Draft Minutes
Biological and Environmental Research Advisory Committee
February 26–27, 2015
Sheraton Tysons Corner
Tysons Corner, Virginia

BERAC Members Present

Gary Stacey, Chair
Sarah Assmann
James Ehleringer (Thursday only)
Susan Hubbard
Anthony Janetos
Andrzej Joachimiak
L. Ruby Leung
Gerald Meehl
G. Philip Robertson
Jacqueline Shanks (via telephone)
David Randall
Karin Remington (via telephone)
David Stahl
Judy Wall
John Weyant
Minghua Zhang
Huimin Zhao

BERAC Members Absent

Dennis Baldocchi
Janet Braam
James Hack
Sabeeha Merchant
James T. Randerson
William Schlesinger
Martha Schlicher

Also Participating

Todd Anderson, Division Director, Office of Biological and Environmental Research, Office of Science, USDOE
Melinda Comfort, Attorney-Advisor, Office of the General Counsel, USDOE
Joann Corcoran, Program Analyst, Office of Biological and Environmental Research, Office of Science, USDOE
Patricia Dehmer, Acting Director, Office of Science, USDOE
Timothy Donohue, Director, Great Lakes Bioenergy Research Center, University of Wisconsin, Madison
Gary Geernaert, Division Director, Office of Biological and Environmental Research, Office of Science, USDOE
Paul Gilna, Director, BioEnergy Science Center, Oak Ridge National Laboratory
Robin Graham, Deputy Associate Laboratory Director, Argonne National Laboratory
Jay Hnilo, Program Manager, Office of Biological and Environmental Research, Office of Science, USDOE
Robert Jacobs, Computational Climate Scientist, Argonne National Laboratory
Janet Jansson, Manager, Fundamental and Computational Sciences Directorate, Pacific Northwest National Laboratory
Bethany Johns, Science Policy Manager, American Society of Agronomy
Jay Keasling, Chief Executive Officer, Joint BioEnergy Institute
Dorothy Koch, Program Manager, Office of Biological and Environmental Research, Office of Science, USDOE

Michael Kuperberg, BERAC Designated Federal Officer, Program Manager, Office of Biological and Environmental Research, Office of Science, USDOE
David Lesmes, Program Manager, Office of Biological and Environmental Research, Office of Science, USDOE
Roy Mariuzza, Department of Cell Biology and Molecular Genetics, University of Maryland
Frederick O'Hara, BERAC Recording Secretary
Sharlene Weatherwax, Associate Director of Science, Office of Biological and Environmental Research, Office of Science, USDOE

About 45 others were in attendance during the course of the two-day meeting.

Thursday, February 26, 2015
Morning Session

Before the meeting started, **Melinda Comfort**, Office of the General Counsel, USDOE, presented an ethics briefing via telephone to the nonfederal Committee members present at the meeting.

The meeting was called to order at 9:02 a.m. by **Gary Stacey**, chairman of BERAC. **Michael Kuperberg**, the Committee's Designated Federal Officer (DFO), described the telecommunication system being used to broadcast the meeting. Stacey thanked the members of the Committee who had recently retired or rotated off the Committee: Warren Washington, Gus Shaver, and Judy Curry. He also recognized David Thomassen, the former DFO, who retired from DOE on December 31, 2014. And he welcomed two new members to the Committee, Gerald Meehl and Sarah (Sally) Assmann. He asked the Committee members to introduce themselves and to give précis of their research.

After the introductions, Stacey asked **Sharlene Weatherwax** to present an update on the activities of the Office of Biological and Environmental Research (BER).

In personnel matters, the position of Undersecretary for Science and Energy has been established, and Franklin Orr has been confirmed to that position. Three BERAC members have departed from the Committee: Warren Washington, Gus Shaver, and Judy Curry. And David Thomassen has retired.

The FY15 budget has been enacted; under that budget, BER's portfolio includes $215.5 million for Biological Systems Science Research, $174.2 million for Climate and Environmental Sciences Research, $117.9 million for Climate and Environmental Facilities and Infrastructure, and $84.5 million for Biological Systems Facilities and Infrastructure.

The FY16 President's Budget Request includes $612.4 million for BER; this is a 3.4% increase over the FY15 appropriation. For the Office of Science (SC), the FY14 appropriation was $5.131 billion, the FY15 appropriation was almost $5.068 billion, and the FY16 request is for about $5.340 billion, an increase over prior years.

Stacey noted that science laboratories and infrastructure in SC have gotten a large increase in the President's Request. Weatherwax explained that the increase was largely for the upgrading of the infrastructure (water systems etc.) of the national laboratories. One item is for a new building for the Joint Genome Institute (JGI) on the Lawrence Berkeley National Laboratory (LBNL) campus.

The question has been raised, how can increases across the Department be leveraged? One answer is by cross-cutting programs across offices to address large-scale problems. Managing across offices is challenging. In the proposed FY16 budget, BER is contributing to two of these DOE crosscuts: exascale computing and water energy. In essence, the Office is asking for hardware and software upgrades to do the research that it needs to do and to address the large-scale human problems like water availability. As part of these cross-cutting programs, the BER FY16 budget request asks for $294.3 million for biological systems science and $318.1 million for climate and environmental sciences.

Stacey asked what the philosophy was that went into the shift of funding that is evident here. Weatherwax replied that there are always more ideas than there is funding for. It often comes down to opportunities that present themselves. The program managers stay prepared to proffer an idea if a favorable opportunity presents itself. With this funding, the Office wants to support programs in genomic sciences; mesoscale-to-molecules; JGI's high-quality genome sequence data, synthesis, and analysis; climate and Earth-system modeling to understand the interdependencies of water, energy, and climate change; climate-model development and validation; the Atmospheric Radiation Measurement Program (ARM); climate and environmental data analysis and visualization; and the Environmental Molecular Sciences Laboratory (EMSL).

The Congressional budget cycle is a three-fiscal-year process, starting anew each September/October. As a result, the budgets for three fiscal years are in play at any given time: one in the information-gathering stage, one in the budget-development stage, and one in the implementation stage.

Toward the end of a fiscal year, agencies will gather information from (1) advisory committees and their workshops, studies, and town-hall meetings; (2) reports, guidance, and recommendations from other agencies, such as the National Research Council; and (3) proposals and suggestions from program managers and offices. Roughly a year is then spent on budget preparation.

To start the budget-preparation process, priorities are set by the White House and promulgated to federal agencies. For DOE, this is done through the Office of Science and Technology Policy (OSTP). Guided by these priorities, senior departmental officials set agency-specific priorities, define key initiatives, and issue a unicall, a request for program managers and offices to submit budget requests for their proposed activities. The offices and program managers draw upon the results and reports from advisory-committee discussions, requested studies, and community workshops to gather input to inform and justify their proposal submissions.

After deliberations at the office and agency levels, agencies winnow and refine the funding proposals, and an initial budget request is drafted by the agency for submission to the Office of Management and Budget (OMB). The OMB analyzes these agency budget requests and invites agency leadership to present briefings to and have discussions with its staff. Shortly before Thanksgiving, the OMB-vetted version of the proposed budget is passed back to the agencies for alterations and fine tuning. OMB then reviews the revised proposed budget and prepares the President's Request to Congress. The President's State of the Union Address previews high-level points in the President's Request before that request is passed on to Congress.

House and Senate subcommittees and committees then hold hearings on the proposed budget. At those hearings, senior agency officials are invited to present briefings and testimony. Community engagement by professional societies, citizen groups, national laboratories, and other stakeholders comes into play at this point, also. The appropriate committees then "mark up" the proposed budget, making final changes before that budget is presented for adoption by the respective chambers.

Many of these latter activities occur simultaneously in the House of Representatives and in the Senate. Stated more completely, the House subcommittees make recommendations, a full committee report is presented to the full House, and the House's version of the budget is passed. At the same time, subcommittee recommendations are put forward in the Senate, a full committee report is presented to the full Senate, and the full Senate version is passed. The House and Senate versions then go to a conference committee; and after some negotiation, both chambers eventually agree to a budget. That bill is then sent to the President for his signature.

However, for years now, this process has not happened as expected, and the ensuing delays (often involving temporary extensions of the previous year's budget, referred to as continuing resolutions) complicate the management of federal agencies in many ways. For example, continuing resolutions generally prohibit the startup of new programs and the termination of old ones. Thus, funding may be continued for a construction project even though that construction may be complete.

When a budget is finally adopted and signed into law and after appropriation bills are passed to provide the funds called for in the budget (involving another round of Congressional hearings, votes, and joint-committee negotiations), the funded activities are carried out during the following fiscal year.

Upon completion of a fiscal year, agency staff initiate a period of evaluation and analysis of the activities that have been performed. These evaluations and analyses are used to inform the budget deliberations for the next two budgets that are already under consideration.

The reports and advice from BERAC are important in informing all of these budget deliberations and the program planning within BER.

Joachimiak said that it was great that the budget was going up. He asked how funding for facilities was going to be handled. Weatherwax replied that the Office coordinates with other agencies. If a facility is to be ended, the staff checks to see how this affects other agencies' programs. BER does not have a lot of facilities. It needs to leverage its facilities to support its research.

Shanks asked if the Office were considering food, energy, and water programs and asked how the Office coordinates with other agencies on these issues. Weatherwax replied that the Office is interested in food productivity and security and water availability, but it is not addressing these issues directly. Rather, it is supporting other agencies' efforts.

