Public Meeting Minutes
Biological and Environmental Research Advisory Committee
October 28–29, 2015
Gaithersburg Marriott Washingtonian Center
Gaithersburg, Maryland

BERAC Members Present

Gary Stacey, Chair
Sarah Assmann
Dennis Baldocchi (Wednesday only)
James Ehleringer
James Hack (via telephone)
Susan Hubbard
Anthony Janetos
Andrzej Joachimiak
Gerald Meehl
Sabeeha Merchant
David Randall
James T. Randerson
Karin Remington (Wednesday only)
G. Philip Robertson
Jacqueline Shanks
David Stahl
Judy Wall
John Weyant
Minghua Zhang
Huimin Zhao (Wednesday afternoon and Thursday only)

BERAC Members Absent

Janet Braam
L. Ruby Leung
William Schlesinger
Martha Schlicher

Also Participating

Todd Anderson, Division Director, Office of Biological and Environmental Research, Office of Science, USDOE
Michelle Buchanan, Associate Laboratory Director for Physical Sciences, Oak Ridge National Laboratory
Allison Campbell, Acting Associate Laboratory Director, Earth and Biological Sciences Directorate, Pacific Northwest National Laboratory
Julie Carruthers, Senior Science and Technology Advisor, Office of Science, USDOE
Joanne Corcoran, BERAC Committee Manager, Office of Biological and Environmental Research, Office of Science, USDOE
Alfred “Joe” Cornelius, Program Director, Advanced Research Projects Agency-Energy, USDOE
Patricia Dehmer, Acting Director, Office of Science, USDOE
Timothy Donohue, Director, Great Lakes Bioenergy Research Center, University of Wisconsin, Madison
Douglas Friedman, Senior Program Officer, Board on Chemical Sciences and Technology, National Academy of Sciences
Gary Geernaert, Division Director, Office of Biological and Environmental Research, Office of Science, USDOE
Frederick O’Hara, BERAC Recording Secretary
Franklin Orr, Under Secretary of Energy for Science and Energy, USDOE
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.

Wednesday, October 28, 2015
Morning Session

The meeting was called to order at 9:01 a.m. by the chairman, **Gary Stacey**. He had the members introduce themselves and noted that Susan Hubbard and Sabeeha Merchant were rotating off the Committee after this meeting.

Sharlene Weatherwax was asked for an update on the activities of the Office of Biological and Environmental Research (BER).

After a long time with several positions unfilled or unconfirmed, the Department of Energy now has a Secretary, a Deputy Secretary, and an Undersecretary for Science and Energy. The last is Franklin Orr. Patricia Dehmer is the Acting Director of the Office of Science (SC). Several new personnel have joined BER, also: Jared Deforest (an IPA) in the Terrestrial Ecosystem Science Program; Shaima Nasiri in the Atmospheric Systems Research Program; Dawn Adin, a microbiologist; and Ramana Madupu, a computational biologist. Actions are also pending for a biologist in the Biological Systems Science Division (BSSD) and a senior technical advisor for the Office. Michael Kuperberg is now on loan to the Executive Office of the President.

Fiscal year 2015 has been wrapped up. The government is now under a continuing resolution funded at under the FY15 level. When a budget is agreed to, appropriations will be made. The proposed budget for BER in FY17 is at the Office of Management and Budget (OMB) for review; passback is expected on Thanksgiving weekend.

The BER Long Term Vision plan should probably be updated next year.

The Office of Fusion Energy Science (FES) and BER have the biggest differences between the House and Senate marks of the FY16 proposed budget. The FY16 House mark for BER is $538 million; the Senate mark is $610 million. A new budget agreement has been made in the past few days, but it is not clear how it will affect BER's funding.

BER researchers have received recognitions from government agencies, professional societies, the National Academy of Sciences, foreign governments, and foundations.

The BER Early Career Program's 2015 topics were (1) systems biology research on microbes relevant to biofuels production and (2) land–atmosphere interactions. Two awards in systems biology were made to Elizabeth Sattely and Jeffrey Gardner, and two awards were made in the water cycle to Yunyan Zhang and Pierre Gentine. The BER Early Career Program's 2016 topics are (1) systems-biology-enabled research on the role of microbes and microbial communities in plant–soil–environment interactions, (2) improved understanding of changes in tropical-forest ecosystems' functions and feedbacks to climate change, and (3) the human component of the Earth-system models (ESMs).

Last year, BERAC wrote a report on the Assessment of Workforce Development Needs in the Office of Science Research Disciplines. The DOE Office of Science Graduate Student Research Program gives graduate students opportunities to work with national-laboratory scientists. That program has now gone to a twice per year application cycle. The BER priority research areas for 2016 are computational biology and bioinformatics, biological imaging – mesoscale to molecules, plant science for sustainable bioenergy, environmental system science, atmospheric system research, Earth-system modeling, and regional and global climate modeling.

Robertson said that it was great to see support for student programs and early-career awards and asked if there were plans to grow these programs. Weatherwax replied that the Office has grown the amount of funding in the past few years. The number of awards depends on budget funding.

Wall asked how big those awards will be. **Julie Carruthers** replied that, in 2016, there were 65 awards; in 2015, there were 47 awards.

Zhang asked when the House and Senate numbers will be set. Weatherwax replied that, with the budget agreement, the issue will go to the House and Senate subcommittees. She did not know how quickly that will progress.

Stacey pointed out that there is a new law setting minimum compensation for postdocs. He asked if this were being factored into budget discussions. Hubbard added that the law calls for the payment of overtime, also. Stacey noted that it will have a trickle-down effect on DOE's funding. Weatherwax said that such things are always considered before setting the funding floor. Janetos observed that it is difficult to track the existence of postdocs in a university, let alone address their individual funding. This issue is still under the radar.

Gary Geernaert was asked to present an update on the Climate and Environmental Sciences Division (CESD).

He noted that a lot of news reports were being issued about El Niño. Those reports focused mainly on the projections of El Niño's effects over the coming months. However, these low-frequency events like El Niño have long-lasting effects on climate and have a chance to change in amplitude and duration as climate evolves. The current event is a super El Niño, which occurs every 20 years.

CESD is updating its strategic plan in FY16. That plan will focus on the science of prediction to understand climate. Among the new topics that it will likely address are problems demanding exascale computing, hybrid integrated-assessment and impacts-adaptation-vulnerability components, major long term field campaigns required to advance predictive capabilities, and U.S. Global Change Research Program (USGCRP) linkages to "seamless predictability." Big-data analytics will be included in terms of complex observed and model-generated data, metadata compatibility, metrics, skill, and uncertainty quantification. BERAC's input will be needed on which of these topics to pursue.

The long-term trend in climate modeling is toward increasing sophistication, as reflected by the modeling initiative, the Accelerated Climate Model for Energy (ACME). ACME integrates the various atmosphere–land modeling components to solve problems DOE is best able to address.

Workshops provide a lot of input to the Office and its activities. An especially important workshop held this past year was on aerial observation needs for atmospheric and environmental sciences, which included both manned aerial platforms and the increasingly sophisticated suite of drones that can be used to collect observations in, e.g., the lowest layers of the boundary layer. Its key findings were that both manned and unmanned aerial systems are essential, improved and miniaturized sensors are necessary to advance science, routine observations are as important as traditional field campaigns, and manned and unmanned activities are useful for other programs. The major specific need identified was miniaturization.

Several solicitations are on the street now, and one more will be issued in the next few months.

Ten major reviews were conducted by the Office in FY15. BER responses to the reviews were well within two months of the panel review, and many of these were completed in the course of two or three weeks. Another group of reviews is in the pipeline for FY16.

A leadership change is occurring at the Environmental Molecular Sciences Laboratory (EMSL). Allison Campbell is moving up, and Harvey Bolton is becoming the interim EMSL director.

Three Terrestrial Ecosystem activities are ongoing: Next-Generation Ecosystem Experiments (NGEE) in the Tropics and Arctic, and Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE).

The Atmospheric Radiation Measurement (ARM) Climate Research Facility is setting up a mobile facility in Antarctica. Another mobile facility is still operating in Brazil until the end of the year and the third mobile facility is on extended deployment to Oliktok, Alaska.

