**Draft Minutes**
**Biological and Environmental Research Advisory Committee**
**March 3–4, 2014**
**Marriott Washingtonian Hotel and Conference Center**
**Gaithersburg, Md.**

**BERAC Members Present**

Gary Stacey, Chair
James Ehleringer
James Hack (Monday only)
Anthony Janetos (via Ready Talk on Monday)
Andrzej Joachimiak
L. Ruby Leung (Monday only)
Sabeeha Merchant (via Ready Talk)
David Randall
James Randerson (via Ready Talk)
Karin Remington (via Ready Talk)
G. Philip Robertson
Martha Schlicher (via Ready Talk Monday only)
Gus Shaver
David Stahl (via Ready Talk Monday only)
Judy Wall (via Ready Talk)
Warren Washington
John Weyant
Minghua Zhang
Huimin Zhao (via Ready Talk)

**BERAC Members Absent**

Dennis Baldocchi
Janet Braam
Judith Curry
Susan Hubbard
William Schlesinger
Jacqueline Shanks

About 50 others were in attendance in person or on the phone during the course of the two-day meeting.

**Monday, March 3, 2014**
**Morning Session**

Before the meeting, **Melinda Comfort** (DOE Office of General Counsel) conducted the Committee's annual ethics briefing. Because of a snowstorm, Comfort, like several other members, attended the meeting via Ready Talk. New members who were not U.S. Government employees were sworn in during the lunch break.

The meeting was called to order by the Chairman, **Gary Stacey**, at 9:00 a.m. The Committee members were asked to introduce themselves and to give précis of their research activities. A quorum was established for the meeting of the Committee.

Stacey welcomed the new members and announced adjustments in the agenda: Patricia Dehmer and James Randerson were not able to attend the meeting because of a snowstorm; James Hack would present a science talk in place of Randerson's.

**Sharlene Weatherwax** was asked to summarize key points from Dehmer's presentation and to present an update on activities of the Office of Biological and Environmental Research (BER).

Dehmer wanted the Committee to know that the process of filling DOE leadership positions is progressing. Marc Kastner, dean of Massachusetts Institute of Technology's (MIT's) School of Science, has been nominated to be the next Director of the Office of Science (SC). Lynn Orr, professor in Stanford's Department of Energy Resources Engineering, has been nominated to be the next DOE Undersecretary for Science. Both nominees are awaiting Senate confirmation.

BER now has an FY14 budget that provides $227.1 million for research and $84.7 million for facilities in the Biological Systems Science Division and $178.8 million for research and $119.1 million for facilities in the Climate and Environmental Sciences Division for a total of $609.7 million for the Office. This almost brings the Office back to the FY12 funding level, when its enacted budget was $609.9 million. The Office is now in a position to undertake some initiatives that had been planned for FY13 but were deferred because of the lack of a federal budget. The FY15 budget request is to be released in the afternoon after the second day of this meeting. BER's FY14 budget is well balanced with a healthy mix of research and facilities.

Two long-term members of the Office have retired: Karen Carlson-Brown and Dean Cole. Three members had completed their terms on BERAC: Jay Mace, Joyce Penner, and Hank Shugart. Jennifer Reed of the University of Wisconsin at Madison, an Early-Career Award winner as a BER-funded researcher, has been named to receive the Presidential Early Career Award for Scientists and Engineers (PECASE). Long-term BER funding led to a 2013 Nobel Prize in Chemistry for Michael Levin for the development of multiscale models for complex chemical systems. Recent awards to BERAC members include the Oak Ridge National Laboratory (ORNL) R&D Leadership: Director-Level Award to James Hack, the 2014 American Meteorological Society Jule G. Charney award to David Randall, and the 2013 Curators' Professor Award from the University of Missouri to Judy Wall. Among BER staff members, Gary Geernaert was elected a fellow of the American Meteorological Society, and Sally McFarlane was elected Secretary of the American Association for the Advancement of Science (AAAS) Atmospheric and Hydrosphere Sciences Section Steering Group.

Within the BER research portfolio, the Green Ocean Amazon (GOAmazon) program kickoff meeting was held in Amazonia, Brazil, on February 18–20, 2014.

SC recently posted a memo on the full-funding of financial-assistance awards, one of the two funding streams, this one being for university or institutional researchers. According to the memo, beginning immediately, the entire value of any grant or cooperative agreement with a total cost of $1 million or less will be obligated when the award is made. SC will implement this policy immediately.