Wall asked what happens when there is a continuing resolution. Weatherwax said that, last year, DOE did not get its budget until December, when the fiscal year had started October 1. That means that there is less time to plan and less time to actually carry out a project. During a continuing resolution one cannot end or start a program. There are often congressional directives (attached strings) that further complicate and hinder management and planning.

Zhang asked whether the funding for the crosscut areas was in addition to BER's budget or limited to what was already in the budget. Weatherwax answered that crosscuts can include both.

Stahl pointed out that Weatherwax had noted the end of the radiation biology program and asked if the radiological sciences (low-dose) program was also going to be ended. Weatherwax replied, yes. To start a new program, one must sunset something else to make room in the portfolio. Therefore, this will be the last year for the radiological sciences. The Office does not have a lot of flexibility.

Robertson asked if there will be a continued need to defend the climate-science request. Weatherwax pointed out that the Secretary had already had one hearing. Climate is linked to a lot of other issues. The Office always had to be rigorous in promoting the request. This year could be no less challenging. All questions are going to be under great scrutiny in these tight budget times.

Gary Geernaert was asked for an update on the Climate and Environmental Sciences Division (CESD) of BER.

All parts of the dynamic Earth system are interconnected. CESD addresses the long-range science challenges to understanding the interdependencies within the physical climate system, which change over time. Those challenges include understanding scale-aware dynamics; physical, chemical, and biological attributes; and deterministic and nonlinear chaotic systems. The Division is building up system modeling to describe (1) internal dynamics and (2) external forcing and responses.

Some of the important scientific questions for identifying priorities are

- Is disturbance a trigger for climate variability and extremes?
- Are there interdependencies and 3- to 10-year interactions between and among the Madden–Julian Oscillation, El Niño–Southern Oscillation, Arctic Oscillation, Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation, monsoons, and circulations?
- Do human economic, demographic, and behavioral responses act as climate feedbacks?
- How do these feedbacks make the components of the Earth system interdependent?

From the 1970s to today, the modeling community has been progressing from models of the atmosphere/land to models including the ocean sea ice; aerosols; vegetation and biogeochemical cycles; clouds; and human influences on water, energy, atmosphere, and land. These models have also reflected higher resolutions so they can state more consistently how a particular event propagates across the system. Even higher resolution, integration, adaptive measures, advanced software, and sub- grid nesting will be required in the future to pinpoint interactions.

The Division has been refining strategic planning through its relationship with the U.S. Global Change Research Program (USGCRP) on water, Arctic, modeling, and observations and through the Climate Modeling Summit for collaborations and for developing common positions. This summit is to be an annual event.

DOE occupies a niche in big science: system science, predictability, uncertainty analysis and quantification, facilities, computing, and big-data analytics. The role of BERAC is to develop bold science frameworks and feed the planning process with new ideas and opportunities.

The Division has held town-hall meetings, such as that at the American Geophysical Union fall meeting and it has developed synergistic partnerships with the Office of Advanced Scientific Computing Research (ASCR), the USGCRP, and the Climate Modeling Summit.

Three funding opportunity announcements have been issued on atmospheric system research, environmental system science (an annual announcement), and atmospheric system science (an annual announcement). Fifteen major reviews will be held in FY15. Ten principal-investigator (PI) meetings and workshops will be held in FY15.

Recent science highlights include:

The project Resolution and Dynamical Core Dependence of Atmospheric River Frequency in Global Model Simulations examines the sensitivity of atmospheric-river frequency to grid size and dynamical cores and identifies differences in the climatology of large-scale conditions responsible for these sensitivities. This modeling activity focuses on the number of atmospheric-river events along the U.S. West Coast. It shows that science is not yet able to predict such major weather events.

The ARM Cloud Aerosol Precipitation Experiment (ACAPEX) examines Western United States snowpack, which is fundamental to the water supply and water cycle of the region. It also looks at atmospheric rivers and their interaction with aerosol and cloud microphysics. Aircraft observations show that dust, soot, and sea salt transported from long distances frequently accompany atmospheric rivers and the supercooled droplets frequently present in orographic clouds.

Observational determination of surface radiative forcing by atmospheric carbon dioxide has been the major purpose of the ARM Program from its beginning. This project published a remarkable paper just one week before this meeting, providing the first observational confirmation of the effect of increasing CO_2 concentrations on the surface energy balance, confirming theoretical predictions. It is a testimony to the effect of the ARM program.

The very sophisticated Community Ice Sheet Model (CISM) Version 2.0 has been released. It is an efficient, portable code suitable for coupled climate simulations of ice-sheet evolution and sea-level rise.

Rhizosphere priming is important in carbon and nutrient cycles because the root-exudation process increases with rising atmospheric CO_2 and affects the temperature sensitivity of decomposition; it will be an important control over ecosystem response to global change.

The project on forest disturbance as a test for gap and big-leaf models is testing whether a variety of forest models could reproduce the resilience to moderate disturbance observed in a large-scale field experiment. This work (1) identifies weaknesses in the existing models to understand carbon-cycle change in forests and (2) points to improvements that will strengthen model performance in forest ecosystems.

A multiscale model has been used to simulate surface and groundwater flow to improve models of ecosystem hydrologic processes by unifying surface water and groundwater simulations. This new approach will improve the efficiency and accuracy of simulations of fluid flow in ecosystems. It enables a greater understanding of the transport of nutrient supplies to ecologically important microbes and of biogeochemical processes affecting the production and release of greenhouse gases.

A project on the geophysical identification of terrestrial environment “functional zones” is a very-small-scale-modeling effort. The functional-zone concept will allow for improved simulation of ecosystem feedbacks to climate by means of detailed representations of small-scale properties that collectively control system behavior.

A study of U.S. water demands for electricity generation demonstrates the interdependence of the U.S. electricity and water systems. The geographical and technological detail of this study provides a useful platform to explore complex system dynamics and emerging issues at the heart of the water–energy nexus in the United States.

At EMSL, the High Resolution Mass Accuracy Capability (HRMAC) project has accomplished its design load of a 21-T magnetic field. Integration of the spectrometer is the next task to be undertaken.

Meehl noted that Geernaert deserved credit for organizing the Climate Modeling Summit, which was called for by the National Research Council report. This effort is important at the national level.

Robertson asked where the interests were in the food, energy, and water issues. Geernaert replied that there are many agencies interested in these issues: the National Science Foundation (NSF), National Oceanographic and Atmospheric Administration (NOAA), U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS), DOE, and the Department of Homeland Security (DHS).

Kuperberg addressed some audio issues being experienced. A break was declared at 11:02 a.m. The meeting was reconvened at 11:19 a.m.

Todd Anderson was asked to present an update on the activities of the Biological Systems Science Division (BSSD) of BER.

A number of reviews and other activities have been completed since the previous BERAC meeting:

- Pacific Northwest National Laboratory Foundational Genomic Science Science Focus Area (SFA) review
- Bioenergy Research Centers annual reviews
- Joint Genome Institute (JGI) Triennial Review
- Early Career Panel reviews
- Small Business Innovation Program (SBIR) process review (in progress)
- Genomic Science Annual PI Meeting
- Pacific Northwest National Laboratory (PNNL) Pan-Omics Project review

Upcoming reviews include

- Panel reviews for FY15 funding opportunity announcements (FOAs)
- Reviews of the bio imaging projects at the national laboratories
- Triennial reviews of the national laboratories' SFAs
- Reviews of the DOE systems biology efforts

Three new FOAs have been issued:

- Novel in situ Imaging and Measurement Technologies for Biological Systems Science (DE-FOA-0001192), an academic complement to the five projects being conducted at national laboratories
- Systems Biology Research To Advance Sustainable Bioenergy Crop Development (DE-FOA-0001207), which follows a recent workshop on sustainable bioenergy research and builds on advances in plant and microbial research within the Genomic Science Program, Bioenergy Research Centers (BRCs), and national laboratory SFAs
- Plant Feedstock Genomics for Bioenergy: A Joint Research FOA from the USDA and DOE (DE-FOA-0001249), which builds on the FOAs issued with the USDA during the past 10 years; it includes a focus on plant–plant-pathogen interactions and complements bioenergy efforts within the BRCs

The FOA Plant Feedstock Genomics for Bioenergy: A Joint Research Funding Opportunity Announcement by the USDA and DOE is scheduled for release next month.

The Genomic Science Program Strategic Plan has just been posted. It covers (1) systems biology for bioenergy research, biosystems design, sustainable bioenergy, and carbon cycling and biogeochemical processes and (2) cross-cutting computational biology, bioinformatics, and predictive modeling.

New features have just been released for the Systems Biology Knowledgebase (KBase), an open-source and open-architecture computational environment for (1) integrating large, diverse data sets produced by the Genomic Sciences Program and other sources and (2) using this information to advance predictive understanding, manipulation, and design of biological systems. It provides access to the best tools for the analysis of large, complex data sets.