He highlighted a number of research results:

- In a study of the dynamics of convection in severe storms, stereo photogrammetry has revealed substantial drag on cloud thermals.
- A study of fog and rain in the Amazon showed that much is not included in current models. The resolution of models was stepped upto capture spatial details of these events and eliminate some bias in models.
- In a study of pristine environments, it was found that natural aerosols explain seasonal and spatial patterns of Southern Ocean cloud reflectivity. These Southern Ocean effects affect long-term climate.

- A field study on the Tibetan Plateau showed that the links between ecosystem multi-functionality and above- and below-ground biodiversity are mediated by climate. The variability of these states needs to be understood and integrated to improve models.
- A study at the Stanford Linear Accelerator Center showed that the oxidation of subsurface uraninite (UO_2) occurs during "hot moments," when dissolved oxygen is abundant in groundwater during seasonal meltwater runoff. The short-term events must be integrated into models to provide long-term projections.
- A synthesis of research on large-scale estimates of the location of permafrost carbon showed that permafrost thaw will increase the carbon released to the atmosphere and oceans, which could speed up climate warming.
- A review of 50 years of research on key advances in water-resources research revealed the emergence of hydrogeophysics for improved understanding of subsurface processes over multiple scales. It resulted in a new vision of subsurface processes that has already been incorporated into the BER investments. This is a major technological breakthrough. This new scientific framework will be used in the next Earth Science Decadal Survey.
- A study led by the National Center for Atmospheric Research (NCAR) showed other scales and variabilities that have periodic, long-term effects of climate besides El Niño, such as the Pacific interdecadal oscillation (PDO) in the Pacific Ocean, which has had significant influence on decadal-scale climate change signals in both the southwestern and southeastern United States.
- The dynamics governing the West Antarctic Ice Sheet (WAIS) and sea-level rise are important topics challenging the research community. There are many different projections of the future of the WAIS reported in the scientific literature, due in large part to either a statistical (versus dynamical) approach and also to a lack of important field data. Geernaert reported a study of discrete ice sheets in Antarctica, and it is now well known that very small changes in water temperature produce large effects on under-ice-sheet melting that in turn affect WAIS dynamics.
- A study of the future population's exposure to U.S. heat extremes reported that extreme events cannot be treated as isolated forcings, but rather the temporal and spatial spacing of extremes can cascade into more severe and wide reaching impacts than if the extreme events were evaluated independentlyThe dynamic coupling of demographics to extremes represented as cascading phenomena is needed.

Stacey observed that there was a totally different amount of money in the offing, and asked how the Office plans its expenditures under such circumstances. Geernaert replied that money is tight, and the Office needs early success stories. The Office is working within the House mark now. It needs to plan new projects no matter what the budget turns out to be. One must ask what can be delayed or what needs to be preserved.

Robertson pointed out that instrument development is important and asked whether the unmanned aerial vehicle (UAV) workshop considered the issue. Geernaert responded that the industry is meeting the need for new instruments. Measuring ice particles and water in clouds is difficult, and there has been some progress in industry to fill this gap. The Small Business Innovation Research (SBIR) program is used to address those needs also. The community is struggling now to determine what can be miniaturized and deployed on UAVs to more effectively advance the science.

Weyant stated that, if one is not cognizant of these interannual effects, one might make mistakes in warning people about extreme events. These events also affect interregional trade. He asked what the plan was for looking at these issues. Geernaert answered that the energy–water nexus and energy–water–land and energy–water–climate change linkages are and have been interconnected components of our investment strategy for a long time. The Office is going to look at energy–water–land feedbacks next.

Baldocchi pointed out that the roles and effects of land management are huge. He asked how one addresses the issue. Geernaert replied that the researchers looked at effects on the hydrologic cycle of different land-management systems. It is a major feedback that needs to be understood.

Zhang asked what process will be used to revise the long-term plan. Geernaert pointed to many topical workshops that reach out to more people. He pointed out that the U.S. Global Change Research Program (USGCRP) will release its updated strategic plan next year. The plan will be used to inform BER's long-range plan.

Randerson asked what the Office's vision was on ocean feedbacks. Geernaert responded that the modeling agenda is rapidly moving towards finer and finer spatial resolutions; that strategy captures smaller processes that often provide feedbacks that have historically been overlooked.

Meehl asked how the Office sees the investigation of ACME and its relationship to CESM and other modeling centers going forward. Geernaert answered that ACME came out of the CESM community, and it maintains a healthy relationship so that ACME and CESM developments can be closely coordinated. After the ACME model is released, i.e., scheduled to occur in 2017, it is expected that the academic community will be entrained into participating in ACME. The second annual Climate Modeling Summit is currently being scheduled for a two-day meeting in March 2016, to coordinate the efforts of the climate modeling programs at National Center for Atmospheric Research, the National Aeronautics and Space Administration (NASA), DOE national labs, and NOAA labs, to foster tighter and more strategic collaborations.

Stacey asked if there were any efforts to standardize data analysis of UAV data. Geernaert answered that a lot of agencies are investing in UAV research. Many UAV communities get together to develop standards, but they are getting off to a slow start.

Stacey noted that, when ACME was announced, there were a lot of nervous reactions. Geernaert agreed, but he reported that nervousness has receded a lot. It has been replaced by collaborations and learning from one another.

A break was declared at 10:50 a.m.

The meeting was called back into session at 11:11 a.m. **Todd Anderson** was asked for an update on the activities of the Biological Systems Science Division (BSSD).

The Division completed 18 major reviews of activities, virtually the whole portfolio, in FY15. Upcoming activities include reviews of the Bioenergy Research Centers and the annual Genomic Science Principal Investigator (PI) Meeting.

Several new funding-opportunity announcements (FOAs) were completed in FY 2015. The first is on novel *in situ* imaging and measurement technologies for biological systems science. Seven awards were made, totaling $15.0 million over three years. The second FOA is for systems biology research to advance sustainable bioenergy crop development, which builds on advances in plant and microbial research within the Genomic Science Program, the Bioenergy Research Centers, and several national laboratory programs. Six awards were made totaling $66.4 million over five years. The third new FOA is on plant feedstock genomics for bioenergy, a joint research FOA with the U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture. It addresses bioenergy plant genomics and the mechanisms of plant response to pathogens. Five awards were made, totaling $14.7 million over three years.

Two solicitations will be coming up in FY16: the first is on systems biology research to understand carbon cycling in the environment; the second is on plant feedstock genomics for bioenergy, issued jointly with the USDA. A future solicitation on the next steps in bioenergy research is on the horizon; it would be guided by a recent bioenergy workshop and will have an expanded focus on biofuels and bioproducts from biomass with an overall goal to produce the basic science needed to produce fuels and chemicals currently produced from petroleum from renewable, sustainable biomass.

A BSSD Strategic Plan has being developed.. It calls for fostering interdisciplinary research, developing high-throughput enabling technologies, integrating high-performance computing into genomic science, and fostering collaboration among DOE user facilities.

Two Early Career awardees have had major publications or awards: Trent Northen (LBNL) had a publication in *Nature Communication*, and Michelle O'Malley (UCSB) was named by MIT as an Innovators under the age of 35.

The Bioenergy Research Centers [the Great Lakes Bioenergy Research Center (GLBRC), Joint BioEnergy Institute (JBEI), and BioEnergy Science Center (BESC)] are undergoing annual reviews. They continue to be very productive and have produced 660 invention disclosures and/or patent applications, 24 patents awarded, 105 licensing agreements, and 1799 peer-reviewed publications.

Major scientific highlights coming out of the Bioenergy Research Centers (BRCs) and within the BSSD portfolio include

- The launch by BESC partner Mascoma of C5 FUEL^{TM}, a yeast engineered for improved cellulosic biofuel production
- The field production, purification, and analysis by the GLBRC of high-oleic acetyl-triacylglycerols from transgenic *Camelina sativa*
- A quality publication from JBEI on the development of an orthogonal fatty acid biosynthesis system in *E. coli* for oleochemical production
- A major paper from the *Biosystems Design* element of the Genomic Science Program on a new method to track combinatorial mutations in engineered cell populations
- A second major *Biosystems Design* paper on a novel technology to engineer microalgae with biofuel-production potential
- A study published in *Environmental Microbiology* on direct electron transfer via nanowires in anaerobic oxidation of methane consortia; part of the carbon cycle/environmental microbiological portion of the BSSD portfolio.
- An elegant study at the Oak Ridge National Laboratory (ORNL) Foundational Genomic Science Scientific Focus Area (SFA) on convergent losses of decay mechanisms and rapid turnover of symbiosis genes in mycorrhizal mutualists
- In the structural biology portion of the Division's portfolio, a study on exploring the repeat protein universe through computational protein design

The Joint Genome Institute (JGI) brings added value to the communities it serves. It had 181 publications in FY15, 127 since the most recent BERAC meeting.