Discussion

Stacey asked how many fewer grants will be funded. Weatherwax replied that, normally, these grants are funded year-by-year. Now, the funds will be fully committed in the first year of the grant. The program managers are currently trying to figure out how this will be done. Full funding will be made for any new grants. Extant, continuing grants will continue to be funded year-by-year until expiry. Oversight mechanisms will have to be adjusted. Collaborations with other agencies will also be affected.

Zhang asked why Congress did this. Weatherwax replied that Congress feels that this gives it more control over funding and results in more stability in funding. Wall asked if this affected the national laboratory funding. Weatherwax replied, no. Ehleringer asked if Congress were trying to affect multi- versus single-investigator contracts. Weatherwax answered that the topic never came up.

Because educational activities have been transferred from DOE and other mission agencies to the National Science Foundation (NSF), the Smithsonian Institution, and the Department of Education, there is a new charge to BERAC to consider what workforce-development education activities are essential to the BER mission that would not be covered under this new arrangement. The charge asks BERAC to identify

- Disciplines not well represented in academic curricula;
- Disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at the DOE national laboratories;

- Disciplines identified in the previous two bullets for which the DOE national laboratories may play a role in providing needed workforce development; and
- Specific recommendations for programs at the graduate-student or postdoc levels that can address discipline-specific workforce-development needs.
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Thomassen added that a short letter report will be due before the June meeting.

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

Since the previous BERAC meeting, reviews have been held for the three Bioenergy Research Centers (BRCs), the SBIR program, the Early Career Awards, and the Biofuels Science Focus Area (SFA). In addition, the Genomic Sciences Annual Principal Investigator (PI) Meeting was held. Upcoming events include the Foundational Genomics SFA triennial review, the Molecular Scale Science Challenges Workshop, a workshop on bioenergy, and a Committee of Visitors (COV) review.

Three new funding opportunity announcements (FOAs) have been issued:

- Plant feedstocks genomics for bioenergy [jointly with the U.S. Department of Agriculture (USDA)]
- Systems biology of bioenergy-relevant microbes to enable production of next-generation biofuels
- Targeted radiochemistry and associated technology development for integrated nuclear-medicine research and training with human application [jointly with the National Institutes of Health (NIH)]

Funding for these FOAs will probably be increased now that there is a budget. The third FOA is expected to be fully funded under the new legislation.

Under the Mesoscale to Molecules initiative, an attempt is being made to understand the translation of genomic information into the mechanisms that power living cells, communities of cells, and whole organisms. Imaging approaches are also being developed to understand the genomic and physical rules governing formation and functions of subcellular mesoscale structures, the organelles and membranes in plants and microbes. These projects are expected to be piloted at the DOE national laboratories this year and will be followed up in FY15 with an FOA for the broader community. The program will look at material transport within and across cellular compartments, at bacterial cell structure and function, and at plant–microbe interactions. This program pulls together theory and experimentation to allow and validate modeling and simulation.

The SBIR Phase-I solicitation seeks to move research results out into the commercial sector. It led to six new awards this year.

In the use of facilities, the next Joint Genome Institute (JGI) community-sequencing program has letters of intent due April 17 and invited proposals due on May 27. The JGI and the Environmental Molecular Sciences Laboratory (EMSL) are continuing their collaborative-science initiative in a second installment; applications are due April 7. There is the hope to tie this work in with the DOE light sources.

The new BRC brochure includes the transition from the first to the second 5 year term of the centers. It updates the scientific progress since the 2010 edition, revises each center's scientific vision for research, and provides a detailed list of significant published advances in the four major areas of emphasis at the centers. It also lists major publications contributed to the field.

Upcoming workshops include: the Bioenergy Research Workshop to determine how the research will progress beyond the current terms of the BRCs. It will be held June 23–25, 2014, in Washington, D.C.,

and will be chaired by Kristala Jones-Prather of Massachusetts Institute of Technology and Erich Grotewold of The Ohio State University. The Molecular-Scale Science Challenges Workshop will be held to guide programs and identify instruments to be provided by the user facilities. It will be held May 27–29, 2014, in Washington, D.C., and will be chaired by Judy Wall of the University of Missouri and James Liao of the University of California at Los Angeles.

Stacey asked what molecular-scale science was. Anderson replied that it referred to the activity of enzymes, molecular-scale actions of biological entities, and aerosols in the atmosphere.

DOE's Systems Biology Knowledgebase (KBase) is taking a major step, the rollout of the narrative interface. The narrative interface is a manuscript in preparation; it is where one puts information about an experiment, an abstract, thoughts, data, analyses of genomic sequences, and collaborative work with colleagues. It allows a dialogue among researchers and should increase the dedicated KBase user number significantly from the current 470.

