of future market characteristics are unaffected by the decisions of agents being considered in the current period.[5] There is no feedback from expected changes in future market conditions to decisions in the current period.

Myopic (or recursive dynamic) models are used as well for climate policy analysis, but intertemporal optimization models enable exploration of certain issues, such as investment/disinvestment decisions and the implications of land owners and firms anticipating future carbon policies and timber markets (e.g., Alig et al., 2010; Sohngen and Sedjo, 2006; Blanford et al., 2009; Tavoni et al., 2009; Rose and Sohngen, 2011). In practice, dynamic optimization models have proven to be highly flexible in examining policy questions, partly because of the specification of intertemporal market welfare maximization in the model objective. This provides a ready basis for driving adaptation to policy change in the market solution.[6]

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[5] As noted in Beach et al. (2010a), the Agricultural Sector Model (ASM) was a predecessor to FASOM-GHG that contained only the agricultural sector and solved for a static equilibrium. Based on exploration of using intertemporal optimization for joint forestry and agricultural GHG mitigation (Adams et al., 1993), model developers recognized that ASM did not adequately reflect dynamic issues associated with forestry management (long-term investment and related behavior) or land allocation between forestry and agriculture. Thus, FASOM-GHG was initially constructed to link an intertemporal model of the forest sector with a modified version of ASM in a dynamic framework.

[6] For example, FASOM-GHG has been used in studies to analyze voluntary carbon offset sales programs on private U.S. forest lands (Latta et al., 2011). Land is enrolled in the program or not as the prospective carbon revenues change land values. Payments for carbon accumulation (or charges for reductions associated with harvests) for the lands enrolled in the program are discounted and added to the objective function. Changes in intertemporal price expectations are accounted for directly in the dynamic objective, and allocation of harvest changes across elements of the inventory (ages, sites, forest types, owners, regions) is determined as part of the market welfare maximizing solution. Although carbon offset sales are discussed as a mechanism for enhancing forest carbon sequestration, recursive dynamic (or static) models have yet to be used to simulate the policy, in part because of the changes needed in the typical static model structure. The primary concerns would be respecification of timber supply functions to include both carbon payments and charges and the identification of rules to

B.1.2 Intertemporal Optimization Models and Applications

Investment behavior and expectations about future markets are important parts of evaluating climate and energy policy. Intertemporal optimization modeling can play a valuable role in the analysis of policies impacting sectors that are strongly influenced by investment behavior, such as forestry and energy, where expectations about future market conditions influence whether to invest today. If it were not for expectations about future returns, many trees would never be planted, and factories, power plants, etc. would never be built.

Intertemporal optimization has been and is currently widely used in many other models employed for climate policy analysis, including:

- Global Timber Model (GTM; Sohngen, Mendelsohn, and Sedjo, 1999);
- Applied Dynamic Analysis of the Global Economy model (ADAGE; Ross, M.T., 2008);
- Intertemporal General Equilibrium Model (IGEM; Goettle et al., 2008);
- Model for Evaluating the Regional and Global Effects of GHG Reduction Policies (MERGE; Manne, Mendelsohn, and Richels, 1995);
- Energy Technology Systems Analysis Program—TIMES Integrated Assessment Model (ETSAP-TIAM) developed in Canada (Loulou et al., 2005);
- Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), developed in the EU (Messner and Strubegger, 1995),
- World Induced Technical Change Hybrid (WITCH), also developed in the EU (Bosetti et al., 2006), and
- European Union FASOM (Schneider and Schwab, 2006).

B.2 Confidence Intervals

The Panel suggested on page 6 that *"the fact that the model is deterministic means that there are no confidence intervals given on any of the predictions and hence no information about the large uncertainties or potential errors that surround them."* Given the size and structural complexity of FASOM-GHG, producing confidence intervals around simulation output is computationally infeasible and inconsistent with the model's primary function in policy analysis. There are thousands of parameters in FASOM-GHG with underlying probability distributions that (if varied) can potentially alter simulation trajectories. FASOM-GHG is not alone in this regard; other complex deterministic economic models do not produce confidence intervals around simulation output. Instead, FASOM-GHG and other large deterministic models usually explore uncertainty through sensitivity analysis by using alternative scenarios to identify and evaluate potentially important assumptions. With a long model horizon, multiple scenarios are more practical than confidence intervals because the underlying distributions on assumptions and coefficients become questionable the further into the future one looks.

Given the highly flexible FASOM-GHG model structure, we can readily explore numerous alternative scenarios. However, we have conducted stochastic runs to generate confidence intervals for certain

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allocate harvest changes across inventory components and regions. Other methods would have to be found to differentiate between lands enrolled and not enrolled in the program (an aspect readily modeled in dynamic models) and to reflect changed expectations about future prices.

results using the agriculture component of the model only. Extending this framework to the dynamic forest sector would require a drastic aggregation and simplification of the current model structure whereby much of the model's usefulness in policy analysis would be lost.[7]

B.3 Fluctuations in Results

The Panel discussed the fluctuations of outputs from dynamic linear programming models (pages 5, 10, 31). On page 4, they stated that *"for several variables, the predicted levels fluctuate considerably across periods, with some activities coming in and out of solution in unexpected ways. If this is simply a lack of 'smoothing,' then it would perhaps be better to report results with longer time intervals (e.g., 10 years rather than 5 years)."* Such fluctuations are endemic in multiperiod models of this type and not unique to FASOM-GHG. The fundamental cause of such fluctuations should be recognized: It is not a deficiency of the model, but a result of inputs that reflect the best estimates of the user for the particular scenario under examination. Unless one enters arbitrary constraints limiting changes in activities between model periods, the model solution may shift between activities as one begins to offer relatively higher returns. Results can be, and have been, aggregated across longer time periods or annuities used in reporting to smooth changes in individual periods, with the most appropriate level of aggregation determined by the analyst for a given application.

We have been exploring some additional limits on movements in activities between periods as a means of moderating these shifts. At the moment, we can use mix constraints to limit agricultural production to linear combinations that lie within historical experience (more on constraints in Section II.E).

B.4 Incorporation of Constant Elasticity of Transformation Functions

As described in Adams et al. (2008) and Beach et al. (2010a), FASOM-GHG is a mathematical programming model that selects between alternative fixed coefficient production processes to optimize market surplus (and find the market equilibrium). Therefore, the model does not have continuous production functions that could be replaced with constant elasticity of transformation (CET) functions, as suggested by the Panel (page 26).

C. Model Validation

The Panel suggested validation exercises *"as a test of whether [FASOM-GHG] can reproduce historical outcomes"* (page 9). Validation checks are an important modeling consideration. But validating a long-run simulation model such as FASOM-GHG (or even a myopic simulation model) is a different exercise than the approach suggested by the Panel (pages 9, 33), which is an approach more appropriate for an econometric forecasting model.

C.1 Different Validation Approaches for Different Model Types

[7] Contained within the model is a stochastic agricultural sector version that we have run on a static basis to generate confidence intervals on a number of results, particularly for alternative climate change impacts in recent applications (e.g., Beach et al., 2010b). However, we do not think it is practical or computationally feasible to have a stochastic version of the combined dynamic forest and agricultural sector model at the scope covered by FASOM-GHG any time in the foreseeable future. Generally, stochastic representations in dynamic models are fairly limited in scope because of the inherent difficulties in developing the probability distributions.

Simulation models are often designed to consider long-run potential futures, which often fall outside historic experience (though it is important to note that such models are also useful for short-run analysis). Thus, analysis of forecast errors based on historical data as a validation method for long-run simulation models can be of limited value. Generally speaking, when the objective of modeling is primarily or exclusively 'predicting the future,' validation is commonly based on an array of forecast error measures and their components, both in- and out-of-sample. If near-term accuracy is a priority, then this validation approach may be practical. This approach has been employed with some static models in the forest sector.[8] However, FASOM-GHG is not designed to predict the future within the boundaries of historic variability. It is designed to entertain potential futures with new technologies and policies that can push market activity beyond history, but consistent with economic theory.

If the intended model application is policy design analysis for longer-run futures (which is a typical application of FASOM-GHG), then the model yielding the best prediction may not be the appropriate choice (Hendry and Mizon, 2000a, b). Correlation does not necessarily imply causality or give insights into causation.[9] A model being used for policy analysis has to structurally include variables affected by policy instruments to be of any use in simulating the impact of applying those instruments. Thus, as Hendry and Mizon (2000b) note, "…policy models require evaluation on policy criteria." The objectives for development of FASOM-GHG are of this latter sort—it is a model designed to evaluate policy and to do so in the longer term.