Stahl noticed that a prior committee of visitors (COV) had recommended that BSSD be more stringent in the pre-application phase of the solicitation process and asked if the Division were following up on that recommendation. Anderson answered that the Division indeed has adopted a more-rigorous documentation of the pre-app phase of proposal submissions, all of which are now documented in the Portfolio Analysis and Management System (PAMS).

Hubbard asked to whom the FOAs were open. Anderson replied, the academic community.

Weyant asked what the air-quality effects were of the new biofuels coming from the national laboratories. Anderson responded that that was discussed at the last BERAC (Mar 2015) by the BRC directors. A recent calculation out of Brazilreported an 80% decrease in air pollution from biofuel combustion; pollution reduction also occurred in the biofuel production process.

Robertson asked if there were plans to continue the sustainability program in FY16. Anderson replied, yes; room has been made for it in the budget.

Joachimiak asked if there were a timescale for merging structural biology and bioimaging. Anderson said that there is a timescale, but it is a longer term activity that would involve the community.

A break for lunch was declared at 11:45 a.m.

Wednesday, October 28, 2015
Afternoon Session

The meeting was reconvened at 1:01 p.m., and **Patricia Dehmer** was asked to give an overview of SC's activities and operations.

As of the day of this meeting, a budget agreement had been reached, and there would be no government shutdown and no default. It looked like there *would be* an FY16 budget, but no budget had been passed. The House and Senate staffers still had to reconcile the different versions.

Cherry Murray, the nominee for Director of the Office of Science, had a hearing early in the previous week. She did very well. The nomination still needs to get voted out of committee and onto a list for Senate confirmation.

During the three weeks prior to this meeting, the accomplishments of all of the SC advisory committees were reviewed by SC leadership. It was a very instructive exercise. Often, the advisory committees have changed the courses of their programs. Their studies and recommendations have been incredibly important to SC and DOE. Congress takes the long-range plans developed by advisory committees very seriously.

The Advanced Scientific Computing Advisory Committee (ASCAC) was charged to (1) determine the potential synergies between the challenges of data-intensive science and exascale computing; (2) determine the ten principal research challenges and the technical approaches required to develop a practical exascale computing system; and (3) review the Department's draft preliminary conceptual design for the Exascale Computing Initiative (ECI), a huge initiative across DOE and the federal government that is ramping up funding in FY15 and FY16.

The Basic Energy Sciences Advisory Committee (BESAC) was charged to provide advice on the future of photon sources in science, considering both new science opportunities and new photon-source technologies. It produced a very short report that completely changed the budgeting and priorities of the Office. That report became a poster child of advisory-committee reports. BESAC was also charged to revisit the BESAC 2007 "Challenges" report, considering progress achieved, impact of the challenges on energy sciences, funding modalities, and new areas of basic research not described in the original report.

The Fusion Energy Sciences Advisory Committee (FESAC) has been charged to (1) assess priorities among and within the elements of the Magnetic Fusion Energy Sciences Program; (2) develop a strategic plan for the Fusion Energy Sciences Program, assuming several different funding scenarios. Its report was delivered December 2014 and raised a lot of controversy (as a result of which, FES is holding a series of workshops engaging wide areas of the scientific community); and (3) assess the connections between research supported by the Fusion Energy Sciences Program and other scientific disciplines and technological applications (a new charge issued in February 2015).

The High Energy Physics Advisory Panel (HEPAP) has a standing subcommittee, the Particle Physics Project Prioritization Panel (P5) that was charged to develop an updated strategic plan for U.S. high-energy physics that can be executed over a 10-year time scale in the context of a 20-year global vision for the field. Delivered in May 2014, that strategic plan has produced a significant change through recommendations to globalize efforts and expand programs. The implementation of that recommendation is progressing faster than anyone anticipated. It is currently driving budget activity at a level of more than $1 billion. This report and the BESAC light-source report have been developed by wide communities in short order with major impacts. HEPAP was also charged to assess the accelerator R&D efforts supported by the HEP program.

The Nuclear Science Advisory Committee (NSAC) has two main thrusts: the radioisotope program and the scientific program. NSAC's reviews have changed the way the Isotope Program is managed and its visibility and importance. The most important was to conduct a new study of the opportunities and priorities for US nuclear physics research, which recommended a long-range plan that will provide a framework for coordinated advancement of the nation's nuclear science research programs during the next decade. The rare isotope beam at Michigan State University, the Jefferson Laboratory upgrade, and other things in the 2007 long-range plan were nearing completion. The new long-range plan will direct the nuclear physics community for years to come.

There has never been such a spate of advisory-committee reports that had so much influence and impact as in the past 24 months. These reports changed the direction of the science and of the budgets of several SC offices.

The Biological and Environmental Research Advisory Committee (BERAC) works in a slightly different manner from the other advisory committees. It is currently recommending initiatives for field-based research (conducted by the so-called Integrated Field Laboratory or IFL) that capture a multidisciplinary approach and build on observations and modeling to (1) define the criteria for selecting sites for future BER field-based research and (2) prioritize the sites identified or described. The list of charges and reports to and from BERAC between 2009 and 2013 is lengthy. Since 2013, BERAC has been building on its major report on Grand Challenges for Biological and Environmental Research: A Long-Term Vision. The long-range plan needs to be updated. A lot has changed. Given what the other advisory committees have done, BERAC might want to take such a charge seriously.

Joachimiak noted that it took BESAC more than 5 years to arrive at a result that was long known. Dehmer replied that the American Physical Society (APS) was originally trying to just upgrade instruments, and that was the wrong thing to do. One can make the same criticism about HEPAP. They knew that another collider was not the next step. However, the whole community had to get together to agree to that opinion.

Stacey noted that the situation is very different today from 5 years ago, when BER's most recent long-range plan was issued. He asked what DOE's vision was for the future. Dehmer referred to Franklin Orr, who was to speak on that very topic the next day of this meeting.

James Randerson was asked to present the science talk entitled "Improving Our Understanding of Carbon Cycle, Drought, and Fire Dynamics During the 21st Century (and Beyond!)."

Atmospheric CO_2 exhibits two types of feedback: climate–carbon feedback and concentration–carbon feedback. The Intergovernmental Panel on Climate Change (IPCC) said that carbon feedbacks on land are 4 to 5 times more important than those on oceans.

The important climate–carbon processes and feedbacks on the ocean are increasing stratification with warming, dissolved inorganic carbon sensitivity to temperature, and biological-pump responses to stratification. Those on land include drought and temperature effects on primary production, soil decomposition increases in response to temperature, response of fires to changes in fuels and drought, and land-use change. Climate–carbon processes and feedbacks not yet modeled in most Earth system models include species range shifts, phosphorus limits on land carbon uptake, permafrost dynamics, peatlands, fires, insect-driven mortality, drought effects on tree mortality, and climate effects on land-use change.

The model CESM1(BGC) uses an experimental design to isolate the effects of specified variables. For example, in a fully coupled run, the biogeochemistry response to CO_2 increases only. In a run with no CO_2 radiative forcing, non-CO_2 anthropogenic drivers influence radiative transfer, and biogeochemistry responds to CO_2 increases. In a run with no anthropogenic radiative forcing from greenhouse gases or aerosols, there is no atmospheric anthropogenic climate change, and the biogeochemistry response to CO_2 increases. The system for validating carbon-cycle processes in CESM with the International Land Model Benchmarking System is being improved.

Model runs were conducted to calculate a number of climate–carbon feedback increases from 1850 to 1999, 2100, 2200, and 2300. The results showed a small gain in carbon on short timescales and almost a tripling at longer timescales, mostly caused by effects of oceans.

At advanced temperature gains, land and ocean have similar climate–carbon feedbacks. The oceans are becoming more stratified. The ocean heating rate is influenced by the stratification. In runs of the CESM, a shutdown in Atlantic meridional overturning reduces carbon uptake. Tropical ocean anoxia reverses after 2100 (the oceans recover), producing a low-productivity ocean.