The accomplishments of the BRCs continue to be impressive. To date, the BRCs have produced 660 invention disclosures and/or patent applications, 24 patents, 105 licensing agreements, and 1799 peer-reviewed publications. The BRCs actively engage industry in dozens of partnerships and license agreements. Science highlights from the BRC program include:

- The study by the BioEnergy Science Center (BESC) of the field performance of modified switchgrass has demonstrated a “Goldilocks effect” in the transformation of low-recalcitrance switchgrass. One transgenic event (out of eight) yielded gains in both biofuel (a 32% increase) and biomass (a 63% increase). Too high PvMYB4 transgene expression was fatal to plants in the field, whereas too low expression was no different from controls; but when optimal expression is achieved, the altered switchgrass produces higher biomass *and* biofuel yields. These gains represent a potential to double biofuel production per hectare over conventional feedstocks. This is the highest potential gain reported to date from any field-grown modified feedstock.
- The study by the Great Lakes Bioenergy Research Center (GLB) of lignin depolymerization for valorized aromatics obtained high-yield, low-molecular-weight aromatic compounds that have intrinsic value or are suitable for downstream processing from native sources of lignin. Lignin depolymerization methods typically result in low yields of aromatics; the lignin oxidation step greatly increases the yield (by more than 60 wt%), and the products are well-defined. This is a more efficient process that potentially may enhance the lignin value chain and improve the commercial and economic viability of lignocellulosic biofuels.
- The study by the Joint BioEnergy Institute (JBEI) of ionic liquids (ILs) derived from biomass provides an effective biomass pretreatment. Three renewable biomass-derived ILs were produced from lignin and hemicellulose in excellent yields.

The Genomic Science Program has produced a new strategy to prevent the proliferation of engineered organisms in the environment. The redesigned proteins are functional and allow the cell to live and reproduce only if a specific nonstandard amino acid (NSAA) is provided in the medium. The lack of that NSAA in natural environments prevents the modified strain from growing outside the laboratory.

The Carbon Cycle Program’s study of methane production at a thawing permafrost site dominated by a single microbial species observed a distinct successional pattern of CH_4 and CO_2 production over the transitional gradient that strongly correlated with shifts in microbial community structure and associated functional processes. CH_4 production in recently thawed sites was dominated by a single microbial species, *Methanoflorens stordalenmirensis*. This work provides a new approach for integrating microbial community structure/function data with isotopic biogeochemistry analyses at the ecosystem scale.

The Genomic Science Program has been investigating nitrogen fixation in a photosynthetic microbial community. It has used a combination of metatranscriptomics and nanoSIMS analysis to broadly assay functional potential and quantitatively measure nitrogen fixation at the single-cell scale. Metatranscriptomic analysis of gene expression identified several nitrogen potential candidates as important nitrogen fixers, while high-resolution functional analysis with nanoSIMS more clearly identified *Lyngbya spp*. cyanobacteria as the dominant organisms for this process. This work highlights the importance of pairing genomics and gene-expression profiling with complementary approaches that provide quantitative functional measurements.

The Genomic Science Program has also been elucidating control of secondary-cell-wall synthesis through the use of the network-based approach to characterize transcriptional regulation of secondary-cell-wall biosynthesis. This work provides a framework to further dissect and refine specific gene functions and allow targeted manipulation to produce high-yielding plant feedstocks for bioenergy production.

Investigators funded by the Early Career Program have found that nitrogen gas is a cost-effective supplement for bacterial production of cellulosic ethanol. When nitrogen gas was supplied, it was readily used by *Z. mobilis* without decreasing ethanol production, which was close to the theoretical maximum. The use of nitrogen in bioreactors can decrease the cost of ethanol production by a factor of 10, making *Z. mobilis* an alternative to yeast for high-yield ethanol production.

At the Structural Biology Facility, researchers have investigated the structural evolution of differential amino acid effector regulation in plant chorismate mutases to understand the structural basis for how a key enzyme regulates production of valuable biofuel and chemical products in plants. In this study, the structures of the enzyme complexes show how the pathway is controlled by metabolites, such as tyrosine and phenylalanine.

Researchers at the JGI have completed the eucalyptus genome, which, in combination with other hardwood genomes (e.g., *Populus*, *Citrus*, *Prunus*, and *Vitis*) provides a comparative basis on which to understand the evolution of hardwoods. Eucalyptus is interesting because it displays a wide diversity of specialized metabolites, including terpenes, useful for biofuel and biochemical development.

Researchers at the JGI have been sequencing the microbial community in the shipworm, which is historically famous for its ability to digest the wood in the hulls of ships. Enzymes that carry out wood digestion in the shipworm were found to originate from microbes in the gills, not the microbes directly acting in the gut (which is free of bacteria). This work expands the known biological repertoire of bacterial endosymbionts to include food digestion and identifies previously undescribed enzymes and enzyme combinations of potential value to biomass-based industries, such as cellulosic biofuel production.

The JGI has issued its next Community Science Program (CSP) call. Letters of Intent are due on April 16, 2015. The JGI–EMSL Collaborative Science Initiative is also open with letters of intent due on April 6, 2015.

The JGI has published 40 publications since the previous BERAC meeting.

Wall asked what kept the microbes out of the gut. Anderson replied that it is not clear how the enzyme moves to the gut.

David Lesmes was asked to report on the findings of the Workshop on the Building of Virtual Ecosystems.

Today's software will not run on tomorrow's computers, so the purpose of the workshop, Building Virtual Ecosystems: Computational Challenges for Mechanistic Modeling of Terrestrial Environments, was to develop design requirements, principles for governance, and a phased approach for building a community modeling framework to advance a mechanistic, multiscale, and multiphysics understanding of complex terrestrial environments extending from plants to plots to watersheds and beyond. The workshop followed two other workshops.

Understanding complex biological, climatic, and environmental systems across vast spatial and temporal scales requires higher resolutions, higher fidelity, and mechanistic understandings at a wide range of scales. The tools needed to address these issues do not exist. Instead, different scientists work at different scales with their own, specialized models. It would be good to have the code resemble the functional system. What is needed is a multiscale-multiphysics framework that is modular, interoperable, extensible, agile, and easy to use across platforms, all supported by a comprehensive workflow model.

To build such an integrated software ecosystem is a computer science grand challenge. One has to start with appropriate library components. The libraries need to be designed for the machines of the future (which are uncertain). Field sites are at an intermediate scale. What is needed is a modular framework that would allow application at levels from plants to plots to watersheds. Models of different scales need to work together. Integrated software ecosystem systems are under way.

Why is a virtual plant-soil system needed? Having (1) more realistic plant-functional-types in Earth-system models (ESMs) and (2) a mechanistic basis for extrapolating plant structure-function relationships to future climate states with plant functional types (PFTs) and trait-based models would be very helpful. An integrative framework for understanding plant-soil systems, where implications for discovery at smaller scales can be examined at the whole-plant and crop scales, would support hypothesis generation and testing. Allowing optimization algorithms to identify more resource-efficient ideotypes would guide the breeding of emerging sustainable bioenergy crops. Integrating isolated models of plant components and processes would allow the development of a framework to mechanistically capture the structure and function of whole plant-soil systems. One should start with biophysical models of one to two sustainable bioenergy crop monocultures with robust aboveground and belowground plant components coupled to reactive transport models (RTMs) of soil. Compelling science questions will be used to drive an iterative cycle of code development and testing to increase model fidelity and range of species. Plant and microbial genomic information should be incorporated.

The workshop report is posted on the BER website: http://doesbr.org/VirtualEcosystems/. The IDEAS [Interoperable Design of Extreme-scale Application Software] productivity project is supported by ASCR and BER. An Environmental System Science (ESS) Working Group is being developed on model-data integration. Two publications are coming out from the workshop discussions.

An integrated software ecosystem that will affect a wide range of application areas will be built by computer scientists and ecologists.

Robertson observed that each scientist has his or her own model and asked how this idiosyncrasy can be overcome. Lesmes replied that that is the whole point: to use a more democratic approach to model development. The couplings that hold the models together are the difficult part.

Assmann noted that the NSF has invested a lot in the iPlant Collaborative and asked if there were any effort to interface this effort with iPlant. Lesmes responded that what DOE and NSF are doing are different. DOE would build a biophysical model of the plant first. That would provide a framework that the genomics can be brought to. It is a different approach.

Stahl asked if there were a point of diminishing returns in modeling increased complexity, and how would one know when one reached it. Lesmes answered that the goal is parsimony, designing a framework and seeing how successful it is in handling more and more complexity.

Zhang asked how this effort was going to be jump started. Lesmes said that it was going to be started in the ESS portfolio and be allowed to develop governance from there, bringing in representatives from the community.

A break for lunch was declared at 12:12 p.m.

Afternoon session

The meeting was called back into session at 1:46 p.m.

John Weyant was asked to present the meeting's science talk on the Program on Integrated Assessment Model Development, Diagnostics, and Intercomparison (PIAMDDI).

Integrated assessment of climate change can include any analysis involving two or more major Earth-system components including at least one natural and one human component. It can be done with or without models. Most "formal" integrated assessment models (IAMs) cover much of the global Earth system as possible. The purpose of integrated assessment is to understand complicated interactions and feedbacks among components, to develop information and insights not available from individual disciplinary models, and to focus on where and at what scale major interactions between components can occur. The major components of an integrated assessment are human activities, atmospheric composition, climate, sea level, and ecosystems.

In ocean/atmosphere/atmospheric chemistry, the basic concepts of integrated assessment are conservation of momentum, conservation of mass, conservation of energy, and chemical reactions. In ecosystems, they are photosynthesis, conservation of mass, conservation of energy, and biogeophysical-chemical processes. In the socio-economic system, they are birth and death; resource allocation, optimization, and market equilibrium; technology change and choice; and investment and economic growth. Some attributes are found in the social sciences but not in the physical sciences. Humans have preferences, expectations, the ability to adapt, and the ability to make contingent decisions. These characteristics may lead to differences in framing questions, modeling systems, integrating models, and assessing models.

IAMs integrate human and natural Earth-system climate science and provide important, science-based decision-support tools. Some IAMs have focused on cost-benefit analysis (i.e., weighing the costs of mitigation against the costs of inaction). These models have very simple representations of the economy but incorporate all potential feedbacks from the climate system to the human system. Other IAMs have focused on cost-effectiveness analysis (i.e., quantifying the transition pathways and costs associated with stabilizing climate at a predefined level). These models have more complex representations of the economy but have largely excluded feedbacks from the climate system to the human system.