C.2 Validation of Simulation Models

Validation for simulation models can consist of review of parameters and conceptual structure, theoretical and practical reasonableness of responses, and comparison to historic trends—all in light of the assumptions. Since the peer review was initiated, members of the FASOM-GHG team have worked to address some of the concerns about parameters raised by the Panel (for instance, work on future commodity demand and yield growth, covered in Sections II.H and II.I, respectively).

In addition, although validation of models such as FASOM-GHG may involve simulation comparisons with history, another key aspect of validation is an evaluation of whether the model produces policy simulation results that meet analysts' qualitative expectations of future change and, to the extent possible, are supported by results from other models of whatever type. For an example of such a process, Baker et al. (2011) compare observed trends in agricultural markets, input use (particularly land use and synthetic nitrogen fertilizer application), and GHG emissions to baseline projections over the medium term (2010 to 2030). Baseline projections from this study harmonized favorably with the past, providing a qualitative validation of results under anticipated business-as-usual conditions. In the future,

[8] For example, Buongiorno et al. (2003) report historical model forecast errors for a version of the Global Forest Products Model (conditional on given roundwood supply shift rates over the historical period). Adams and Haynes (2007, Chapter 8) describe a similar process with the Forest Service's TAPS modeling system, which FASOM-GHG relies on to inform future supply and demand in the forest sector (see Section D and Peer Review page 9). In that instance, validation was done in only a restricted way given the lack of historically comparable forest inventory data over time. This latter limitation would also be an issue for FASOM-GHG in a similar exercise. No more than one or two historical 5 year periods could be compared, because usable inventory data are not available before 2000.

[9] Models that provide the best predictions may have no basis in economic theory or have an economic structure that provides insights into target variables and policy instruments of interest to policy analysts. For example, technical stock market analysts have found high levels of correlation between annual stock market performance and the conference winning the Super Bowl, among numerous other barometers (Kreuger and Kennedy, 1990; Kester, 2010).

the FASOM-GHG development team will perform similar validation exercises to ensure that baseline results line up reasonably well with observed history. Lastly, we can compare results with the latest USDA projections (though only short-term comparisons are possible because USDA routinely only projects 10 years into the future). If a longer-term validation exercise is necessary, we can compare overall commodity price and U.S. production trajectories to International Food Policy Research Institute (IFPRI) or International Institute for Applied Systems Analysis (IIASA) projections, though these are vastly different models that handle land use, international trade, and U.S. production possibilities differently than FASOM-GHG.

D. Model Documentation

In this section, we discuss the documentation and other information on FASOM-GHG that was shared with the Panel for this review as well as planned improvements in documenting model developments in the future.

D.1 FASOM-GHG Documentation, Papers, and Outputs Shared with the Panel

The Panel asserted that their review was inhibited by a lack of information (page 8). At the outset of the review, the Panel received electronic copies of the following documentation and papers and articles:

- Documentation:
  - Beach et al. 2010a. Model Documentation for the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG).
  - Beach and McCarl. 2010. U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM-GHG Results and Model Description.
  - Adams et al. 2008. FASOM-GHG Conceptual Structure, and Specification: Documentation.
  - Adams et al. 1996. The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Applications.
- Papers:
  - Beach, McCarl, and Thomson. 2010. Climate Change Impacts on US Agriculture. Contributed paper at the IATRC Public Trade Policy Research and Analysis Symposium "Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security." Universität Hohenheim, Stuttgart, Germany, June 27–29, 2010.
  - Beach, Birur, and McCarl. 2010. Impacts of Large-Scale U.S. Biofuels Production on Agriculture, Forestry, and Land Use. Paper for presentation at the International Energy Workshop, Stockholm, Sweden, June 21–23, 2010.
  - Baker et al. 2010. Net Farm Income and Land Use under a U.S. Greenhouse Gas Cap and Trade. *Policy Issues*. April: PI 7.
  - Beach et al. 2009. Modeling Alternative Policies for Forestry and Agricultural Bioenergy Production and GHG Mitigation. Paper for presentation at the Association of Environmental and Resource Economists Workshop Energy and the Environment. June 18–20, 2009. Washington, DC.
  - Alig et al. 2001. Alternative Projections of the Impacts of Private Investment on Southern Forests: A Comparison of Two Large-Scale Forest Sector Models of the United States.

- Sohngen and Alig. 2000. Mitigation, Adaptation, and Climate Change: Results from Recent Research on US Timber Markets.
- McCarl et al. 2000. Effects of Global Climate Change on the US Forest Sector: Response Functions Derived from a Dynamic Resource and Market Simulator.

In addition to these publications, the Panel also received a set of model results for various carbon price scenarios and related Excel™ sheet tables that highlighted key tables often used by the model developers. They were also offered access to the model code and the opportunity to confer with the model developers, which were not used. Lastly, many reports and papers are publicly available on the websites of model development team members as well as other documents that would have been provided upon request. For instance, hundreds of pages of existing documents describing FASOM-GHG are readily available online. As a result, we believe that the Panel had ample documentation and access to information to conduct a full review.

D.2 Documentation of Dynamics

With any model, documentation updates are important and often challenging because of continual model developments and updates.[10] FASOM-GHG documentation was updated for purposes of the peer review in 2010. The Panel referred to *"the lack of comprehensive documentation is in contrast to other models used for climate change analysis, such as the DICE model"* (page 8). We followed up on the Panel's suggestion of the DICE model documentation as an example to emulate. On web pages for that model,[11] we found a publication from 2000 (Nordhaus and Boyer, 2000) as the most recent comprehensive documentation, though there are updates on the 2007 version of the model available within Nordhaus (2007). This is similar to the FASOM-GHG documentation given to the Panel (e.g., comprehensive documentation from 2005 and an update from 2010). The Panel also suggested that *"it would be very useful for individuals to have access to a complete mathematical description of the model, including the dynamics, and to all the data, in the same document or website"* (page 9). Such an effort for FASOM-GHG would consist of thousands of pages of data and code. The level of detail provided in models like DICE does not approach that provided by FASOM-GHG; thus, this is not an equitable comparison for either model.

D.3 Ongoing Efforts to Improve Documentation

The FASOM-GHG development team acknowledges the need to update the model documentation more regularly as suggested by the Panel (pages 3, 8), because changes are routinely made to the model. This will be a priority in the future. We now have efforts in place to provide three categories of documentation online as well as improved output table formats for easier dissemination and assimilation by those not familiar with the model outputs. Lastly, we plan to improve representation and accessibility of FASOM-GHG-related documentation and papers online.[12]

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[10] The Common Agricultural Policy Regional Impact—The Rural Development Dimension project "The Literature Review of Methodologies to Generate Baselines for Agriculture and Land Use" (Blanco-Fonseca, 2010) looks at assumptions and documentation availability for a variety of models, including for example FAPRI (page 13), used for world agricultural markets projection baselines.

[11] http://nordhaus.econ.yale.edu/dicemodels.htm and http://nordhaus.econ.yale.edu/DICE2007.htm.

[12] Currently FASOM-GHG materials can be found at http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers.htm and http://www.cof.orst.edu/cof/fr/research/tamm/FASOM_Documentation.htm

The first category of documentation is a longer, comprehensive document that will provide an updated and enhanced version of Adams et al. (2008). The second category will include updates focusing on model changes that have occurred since the previously mentioned larger update. These shorter, timely updates highlighting key changes to the model will provide a valuable complement to the full model documentation and should facilitate communication with those interested in detailed information on the latest model developments. An example of this second category is the documentation we prepared specifically for the peer review (Beach et al., 2010a), highlighting key model assumptions and providing information on current assumptions and updates (e.g., the expanded bioenergy sector) not available elsewhere. Third, we are planning to provide a brief executive summary of model developments that will accompany the periodic updates. This level of documentation would be aimed at those seeking a top-level overview of the current status of the model coverage and capabilities.