Model runs indicate a reduced carbon uptake by soils during the 21st century, with 100 petagrams of carbon being taken up in the soil. Experiments have shown that carbon turnover times in soil are 4 to 6 times longer than those used in models. Thus, the soil-carbon response is weakened.

An ensemble of 39 models with a large amount of model uncertainty indicates precipitation reductions in neotropical forests driven equally by radiative and physiological effects of CO_2. Forests in Central and South America exhibit a high degree of vulnerability to climate-change-induced carbon loss. There are serious implications for trade and South American political stability in these results. The Amazon region gets more vulnerable to fire loss as time goes on. A global early warning system for fires is needed. El Niño causes the water table to drop, drying out forests. Wildlife habitats will suffer.

A conceptual model for fire predictability in the Amazon is based on a forest soils' capacitor mechanism. That is to say, during the dry season, evapotranspiration is limited by soil moisture reserves; in the wet season, evapotranspiration is limited by radiation. High-fire years and low-fire years were looked at by a series of models to characterize temperature and precipitation. These model results allow an eight-month lead time in predicting fire risk from ocean data.

Capturing fire-mediated feedbacks in Earth system models may require representing species-level effects. Boreal forests will have a different fire profile than forests in Eurasia would. Boreal forests burn hotter, killing those trees located around the burning trees, allowing more ground snow cover during the winter, reflecting sunlight and lowering solar input. In Eurasia, trees have thicker bark and few branches stretching out.

These results indicate that

1. The understanding of Earth-system dynamics, including processes that may contribute to ecosystem collapse, is woefully incomplete beyond 2100. There is a moral imperative to figure out what is going on.
2. The ocean contribution to the climate–carbon feedback increases considerably over time for a "business as usual" scenario, and exceeds contributions from land after 2100. Land feedback will likely be reduced by land-use change. Ocean feedback strength is closely related to ocean heat content and Atlantic Meridional Overturning Circulation (AMOC) shutdown.
3. Forcing from non-CO_2 agents for the RCP8.5 scenario is almost enough to surpass the 2 °C dangerous-interference limit.
4. Tropical forests in Central and South America have a higher vulnerability to climate change than do those in other tropical regions.
5. A better understanding and representation of fire processes in Earth system models is essential for accurately predicting carbon-cycle dynamics in drought-prone areas.

Stacey asked whether some cities in the Middle East might become uninhabitable because of rising temperatures and humidity. Randerson replied, yes.

Randall pointed out that the frequency of lightning strikes may change over time and asked whether that might change wildfire projections. Randerson answered that increases in lightning strikes have been seen before rises in fire frequency and severity.

Stahl pointed out that the temperature and stability of the North Atlantic may be sensitive to ice-sheet melting and asked how that would affect model results. Randerson said that that is not factored into the models, yet, but it must be included in the future. That process is not understood well at this point.

Meehl asked whether eight-month projections would be able to inform governments so they can take steps to limit open burning. Randerson replied, yes; it would also allow them to improve fire-fighting capabilities.

Janetos asked whether anyone had been able to check these eight-month early warnings. Randerson said that the models got it right 3 out of 4 years. In the fourth year, the projected rate of hurricane occurrence was wrong, and that threw off the model results. Janetos pointed out that most of the fires of the world are purposely set on agricultural lands and asked whether this fire-projection system will be able to predict such savanna fires getting out of hand. Randerson pointed out that Brazil's deforestation rate (predominantly driven by swidden agriculture) had declined by 80% during the past 5 years.

Robertson pointed out that the major increase in carbon dioxide and methane release from the soil is from agricultural lands and asked if that fact were reflected in the projections. Randerson replied, yes; and more is coming from methane than from NO_x.

Zhang said that, in the past, different models gave different signs (+/-) of climate–carbon feedback and asked if this were still true. Randerson said, no; today, most calculated ocean and land feedbacks are positive.

Weatherwax introduced **Alfred "Joe" Cornelius** to speak on work going on in the ARPA-E program.

The Advanced Research Projects Agency – Energy (ARPA–E) is a relatively new organization set up to ensure America's national security, economic security, energy security, and technological leadership. Its first program in 2010 was PETRO (Plants Engineered To Replace Oil); TERRA (Transportation Energy Resources from Renewable Agriculture), a program for accelerating crop genetic gain for fuel-food-feed-fiber productivity, was launched this year. The next program, for enhancing soil health for crop resilience and carbon capture, will be launched in early 2016.

Biology makes a significant contribution not only to the problem but also to the solution of sustainability, touching on economic, environment, and natural resources. The nation can provide a billion tons of feedstock to replace petroleum sources. Corn gets 80% of private research funding; wheat, rice, and soybeans are getting much less.

In breeding cultivars to optimally produce certain traits, one must ask: What are the drivers for winning crop varieties? What data should the reader collect? And which genes should the reader try to discover and use? Phenotyping is the bottleneck for trait discovery, and cultivar development is slow, expensive, and unpredictable. One has to look at how a specific cultivar does in the harvest. It is difficult to tie improvements to causes. Many technologies are intersecting. Systems biology pulls these influences together.

Researchers are building on plant genomics. The robotics and sensors are building off other uses. A systems approach is necessary.

TERRA enables readers to accelerate genetic gain. Food production must be doubled by 2050. There are not a lot of growing cycles available in which to evaluate new cultivars.

Six teams have been set up in TERRA: the public reference data team, two full-system teams, and three “component”-focus system teams. The primary crop to be focused on is sorghum (a food, fuel, and feed crop). Engineering has brought the cost and time of sensing down. New technologies log data to quantify genotype by phenotype by environmental interactions with cameras that capture signals from the visible and infrared spectra of light.

TERRA has developed robotic platforms that are diverse and data-rich. They can be continually upgraded. A test laboratory has been established in Maricopa, Arizona, allowing four crop cycles per year.

One type of phenotype sensing is the measurement of drought stress with 3-D photos taken from drones. An integrated phenotyping network is currently being constructed. Projects scattered from coast to coast are connected. A national and international phenotyping network could produce a second green revolution.

The next step is to look at belowground phenotyping (root structure etc.), studying soil health.

ARPA–E is a pipeline between government agencies and the private sector. It encourages additional investors in the program from foundations and private-sector entities.

Robertson asked if TERRA deals broadly with soil health rather than soil carbon. Cornelius said that it is going in that direction.

Wall asked if there were enterprising approaches to the miniaturization of the biology. Cornelius replied, yes; it is all about biology. Miniaturizing robotics is easy. The payoff is in miniaturizing biology.

Meehl asked if more marginal land was being tapped for crops and forestry. Cornelius answered, no; an effort is being made to make land more productive and to reduce land-use changes.

Baldocchi asked if ARPA-E were working with data scientists to mine these data. Cornelius replied that computational analytics is critical, and a computational analytics team is in place. IBM is on the team. Other teams also have other big-data organizations involved.

Janetos pointed out that NASA has done a lot with multispectral imagery of forests and that imagery should be applicable to agriculture, also. Cornelius agreed.

Shanks noted that Slide 7 in Cornelius’s presentation looked at the design process and asked whether any consideration had been made of the possibility that there may be something missing that affects the projections. Cornelius allowed that there may be something missing and would be grateful if other researchers could point out what might be missing.

Stacey asked how people could get involved in this project. Cornelius said that the workshop information is available to all. Anyone can get back to the project with any ideas.

Joachimiak asked how the connection is made from phenotypes to genotypes. Cornelius said that bioinformatics and genomics are used. A genetic reference team ties everything together.

A break was declared at 3 p.m.

The meeting was called back into session at 3:15 p.m. **Michelle Buchanan** was introduced by Weatherwax to provide a briefing on the Workshop on Basic Research Needs for Environmental Management.

The workshop was held on July 8–11, 2015. It was motivated by the complexity of the DOE Office of Environmental Management's (EM's) mission and challenges and by the Secretary of Energy Advisory Board's (SEAB's) Task Force recommendations.

Since 1989, EM has completed its cleanup mission at 91 of the 107 major nuclear weapons and nuclear research sites. A lot of knowledge was gained from this exercise. Some waste has been left behind and poses significant cleanup challenges. Highly radioactive liquid waste is stored in more than 220 underground tanks. Those wastes have to be pumped out of the tanks, separated, encased into a matrix, put in cans, and put into deep geological repositories. The wastes in the tanks are inhomogeneous, highly caustic, and highly radioactive. It is expensive to work with; just taking a sample costs $1 million. Certification of storage casks is needed; in addition, there are 93 $mi.^2$ of contaminated groundwater that need to be remediated.