Integrated-assessment research and model development is problem driven. In the 1980s, IAMs covered energy, economy, and climate. In the 1990s, they covered energy, technology, and mitigation. In the 2000s, they added land use. Today they include integrating impacts, adaptation, and vulnerability.

PIAMDDI is a transdisciplinary network of researchers engaging in empirically driven research that provides valuable tools and insights to the IAM community and other global-change research communities. Given the diversity and orientation of the research group, it does not favor any one approach. It strives to be a group of researchers who evaluate alternative approaches in a consistent and balanced way. It brings together a team of researchers considered experts in their fields, who serve or could serve as advisors to the IAM community and other global-change communities.

PIAMDDI's goal is to improve the way feedbacks and interactions are captured in IAMs, investigating

- the direct coupling of models;
- emulators of more-complex earth system modeling (ESM) and impacts, adaptation, and vulnerability modeling (IAV) that can be coupled with IAMs;
- pattern scaling, dynamical downscaling, and statistical emulations to be incorporated directly into IAMs; and
- integration and translational tools for facilitating the flow of information across models.

Each of these areas requires parallel efforts in basic research, research co-ordination, and model diagnostics and validation. These three activities need to be tightly coordinated within and between the four research areas.

IAMs have uncertainties and differences regarding forcing, responses, and internal variability. Moreover, there are trade-offs in uncertainty coverage for a given computational power as process and spatial resolution increases.

At a recent integrated-assessment workshop, researchers reported that:

- Global teleconnection operators can be used to estimate regional climate changes driven by sea-surface-temperature changes.
- Observed changes in extreme-temperature occurrences are driven in part by changes in atmospheric-pattern occurrence and in part by the extent of extremes within a region when that pattern occurs.
- Simple physical feedbacks render geo-engineering inefficient to reverse sea-level rise resulting from the melting of the Greenland Ice Sheet. Semi-empirical models used in IAMs typically missed this point.
- The rate of ice melting increases if the atmosphere is hotter.
- Adaptation can reduce global discounted costs by a factor of 5.

Some results from integrated climate-change impact assessments show that:

- An additional 1°C of global warming increases the occurrence of extreme heat, which leads to about a doubling in the volatility of U.S. corn yields.
- The future integration of world markets changes the greenhouse-gas consequences of the Green Revolution.
- Constraints on irrigation expansion will shape future patterns of land use and associated greenhouse-gas emissions. Irrigated area accounts for 40% of crop output worldwide. When irrigation expansion is constrained in water-scarce regions, rain-fed area expands. Under U.S. ethanol-driven cropland expansion, including the irrigation constraint boosts greenhouse-gas emissions by 25%.
- Unsustainable mining of groundwater depletes the aquifer.
- International market integration will moderate the most severe nutritional impacts of climate change.

In uncertainty and diagnostics, research results indicate that the Community Earth-System Model ensemble exhibits considerable skill in simulating interannual climate variability, and it captures key statistical characteristics of temperature/precipitation extremes. Results point to new model diagnostics based on variability and extremes that can be used to evaluate model skill, quantify decision-relevant uncertainty, and inform regional-impact analysis.

Land-cover inconsistencies across IAMs and Earth-system models can alter the calculated global carbon cycle.

Energy and carbon intensities in IAMs adjust to carbon constraints. Each model assumes different states at the beginning of the runs. MERGE [a model for estimating the regional and global effects] anticipates future changes. The Emissions Prediction and Policy Analysis. (EPPA) model shows almost no reduction in carbon intensity until the carbon price reaches $200; then suddenly switches to all carbon reduction.

Sensitivities of outputs from IAMs differ by scenario.

Uncertainty in the results of IAMs of climate change is pervasive and has critical policy relevance. Uncertainty is examined in three key variables that can be harmonized across models: population, gross domestic product, and climate sensitivity. Each model is run 5 × 5 × 5 times with a grid of the three variables used as inputs. A surface-response function is fitted to the results. With the use of developed probability density functions of the three variables, a Monte Carlo is run to estimate the output distributions.

Meehl noted that, in the groundwater mining paper, three models with huge differences in climate regimes were cited. He asked how one deals with that. Weyant said that there are certain advantages in using an ensemble, but one cannot avoid the differences introduced thereby.

Joachimiak was curious about the European hot spells and whether they were related to the East Coast cold spells. Weyant replied that that was a leading theory, but one cannot say for sure.

Meehl asked how the hindcasting was going. Weyant replied that the socioeconomic data are not good, especially for before the Great Depression. One might be better off doing small tasks rather than large ones. The value of doing a conditional hindcast is that one can use more-specific and more-certain data. Technological developments need to be better understood.

Robertson asked why there were more emissions from the expansion of African agriculture. Weyant answered that the result is driven by the fact that African producers are less efficient to begin with.

Todd Anderson was asked to respond to the BSSD Committee of Visitors (COV) report.

The COV was held in July 2014, and the report and BER's response are available on the BER website.

The COV recommended that BER deal with its understaffed conditions and the underfunding of staff travel. New positions have been posted for a microbiologist (no one accepted the offers made), a computational biologist (posted twice), and a biophysicist (no qualified applicant came forward). Travel funds come out of a larger SC budget and are constrained by that budget.

The COV recommended the conversion to electronic records and the inclusion of information for SFAs. All new FOAs, proposals, and review information are now done electronically in the new Portfolio Analysis and Management System (PAMS). Iteration 5 of PAMS will include a COV module for FOAs. Laboratory SFA materials will also be included in PAMS but at a later date.

The COV requested that background information be provided on FOA and SFA development. Almost all of BER's FOA and SFA development stems from workshops and/or are informed by workshop reports, which are generally cited in the FOAs or referenced in the white paper solicitations for new SFAs at the national laboratories. Only congressionally directed activities would not be fully referenced by workshops or reports.

The COV recommended that new JGI capabilities be shared with KBase. BSSD reviewed both JGI and KBase this past year, and the COV's concerns were echoed by the reviewers.

The COV recommended that the review process for JGI be externally staffed. The JGI-EMSL and DNA-synthesis capabilities are externally reviewed. The Emerging Technologies Opportunities Program (ETOP) is run by JGI, but the results are reviewed in the context of the triennial facility review.

The COV wanted to make sure that the JGI does not replicate commercial DNA analysis. This comment was also echoed by reviewers at the recent JGI triennial review.

The COV suggested supporting a joint databank with the National Institutes of Health (NIH). BSSD is continuing its collaboration with the NIH. The Protein DataBank was renewed in FY14.

The COV pointed out the need to plan for an upgrade of BER facilities. Upgrades and/or new equipment have been provided to the High-Flux Isotope Reactor (HFIR) and to the Linac Coherent Light Source (LCLS). Upgrades are often done on a funds-available basis, but BER agrees that there should be a formal plan.

The COV recommended a succession plan for the Structural Biology portfolio. BER agrees.

The COV recommended (1) the creation of a formal, documented, and reviewed process for the establishment of new SFAs and (2) the development of a clear process and documentation of the decision process when redirecting or terminating an existing SFA. BSSD will clarify this issue in future reviews.

The COV encouraged dialogue among related SFAs and between biofuel SFAs and the BRCs, Kbase, and the JGI. Program managers work closely with the national laboratories to develop programs that take advantage of unique capabilities at those laboratories and that complement the portfolio. Much of this interaction is via regular interactions with the program managers and at the PI meeting.

The COV recommended maintaining a balance between plant and microbial data in Kbase. KBase's emphases will reflect current efforts in the program. Plants constitute a major part of the bioenergy research within the Division.

The COV recommended that the Division keep an eye on computational needs going forward, especially for Kbase. BER agrees. As Kbase grows, its infrastructure needs will rapidly grow, as well. BSSD is very much aware of this issue. Some assets are available now, but a longer-term computing infrastructure plan will be needed.

The COV recommended the establishment of a formal mechanism for cooperation between JGI and Kbase. BER agrees.

The COV expressed support for the low-dose and radiochemistry programs. The FY16 budget proposes to end the radiological sciences portion of BSSD's portfolio, which includes the low-dose program and the radiochemistry and imaging instrumentation program.

The COV encouraged BSSD to continue support for the Ethical, Legal and Social Issues (ELSI) program as an integrated component of ongoing scientific programs. ELSI issues will continue to be integrated within ongoing science projects, particularly in the Biosystems Design portfolio.

The COV stated that a more-rigorous pre-screening process was needed for FOAs. BER agrees. A rigorous pre-application screening process is now in place for all BSSD FOAs.

The COV recommended that all SC open-FOAs be grouped together. The PAMS system and the new COV module currently under development will address this issue before the next COV review.

The COV recommended that an appropriate level of funding should be retained to maintain essential training and workforce development in key radiochemistry areas. Training is an integral component of all research supported by SC.

The COV recommended that review and oversight should be maintained over the BRCs. BSSD will continue to maintain a robust annual review process for the BRCs to ensure complementarity with the larger portfolio.

The COV recommended that a unified strategic plan be developed for the BRCs and biofuel SFAs. BER agrees. The biofuels SFA programs are complementary to the BRC efforts except for the algae work.

Jay Hnilo was asked to speak about CESD data activities.

BER supports diverse programs representing state-of-the-art research in several disciplines. There is an opportunity to empower these advances by integrating CESD's high-quality data streams. CESD data resources include the Carbon Dioxide Information Analysis Center, Earth System Grid Federation, Environmental Molecular Sciences Laboratory, Atmospheric Radiation Measurement Program, and Ultra-Scale Visualization–Climate Data Analysis Tools.