E. Model Constraints

The Panel stated that:

> *FASOM-GHG includes a number of constraints on choices. While some of these serve simply to reduce solution time, others have the potential to rule out choices that might be optimal under certain scenarios. The model documentation should clearly identify which constraints are potentially binding (change choices) and which are not. For those that are, the rationale for these constraints needs to be carefully explained and the sensitivity of the results to inclusion of the constraint should be provided.* (page 3)

However, it is not possible for the model documentation to clearly identify constraints that are or are not potentially binding because this is an empirical question, depending on the specific case being analyzed rather than a general conceptual issue. In general, constraints are not included in the model structure unless there are expected to be at least some cases where they would be binding. We will nonetheless endeavor to add clearer discussion on the nature of the constraints within the documentation.

E.1 Applicability Outside Historical Experience

Similarly, the Panel stated that, *"if the model is used for the analysis of policies that go beyond historical experience, care must be taken to ensure that the sub-optimality assumption embodied in the constraint continues to be valid"* (page 10). The Panel is right that the validity of imposing constraints depends on the context of the specific simulation. For instance, in the Panel's example of industrial forestland in the future possibly going into agriculture (pages 10, 30), the reviewers recognize that significant amounts of forest industry (FI) timberland have not moved into agriculture historically. Instead, there has been a major migration of nonindustrial private lands (NIPF) lands to agriculture, and almost none from FI. A partial explanation of this behavior is that industrial ownerships typically contain limited areas suitable for agricultural use. However, over time, timberland ownership and management have changed. Land ownership has been extensively decoupled from manufacturing operations. Assuming the availability of information on the agricultural productivity of convertible industrial timberland, we could model and run sensitivities on this land use change option.

E.2 Bioenergy Production

Lastly, as explained to the Panel in October 2010, the results provided for the review loosely reflected a constraint on biofuel production that limited total production to be consistent with the Energy Independence and Security Act (EISA) (U.S. House of Representatives, 2007).[13] Also, based on analysis performed by EPA (USEPA, 2010a, 2010b), most new corn ethanol capacity is expected to be from dry mill construction, not wet mill construction. Therefore, over time, as older facilities are retired, the share of wet mill ethanol facilities is expected to decrease. Although corn ethanol production may be profitable, it could be less profitable than sweet sorghum ethanol production in some regions under conditions specified for this model run, leading to a reallocation of feedstocks used to meet the specified volume requirements away from corn toward sweet sorghum in this particular scenario. It should be noted that the individual biofuel volumes in the results reviewed by the Panel do not match the individual biofuel volumes in EPA's analysis of the RFS2 (e.g., sweet sorghum and sweet sorghum pulp are not currently approved pathways under the Renewable Fuels Standard (RFS2) program). For more information regarding EPA's RFS2 analysis, refer to the final rulemaking analysis. Furthermore, the version of the model used to generate the data sent to the peer review panel is substantially different from the version of the model used to analyze the RFS2 program for EPA (USEPA, 2010). Specifically, the version used to analyze the RFS2 program included higher resolution geographic detail for land use.

F. Level of Detail and Disaggregation

The Panel stated that FASOM-GHG has too much detail (pages 2, 6, 8, 23, etc.). The Panel nonetheless acknowledged that disaggregation can be a strength and that *"an advantage of using such a disaggregated model is that it allows for inclusion of parameter values and other model features that are specific to individual commodities, activities, land characteristics, environmental impacts and regions"* (page 6). We agree with the latter statement. FASOM-GHG is a large model built on a data structure that accommodates a detailed commodity and market data structure. Ultimately, as discussed below, the model developers and users employ the model for many different purposes and find that being able to aggregate the results in different ways is a valuable attribute. This means that a substantial amount of disaggregation in the model across products and regions is desirable.

F.1 Model Flexibility

A key consideration in FASOM-GHG development is the need for flexibility in analyzing a diverse array of policy questions posed by researchers and clients. This is also noted by the Panel: *"It is clear from the variety of contexts in which FASOM-GHG has been used that it is a flexible model that is capable of analyzing a wide range of policy options … That the model has been used many times in the past to investigate such strategies can be taken as an indication of its usefulness and its ability to analyze multiple regulatory options"* (page 33). FASOM-GHG accommodates a broad range of biophysical, land use, and market factors including emission factors, crop and livestock yields, water availability, and irrigation. Using a more aggregated structure would entail averaging across sectors, commodities, and regions, potentially masking or missing important responses to policy changes. In addition, more disaggregated versions of optimization models tend to be more restrained in their response than aggregate representations because important differences between sectors, commodities, and regions

[13] The individual biofuel volumes used in the scenario for the peer review panel do not match the biofuel volumes used in EPA's analysis of the RFS2 program (USEPA, 2010b).

can lead to differences in the optimal response across individual sector/commodity/region combinations.

Ultimately, the level of aggregation that is most useful for researchers or policy makers depends on the research or policy question being posed as opposed to a general rule concerning what is or is not the *"appropriate level of disaggregation"* (page 21).

F.2 Providing Relevant Policy Insights

In comments about disaggregation leading to a sense of false precision (page 2, etc.), the Panel incorrectly assumed that users of FASOM-GHG *"claim that any model could reliably make predictions about [a specific] commodity … 60 years from now"* (page 6) and typically report the information at the level of detail as seen in the HTML output file given the Panel.

As recognized earlier in this document, the primary purpose of simulation models is to provide insights into possible future outcomes of policies and policy changes (Introduction, Sections II.A and II.B), not to predict specific commodity conditions far into the future. In long-run FASOM-GHG applications, it is the directionality and magnitude of possible future effects that provide insights about potential policy impacts.

It is also important to highlight that the results are commonly reported at some level of aggregation (e.g., national GHG accounts, land use categories, and annualized results) deemed most appropriate for the analysis being conducted. The high level of detail in the results provided to the Panel was to help them understand the model and the breadth of analysis possible with FASOM-GHG. We emphasize that high levels of detail, especially in long run results, are seldom reported in studies, as evident in the published papers shared with the Panel. For instance, a recent paper by Baker et al. (2011) used FASOM-GHG to examine the aggregate land use and GHG implications of alternative U.S. biofuel mandates. Results from scenario analysis in Baker et al. (2011) were primarily presented as absolute or percentage changes from the baseline, typically at the national level. Such a format is typically how FASOM-GHG simulation results are presented in reports and journal articles.

In addition to reporting aggregates, though FASOM-GHG can employ a 100-year simulation period, many users choose to examine outputs only as far into the future as the policy under evaluation dictates. The example papers and some of the data submitted to the Panel reflect that users rarely report output for later periods of the model simulations, partially due to the influence of terminal conditions (addressed in Appendix response number 5).

F.3 Modeling Errors and Disaggregation

There is no general rule that errors in modeling aggregates will be less than those associated with modeling components of an aggregate, as suggested by the Panel (pages 2, 6). For example, the comments state that *"[a] more aggregated model is likely to produce more defensible results and be more useful"* (page 2). Although this may be true in some specific cases, there is no statistically generalizable basis for this claim. Using aggregates can also generate specification problems in behavioral relationships. For example, the Panel found that *"the level of disaggregation in the forestry sector (both across products and regional) seems more than is necessary (and perhaps even desired) to capture important policy impacts"* (page 6) and that *"[o]ne single domestic demand region, namely the* *entire U.S., may be enough to describe the demand for forest products"* (page 23). With respect to the latter question, FASOM-GHG does use only a single U.S. demand region, with supplemental exogenous demands for certain products represented at the regional level (see response number 20 in the Appendix). Combining product categories, while it reduces model size, can also lead to specification issues. This is of particular concern when failing to recognize differences in demand characteristics across end-use categories (e.g., housing, manufacturing, nonresidential construction). Estimated derived demand relations for composites of heterogeneous elements often produce price and output elasticities that are not concordant with observed behavior.