These engineering problems are complicated by scientific problems: slurry yield stress often does not scale with colloidal size distributions, sonication of waste slurries can sometimes make colloids larger, dilution of waste slurries can sometimes cause precipitation, and finely divided materials are often more refractory than larger crystalline solids.

The SEAB Task Force recommended the formation of a fundamental research program in SC to address the scientific problems. That program should develop new knowledge and capabilities that bear on the EM challenges, be managed by SC in close coordination with EM, have a budget of about $25 million per year, and commence with a workshop involving all potential participants to develop a strategic research plan to inform requests for proposals.

The workshop was charged to look at waste-stream characterization, transformation, and separations; waste forms; and contaminant fate and transport in geological environments.

Before the workshop, some grand challenges were identified: (1) interrogation of inaccessible environments over extremes of time and space and (2) understanding and exploiting interfacial phenomena in extreme environments.

A list of priority research directions is being drawn up from the workshop results. Currently, that list includes

- High-dimensional interrogation of inaccessible environments with diverse data
- Predicting and controlling chemical and physical processes far from equilibrium
- Understanding critical physicochemical interfacial reactions across scales
- Long-term evolution of nonequilibrium structures
- Harnessing physical and chemical mechanisms to revolutionize separations
- Mechanisms of materials degradation in harsh environments
- Mastering hierarchical structures to tailor waste forms
- Scale-aware prediction of terrestrial system behavior in response to perturbations

This topic is important now because, during the past decade, incredible strides have been made in nanoscale material science and computing, imaging, biogeochemical system science, and data analytics, creating opportunities to pursue complexity and heterogeneity, to span unprecedented scales of time and space, and to access and assess the inaccessible. The time is right to apply these advances to develop a foundational knowledge of complex, coupled radiological and chemical systems. In addition, DOE user facilities, such as light and neutron sources, nanoscience centers, high-performance computing, and other state-of-the-art facilities are available to enable research success.

Stacey stated that, years ago, the Savannah River Site had an organic-contaminated plume with a pH of 2.

Merchant asked what information was available on the tanks' contents. Buchanan answered that there are records of what was put into the tanks. Over the years, however, there were additives put in to "help."

Also, some tanks were used for a variety of waste streams. As a result, the contents can be very mixed, and the documentation about them either missing or not helpful.

Randerson asked about the residuals at shut-down nuclear plants. Weatherwax replied that the responsibility for dealing with spent fuel is distributed among the utilities, states, and DOE.

Merchant asked how often the tanks were sampled. Because Buchanan is not an expert on that topic, she deferred answering, but noted that sampling is done periodically, both of the slurries in the tanks and of the off-gases. (Nuclear and chemical reactions in the slurries can produce hydrogen and other gases.)

Meehl asked if the tanks can't just be encased where they are. Buchanan replied that that is not an option. The contents are highly corrosive and radioactive. Leakage of the current tanks is a major problem. Joachimiak noted that DOE has extreme-radiation-effect studies that could be brought to bear on the materials of the tanks and their liners.

Janetos pointed out that there is also pressure to solve this problem quickly and asked if the workshop talked about that constraint. Buchanan answered that the timeline goes out to 2026. It is not clear that the technology available can meet that deadline.

Hubbard noted that there have been other investigational efforts and asked if the program were aware of the recommendations resulting from those investigations. Buchanan said that they had become aware of some of those reports and recommendations, but some have not been shared.

Stacey opened a discussion of the BERAC report on the proposed IFL. He had drafted a letter to Dehmer about that report and would like to hear reactions to the letter, leading to a consensus vote to accept it.

Robertson said that it was a well-crafted letter and that it was well-balanced. He would like to see more of the BSSD side of BER and of genomics systems reflected in the text of the letter.

Stacey noted that Page 2, Line 4, refers to an "overwhelming consensus." He asked if that terminology should be changed to a "strong consensus."

Hubbard did not remember a consensus being formed about urban environments. Stacey said that he remembered one coming out of a long discussion, and the urban environment was the topic of the workshop.

Janetos said he would be happy taking out the adjective altogether. He remembered a discussion with a focus and agreement on the urban environment. The letter captures the sense and conclusions of the discussions well. Stacey agreed to delete "overwhelming."

Assmann said that the urban environment was pulled out as an exemplar; but in some places, "urban" should be deleted. She had those places flagged and offered to share them with Stacey. Also, she questioned the use of the term "non-science data." Merchant suggested substituting "non-science data" with "other types of data."

Hubbard referred to the use of the term "gradients" and the vague distinction made between coastal and urban systems. Stacey agreed to make those terms more precise.

Weyant suggested that inserting some examples might be good or bad. Stacey said that this is to be an executive summary, not a rehashing of the white papers. The white papers have many examples in them.

Ehleringer noted that Dehmer had asked for *specifics*. Stacey responded that this is an advisory exercise, not a micromanagerial exercise.

Randerson said that there should be an indication of the competitive nature of the selection of sites and experimental techniques. Stacey responded that the letter does refer to the need to engage stakeholders. Where that engagement should be implemented should not be too prescriptive. If suggestions were made of additional text, they could be incorporated in the letter.

Stahl pointed out that the sites are not prioritized. Stacey said that such prioritization could be done, but there would be a trade-off in flexibility.

Randerson asked if there would be multiple IFLs in different urban environments. Ehleringer said that the point was made during the spring meeting of BERAC that multiple sites would be needed to reflect multiple environments.

Robertson hoped that there would be multiple regions characterized by the IFL. Five key regions had been identified. Stacey pointed out that the number of regions would probably be constrained by funding.

Assmann suggested that each IFL could have an urban site included and then a transit to a coastal, agricultural, etc. region. Then prioritization would not be needed. Stacey agreed that the recommendation could be made to investigate gradients from an urban environment to one or more focus regions. Hubbard pointed out that that idea does pop up in the text occasionally but is not consistent.

Janetos argued that none of these topics was brought up at the workshop. It should be made clear that this is an overarching programmatic recommendation from BERAC.

Stacey asked if anyone objected to recommending investigating gradients from urban to focus regions. No one objected. Stacey summarized the requested changes and asked for members' suggestions for substitute text.

Janetos noted that soils have different profiles, both in biologic entities as well as geologic properties.

Merchant pointed out a typo on page 3. Assmann said that there were others and would pass them on to Stacey.

Joachimiak was concerned that the research is not particularly strong. It should point to a particular site.

Ehleringer suggested that the last paragraph should have a recommendation in it. Stacey suggested a restatement of the last paragraph on the first page. Ehleringer said that that paragraph should underscore the need to study a gradient from an urban to a natural environment.

Assmann said that the letter should address DOE's mission here and why IFLs are needed, given the National Ecological Observatory Network (NEON) and Long Term Ecological Research (LTER) Network sites. Stacey noted that it *is* pointed out why *DOE* should do that. The NEON urban sites have been canceled; LTER has only two urban sites.

Meehl asked why NEON was canceled. Ehleringer said that it was probably because the program was way over budget, although no one has been forthright about the reasoning.

Stacey opened the floor for general discussion.

Joachimiak stated that the Committee should respond to Dehmer's suggestion of reconsidering the grand challenge survey from 5 years ago. Stacey said that it should be decided whether the whole grand-challenge process should be redone or whether the recommendations should be reviewed. Janetos said that 5 years was a short time for redoing a grand challenge study. Joachimiak agreed. Zhang said that it depends on how much things have changed, and the whole document should probably be reviewed. Wall suggested that maybe a whole new document would be needed. Stacey suggested that everyone go back and reread that document.

The floor was opened to public comment.

Tim Donohue from the University of Wisconsin noted that Pres. Carter called for changing how we get oil, and then the price of gas went down, and that program was thrown away. That program should be restarted, and the nation should invest in biological processes for fuel production. He called attention to an article in the day's *New York Times* by Carl Zimmer about the Unified Microbiome Initiative. The article referred to papers in the current issues of *Science* and *Nature*, calling for an international initiative centered on the role of microbes.

There being no further comments, the meeting was adjourned for the day at 4:41 p.m.

Thursday, October 29, 2015

The meeting was reconvened at 8:30 a.m. Stacey noted that a revised version of the charge-response letter had been distributed to the membership overnight. He asked the Committee members to review the draft so it could be discussed later in the meeting

Weatherwax introduced **Franklin Orr** to speak about the *Quadrennial Technology Review* (QTR).