BER data reside within programs, facilities, and ongoing community research projects. There is an exponential growth in the volume, acquisition rate, variety, and complexity of these scientific data. Metadata standards are varied or nonexistent across programs, so too much time is spent rewriting data to a usable form. Furthermore, analytic and visualization capabilities are not harmonized across user groups. These situations all act to complicate the accessibility, availability, and usefulness of high-quality research data to address multidisciplinary problems.

A solution would be to develop a sophisticated data environment as a "one-stop shop" to access multiple archives of observed and/or modeled data, common analytical tools, and visualization capabilities. Data access and computation would be coupled in this environment, which would integrate observational, modeled, and experimental data. Data mining and knowledge generation would be aided. A modular and scalable design would be needed.

Data integration and a computational environment would be needed. They would require integrating complex-data-generating systems, high-throughput networks, data collection and management, data analytics, human–computer interfaces, and decision control and knowledge discovery.

Data integration would require developing consistent metadata and libraries to allow cross-talk between data.

Data analytics in the computational environment would require leveraging existing and future DOE leadership-class computational facilities; implementing an analysis platform; developing visualization/intercomparison tools; and providing provenance, automation, and human–computer interaction. Input for this component will require extensive community involvement via workshops involving university and national-laboratory scientists from across the climate and environmental sciences.

The benefits to the community from this type of environment would include open and ready access to CESD data of a known quality and format; user-friendly access; and an ability to rapidly prototype, run, and assess new process algorithms.

Community input has already been received at a CESM Advisory Board meeting, a town-hall presentation at the Annual American Meteorological Society Meeting, the Earth System Grid Federation (ESGF) governance structure, and a review of the *Annual ESGF & UV-CDAT F2F Conference Report*. A white paper was written by data experts at national laboratories and submitted to BER. A workshop will be held in late 2015.

Current efforts are looking at extending the ESGF's data capabilities to better represent BER's diverse portfolio. From 2015 to 2017, the effort will focus on metadata interoperability and connectivity for the ARM facility and the Carbon Dioxide Information and Analysis Center. In late 2015, the effort will begin the development of the analysis/computing platform, leveraging the late-2015 workshop.

Recent accomplishments include ESGF's user interface being migrated to a content-management system and a wiki for scientific projects, ESGF's data transfers incorporating Globus secure data transfers, ESGF's being able to store and access multiple data forms, and initiating the development of server-side analysis and visualization within ESGF.

CESD's integrated data ecosystem and workflow incorporates data collection and management, data-intensive computing, data analysis, policymaking by decision and control design optimization, and critical complex-data-generation systems.

Stacey stated that this effort seems to be an independent, parallel effort to Kbase. Hnilo replied that this will be a model for all data-storage systems, including Kbase and will be developed cooperatively.

Meehl pointed out that there is no mention of the NSF's efforts. Hnilo answered that he had not seen the plans for their massive portfolio.

Hubbard asked how much of the effort was cooperative projects versus BER only. Hnilo said that a lot of these communities are doing excellent research but have not developed a metadata standard. BER is happy to do that for them. It will be done on a case-by-case basis.

A break was declared at 3:35 p.m. The meeting was called back into session at 3:47 p.m.

Dorothy Koch was asked to provide an update on the Accelerated Climate Model for Energy (ACME).

ACME was officially launched in July 2014. It is a branch of the Community Earth System Model (CESM). It will advance a set of science questions that demand major computational power and advanced software, provide the highest resolution for climate science (15-25 km) with adaptable grids <10 km, and provide a fully coupled climate simulation with a time horizon from 1970 to 2050.

The code is designed to effectively use next-generation and successive generations of DOE leadership-class computers through the exascale. The project is based on a consolidation of previous DOE national-laboratory model-development projects and is therefore an efficient use of existing resources. It is organized around three science drivers: the water cycle, biogeochemistry, and the cryosphere. The new capabilities include resolutions to resolve extreme phenomena, integration of the human/energy component, and dynamic coupling of ice–ocean and sea-level rise.

ASCR acquires cutting-edge, increasingly disruptive computational facilities, which are exceedingly challenging for all domain scientists to use effectively. ACME embraces this challenge, risk, and opportunity as it develops software and algorithms to use current and future computer architectures efficiently.

Before ACME, DOE sponsored seven model-development activities across eight national laboratories, and those have now been combined into one large model-development project.

ACME was reviewed by a panel in March 2014. BER approved the project in July 2014. BER held a community workshop in October 2014 to consider how best to address and model energy/societal elements together with Integrated Assessment and Impacts Adaptation Vulnerability approaches and communities. There will be a follow-up review after six months. A management "in progress review" was held in January 2015.

The ACME management structure is headed by the ACME Council, made up of representatives from many national laboratories. It has seven groups: land, atmosphere, software coupling, workflow, ocean/ice, coupled simulations, and performance/algorithms. There are also a couple of simulation groups. An ACME development roadmap has been developed.

The water-cycle-experiment strategy is to explore the role of physical processes and parameterization in climate models influencing river flow and fresh-water supply. It will produce accurate simulation of river flow for major river basins: the Mississippi, Amazon, and Ganges. These basins represent very different climatic and hydrologic regimes, large-scale ocean–atmosphere interactions, regional land–atmosphere interactions, and local human activities.

The biogeochemical experiments will address the impacts of nutrients on terrestrial carbon–climate feedbacks.

The cryospheric experiments will develop a coupling of a new dynamic ice sheet to a new MPAS (Model Prediction Across Scales) variable-mesh ocean and sea ice to simulate ice-sheet instability, calving, and sea-level rise to model complex geometries and structures.

DOE-ASCR has two computational architecture paths for today's and future leadership systems: hybrid multi-core systems (like Titan) and many-core systems (like Sequoia/Mira). It is a significant challenge for ACME to design code for both architecture types. ACME computation needs to design code to run on DOE's leadership-class computers, both existing and next-generation; develop software for portability, rapid testing, and modularity; provide end-to-end model configuration, testing, validation, analysis, and provenance; and develop variable-mesh refinement and physics in regions of interest or requirement.

ACME's next steps include a proposal invitation on Global Change Assessment Model (GCAM), ACME carbon cycle, water management, and biofuel crops. ASCR's next steps include active discussions on accelerated climate modeling collaboration, SciDAC4 [Scientific Discovery Through Advanced Computing, Phase 4], and the early-user programs at the National Energy Research Scientific Computing Center (NERSC) and the Oak Ridge and Argonne leadership computing facilities (OLCF and ALCF). The community's next steps are to release the ACME v1 code and simulation (in July 2017).

ACME embraces this challenge, risk, and opportunity as it develops software and algorithms to efficiently utilize current and future computer architectures.

Janetos asked how the team was going to deal with managed river systems. Leung answered that the algorithms will try to simulate river and dam management.

Meehl noted that DOE supports a very great breadth of modeling efforts unequalled elsewhere in the world.

Zhang asked who the university partners were and what their roles were. Koch replied that the process is to access the code and learn how to use it and then compete with others to develop applications to use it, possibly in collaborations.

Randall asked why the MPAS atmosphere is not part of this effort. Koch responded that scalability is an issue.

James Ehleringer was asked to present the report on the Workshop on the Development of an Integrated Field Laboratory (IFL).

There was a discussion of the charge at the previous BERAC meeting. The workshop was held January 29–30, 2015, in Germantown. Grand-challenge questions were identified:

1. What are the energy, water, and greenhouse-gas flows of urban and adjacent systems in a changing environment?
2. What are the drivers, controls, and feedbacks between the Earth and human systems from the global scale to finer-grain scales more immediately relevant to the human experience?
3. How can this knowledge inform Earth -system communities?
4. How can this information be used to inform stakeholders about ways to mitigate environmental impacts and lead to more resilient and sustainable urban systems?

IFL should be relevant to stakeholders, and stakeholders should be involved in its design. The IFL should bring in socioeconomic drivers as well as geographic drivers.

A frequent question is about heterogeneity. Heterogeneity is variable but similar at the same scale even with radically different landscapes.

DOE leadership is essential. DOE has unique capabilities and is highly engaged with the scientific community.

Discussion of implementation should take advantage of existing urban observation capacities and research efforts. Partnerships would be essential.

In terms of criteria for site selection, there is no single location that would answer all questions. A network of sites would be needed to address hydrology, wind fields, population, etc.

gradients. DOE has looked at desert and forest gradients but not urban distributions. There is a history of distributed sites (e.g., ARM).

Janetos reiterated that DOE leadership could go a long way. Leung said that Ehleringer had done a great job leading the workshop. Stacey thanked all involved in the workshop. He called attention to Dehmer's request, which said "BERAC should (1) define the criteria for selecting sites for future BER field-based research and (2) prioritize the sites identified or described." It does not call for an urban/rural IFL siting but rather a hierarchy of types of sites, such as urban/rural, forest, desert, etc. The Committee needs to write a progress report to Dehmer; Stacey volunteered to develop that letter. Weatherwax was open to having another BERAC meeting, workshop, or follow-up conference call.

Assmann said that the report is fascinating. Managed agricultural systems, forests, and rangelands seem to be left out and perhaps should be discussed.

Janetos noted that, at the prior BERAC meeting, the Committee identified urban areas as *one* potential area, and that does not come out too well in the hastily written report.