For example, conditional demand curves for an aggregate like all softwood lumber that include housing starts as an explanatory variable often give unreasonable projections of the change in lumber demand per unit change in housing starts precisely because of overaggregation.[14]

F.4 Runtime and Maintenance

When assessing the usefulness of the model, the Panel found that *"the modeling of domestic sectors is very detailed, in terms of products and regions, at times perhaps too detailed, leading to complexity, high maintenance cost and very long run times (one to two days), diminishing the ability to conduct experiments and do sensitivity analysis"* (page 32). Though run times of 1 to 2 days may seem long to analysts used to smaller models, run times of this length are not unique to FASOM-GHG and do not deter developers and clients from using or running sensitivities with the model. The Panel stated that *"the long run time prevents one from 'playing with' the model to get a better understanding of what is driving the results or testing the sensitivity of the results to, for example, alternative parameter specifications or the various constraints that are imposed on the model's solutions"* and concludes that *"[b]ecause of FASOM-GHG's complexity, such [sensitivity] analyses are prohibitively costly in terms of both time and resources"* (page 8). These statements are speculative and result in an erroneous conclusion. Run time and maintenance costs have not deterred model developers and users from conducting experiments and sensitivity analyses or using FASOM-GHG for a wide variety of research applications.

F.5 International Representation

[14] In a recent paper, Song, Chang, and Aguilar (2011) estimate a demand equation (as well as domestic and import supply) for all U.S. softwood lumber. In specifying their demand equation, only housing starts appears as a measure of output of the end-using industry, even though softwood lumber is used in residential upkeep and alterations, nonresidential construction, shipping, and manufacturing. In fact, in 2006—the last year of their data sample—more is used in these other end uses than in new residential construction. Demand in these other end uses does not generally follow the same pattern as housing starts over time, though some share similar trends over some time intervals. However, Song, Chang, and Aguilar (2011) aggregate all end-use categories into a single demand equation and use an output measure for only a single sector (housing). They find that the long-run elasticity of consumption with respect to end-use industry output (starts) is 1.0. For their sample period, total housing starts averaged 1,546.7 thousand starts (per month on an annual basis—see their table 2). Mean monthly demand (consumption) was not shown in their data table but is readily computed from industry statistics as 4,376.6 million board feet. So if dD/dh=e*(D/h)=1*(4,376.6/1,564.7)=2.830 mbf/start, their results indicate that one new start increases lumber consumption by 2,830 board feet. But over their sample period (1990 to 2006) average wood use per new start in the United States was in the range of 8,000 to 10,000 board feet. How should their elasticity of softwood lumber demand with respect to starts be interpreted, and how has failure to account for variation in the output of other softwood lumber end-using industries influenced other key elasticity results in their model? There are many cases where greater aggregation such as that suggested by the Panel can cause difficulties in model specification and interpretation of results.

Lastly, the Panel asserted that using a detailed model like FASOM-GHG to make long-term projections makes it nearly impossible to extend the model to consider the role that international trade plays (page 7). As discussed in the next section, this concern is unfounded and, in a way, contrary to the Panel's position on the size and level of disaggregation in the model (page 7).

G. Characterization of International Markets

The Panel stated that *"using a detailed model to make long-term projections makes it nearly impossible to extend the model to consider the role that international trade plays"* (page 7) and that the *"international dimensions [in FASOM-GHG] may be too sketchy"* (page 32). It is important to note that FASOM-GHG does have endogenous international trade effects, such as international supply regions (18 regions) for seven agricultural traded commodities with import supply functions (Adams et al., 2008). The forest sector includes endogenous activities for virtually all forms of trade with Canada as well as other significant trade flows to off-shore regions (e.g., softwood lumber trade with non-Canadian regions).[15] Details on FASOM-GHG's international components are discussed in the documentation given to the Panel (Beach et al., 2010a; Adams et al., 2008).

G.1 Interactions with International Markets

The Panel also stated that *"it is possible that the future of U.S. agriculture and forestry will be determined in large part by developments in the rest of the world. To the extent that this is true, the usefulness of FASOM-GHG will be diminished because of its limited ability to capture critical international influences and feedbacks (see, for example, Sohngen, Sedjo, and Mendelsohn (1999)"* (pages 32, 33). International markets do and will continue to play an important role in estimating U.S. land use and related commodity production and prices. It is important to note that in certain policy analysis applications, FASOM-GHG can be and is run in coordination with detailed international models to simulate international market and land use effects, including global forestry models, such as the Global Timber Model (Sohngen, Sedjo, and Mendelsohn, 1999), as well as U.S. economy-wide and energy sector models, such as ADAGE, IGEM, and IPM (e.g., USEPA, 2009). In this context, the growing international market, the effects of international policies, and domestic-international market and land use interactions can be captured within other global and economy-wide models. Model integration of this sort allows us to simulate international land management and global market responses to U.S. policies, while maintaining the detailed representation of the U.S. agricultural and forestry sectors offered by FASOM-GHG. Thus, FASOM-GHG is used to model detailed domestic implications of interest to U.S. policy makers at a level of disaggregation not available in the other models while maintaining consistency with those models.

FASOM-GHG's international agriculture and forest product trade components have been, and will continue to be, updated to reflect global circumstances. Since 2010, some members of the FASOM-GHG model development team have been engaged in a collaborative effort with the International Institute for Applied Systems Analysis (IIASA) based in Austria to integrate the detailed agricultural module of FASOM-GHG with GLOBIOM (Global Biomass Optimization Model), a model developed at IIASA with

[15] Canada accounted for 70% of U.S. imports of all forest products (by value) in the years prior to the recent recession and even larger proportions (by volume) of major commodities such as softwood lumber and newsprint. In the specific case of softwood lumber, the model includes behavioral relations for all of the global sources of U.S. imports. Export demand relations are also included for softwood logs (a major and volatile component of U.S. exports by volume).

global representation of the forest and agricultural sectors. Such model integration is anticipated to allow us to project international land management and global market responses to U.S. policies, while maintaining the detailed representation of the U.S. agricultural sector offered by FASOM-GHG. Among other enhancements, the changes to the export demand and import supply specifications will help ensure that FASOM-GHG better reflects the changing role that international markets are likely to have.

G.2 Level of International Disaggregation

Lastly, though we agree with the Panel on the importance of international considerations, we disagree that FASOM-GHG should include all international markets at the same level of detail as the United States to be useful for U.S. policy analysis, as suggested by the Panel (page 7). The model was designed and is used to dynamically assess U.S. GHG, land use, and related market interactions. Adding international data, such as product and market relations at the level of detail used for the United States would greatly increase model size, data requirements, and solution time. In that regard, additional international detail could possibly require a reduction in domestic detail, which would diminish the value of the domestic information from the model. Additional international detail also seems inconsistent with other reviewer comments about model size (e.g., that the model is currently too large, pages 2, 6, 8, etc.).

H. Role of Socioeconomic Drivers in Future Demand

The Panel raised the concern that some key parameters in FASOM-GHG are not tied to socioeconomic demand drivers, such as population, income, and technical change (page 7). We concur with the Panel on the importance of socioeconomic drivers and related impacts on future demand (pages 3, 7, 12, etc.). FASOM-GHG input files have traditionally included demands for individual commodities based on separate econometric estimation. In the results given to the Panel, the input files had not included specific time series of projected future population and income. However, the model now does have a process similar to that described above for yield growth that is being used for commodity demand on the agricultural side. Specifically, coincident with the Panel's advice, the FASOM-GHG development team will soon complete respecification of the dynamic projections used in the model to include population and gross domestic product (GDP) in projecting demand growth for both the forestry and agricultural sides of the model. Also, all of the yield and trade growth parameters have been re-estimated econometrically based on USDA or Food and Agricultural Organization (FAO) data.

H.1 Forestry Markets

Previously, population, income, technological change, etc. were reflected in the development of future demand function parameters that were estimated outside of FASOM-GHG and input into the model. On the forestry side, this process involved running the Timber Assessment Projection System (TAPS) and extracting aggregated demand and nonwood factor supply curves from the base projection (out to 2050). The demand and supply relations in the TAPS system were all estimated using econometric approaches with data from the 1950 to 2002 period. Since the projection interval in TAPS (Adams and Haynes, 2007) is annual, demand functions were aggregated to 5-year periods as needed by FASOM-GHG. Product demand curves were also aggregated to the national level, since FASOM-GHG does not have demand regions for most forestry products. Thus, the shifts in the FASOM-GHG forest sector demand curves follow those in TAPS, and the underlying macro projection in the FASOM-GHG forest sector is that in the TAPS models.