The *QTR* begins by pointing out that water, energy, agriculture, and climate are interdependent. There is progress in interconnecting these topics, and there is a great opportunity space represented out there. The President recognizes climate change as a challenge and has set some goals to address it. There is plenty of room for discovery science and for discussing what the major challenges are. They certainly include economic security (to be addressed through cost-efficient energy systems), energy security (to be addressed through energy systems that have multiple supply options and are robust and resilient), and environmental security (to be addressed through much lower emissions of greenhouse gases and other pollutants). There is an opportunity here to create and manage linked, complex systems that deal with all three of these challenges.

An analysis of energy flow on Planet Earth in the *QTR* shows that there is a large variety of energy resources that can be used. There is no shortage of energy. What is needed is to learn how to extract energy services.

The Enabling Sciences Chapter in the *QTR* is especially important and relevant. It contains technology assessments of 19 clean electric power systems, from advanced plant technologies to wind power.

Two of the six chapters in the *QTR* talk about electrical energy. That is because electricity (and how it is generated and used) is fundamentally important to today's society. Electricity is supplied to society by the grid, which has gone from centralized production and radially distributed electricity to a network with a backbone. The grid has many types of generating sources and microgrids, controls, and sensors. Historically, there was operator-based grid management, centralized control, and off-line analysis and limit setting. What is emerging are flexible and resilient systems, ubiquitous sensor deployment and data acquisition, algorithms and computer infrastructure, multilevel coordination, precise control, and faster-than-real-time analysis. The major challenge is the integration of intermittent renewable energy sources, matching them to a demand curve that is cyclical and highly variable in its own right. Energy storage at many scales, from vehicle batteries to pumped storage, can ameliorate the problems of power peaking.

The grid must be fixed, but it must have clean electric power to distribute. One way to clean up emissions is through carbon capture and storage. It can be done; it is done industrially every day. The CO_2 captured has few uses, however; so its removal is almost pure cost. Separations science is being advanced with DOE support.

Nuclear power is a contributor of carbon-free power. However it has its own challenges: waste storage, consent-based siting, and the streamlining of the siting and licensing processes.

About 40% of the water withdrawn from surface waters is used by power plants. There is room for improvement in the management of linked water sources.

Wind provides promising potential and is now competitive (with subsidies). The challenges it faces are wind-plant optimization, accessing the best wind resources, and transmission capacity. Because the best wind resources are often well above ground level, strength-of-materials research will play a major role in solving this problem.

Solar energy also offers significant potential, as does enhanced geothermal-energy production. Today, hot rocks near the surface are tapped for geothermal energy. Tomorrow, enhanced geothermal power could provide more than 500 GW of baseload renewable power.

Building efficiency is investigated as part of building systems. With little additional cost, improvements can be made in window innovations; lighting efficiency; more-efficient heating, ventilation, and air conditioning (HVAC) and refrigeration; highly efficient building designs; grid integration; and sensors, controls, and decision science.

Electric propulsion will be important, but combustion will be a main source of locomotion for decades to come. As a result, combustion efficiency, co-optimization of fuels and engines, and lightweighting of vehicles provide opportunities for improvement.

Today, most manufacturing is reductive in nature. That is to say, a large block of material is machined to remove some portion of it, resulting in a usable product. Additive manufacturing produces lighter products with less source material (e.g., ore) and decreased refined material (e.g., metal).

Use-determined research is setting the directions of research. This process is leading to an understanding and controlling of matter at the atomic scale. Modeling and simulation of complex phenomena are very important to advancing science.

The conclusions of the *QTR* are that

- Considerable progress has been made in energy technologies, but much more remains to be done.

- There exists a very-wide-ranging opportunity space for individual technologies and for improved systems.
- A portfolio approach is needed, fully stocked across primary energy resources, conversion technologies, systems, and timescales. Attention must be paid to efficiency everywhere.
- Enabling science and computing are essential to the nation's energy success.

Stacey asked what was seen as the future for biofuels, and specifically if there were a political wind building. Orr responded that, in the 1980s, when the price of energy dropped, the United States stopped paying attention to alternative energy research. He hoped that the nation has learned its lesson. A case can be made for scientific research in this area. This Committee has an important role in developing and implementing integrated observatories, modeling, investigating how people interact with climate, and environmental management. He thanked the Committee for its hard work and advice.

Weyant asked where the nation stood on shale gas. Orr replied that shale gas has changed electric-power generation in the United States. There is still a lot that is not understood about hydraulic fracturing. Some wells produce for a much longer time than they should. Controlling fracturing is another area for research.

Zhang asked if the QTR looked at technologies used by other countries. Orr responded that the broad assessment is applied across the world. The upcoming climate-change meeting in Paris in December will bring countries together to exchange ideas about how to meet CO_2-reduction goals. China has committed to build a huge renewable-energy network.

Robertson stated that the storage part seems to be more difficult and asked if progress had been made. Orr replied that the biggest costs are on the capture side. Carbon capture and storage has to be part of a portfolio of approaches.

Joachimiak asked if climate change were incorporated into the model of energy use. Orr answered that understanding the impacts of mitigation is important as are modeling and observation centers.

Ehleringer asked if there were going to be grid problems as more diverse sources of power and battery storage came online. Orr said it will require new system architectures, sensors, controls, microgrids that are islandable, short reaction times, demand response, and a largely different system from what there is now. It is a complex problem, but if it is solved, the nation will gain a competitive edge in the world.

Weatherwax introduced **Douglas Friedman** to speak about the industrialization of biology, a National Academy of Sciences (NAS) study sponsored by BER.

BER requested of the NAS a peer-reviewed report on the industrialization of biology: a roadmap to accelerate the advanced manufacturing of chemicals. In this report, chemicals are defined very broadly. Fundamental science is an enabler for all the things we want to do. The NAS was tasked to do four things:

- Identify the core scientific and technical challenges that must be overcome;
- Identify and set a timeline for tools, measurement techniques, databases, and computational techniques needed to serve as the building blocks for research and applications;
- Determine how to develop, share, and diffuse common interoperable standards, languages, and measurements; and
- Assess when and how to integrate nontechnological insights and societal concerns into the pursuit of the technical challenges.

Data were gathered by a group of experts with broad and varied experience, representing industrial, academic, and legal expertise. In addition, an information-gathering workshop was held, a literature review of peer-reviewed research was conducted, and community input was received through a website.

This study was apropos at this time because bio-based product markets are already significant in the United States, representing more than 2.2% of gross domestic product in 2012. In addition, current global bio-based chemical and polymer production is estimated to be about 50 million tons each year. Also, the manufacturing of chemicals by the use of biological synthesis and engineering could expand even faster; the addition of new bio-based routes to chemicals could open the door to making and marketing chemicals that cannot presently be made at scale or may allow the use of new classes of feedstocks.

The biomaterials competitive landscape is broad and diversified. The economic drivers are profits. Gross-margin data are difficult to obtain from industry. Data from public companies show that pharmaceuticals and biofuels offer especially attractive profit margins.

The science of bio-based chemical feedstocks is advancing. The past decade has seen an explosion in the technologies to compose, read, write, and debug DNA. These developments have rapidly increased the scale of sophistication of genetic-engineering projects, and in the near term this will lead to more complex chemical structures and composite nanomaterials, which require precise control over dozens of genes. Moreover, there is an increasing use of biology to produce high-valued chemical products that cannot be produced at high purity and high yield through traditional chemical syntheses; biology represents a better synthetic pathway. For new-product development, chemical manufacturers now consider biotechnology along with traditional chemical manufacturing processes.

If bio-based production is designed well, it could lead to advanced chemical manufacturing based on biological sources, such as plants, algae, bacteria, yeast, filamentous fungi, and other organisms, replacing many chemicals now derived from petroleum or other fossil fuels. Those bio-based production processes could also improve energy efficiency. Bio-based production has the potential for generating fewer toxic by-products and less waste than traditional chemical manufacturing. The increased use of biomass as a feedstock for the production of specialty chemicals, plastics, fuels, and commodity chemicals provides new opportunities for innovation and sustainable agriculture.