Meehl said that more people live in urban environments than in rural ones. The section on other agency efforts was striking. From a modeling perspective, what one wants are a lot of coordinated measurements in different environments. He asked if DOE would be a coordinating agency, pulling other agencies' efforts together and housing the data for them. Ehleringer replied, yes. There might be observatories [e.g., the Long Term Ecological Research Network (LTER) and the National Ecological Observatory Network (NEON)] that are separated from each other. This facility could pull them together.

Robertson noted that the Committee had discussed going from bedrock to cloud. The Committee might be remiss if it put all of its effort into one type of site; the facility should cover different types of sites. The IFL's strength is to integrate across different environments.

Stacey noted that someone had brought up mountains as an important type of site. Leung responded that mountains often connect different types of hydrologies, airflows, and other processes. Ehleringer said that the Subcommittee had not had a chance to get into a lot of environments. If it had had more time, it could have gotten to those diverse environments.

Zhang noted that urban environments have complex hydrologies. How water flows to, through, and out of an urban environment is very complex.

Stacey asked how the subsurface fitted into this discussion. Hubbard said that both vertically and horizontally integrated data are needed. She did not know who "owns" urban development, energy flows, and water flows, let alone how to integrate new data into that matrix.

Stacey noted that the Amazon project was able to represent a large ecosystem and asked whether that was the type of IFL that the Committee was talking about. Geernaert said that the Amazon project also was an attempt to get data on a clean environment. The Manaus study focused on the atmosphere and its movement. Janetos said that previous programs in Brazil were in forest/agricultural regions and did not deal with urban systems at all and were all about above-ground processes. Urban settings should be looked at as anchors of transects across coastal and forest sections. That would let the scientists do a better job of doing bedrock-to-cloud assessments. Ehleringer said that the Committee had been thinking of gradients. It wanted to look at an environment that was human-affected. Long-term measurements are needed covering 10 years or longer, and they need to be multidimensional.

Weyant pointed out that there have been a lot of data on urban sites; the transect idea is new and needed. Wall said that cities offer large numbers of gradients and impacts on groundwater and air temperature. There is a huge wealth of information to glean in both the atmospheric and subsurface sciences.

Zhang pointed out that the microbial world would be important both in response to climate and in response to other variables.

Stacey asked if the Committee were going to gravitate to gradients or sites. Weyant said that it has been suggested to instrument a large city to measure variables.

Ehleringer said that this Committee needs to come up with a document to tear apart or expand and asked whether another workshop were desired, or what.

Robertson said that a transect is preferred with observations across the gradient. However, a transect in just one location may not provide sufficient diversity. It may be useful to propose three or four types of sites along the transect or a vertical gradient.

Stacey said that intrinsic scientific value or value to the DOE mission should be considered. Ehleringer pointed out that BER was not operating in a vacuum. There are others in DOE and in other agencies interested in these topics. The Committee needs to coordinate with them.

Meehl asked if the Subcommittee had looked at other countries that studied gradients. Ehleringer replied that cities are not waiting for nations to make decisions and are asking and investigating these questions themselves.

Stahl asked how this concept of IFLs fitted into integrated assessment. Ehleringer answered that there are many gaps in integrated assessments to be filled, but the Subcommittee would like to pursue an integrated approach.

Weyant asked Leung what research she had done on such work. She replied that a wide range of problems is being addressed that could be answered about the carbon, water, and energy cycles. Janetos added that an understanding was being sought of some of the vulnerabilities to extreme events. These extreme events (floods, hurricanes, tornadoes, wildfires, blizzards, etc.) and associated vulnerabilities are of great import to cities across the world. More rigor is needed in researching and modeling them.

Stacey summed up that he had heard: (1) mountain sites, (2) urban/rural sites, and (3) managed sites. Ehleringer agreed that gradients across such sites are needed. Wall pointed out that deserts had not made the list despite the fact that there are many drought-affected areas now. Stacey asked if the Committee wanted to add deserts to the list of sites. Ehleringer added that it was desired to consider the vulnerability of the sites, also. Stacey said he was open to further discussion during the evening to offer steps forward in the following day's deliberations

Ehleringer noted that the workshop Subcommittee had benefited from nearly 25 white-paper documents that the Committee members might want to review. Hubbard stated that the Committee should consider how to optimize the use of any transect or other sites selected. Joachimiak said that it seemed that the Committee might need a larger breadth of input.

Stacey asked if there were a need for a workshop to define what an IFL is. It should be something that looks horizontally and vertically, has transects, sites, etc. Ehleringer worried about shopping lists. He would like to keep the discussion broad. Socioeconomic data also need to be considered. If there were another workshop, the Committee would need to discuss what types of participants should be included.

Janetos asked whose workshop it should be: BERAC's, BER's, SC's, or whose. The planning effort for NEON went on for many years before the selection of the first site.

Weyant noted that Google cited C4OC (Caring for Our Country), an Australian climate-leadership group that analyzes the urban environment.

There being no other discussion or new business, the floor was opened for public comment.

Janet Jansson said that, if one thought about the extensive biological questions of interaction in coastal-terrestrial or the terrestrial-aquatic interface zones, that would be an element for discussion and debate, as well, particularly to get a stronger component.

Robin Graham had participated in the IFL workshop and said that it was an excellent event and that everyone was engaged. If there were to be another workshop, socioeconomic modeling scientists should be involved. Many participants were very well informed about what was going on around the world. Everyone agreed that some rigorous science was needed.

Roy Mariuzza was concerned by the ending of the synchrotron X-ray crystallography program, which was very important and had 2000 users. The information is critical to the development of new drugs, most recently for Ebola but also for many cancer studies and vaccines being developed.

There being no further comments, the meeting was adjourned for the day at 5:24 p.m.

Friday, February 27, 2015

Chairman Stacey called the meeting back into session at 8:30 a.m.

He introduced **Patricia Dehmer** to present a summary of the FY16 federal budget.

SC funds 47% of the U.S. federal support of basic research in the physical sciences. It supports about 22,000 PhD scientists, graduate students, engineers, and support staff at more than 300 institutions, including all 17 DOE national laboratories. It operates the world's largest collection of scientific user facilities operated by a single organization, and they are used by 31,000 researchers every year. SC is a world leader in high-performance computing and computational sciences and it is a major U.S. supporter of physics, chemistry, materials sciences, and biology for discovery and for energy sciences.

SC's proposed budget for FY16 is 5.3% higher than its FY15 enacted appropriation, which was $5.071 billion, which in turn was slightly higher than the $5.070 billion in FY14. Some offices within SC got major proposed increases or cuts for FY16. ASCR is proposed to receive a 14.8% increase in FY16, much of which will be used to provide computing services to BER and other SC offices. Fusion Energy Sciences is proposed to lose 10.2% of its current budget.

Congress is supportive of the user facility program. For FY15, all of the construction that was requested by SC was fully funded, including a new building for BER at Lawrence Berkeley National Laboratory (LBNL).

The SC FY16 budget request breaks down as follows: 39% for research, 37% for facility operations, 11% for construction, 3% for major items of equipment, 7% for other, and 3% for SBIR/STTR [Small Business Technology Transfer]. That budget is dominated by large user facilities. For ASCR, there is a significant increase for the exascale initiative to support high-performance computing vendors to design and develop exascale node technologies and systems. This initiative has struggled for 2 years to get included in the budget until the Secretary himself sent a letter to the President's science advisor supporting it. For BER, there is a significant bump-up for climate and Earth-system modeling, with the largest increases for climate model development and validation and integrated assessment. Some decreases elsewhere in the BER budget offset these increases. The facilities run by ASCR, BER, Basic Energy Sciences (BES), and High Energy Physics (HEP) operate at or near their optimal levels (greater than 98%) and are robustly supported. The major construction funding this year goes to the Linac Coherent Light Source in BES, the International Thermonuclear Experimental Reactor (now ITER) in Fusion Energy Sciences (FES), the Long Baseline Neutrino Facility and Muon to Electron

Conversion in HEP, the Continuous Electron Beam Accelerator Facility upgrade and Facility for Rare Isotope Beams in Nuclear Physics (NP). There are special line items for infrastructure upgrades at the national laboratories and for the materials design laboratory at Argonne National Laboratory (ANL).

Five of the top ten computers in the United States are owned by DOE and enable the science conducted by BER and others. All three SC supercomputers are currently in the upgrade mode. Future computing research efforts include major upgrades in advanced software code development, the development of downscaling methodologies, and the validation of codes against data from test beds in the United States.

The Department owns assets that no one else has. In BER, those assets include:

- The ARM Climate Research Facility,
- The Next-Generation Ecosystem Experiments (NGEE),
- Ameriflux,
- A DOE data informatics capability to store, analyze, and coordinate data from ARM, NGEE, and Ameriflux, and
- The petascale leadership computing facilities (LCFs) at Oak Ridge National Laboratory (ORNL) and at ANL.

That is why DOE, SC, and BER should lead climate research.

SC grand science challenges that frame priorities include:

- Atmospheric and terrestrial process-level interactions, in particular cloud, aerosol, ecological, hydrological, and biological processes that affect the Earth’s energy balance at various scales
- Understanding the processes that control internal climate variability and extremes
- Understanding the uncertainty of the climate system

These challenges are part of the mission of the organization.

DOE is a leader in climate science and has been since the 1950s, when the Atomic Energy Commission was charged with understanding atmospheric transport for national security and, later, the impacts of CO_2.

At the national laboratories, workforce development for teachers and scientists supports more than 1000 students and faculty annually: 760 science undergraduate laboratory interns, 90 community college interns, about 100 graduate students engaged in PhD thesis research, and 65 faculty and 30 students in the Visiting Faculty Program.