H.2 Agricultural Markets

On the agricultural side, we recently developed econometric estimates of domestic demand and export demand (by international region) for each commodity that is traded internationally within the model. Per capita domestic demand was estimated as a function of time, gross national product (GNP) in the appropriate region as a measure of income, and commodity price using both linear and double-log functional forms using historical data from 1960 to 2009. Similar to the procedures employed for estimating yield trends, we estimated regressions using multiple functional forms and breakpoints and allowed for selection of which model results are used in FASOM-GHG scenario runs. We are currently working to improve on this specification by using population and income projections from the World Bank, USDA, U.S. Census Bureau, and other sources in combination with our fitted equations, which are defined as a function of income and population, to project commodity demand. Thus, our domestic, import, and export demand projections will be tied directly to external projections of key demand drivers, which is consistent with suggestions provided by the reviewers. A similar process is being implemented for the forestry side of the model to explicitly tie timber and forest product demand projections to population and income growth.

I. Technical Change/Yield Growth in Agriculture

Starting on page 12, the Panel highlighted various issues and concerns related to the representation of technical change and yield growth in FASOM-GHG. We agree with the Panel's point that, for any model, *"assumptions should be critically evaluated for consistency with other data"* (page 3). However, we disagree with the assertion that *"some of the demand and yield growth assumptions are unsupportable by existing data or common sense, especially when projected out far into the future"* (page 12). The primary sources of publicly available baseline projections for agricultural production through 2050 are the FAO, the IFPRI, and the IIASA. There are some differences in agricultural productivity growth between them, but they generally have crop yields/productivity growing at around 0.5% to 1.5% per year (Fischer et al., 2009; FAO, 2008; also Valenzuela and Anderson, 2011 based on their assessment of World Bank and Organisation for Economic Co-operation and Development [OECD] projections), which is very similar to crop yield growth rates that have been used in FASOM-GHG.

I.1 Characterization of Livestock Productivity

Livestock yields are not assumed to grow in terms of output production per unit of feed, but output per head does increase over time in the model (e.g., pounds of milk per dairy cow is increasing, but feed consumption per pound of milk is assumed to remain constant). Although the Panel raised concerns about feed demand being too low (pages 16), they accounted only for pounds of corn fed per pound of hog slaughtered in their example and did not include increases in other feeds being used for livestock production (see additional discussion on this topic in Appendix response number 1).

I.2 Alternatives for Technical Change

In the past, FASOM-GHG yield growth has used percentage growth rates based on historical data that are assumed to remain constant over time, as noted by the Panel (page 12). Members of the model development team have worked to modify how yield growth is represented within the model. We have been collaborating with USDA to coordinate FASOM-GHG assumptions with USDA projections, which currently are available only 10 years into the future. If USDA develops longer-term projections, we can calibrate the model baseline to be consistent with those projections. In the meantime, in the absence of such projections, we have econometrically estimated changes in yields over time for all crops and livestock included in the model based on historical USDA data. Yields have been estimated as a function of time using both linear and double-log functional forms. Regressions were performed over the full 1950 to 2009 dataset as well as using multiple breakpoints to test for structural change and allow a more contemporary estimation of yield growth. The best fit was selected based on adjusted R^2 over the alternative fits, choosing both the best functional form and structural breakpoint (if any). The model can now be run specifying either best overall fit, best linear fit, or sensitivity cases around these best fits. Alternatively, one can apply constant annual percentage change parameters that have been used in the past.[16] The Panel's suggestion for *"more aggregate production relationships"* notwithstanding (page 7), updated technological demand growth projections are still disaggregated to be commodity specific. As discussed above, a similar exercise was conducted for domestic demand, import supply, and export demand, with efforts also under way for each trading country partner.

III. Summary and Conclusion

We thank the Panel for the time and effort they devoted to conducting this peer review. The comments offered some useful observations and recommendations for future action and will help us define our priorities for future model development, documentation, and application.

In their comments, the Panel stated that:

> *[i]t must be recognized that no model should be viewed as providing definitive information about what will happen if a particular policy is adopted. … [FASOM-GHG] should be recognized as one special representation of the U.S. agricultural and forestry sectors and the linkages between the two, and in the end it should be acknowledged that this and similar models are mostly useful for telling a coherent story, without obvious contradiction, for possible outcomes when a very complex system is subjected to a policy-induced perturbation. The ultimate test of any model's usefulness is whether it provides meaningful insight into possible policy-induced outcomes.* (pages 9, 10, emphasis added)

We agree with this statement and feel it is exactly the right way to think about and evaluate FASOM-GHG and similar models.

The Panel also stated that *"[FASOM-GHG] is a very powerful tool for agriculture/forestry sector analysis that has already been found useful in [projecting] the effects of GHG emissions"* (pages 20, 21).

However, many of the Panel's comments seem at odds with these perspectives. In particular, the Panel in many instances mischaracterized the model's purpose, function, and applicability. They also made inaccurate assumptions about the use of sensitivities to test model parameters and validate results. In so doing, they made statements questioning FASOM-GHG's credibility and function (e.g., dynamics,

[16] Although it is not feasible to place confidence intervals around final model results given computing requirements, the model development team conducts numerous sensitivity analyses to test results and model parameters, including examination of impacts within confidence intervals placed around key econometrically estimated parameters.

aggregation, and validation) that are inconsistent with the model's primary purpose and usefulness to the policy community.

Specifically, the Panel's mischaracterization leads to their applying incorrect evaluation criteria for a model of this type. FASOM-GHG is not used to "predict" future conditions, but rather to simulate and provide insights about what could occur given assumptions about the future and policy scenarios. FASOM-GHG is designed to simulate possible future impacts of policy decisions on U.S. land use, GHG emissions, and the agriculture and forestry sectors over various time frames.

To respond directly to specific comments made by the Panel, we have made a number of points and specific clarifications in this response document (in the Sections above and the Appendix) that need to be taken into account along with the Panel's review. These responses are meant to provide a clearer picture of the model, how it functions, and how suggestions by the Panel may or may not be applied.

As discussed in Section II above, we have implemented or plan to implement several recommendations, such as those on improving documentation, improving characterization of future agricultural commodity demand, providing more detailed international linkages, and conducting additional model validation exercises. Model documentation updates, updating of parameters, and validation of model components are common to most complex models, including FASOM-GHG, and we will continue working to maintain and improve these efforts going forward. For example, we have been engaged in ongoing efforts to update and improve many aspects of the model including areas where the review made specific suggestions for future efforts, such as technological and international representations in the model.

The model could be made even more valuable through improved documentation and periodic review and updating of input data, parameters, and constraints. As new versions of FASOM-GHG are introduced, we will simplify the documentation by providing written updates focusing attention on changes that have been incorporated into the model since the previous version. We will regularly compile and make accessible the substantial body of peer-reviewed literature pertaining to the FASOM-GHG model, because this repository represents many different applications, sensitivity analyses, and documentation of the model as it has been improved and extended since the mid-1990s.[17] We believe that lessons learned from FASOM-GHG development, testing, and application for more than 15 years can be quite useful to others that are constructing models to support land use and climate change program analyses in other contexts.

The review will be of substantial value in helping to inform the setting of priorities for such future research and development. Through further exploration of the improvements suggested by the Panel and incorporation of appropriate modifications to the model, we are confident that FASOM-GHG will prove even more useful and flexible in the future for evaluation of alternative climate and land use-related policies.

[17] FASOM-GHG-related literature can be found at http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers.htm and http://www.cof.orst.edu/cof/fr/research/tamm/FASOM_Documentation.htm.