The core technical conclusion of the report is that biomanufacturing of chemicals is already a significant element of the national economy and is poised for rapid growth during the next decade. Both the scale and scope of biomanufacturing of chemicals will expand and will involve both high-value and high-volume chemicals. Progress in the areas identified in the report will play a major role in achieving the challenge of increasing the contribution of biotechnology to the national economy. A roadmap of what can be achieved was developed. While the roadmap is clearly designed to push forward industrial biotechnology, there are many aspects of fundamental research needed to develop bioproducts that can be applied broadly to other fields, such as health, energy, and agriculture.

The key elements of the roadmap are a design toolchain, fermentation and processing, feedstocks and preprocessing, test and measurement, and organisms. In terms of feedstocks, there are lots of products, some of which use CO_2 as a feedstock. New microorganisms will be developed. In test and measurement, coupling testing and data analytics will be an important driver.

This roadmap is for BER and the National Science Foundation (NSF) to develop programs and for the community to develop new products and processes. Because of the rapid developments in this field, this roadmap should be revisited frequently.

The main recommendations that came out of the study are

- The United States government should perform a regular quantitative measure of the contribution of bio-based production processes to the U.S. economy to develop a capacity for forecasting and assessing economic impact.
- Industrial biotechnology firms individually and through industry groups should strengthen their partnerships with all levels of academia, from community colleges and their manufacturing training to graduate institutions, in order to communicate changing needs and practices and industry and to inform academic instruction.
- Federal agencies, academia, and industry should devise and support innovative approaches toward expanding the exposure of student trainees to design-build-test-learn paradigms in a high-throughput fashion and at industrial scale.

The study also made a number of governance recommendations: (1) Relevant agencies should work together to broadly assess the adequacy of existing governance, including but not limited to regulation, and to identify places where industry, academia, and the public can contribute to or participate in governance. (2) Science funding agencies and science policy offices should ensure outreach efforts that facilitate responsible innovation by enabling the extension of existing relevant regulatory practices, concordance across countries, and increased public engagement. (3) Government agencies should establish (a) programs for both the development of fact-based standards and metrology for risk assessment and industrial biotechnology and (b) programs for the use of these fact-based assessments in evaluating and updating the governance regime.

It is noted that the framework for the regulation of biotechnology is being upgraded in the near future.

He acknowledged the NSF and DOE for sponsoring this effort and noted that the Chinese government is now using this report to guide funding of R&D in biotechnology.

Zhang asked what agency was targeted for the roadmap. Friedman said that the Committee did not focus it on a government agency but rather on an area of the manufacturing cycle.

Wall asked if there were discussions of the bioenergy frameworks that would be developed. Friedman said that there was a discussion of several microorganisms that have been developed. The Committee did not pick favorites.

Joachimiak said that it was a useful report; but 20 years ago, a similar roadmap was developed but went unused. He asked about U.S. competitiveness. Friedman said that that topic came up. The NAS operates under many rules, the major of which is that everything has to be out in the open. As a result, a panel such as this has to address plans already in use to get relevant information to feed into government agencies' activities.

Allison Campbell was asked to provide an update on EMSL's activities.

Last year, EMSL developed a strategic plan and focused on molecular-level processes that will have an impact on the environment and society. The plan describes BER and DOE challenges where EMSL can have a sustained scientific impact. It provides a science lens for funding and hiring decisions. The plan was well received. It addresses four themes:

- Biosystem dynamics and design, which seeks to understand and optimize biological pathways in plants and microbes that are central to biofuel production in the global carbon cycle;
- Atmospheric aerosol systems, which seeks a molecular-scale understanding of key chemical and physical properties of aerosols to improve the prediction of climate models;
- Terrestrial and subsurface ecosystems, which seeks to understand the dynamics of nutrients, metabolites, and contaminants at biogeochemical interfaces to improve their representation in Earth-system models; and
- Energy materials and processes, which seeks to understand the physical and chemical properties of interfaces needed to design new materials and systems for sustainable energy.

These themes are underpinned by technical capabilities, especially to new instruments designed and developed to enable new science: the High-Resolution Mass Accuracy Capability (HRMAC), an ultrahigh-resolution 21-T Fourier transform ion-cyclotron resonance mass spectrometer, and the Dynamic Transmission Electron Microscope (DTEM), a near-atomic-resolution, time-resolved transmission electron microscope.

HRMAC was designed for the analysis of secondary organic aerosols and soil–microbe–plant–atmosphere interactions. It is made up of a spectrometer, the 21-T magnet, and the data/control system. The spectrometer was designed and built at EMSL. The budget was $17.5 million during the 2009–2015 project. The project was delayed by a wire shortage and achievement of the 21-T field. However, the project came in on time and under budget.

The machine surpassed its key performance goals. The resolving-power goal was 3 million, and the actual performance is 12 million. The mass-measurement-accuracy goal was less than 0.5 ppm, and the actual performance is 0.1 ppm.

EMSL issued a special science call for HRMAC in April 2014. Eleven proposals were received, and six projects were selected. About 15 technical papers (most on the technical development of the magnet) and three or four publications have been produced by the project.

The first-science results included the characterization of dissolved organic carbon and wetland sediments and of the microbial community found there. At 21 T, the machine can resolve many more species and confidently identify them. Work on switchgrass root exudates positively identified dioscin in rhizosphere soil organic matter. This system allows using top-down proteomics to correlate protein modifications and microbial activity. On the horizon is an understanding of plant–soil–microbe interactions with spatial specificity, showing where specific components are in a sample. A laser is used to energize a specific molecule and to ionize it for spectral analysis.

The development of the DTEM has been a multi-year effort. Many versions of the device were developed over the course of this project as challenges were encountered and overcome. This system allows looking at the dynamics of conformational changes of soluble protein complexes to allow the understanding of nitrogen fixation.

New ideas have evolved from two workshops. One of those ideas is to explore integrated plant–aerosol–soil sciences and the development of a facility to do that

Plants are becoming a more important portion of EMSL's users' research portfolio. New hires are needed to provide expertise in this area.

In summary, EMSL has developed and implemented a new strategy, it has developed and is deploying new capabilities, it is engaging the user community, it will issue its annual proposal call in December or January, and a new director is coming on board.

Stacey asked if he were correct in that only two 21-T spectrometers existed in the world. Campbell replied, yes; the other is used for "petroleomics."

A break was declared at 10:19 a.m.

The meeting was called back into session at 10:32 a.m. **Todd Anderson** was asked to review activities on the development of a strategic plan for BSSD.

Development of the BSSD Strategic Plan takes into consideration the BER mission drivers:

- Support the development of biofuels as a major, secure, and sustainable natural-energy resource
- Understand the potential effects of (1) energy-related greenhouse gas emissions on Earth's climate and biosphere and (2) feedbacks to future energy systems.
- Predict and control the cycling and mobility of materials in the subsurface and across key surface–subsurface interfaces in the environment.
- Develop new tools to explore the interface of biology with the physical sciences.

The DOE Strategic Plan cites the DOE mission to enhance U.S. security and economic growth through transformative science, technology innovation, and market solutions to meet the nation's energy, nuclear-security, and environmental challenges. In this plan, DOE's number one strategic goal is to advance foundational science, innovate energy technologies, and inform data-driven policies that enhance U.S. economic growth and job creation, energy security, and environmental quality, with an emphasis on implementation of the President's Climate Action Plan to mitigate the risks of and to enhance resilience against climate change. Among the Administration's priorities are the development of clean energy and innovation in life sciences, biology, and neuroscience.

In BSSD, an overarching goal is to provide the necessary fundamental science to understand, predict, manipulate, and design biological processes that underpin innovations for bioenergy and bioproduct production and to enhance the understanding of natural environmental processes relevant to DOE. This goal is to be attained by

- Providing a basic understanding of plant and microbial biology to underpin the production of biofuels and bioproducts from sustainable plant biomass resources;
- Developing the fundamental understanding of genome biology needed to design, modify, and optimize plants, microbes, and biomes for beneficial purposes;
- Gaining a predictive understanding of biological processes controlling the flux of materials (carbon, nutrients, and contaminants) in the environment and how these processes impact ecosystem function;
- Developing the enabling computational, visualization, and characterization capabilities to integrate genomic data with functional information on biological processes; and
- Broadening the integrative capabilities within and among DOE user facilities to foster a more interdisciplinary approach to BER-relevant science and to aid interpretation of plant, microbe, and microbial-community biology.

Science directions in the plan are informed by input from the scientific community via workshops, planning documents, and NAS studies.