There is a brand-new Under Secretary for Science and Energy: Lyn Orr, a former Basic Energy Sciences Advisory Committee member who headed up two research facilities at Stanford University. Marc Kastner did not get confirmed as the Director of SC and has taken a new job.

Science Laboratories Infrastructure had three new starts this past year: the Materials Design Laboratory at ANL, the Photon Science Laboratory building at SLAC, and the Integrative Genomics building at LBNL. Importantly, funding is also provided for general-purpose infrastructure electrical upgrades at SLAC and ANL and facility improvements at the Fermi National Accelerator Laboratory (FNAL).

Stacey introduced a series of talks about the Bioenergy Research Centers (BRCs). **Paul Gilna** was asked to present an update on the BioEnergy Science Center (BESC).

The BioEnergy Science Center is a multi-institutional, DOE-funded center performing basic and applied science dedicated to improving yields of biofuels from cellulosic biomass. It is made up of 300 people from national laboratories, universities, and industrial companies. Its mission is to enable the emergence of a sustainable cellulosic biofuel industry by leading advances in science and science-based innovation resulting in the removal of recalcitrance as an economic barrier to cost-effective production of biofuels.

Access to the sugars and lignin of cellulosic biomass is the current critical barrier, and it requires a multidisciplinary approach. BESC believes biotechnology-intensive solutions offer the greatest potential. The vision is to develop dedicated bioenergy crops, consolidated bioprocessing (cellulase production and ethanol fermentation combined), advanced biofuels beyond ethanol, and improved pretreatments.

The key strategic goals are to develop a fundamental understanding of the molecular basis of recalcitrance and cell-wall formation; to identify and characterize a high-performing set of *Populus* and switchgrass TOP (transgenic operative products) reduced-recalcitrance lines; to understand microbial cellulose use; to achieve proof-of-concept for consolidated bioprocessing (CBP) with *C. thermocellum*, yeast, and *Caldicellulosiruptor spp.*; and to develop and apply chemical, immunological, physical, and imaging methods to characterize biomass and to build models that predict the relationships between biomass structure and recalcitrance.

These efforts are organized around the three strategic goals: better plants, better microbes, and better tools and combinations.

In 2007, lignin and cellulose were believed to be the primary bases for recalcitrance, there were low transformation efficiencies for switchgrass, and the range of natural variation and genetic control of recalcitrance within a species was not established. Today, the core concept that multiple genes, many outside of the lignin pathway, control plant-cell-wall recalcitrance has been proved; the BESC transformation pipeline has been used to target about 900 candidate recalcitrance-gene constructs; multiple reduced-recalcitrance lines have been verified in *Populus* and switchgrass, and more than 900 TOP lines have been selected for deeper study; and data are now being gathered from field trials of initial transgenic lines.

In other advances, high-throughput transformation of *Agrobacterium*-mediated switchgrass has achieved an efficiency of more than 90%, vastly improving the prior 5% efficiency. The system has been effectively used for producing large numbers of transgenic switchgrass plants.

Catechol-O-methyltransferase (COMT) modification improves biofuel yield, increasing the amount of both biofuels and commercially valuable byproducts. A field study of transgenic switchgrass with reduced cell-wall recalcitrance showed that conversion phenotypes can be maintained in the field. Results from greenhouse studies are holding up in those field studies. Lignin-modified transgenic switchgrass had similar gains in sugar release (up to 34% higher) and biofuel production (up to 28% higher) as those observed in the greenhouse. Prior BESC work created the transgenic switchgrass, the greenhouse experiments, and the composition analyses. This work achieved Animal and Plant Health Inspection Service (APHIS) field permits and cultivation, compositional analyses, saccharification tests, and separate hydrolysis and fermentation (SHF) fermentation tests.

The genome-wide adaptive variation in *Populus* has been revealed by population genomic analysis. This study was the first to explore the genomic legacy of selection across an entire tree genome and highlight both the wide range of selection pressures as well as the climatic influence on phenological systems and growth. The specimens are now growing in gardens, and natural variants are now producing reduced-recalcitrance lines. Field tests are being conducted in South Carolina (40+ *Populus* constructs), the Pacific Northwest (1000+ *Populus* genotypes in four common gardens), Texas (genetically improved switchgrass), and Tennessee (genetically improved switchgrass).

More than 20 reduced-recalcitrance TOP lines have been selected for deeper study. Each of the TOP lines combine insights from multiple institutions and simple-to-complex analytics.

In 2007, few cellulases had been expressed in yeast. Functional genetic systems for cellulolytic thermophiles were not available, modes of ethanol inhibition were not understood, and there were few models and mechanisms for multifunctional cellulolytic enzymes available. Now several new structures and models are being used, new genetic tools have been developed, and improved ethanol yields have been demonstrated.

Early results on the microbial solubilization of plant cell walls have shown a better than 74% cellulose conversion of five grassy feedstocks by *C. thermocellum* with minimal pretreatment. Studies of cellulase architecture and mechanisms offer new possibilities for creating synergistic mixtures of biomass-attacking enzymes drawn from different organisms. The activity of CeIA on Avicel is seven times higher than the common exo/endo cellulase standard mixture of Cel7A and Cel5A.

In addition, BESC has reported the successful DNA transformation of both *C. thermocellum* and *C. bescii.* Several engineering strategies have improved ethanol yield by *C. thermocellum.* The conversion of switchgrass to biofuel using engineered *C. besii* has demonstrated the direct conversion of plant biomass to a fuel without pretreatment. The work has focused on advanced biofuels (e.g., isobutanol) at an industrially relevant scale, doubling production.

Including cellulase expression and glycerol reduction in the C56X yeast has improved yield 8 to 10%, and industry is asking to see these advanced feedstocks and yeasts.

Sample-analysis pipelines have been developed and used for high-throughput, medium-throughput, and low-throughput analytical procedures. More than 65 analytical techniques are now available for various assays and characterizations.

BESC published the first report of the use of an engineered microbe to produce increased amounts of a biofuel from a bioenergy feedstock modified for the same purpose. These results demonstrate the potential additive advantages of combining a modified feedstock (switchgrass) with an engineered consolidated bioprocessing microorganism (*C. thermocellum*).

Community outreach in bioenergy science education is now self-sustaining. Of those researchers who have worked at BESC, about 50% are employed in industry and about 50% in academia. The value of BESC lies in its focus on impactful recalcitrance science, a high-functioning team of world-class scientists, a close connection to industry, the acceleration of research and technology outcomes, and the growing core of well-trained young research staff.

Timothy Donohue was asked for an update on the Great Lakes Bioenergy Project.

The Great Lakes Bioenergy Research Center calls the University of Wisconsin-Madison home and has sites in universities across the United States and Canada and at national laboratories, engaging about 400 researchers. The Center has set up a materials production team to follow the production chain from cropping systems to pretreated biomass to hydrolysate to fermentation-produced biofuels and chemicals. In each step, one needs to understand the material being dealt with and how it affects the activities going on downstream. The Center assembled experts and assets in feedstocks, deconstruction and conversion, and analytics. It included not only BER people but also those from other federal agencies and private organizations. It does cell-wall analytics, looks at hydrolysis yields, and studies hydrolysate composition and functions.

The reiterative microbial design (Redime) process targets sites for strain improvement and employs a number of analytics, such as cell-wall analytics, looking at hydrolysates, analyzing their composition, and monitoring the performance of microbes. There are more than 75 organic and inorganic materials after ammonia fiber extraction (AFEX). These materials are complex organic and inorganic mixtures that are being fed to microbes to make into fuel. A gene-expression pattern in AFEX-treated corn-stover hydrolysate (ACSH) is used to see variety in differences between treatments of the corn stover, as measured by sugar disappearance and ethanol production. The purpose is to see what is going on in these cultures that leads to these differences in performance and genome expression so one can see how best to change the attributes of pretreatments, enzymes, and plants.

In one experiment, bacterial cultures that make ethanol (here *E. coli*) were treated with natural and synthetic hydrolysates of corn stover, and the process was monitored with flux balance. The study showed that the aromatics in the corn stover inhibited growth of the microbes in the samples. There were more than two dozen of these aromatics (major among them being feruloyl amide) that came predominantly from the lignin. This experiment was an example of fermentation multi-omics and computational modeling, another way to interrogate the samples. When the aromatics are left out, there are several differences, especially the induction of a large set of genes that are involved in pumping the aromatics out of the cells. Another difference is the induction of genes involved in the detoxification of aldehydes. Thus, the cells are expending a lot of energy in dealing with these aromatics. With gene labeling, feruloyl amide was found to significantly inhibit growth, increase phosphoribosyl pyrophosphate (PRPP) pools, and block nucleotide triphosphate synthesis. This knowledge points out the site in the cell where these aromatics block metabolic activity. Chemical genomics was used to show that this effect occurred not only with *E. coli* but also with other microbes.

Genomic fingerprinting is being used to see which genes have the greatest sensitivity to lignin toxins, most of which are involved in nucleotide synthesis and energy production. This pathway can also be used to analyze material produced by poplar, miscanthus, switchgrass, native prairie, and mixed feedstocks. The yearly/regional feedstock variations are being assessed, and the impact of biomass-trait modifications is being determined. A second utility of this production chain is the analysis of other polysaccharide hydrolysates and lignin streams from other pretreatments, such as gamma-volerolactone (GVL), alkaline, ionic liquids, and changes in enzyme cocktails. These enzymes have been characterized at other user facilities. What is being studied now are additional fuels and chemicals, the impact of changes on producing microbes, and different single-species/consortia for optimizing microbes to remove lignotoxic aromatics.