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Appendix: Technical Clarifications

1. Livestock feed usage and animal productivity growth (pages 2, 3, 13, 14): On page 2, the Panel found that *"the model's assumptions about productivity increases and resulting livestock numbers are not supported by recent data and they do not result in reasonable projections of livestock numbers."* Technological progress is matched by feed usage increases. In the model structure an assumption is made on the elasticity of input usage response relative to technological progress, where a 1% increase in livestock technological progress is matched by a 1% increase in feed demand. The FASOM-GHG development team has reviewed this carefully in the time since this review was received and found a small omission in the code that has now been repaired. We are grateful to the reviewers for bringing this to our attention. Although the Panel raised concerns about feed demand being too low, they accounted only for pounds of corn fed per pound of hog slaughtered in their example and did not include increases in other feeds being used for livestock production. For instance, there is a large increase in the use of Dried Distillers Grains (or DDGs, a co-product of ethanol production from grains) being used in livestock feed as well as reallocation toward products other than corn over time. As shown in Table 41 of the model results provided to the Panel, total feed consumption increases by 82.8% on a total weight basis between 2000 and 2050. This is a larger percentage increase than total meat production over that time period as shown in Table 30 of the results provided, though the relationship between feed and liveweight varies by species.
2. Elasticities (pages 3, 31): The Panel argued that cropland response is too high and simultaneously note that forest area response in the model to a carbon price is relatively small (pages 3, 31). The Panel stated that *"the projections of a significant contraction in agricultural land due to a \$30 price of CO_2 despite a significant increase in returns to cropland indicate that the elasticity of supply of cropland is too high. The model's predictions need to be critically assessed to determine the source of these inconsistencies, and, if necessary, changes should be made to ensure consistency with underlying economic principles*" (page 3).
   The Panel expanded on this point later in the review (page 31), again arguing that cropland response is too high, though they simultaneously noted that forest area response in the model to a \$30/tCO_2 price is relatively small. It is not clear what information the Panel used to conclude that the simulated contraction in agricultural land is too large or how that is consistent with their statement that *"forest area increases by about 88 million acres, or about 25%, relative to the base scenario. This is a very small response relative to other studies of afforestation policies, including the Adams et al. 1993 Contemporary Economic Policy study that used a precursor to FASOM-GHG"* (page 31). The allocation of land between the two sectors depends on the relative returns available. A \$30/tCO_2 carbon price may increase the returns to cropland but also lead to a very substantial increase in the returns to forestland. The increase in returns to agricultural land is reflective of an equalization process where landowners are moving land between sectors until the marginal value of land is equilibrated between alternative uses. After initially noting that afforestation is actually relatively small in our results because of the competition for agricultural land captured within FASOM-GHG, the rest of the comments on cropland response appear to entirely ignore the increased returns available for forestry, competition for land, and the implications for landowner decision making. An increase in returns to agriculture does not in itself imply that land in agriculture will increase if returns to forestry increased even more. In fact, this discussion implicitly highlights the importance of

using a model such as FASOM-GHG to explore potential land use implications of policies that may strongly affect the potential returns to various forest and agricultural land uses simultaneously.

3. Fluctuating results (pages 4, 31, etc.): The Panel highlighted how for several variables the projected levels fluctuate across periods, with some activities coming in and out of solution in unexpected ways:

   > "…there are other instances of abrupt land-use changes under the baseline that do not comport with how land-use changes have happened historically. For example, afforestation in the Southern region is 2.0 million acres in 2000, 4.1 million acres in 2015, 12.2 million acres in 2045, and 0 acres in every other period. The FASOM team explained that these lumpy changes are a reflection of the way the model is solved. While that may be true, it raises questions about the reliability of projections made at a 5-year time step." (page 31)

   These cycles and shifts observed are a function of model structure. Multiperiod models do not have to be smooth one period from another and often are not. However, one could impose smoother shifts over time by entering an arbitrary constraint where activity in the current time period is a function of activity in the previous time period using, for example, the so-called flexibility constraints of Richard Day (where $x(t) \leq (1 + tol)\, x(t-1)$). This rationale stems from Richard Day's 1950 discussion about this constraint as stated with a classic cobweb model. FASOM-GHG does not have this arbitrary constraint. Various users use other approaches for analyses rather than reporting in 5-year results. For example, in some cases users use annuities to smooth out results. Annuity values are generated as part of the standard FASOM-GHG outputs and can be used in reporting, but whether this is suitable depends on the analytical needs of a given application. *"If this [fluctuating] is simply a lack of "smoothing", then it would perhaps be better to report results with longer time intervals (e.g., 10 years rather than 5 years)"* (page 4). The most appropriate level of aggregation for reporting is determined by the analyst as appropriate for a given application. The FASOM-GHG development team quite frequently uses dynamic annuities to summarize results. Other long-term simulation models, such as the Global Forest and Agriculture Model (GFAM), rely on moving averages (30-year moving averages in the case of GFAM) to report smoother results that avoid short-term fluctuations.
4. Regions (page 5 and several other places): Significant forestry activities are modeled in nine regions, while in the two Plains regions only agricultural production is modeled. A map of the nine forestry regions is given in Figure 1 by Adams et al. (1996).
5. Model time span (pages 2, 6–7, etc.): The comments state that *"the model 'drivers' are very detailed projections over 30 to 100 years for individual variables" (*page 6). Though FASOM-GHG can simulate up to 100 years, users should not use results from later years in policy analysis applications. The example papers submitted to the Panel indicate that users do not typically report output for later periods of the model simulations precisely because of the influence of terminal conditions. We can make this clearer in the documentation. In addition, while outputs for individual commodities and other results are generated by the model, they are not typically reported at that level of detail for results far into the future. The appropriate level of disaggregation for reporting results depends on the specific questions being addressed in individual applications.

6. Sensitivities (page 8): FASOM-GHG users and developers conduct sensitivity analyses, examples of which are in the papers provided to the Panel. We understand this is a critical part of model development and refinement, as well as researching results of various policy simulations.
7. Predictions (page 9): FASOM-GHG's results should not be viewed as exact "predictions" of the future, but instead as insights as to what may happen under scenarios of plausible potential futures, where the primary focus is often on the simulated changes in outcomes under a policy case relative to the projected baseline. Some experts rely on forecasting models for use in policy analysis and find that econometric approaches are the only way to parameterize such models. There are, however, many approaches to policy "futuring" and scenario analysis. One example of an alternative approach in a current application is the agent-based model ENVISION (http://envision.bioe.orst.edu/Publications.htm) used to model outcomes under alternative scenarios. An older, and widely used, approach called "industrial dynamics" was developed by J. W. Forrester in the early 1960s. Example applications include Industrial Dynamics (1961) Pegasus Communications: Waltham, MA; and World Dynamics (1971) Wright-Allen Press. Both of these approaches can use econometric data on behavioral relations, but both also demonstrate that there are many ways to include information about agent decisions.
8. Constraints (page 10): The Panel stated *that "the model also includes constraints designed to produce 'reasonable' projections by, for example, restricting regional crop mix or livestock mix to be a convex combination of historical mixes for that region … [and] these constraints are designed specifically to alter predicted outcomes"* (page 10). These constraints are present to help with the aggregation characteristics of the model. They reflect more detailed subregional-level conditions produced by aggregating production into larger regions and are theoretically justified based on arguments as used in production duality theory and Dantzig Wolfe decomposition. These are phased out further in the future as we have a model feature defining the last year in which the full mix constraint will be in place and the last year in which any mix constraint is active with a linear phase out in between. These are explained in the more detailed document (Adams et al., 2008) and journal articles by McCarl in the 1982 AJAE and in 1985 December AJAE and by Onal and McCarl (1991) in the *Canadian Journal of Agricultural Economics*.
9. Agricultural demand growth (page 12): The Panel noted that in FASOM-GHG

   > "domestic demand for fed beef shifts out by 0.75% each year. Export demand for fed beef shifts out by 1% each year. The effect of an annual 0.75% increase in demand is that over 40 years, demand has increased by about 34%. However, the USDA long-term commodity projections that were apparently used to generate these projections only extend to 2019, and are not intended to be predictive of demand shift in 50 to 60 years. In addition, much of the demand growth for U.S. commodities is likely to occur in other countries because it is highly unlikely that China, India, Vietnam, and other fast-growing countries can increase their food production fast enough to keep up with increases in food demand. That means the U.S. will either be exporting an increasing share of domestic production of livestock feed or products made from U.S. animal agriculture in the future. The approach taken by FASOM-GHG to model demand growth is ad hoc in that it is not based in a transparent way on assumptions about population and income growth in the U.S. and in the rest of the world." (page 12)

   It is not clear whether the Panel felt an increase in domestic demand of 34% over 40 years is too high or too low or what they relied on for comparison. Again, this is in the range of long-run model results presented using other models. Also, we have export demand growing faster than domestic demand in this case, as mentioned by the Panel, which reflects the more rapid growth in demand internationally. Although the increases we have assumed in the past are consistent with long-run projections from other models, we agree that it is preferable to specify changes in future demand as a function of population and income. As described in Section II.E, we have modified FASOM-GHG to calculate future demand as a function of exogenous projections of population and income based on econometric estimates of the relationships between population and income and per capita demand.