The BSSD portfolio has changed radically. It now supports a diverse array of fundamental research and technology development to achieve a predictive systems-level understanding of complex biological systems. It now supports the BRCs, plant feedstocks research, a new element in sustainability research, biosystem design, computational biology, bio-imaging technology development, the Joint Genome Institute, and efforts in structural biology infrastructure.

At its heart, the program is interested in fundamental science with a broad interest in plants and microbes; complex bioenergy and environmental systems; and enormous and diverse data sets of genomic, omics, and experimental data. There is a need for integrative analyses and a need for understanding across scales.

The Division has a broad set of capabilities to accelerate the understanding of biology for DOE missions in bioenergy and the environment. It is interested in supporting interdisciplinary research, developing enabling technology, leveraging high-performance computation systems to facilitate analysis and collaboration, and integrating unique capabilities across user facilities. It is trying to couple the capabilities of the research community and to integrate genomic data; computation, modeling, and simulation; and experimentation and observations.

The Division's major goal is to provide a basic understanding of plant and microbial biology to underpin the production of biofuels and bioproducts from sustainable plant-biomass resources. This goal has two subgoals: the first is to provide the basic science to enable a sustainable and commercially viable lignocellulosic biomass-derived advanced biofuels and bioproducts industry. It is taking three paths to achieve this first subgoal:

- Developing the basic understanding of plant biology needed to produce dedicated, sustainable feedstocks with beneficial traits for bioenergy production,
- Creating new methods to cost-effectively deconstruct biomass, and
- Exploring a range of new microbial-based methods to convert plant-biomass-derived components to next-generation biofuels and related bioproducts.

The second subgoal is to develop new approaches to bioenergy agriculture that cost-effectively provide high yields of biomass on marginal lands requiring few or no inputs with plants that are highly adaptable to changing environmental conditions and have minimal to no impact on the ecosystem. It is taking three paths to achieve this second subgoal:

- Gaining a fundamental understanding of plant–microbe interactions;
- Linking mechanistic understanding of plant–microbe interactions to biogeochemical processes in soils; and
- Developing process-based, multiscale models of plant performance under changing environments.

The Division also intends to pursue biosystem design. Here the goal is to develop a fundamental understanding of the genome biology needed to design, modify, and optimize plants, microbes, and biomes for beneficial purposes. This goal will be achieved by developing

- A better understanding of the underlying principles needed to engineer new traits into plants and microorganisms,
- Improved computational and experimental tools for biosystem design,
- A diversified range of model microbes and plants, and
- Biocontainment mechanisms that permit incorporation of multiple, redundant safeguards at each step of the design process.

In environmental research, the goal is to gain a predictive understanding of biological processes controlling the flux of materials (carbon, nutrients, and contaminants) in the environment and how these processes affect ecosystem function. This goal will be pursued through

- Systems biology studies on microbes, microbial consortia, and microbe–plant interactions involved in large-scale terrestrial carbon-cycling processes;

- Determination of the role of microbial communities as key contributors in major biogeochemical cycles (e.g., carbon, nitrogen, sulfur, and phosphorus); and
- Scale understanding of biological processes from individual organisms to complex communities operating at ecosystem scales.

Modeling will play a major role in carrying out these tasks.

Developing and providing enabling technologies include developing the enabling computational, visualization, and characterization capabilities to integrate genomic information with functional information on biological processes. A change in the portfolio will be the addition of molecular-scale science and bio-imaging technology for systems biology. It would be good to discuss this topic in a future workshop.

In user-facility capabilities and integration, the goal is to broaden the integrative capabilities within and among DOE user facilities to foster a more interdisciplinary approach to BER-relevant science and aid interpretation of plant, microbe, and microbial-community biology. The major effort here is genome-sequence production and interpretation at the JGI.

Close ties and collaboration are being maintained with the USDA, ARPA-E, DOE's Office of Energy Efficiency and Renewable Energy (EERE), BER's CESD, NSF, DOE's Office of Advanced Scientific Computing Research, and DOE national scientific-user facilities in addition to coordinating under the umbrella of the National Science and Technology Council (NSTC).

Weyant said that it would be good to pull together information on the land–atmosphere boundary and asked what the prospects for that were. Anderson replied that an attempt is being made to identify the uncertainties and to set priorities. Weatherwax added that there is a lot of work at the process level and scaling up from the microbial level. Geernaert said that there are a lot of signals, making this a complex system. Modeling is very tough to do. Any measurement is characteristic of the time and place that the measurement was made. The question arises of how to generalize that data or information. Disturbances complicate the situation. Also, there is the question of how information should be incorporated if it is at the edge of a threshold.

Hubbard was happy to hear that there was work to be done at the intersection of the BSSD and CESD and wanted to encourage that breaking down of the silos.

Joachimiak said that there is a need to identify gaps in data needed for modeling. Anderson pointed out that the community has KBase and is working with others who operate similar and complementary data systems.

Randerson said that it would be good to develop examples to create threads from genomics up to Earth-system modeling. Anderson responded that the influence of nitrous oxide on climate is a good example. The cycle and fate of nitrogen is important, too.

Zhang asked if it were possible to model leaf growth so climate modelers can account for that link. Joachimiak replied that it is important to link lands, microbes, air, and soil. Weatherwax added that other agencies look at that subject (e.g., crop modelers in the Department of Agriculture), and those data need to be mined.

Robertson said that he had not heard anything about KBase in Anderson's presentation. Anderson said that it is part of high-performance computing. That trajectory is still strong.

Merchant commented that KBase's incorporation of plant-biology data is going slowly. Anderson responded that it has been focusing on research areas that are very robust.

Stacey opened a discussion of the charge-response letter. Weyant suggested generally referring to gradients from urban centers to other regions.

Randerson said that the last sentence of the document should refer to each IFL being awarded according to competitions among consortium-based teams, with national laboratories and others as team members.

Zhang suggested adding to the summary: "for the bioeconomy and human environment." Stacey suggested that the term be "regions that are important to the economy." Robertson pointed out that the term "bioeconomy" was cited in the charge letter. Stacey suggested the term, "economy and sustainability." There was general consensus that that term should be used.

Assmann pointed out some typos, and Hubbard had some little edits that she would like to make before the letter was sent out. She also pointed out that the list of contributors is not specific. Stacey said that that was done on purpose because it was unclear who contributed what.

Stacey asked for a vote of approval. Acceptance of the letter was approved unanimously.

Stacey turned the discussion to a new charge from the Secretary's office.

Weatherwax stated that BER Low Dose Radiation Research Program has been operating under a strategic plan written in 1998. SEAB suggested a reevaluation of a low-dose radiation program, including determining who would have equity in the future program.

Stacey announced that Judy Wall had agreed to chair that Subcommittee. Volunteers for Subcommittee membership will be appreciated.

Janetos noted that the charge is very ambitious and asked what if there were *no* program for "conclusive results." Stacey said that he had asked that same question and was told that it would be a legitimate topic of discussion by the Subcommittee.

Weyant said that a literature summary should be performed to inform the Subcommittee. Low-dose radiation effects is a big issue on the international scene. Wall agreed, noting that the European Union has a big committee looking at the issue. It is not going away. Nuclear power is going to be a source of low-dose radiation for long time.

Stahl noted that there has been a ramping down of the low-dose program for a long time, resulting in a loss of investment. He asked if the ramp-down resulted in the charge being issued. Weatherwax said that she could not speak to the motivation of the Secretary, from whom the charge came. Moreover, the Secretary *owns* the budget and thus has approved funding trajectories. Weyant said that one problem is that, if DOE does not carry out the low-dose program, it might be that no one else will. Weatherwax said that there are other agencies that DOE has worked with on this program in the past. Transferring the program to them is a possibility. The Subcommittee should discuss this topic.

Stacey announced that David Randall has volunteered to head up the COV to CESD.

Stacey opened the floor to general discussion.

Zhang asked if the Committee should proceed in identifying grand challenges. Weatherwax said that there will be a discussion of that subject at the next meeting of BERAC, when a formal charge may be presented.

Weyant asked if this Committee should weigh in on world competitiveness. Stacey said that that argument no longer seems to be persuasive in the halls of Congress. Weatherwax suggested that it may be worked into the grand challenges.

Stacey opened the floor to public comment; there being no public comment, the meeting was adjourned at 11:35 a.m.