Jay Keasling was asked for an update on the Joint BioEnergy Institute (JBEI).

The JBEI has seven partners located at one site; about 98% of its staff are at the Emeryville, Calif., site.

Eight key factors have the biggest impact on the price of biofuels: CO_2, feedstock, biomass, pretreatment, cellulose and hemicellulose, enzymes, sugar, and microbes. The Institute is investigating engineering the cell-wall deposition in fibers and addressing two challenges: (1) high-density biomass would reduce transport costs and increase fuel yields and (2) producing more sugar and less lignin.

In engineering the cell-wall deposition, the Institute is looking at overexpressing transcription factors and seeing if it can fill up the cell with sugar rather than lignin. It has already doubled the amount of sugar, and companies are trying the technique in switchgrass and rubber plants.

The Institute expresses a gene (a bacterial 3-dehydroshikimate) in the fiber cells that allows the production of a particular aromatic intermediate. Doing that produces a 50% drop in lignin and an increase in the sugar that is coming out of the cell wall.

Inexpensive processes and lower enzyme usage are needed along with better pretreatment processes that yield cleaner cellulose/hemicellulose products. Two pretreatments are currently used: ionic liquid (which is new) and dilute acid (which is the industry standard). The new process has one-tenth of the enzyme usage of the old one, driving enzyme costs from $2.00 per gallon of fuel to $0.20 per gallon.

Helping to keep costs low were the 92% recovery and recycle rate of the ionic liquid and the 90% efficiency retention of the recycled material. Ionic liquids can be made from lignin to produce biotic liquids. Two of these renewable biotic liquids work almost as well as the ionic liquid [C_2mim][OAc].

There are still some key challenges in converting lignocellulosic biomass to fuels: Biofuels are needed for all kinds of engines, particularly diesel and jet engines. Also, many fuel-producing organisms can only use a fraction of the sugars from biomass. The Fuel Synthesis Division is investigating gasoline, diesel, and jet fuels. Microbes are being engineered to convert sugars into advanced biofuels and fatty acids into hydrocarbon fuels. Methyl ketones, which are in the diesel range, are being produced with *E. coli* with titers exceeding 40% of the maximum theoretical yield. Some advantages of these hydrocarbon fuels are that the fuel self-separates (it floats on water) and it has a high octane number.

Engineered microbes are being used to convert sugars into advanced biofuels like methyl ketones, bisabolane, alpha-pinene, and isopentanol. Isopentanol production was improved with proteomics and metabolomics, and the process was used on switchgrass sugars with engineered microbes. It worked extremely well.

JBEI's research program has reduced the synthetic-fuel cost by a factor of 10,000 from what it was originally. As a result, the price of fuel with current technology is $39.76 per gallon, and the price of fuel produced with best technology is $3.66 per gallon. If one sells heat from the lignin, the price of fuel made with these advanced technologies is reduced to $2.21 per gallon.

A suite of tools has been created. That software is given away, and the research results are being put in Kbase.

Overall, the BRCs have produced 1800 publications, 427 invention disclosures, 233 patent applications, 24 patents, and 105 licenses/options. There is an extensive group of companies using the research results and technologies coming out of the BRCs.

Stacey asked: Looking at a future with cheap oil, what should the BRCs do? Kiesling said that oil and natural gas were cutting back on research; research is needed in this field; the price of oil will go back up; hybrid car sales are slacking off; biorefineries can produce a lot of the chemicals that are now derived from petroleum. There is a lot more that the BRCs can do in sustainability. Donohue added that society has not addressed new cropping systems for fuel production; the centers can produce new transportation fuels and chemicals. Gilna said that the program could take the long view now; there is no sense of emergency.

Stacey asked how the removal of biomass affects soil fertility. Gilna said that the BESC started with using agricultural residue; now it is going to bioenergy crops that will not reduce soil inputs from residues. Donohue said that these important issues are regional; Wisconsin has agriculture, forestry, and prairie residues to exploit without affecting soil inputs as opposed to Iowa, which is converting corn kernels and stover side by side.

Weyant asked if there were any sense of the timing of the least-cost gasoline. Keasling said that advanced biofuel companies have produced high-value byproducts by using the technology to lower fuel prices.

Gilna added that, once the plants achieved fuel production from the biomass, they started asking "what else can we produce from lignin?"

Meehl asked whether biofuels or gasoline had lower CO_2 emissions. Keasling said that, in Brazil, petroleum produces more CO_2; there is an 80% reduction in the production of CO_2 with the use of sugarcane-derived methanol biofuels.

Assmann had heard in the talks that aromatics were a good starting point for high-value fuels and chemicals *and* that they were an inhibitory influence on sugar extraction and fermentation. She asked if they could be processed out. Keasling replied that the aromatics can be very valuable, so one wants to remove them before the fermentation process. Donohue added that one can also use a variety of other strategies. Zhang pointed out that, in addition to sugar condensates, one can increase photosynthesis. Keasling and Donohue added that that topic was not being worked on right now because the BRCs are not charged to do that.

Wall asked whether they would apply economic analysis to grasses versus poplars. Gilna replied that a rigorous analysis had not been carried out at this stage; in the coming year, the BESC will apply its TOP lines to other feedstocks.

A break was declared at 10:21 a.m. The meeting was called back into session at 10:31 a.m. Stacey resumed the discussion of the charge about IFLs.

Hubbard said that the Committee needs to think about whether IFLs will address climate change, bioenergy cropping, the water cycle, etc. It also needs to consider the site/gradient issue. One does not want to get into a 10-year planning process. What can be done by September?

Janetos said that BER has chosen to develop a variety of tools for dealing with atmospheric CO_2 and how the climate system works. A big gap is what the greenhouse-gas loading of the atmosphere is and what the primary contributor to that loading is. It needs to be understood how the planetary system will respond. This Committee needs to consider (1) how one best starts doing that and (2) what direction that leads the investigation into. Feedback is needed on that question and to fix the weaknesses in the report.

Robertson said that the original proposals for IFLs in 2013 call for high instrumentation of representative ecosystems of vertically integrated sites and large, rapidly changing regions important to the economy. That definition might include deserts, mountaintops, or biofuel-feedstock-production areas. Different types of IFLs might be proposed.

Stacey noted that a critic had said that this is all just pie-in-the-sky and unachievable. Some infrastructure may be achievable.

Joachimiak noted that Dehmer's charge is quite specific: What is the highest-priority capability that is needed that does not exist right now.

Janetos said that the costs of horizontal- and vertical-looking IAM facilities are known.

Zhang stated that the focus must be on the urban sites because that is where CO_2 production is focused and where the greatest fuel consumption and CO_2 flows occur.

Wall said that the workshop addressed where the climate-change impacts are most severely felt. That would probably point to an urban coastal site and to an arid site. Assets already located in such sites should be looked at. Weyant said that probably the most interesting location for global modeling would be a transect from Northwest China through Beijing.

Stacey steered the conversation to logistics. He will send a letter to Dehmer saying that the Committee is moving to consensus with a gradient from a natural to an urban system. Two or three sites might provide diversity. Shanks agreed that that would be a good response. Shanks asked what the next steps would be. Weyant pointed out that there was a fall deadline for the final report. Another workshop could be conducted by then. Assmann called attention to the fact that the Committee does not know the budgeting constraints. As a result, the Committee could provide a list of things, and the Office could cherry pick what could be affordable.

Janetos stated that one approach could be to set a one-month comment period on the report from the first workshop and thereby broaden the discussion. The philosophical approach needs to be identified. That could be done online and would require an intermediate BERAC meeting. Stacey pointed out that the report did not comment on implementation. A description of the infrastructure needed to do the science is required.

Zhang suggested that the workshop report be used to recommend one or two sites. Janetos wondered whose responsibility that would be. A period of analysis would be needed. The national laboratories would probably propose some interesting approaches. Robertson suggested that it might be more productive to have workshops following the recommendation of one or two sites, and that should meet the charge. Recommendations from climate scientists and others are needed to articulate what those sites should be.

Hubbard asked whether it would be sufficient to prioritize the types of sites. Hubbard quoted Dehmer's charge letter as saying that the goal was "to recommend the major next initiatives for field-based research that capture a multidisciplinary approach and build on observations and modeling. As part of this charge, BERAC should (1) define the criteria for selecting sites for future BER field-based research and (2) prioritize the sites identified or described."

Stacey commented that the Committee seems to have produced the contents of the letter to Dehmer: a scientific justification of why IFLs are needed, BERAC's deliberations, the science package, a discussion of the limitations needing further study, and a description of the potential future workshop(s). A subcommittee could pull that together, and a BERAC conference call meeting could be used to review and perhaps approve it. Ehleringer would lead the effort. Stacey asked for consensus for this plan. No objections were raised.

The floor was opened to new business. There being none, it was opened to public comment.

Bethany Johns of the American Society of Agronomy asked how one could make sure that carbon is returned to the soil. Stacey replied that several studies (e.g., those by Martha Schlicher of this Committee) have been done and have identified the percentage of stover that can be removed from the soil without reducing the carbon of the soil. Weatherwax added that a lot of thought has been devoted to this topic; a workshop specifically on that topic has been held; and an FOA is out on the street to conduct research on the topic.

Robert Jacobs of ANL asked the rhetorical question: Where do we need to do a better job of forecasting climate? He answered, the cities. The timing is critical. Cities are deploying infrastructure now to mediate the effects of climate change.

No further comments being made, the meeting was adjourned at 11:15 a.m.