10. Terminal Conditions (page 11): *"In addition, results for 2065 (the second to last period in the analysis horizon) should not be printed in the output, since considerable end effects are still apparent"* (page 11). There are terminal period effects on results in the last few periods of FASOM-GHG simulations, as in other dynamic models. Users can evaluate what to include in reporting, but using the last few periods is not recommended.
11. Yield Growth (page 15): Although the Panel elsewhere indicates yield growth within FASOM-GHG is too high, here they argued that it is too low for corn and soybeans. Yield growth for corn and soybeans in FASOM-GHG is based on USDA projections through 2019, then based on annual percentage growth rates derived from historical values and USDA projections. As discussed elsewhere, we have since begun using econometrically estimated functions for yield growth over time. As was made clear to the Panel in our October conference call, the model results for average national yield will not increase at the same rate as the annual yield growth rate because of shifting regional production practices and crop mix patterns. Although the yield for each region/production practices combination for a given crop was increasing at the same percentage rate, there is no reason to expect that the overall national average yield will increase at that percentage rate unless regional production level and production practices were held fixed, which they are not.
12. N_2O assumptions (page 15): The Panel stated *"it is unclear how N_2O emissions are linked to applications of N fertilizer and resulting yield increases in the model."* There is a separate elasticity in FASOM-GHG for the way that increased N use is related to technological progress and the N_2O emissions are in turn a function of that as described on page 6-7 of Beach et al. (2010a). The use of DAYCENT model simulation results to calculate relationships between N fertilizer application and other variables and associated N_2O emissions is discussed on pages 7-19 through 7-23 of Beach et al. (2010a).
13. Documentation—Cellulosic ethanol production costs (page 18): The Panel made the point that *"evolution of costs and technology are among the many unknown elements surrounding cellulosic ethanol production. This could make a difference in the baseline results, since cellulosic ethanol production is observed to decline beyond 2025."* FASOM-GHG does include explicit features and data for declining costs and increasing per-ton ethanol yields, which is discussed in the 2010 documentation. Sections 5.1.1 and 6.4.5 discuss the assumed technical change for cellulosic ethanol and how that would lead to an implicit price reduction per unit output. Specifically, *"the cost of [the cellulosic] feedstock per unit over time will depend on market forces, but the quantity required to produce a given amount of [cellulosic] ethanol is expected to decline over time with improvements in ethanol conversion technology, which will tend to reduce feedstock costs per gallon"* (page 6-11). The documentation describes how

processing costs per gallon decline over time (page 5-23 provides more detail, including the exact values assumed, provided on page 6-14).[18]

14. Base year (page 19): The model begins in 2000. 2004 is the end of the first base period. In FASOM-GHG, annual results reported for 2000 are meant to be representative of average annual conditions for 2000 to 2004; 2005 refers to average annual conditions for 2005 to 2009, etc.
15. Disaggregated structure of bioenergy feedstocks (page 18): The Panel suggested that the model should have *"a more aggregated representation of feedstocks—e.g., have two feedstocks designated as land using and non-land using—and then run the model forcing different proportions of each into solution to determine the land use consequences of alternative possible outcomes."* In general, we find that aggregation in this way misses important differences between alternative feedstocks, their relative yields and input requirements, land use, and other differences. This model characteristic—differentiation between agricultural products—is one of the strengths and purposes of FASOM-GHG and such aggregation would defeat that purpose.
16. Probability of correctly selecting feedstocks (page 18): The statistical basis for the statement that having a greater number of feedstocks decreases the likelihood of correctly projecting the actual feedstock in a model is unclear.
17. Documentation—Forest carbon accounting (page 19): *"For CO_2 accounting in FASOM-GHG, according to the latest documentation (p. 1-5) the data were largely derived from the Forestry Carbon (FORCARB) model based on US Forest Service research (e.g., Joyce and Birdsey, 2000). Again, it would be useful to have these data in the documentation."* More details on forest carbon accounting are available in the provided 2010 documentation (Section 7-2, page 7-24).
18. Level of detail (page 22): It should be noted that there are a number of commodities that exist for basic accounting reasons. Some of these relate to handling choices regarding product allocation among competing uses, while others relate to products moving between sectors in the model. The logs "in the woods" as compared with "at the mill" (page 24) is an example of a product designation to allow different product allocation. Specifically we allow logs to be downgraded (e.g., a forest that produces sawlogs could have those sawlogs delivered to a pulp producer instead). In that case, we would have the initial sawlog harvest (in GAMS code terms, as found in Table 2-1 in the 2010 documentation) "PVT_SAWLOG_WOODS" be transformed into "PVT_PULPLOG_MILL." An example of a change in terminology as a commodity moves between production levels would be "hybrid poplar" or "willow" harvested on agricultural land becoming "AGRIFIBERSHORT" when it moves into the pulp and paper sector. In each case, products such as these are used for accounting purposes only.
19. Cost structure (page 22): The Panel found that *"the distinction between pulplog and fuellog seems unneeded."* The forest market structure of FASOM-GHG originates in the Resource Planning Act forest sector models used through the 2005 Timber Assessment Update. Thus, the pulpwood and fuellog delineations are the same as they had been in the RPA assessments. Fuellogs have the highest nongrowing stock to growing stock ratios and supply only exogenous wood fuel demand with the vast majority of that demand being residential heating. The proportion of nongrowing stock to growing stock logs suitable for pulp is substantially less, and

[18] See the cellulosic analysis included in EPA's RFS2 RIA (p. 38). See also Tao, L. and A. Aden. November 2008. Technoeconomic Modeling to Support the EPA Notice of Proposed Rulemaking (NOPR).

this wood is used in various pulp and paper products as well as structural panels that face endogenous demands in FASOM-GHG.

20. Demand regions (page 22): There is a single national U.S. demand region for all forest sector products that are endogenous. FASOM-GHG also includes exogenous demands at the regional level for forest products such as panels, hardwood lumber (which has an endogenous national component as well), hardwood plywood, and miscellaneous products. We agree that more detailed documentation is needed on this.
21. Documentation—Lack of step function details (page 23, Section ii): The values of the step function that go into the model are shown in Table 4-1 of the documentation.
22. Timber supply relations (page 23): The reviewers request more information on timber supply relationships. As has been the case in all published intertemporal optimization models of the forest sector of which we are aware, FASOM-GHG does not use explicit timber supply relationships for the U.S. private sector. See, for example, Berck (1979), Rahm (1981), Sedjo and Lyon (1990), Sohngen and Mendelsohn (1998), Sohngen and Sedjo (1998), Sohngen, Mendelsohn, and Sedjo (1999). From the first-order conditions for an optimum it can be shown that timber is harvested from the inventory to maximize the present value of market surplus. The dynamic equations described generally in Johnson and Scheurman's (1977) treatment of their "model 2" are used in FASOM-GHG. We have described these in other publications (e.g., 2005 documentation) but not explicitly in the 2010 documentation.
23. Management intensity changes (page 24): FASOM-GHG carbon accounting follows the methods of Smith et al. (2006) (sec 7.2.1), but we do not use their yield functions. Each forest management intensity (in each region, forest type, ownership, and site class) has its own associated yield curve (page 6-11 of 2010 documentation) and carbon inventories are computed from these curves. Thus, when forest management is changed, carbon stocks reflect the management regime actually in use. The timber yield curves derive primarily from the 2005 RPA Timber Assessment analysis. These are "empirical" yield curves for regions outside the South and Pacific Northwest West (PNWW), based on averages from FIA survey plots of existing stands. For PNWW and the South, the managed stand yields derive from both growth and yield models and FIA data.
24. Ethanol trends (page 26): When discussing future bioenergy trends, the Panel stated *"ethanol's share of corn production in the baseline increases to 45% in 2055, while cellulosic ethanol production declines. While there very well may be economic reasons for such a trend to occur, the current political will seems to be to manage corn's share in ethanol production and foster growth of cellulosic feedstock production."* In these runs, this is largely a function of technical progress, relaxation of the corn ethanol constraints on which types of renewable fuels can be used to meet the total volume requirement[19], and a limited period over which the cellulosic costs decline with time. Technological progress leads to lower corn prices and the model begins to move back to corn. Note that the individual biofuel volumes in the results reviewed by the Panel do not match the individual biofuel volumes in EPA's analysis of the RFS2. For more information regarding EPA's RFS2 analysis, refer to the final rulemaking analysis (EPA, 2010).
25. Land use changes (page 27): The wording cited in the 2010 documentation regarding how land uses switch is too simple. The process as laid out in the comments (page 29) is correct. Ultimately, the model does look at future use options for the land when it considers a shift.

[19] However, total renewable fuel volume requirements appear to be held constant beyond 2025.

Such possibilities in land use switching are highlighted in one of the reports provided by the EPA to the Panel (Adams and Haynes, [1996] in PNW Research Paper 495, page 18).

26. Constraints (page 26): The Panel suggested that a progressive relaxation of forestry and agricultural constraints over time can be used to minimize impacts on bioenergy rather than binding constraints. FASOM-GHG does have a progressive relaxation that allows the constraints to be phased out over a period of time chosen by the analyst. Also, the Panel suggested that *"another alternative might be to consider constant elasticity of transformation (CET) relationships between production activities to preclude the need for hard limits on activity bounds"* (page 26). We cannot use CET functions directly because we do not have such functions in the model and introducing nonlinear functions like that that are potentially nonconvex could make the model practically not solvable. In addition, the Panel found it difficult to ascertain from the results whether and when "constraints on agricultural production" (Section 3.2.2), which have implications for the bioenergy sector, are binding. When projecting behavior of agricultural producers far into the future, it does not seem that it should be necessary to restrict future behavior to past patterns (page 28). We do not have such constraints on future energy crops but rather limit their market share based on observed patterns of crop specialization. An example would be having no more than 25% of the land area in a region go into such crops based on observations of county-level land use. We also have model features that allow phasing out these constraints over time.
27. Hurdle costs for land use transitions (page 27): The framework for agriculture to forestry hurdle costs is in place, but those costs are very small in the model results provided to the Panel. See page 4-2 in the 2010 documentation for more details on hurdle costs. We have also investigated investment capital constraints and stickiness in land use changes and forest investments in some past work, including reforestation decisions by the heterogeneous NIPF owner class (e.g., Adams et al., 1998, Alig et al., 1999). Possible differences in outcomes when stickiness was introduced in earlier exploratory studies indicate the importance of further exploration and testing of the stickiness factors in the current modeling system through using a scenario approach or sensitivity analysis.
28. Land base estimates (page 29): The Moulton and Richards study was one source for identifying a potentially convertible agricultural land base where tree planting was suitable, along with data from USDA's Natural Resource Conservation Service (NRCS) studies and surveys. We subjected the resulting suitable or convertible land base estimates to external review by land use experts. It is unclear from the Panel's comments which subsequent studies have found these convertible land base estimates "overly optimistic." We did not include conversion of rangeland, because rangeland typically has relatively low forest productivity that reduces its economic attractiveness for tree planting. We did not use the acres identified as economically attractive for conversion by Moulton and Richards. From one part of their study, we used their estimates of agricultural land that potentially was suitable for conversion to forests via tree planting, from which the FASOM-GHG model could then select an economically viable subset for afforestation based on the model's simulations.
29. Documentation—Pasture to cropland conversion constraint (page 30): Please see page 1-3 in the 2010 documentation; conversion between cropland and pastureland is allowed.
30. Static private grazed forestland constraints (page 30): The forest sector in FASOM-GHG models only land productive enough to be classified as timberland. The private lands in forest cover that have grazing are not considered timberland within FASOM-GHG. The amount of land in

forestland-grazing has no impact on the forest sector. Forestland (nontimberland) grazed by livestock is accounted for on the agriculture side of the model. However, allowing changes in the amount of private grazing land on forest might have an impact on the agriculture sector, but it is not clear if that impact would be significant.

31. Range-to-forest conversion (page 28): In the example provided by the Panel, the land transitioning from range to forest cover (likely pinyon-juniper) in the West would often have a relatively low productivity in terms of forestland. In the forest sector, FASOM-GHG only models the subset of forestland that is productive enough to be considered "timberland."[20] Most of the land classed as "rangeland" in the West is not considered suitable for growing tree crops for commercial or carbon sequestration purposes. Hence, allowing this land to be eligible for afforestation, without a filter or limitation of some sort, would not reflect the biophysical reality.
32. Land use classification (page 30): The Panel commented that *"the RPA projects a decline in pasture area of 31 million acres, compared to a 207 million acre increase under the FASOM-GHG baseline scenario (see rfs_waxz_3_regagresults.html). This increase in pasture is implausibly large since it would require land to be drawn from urban uses, the Conservation Reserve Program, and public lands"* (page 30). The Panel is referring to a table that combines all pasture, cropland pasture, and rangeland into a single category called "pasture" for the purposes of that table, but this is not one of the tables typically used in reporting land use. The aggregated land use entries in the regional production table were inadvertently not consistent with land use reported in other output tables. Thus, this comment indicating that pasture area increases by 207 million acres reflects a reporting error in the regional results file. The national acres allocation in the national summary results file and the summary spreadsheet provided to the Panel have the correct acreage allocation by category from the model solution and show changes over time in FASOM-GHG similar to those projected in the RPA. As indicated in Table 58 of the results provided to the Panel (national summary results included in results file "rfs_waxz_1_natresults.html"), the combined area in U.S. pasture and cropland pasture declines from 142.7 million acres in the 2000 FASOM-GHG model period to 101.7 million acres by 2050. This is a decrease of 41.0 million acres of pasture, which is similar to the RPA projections cited by the Panel. Given that the baseline FASOM-GHG results provided to the Panel imposed renewable fuel volume requirements whereas the RPA projections did not, FASOM-GHG results are consistent with expectations that expanded biofuels production would increase movement of land from pasture to cropland.[21] In addition, there appears to be a misinterpretation of the results provided to the Panel in terms of how land use is classified in FASOM-GHG. As discussed on pages 2-16 through 2-26 of the 2010 model documentation provided to the Panel, the model includes representation of a variety of land uses important to the forest and agriculture sectors. Specifically, Figure 2-2 in the documentation reports the initial land use areas. To develop the initial allocation of land across land uses, FASOM-GHG

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[20] Definitions: Forestland is at least 10% stocked with forest trees of any size. Timberland is forestland that is capable of producing crops of industrial wood and that is not withdrawn from use by statute or regulation. Timberland can produce at least 20 cubic feet per acre per year of industrial wood in natural stands. Lands shifting from range to pinyon-juniper are located largely in the intermountain west and almost entirely comprise areas that do not meet the timberland definition.

[21] The version of FASOM-GHG used to generate the data used in this peer review is substantially different from the version of the model used to analyze the RFS2 program for EPA (EPA, 2010). The individual biofuel volumes used in the scenario for the peer review panel do not match the biofuel volumes used in EPA's analysis of the RFS2 program (EPA, 2010b).

developers rely on the Major Land Use (MLU) database and the Natural Resources Inventory (NRI), both published by USDA. The area of land in "pasture" is developed to be consistent with the NRI classification of "grassland pasture" but to avoid overlap with some other land use classes reported in the MLU database. Because livestock can graze on lands in uses other than pasture, FASOM-GHG also accounts for livestock grazing that occurs on rangeland, some cropland (referred to as "cropland pasture" for consistency with the MLU classification), and some forestlands in public and private ownership. In the year 2000, FASOM-GHG allocates about 519 million acres of public and private pasture, cropland, rangeland, and forestland to support livestock grazing.

33. Solid wood products (page 30): The carbon pool in solid wood products is modeled, but the team has not highlighted it as a possible policy option in documentation efforts to date.
34. Comparison with other studies (page 33, first full paragraph): Direct comparison with other studies is complicated by differences in what forest management and afforestation activities are included in the studies. The FASOM-GHG approach seems to be one of the few that has an integrated approach, considering both forest management and afforestation opportunities, which makes direct comparison quite difficult. The contribution of altered forest management to carbon sequestration is substantial, affecting the afforestation opportunities in regard to relative costs. It should be noted that other reviewers of our results have suggested that the increase in afforestation may be too large, rather than too small.
35. Cropland elasticity (page 31): The comments reflect comparison of a short-run elasticity from the literature (Barr et al., 2010) based on the response to increased agricultural returns to a long-run change projected in the model under scenarios where a value is placed on carbon. The introduction of a permanent new market for carbon would be expected to have substantially different effects on long-term land use decisions (particularly allocation between forests and agriculture) than an increase in agricultural commodity returns that producers may see as temporary.