A series of science highlights included a computational-chemistry approach to control lignin polymerization, thereby reducing biomass recalcitrance; a pretreatment process for high sugar production from plants with a biomass-derived solvent (another tool for breaking down woody material into fermentable sugars); new ways to genetically engineer pathways to be dynamically responsive to farnesyl pyrophosphate concentrations; discovery of a novel methanogen (***M. stordalenmirensis***) in thawing permafrost; the production of an expanded microRNA and microRNA cleavage-target data set in *B. distachyon* from several samples and numerous environmental conditions; and a new understanding of the thermal pretreatment of biomass that will enable improvements in biomass conversion.

JGI had 37 publications since the previous BERAC meeting.

Dsicussion

Robertson was impressed with the novelty and usefulness of the SBIR proposals that he had reviewed, especially those in sensors. He asked if sensor technology would be recompeted this year. Anderson said that the solicitation will probably hit that topic again.

Joachimiak stated that the archaea are important and should be explored some more. Anderson said that they are catalyzing methane production, and that sequence has been found across the Arctic. Joachimiak noted that there may be extant information on this topic.

Stahl asked if there were opportunities for researchers to work with the SBIR recipients who work on $N_2O$ production. Anderson said, yes, that would be encouraged.

A break was declared at 10:50 a.m. The meeting was called back into session at 11:07 a.m.

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

Globally, the very cold winter that the upper United States experienced in 2013–2014 was a very small anomaly in a year that was the fourth-warmest January in the Northern Hemisphere.

There have been seven recent and projected FOAs. Proposers to new FOAs will experience a low success rate because of the new rules of full funding. There will be a transitional period until the current steady state of total projects funded is reached. There have been three renewal reviews of SFAs: Lawrence Berkeley National Laboratory Subsurface Biogeochemical Research (SBR), Brookhaven

National Laboratory Atmospheric System Research (ASR) Program, and Lawrence Berkeley National Laboratory Regional & Global Climate Modeling (RGCM) Program. The new Terrestrial Ecosystem (TES) SFA at Argonne National Laboratory was approved. In FY14, reviews will be coming up at the Lawrence Livermore National Laboratory Earth-System Model (ESM) SFA, Lawrence Berkeley National Laboratory ASR and TES SFAs, Pacific Northwest National Laboratory Atmospheric Radiation Measurement (ARM) Facility, Stanford Linear Accelerator Center SBR SFA, Pacific Northwest National Laboratory SBR SFA, and Oak Ridge National Laboratory RGCM SFA.

A large number of PI meetings and workshops are coming up: the ASR PI Meeting March 10–12, Mechanistic Modeling of Terrestrial Environments on March 26–27, Observations for Model Intercomparison Projects (obs4MIPs) Coupled Model Intercomparison Project, Phase 6 (CMIP6) Workshop on April 29–May 1, Ameriflux PI Meeting on May 4–5, Environmental System Science (ESS) PI Meeting on May 6–7, TES Data Needs Workshop on May 8, Modeling PI Meeting on May 12–15, ARM Large Eddy Simulation (LES) Workshop on May 19–20, Molecular Sciences Workshop on May 27–29, Population Dynamics Workshop on June 23–24, and Land-Use/Land-Cover Workshop on June 25–27.

Science highlights include a new method to speed up ocean-model spin-up and enable deep-ocean age testing with new methods to spin-up over tens rather than hundreds of years. A hiatus in the rate of climate warming increase has been analyzed, and the codes used to project that hiatus have been examined; significant cooling of the ocean surface was detected in the Pacific tradewinds cycle, and 17 small volcanic eruptions put large amounts of aerosols into the upper atmosphere; including these effects has brought the model results closer to observations. A new mechanism was discovered that explains how aerosols have impacts on cloud dynamics, not just cloud formation. A new understanding of water-vapor transport and stratocumulus clouds elucidates transport of water vapor and convective-velocity scale, making the model and observations converge more elegantly and showing that vertical extension is more important than previously believed. Measurements of the properties of biomass-burning aerosols have shown that radiative properties have traditionally been simplistically portrayed; more parameters need to be included.

ARM has created two supersites. The Southern Great Plains Site will absorb much of the Tropical Western Pacific Site as the latter is closed down, producing a supersite that will be available to research cloud parameterization. The North Slope of Alaska Site will begin piloted flights between Barrow and Oliktok during the summer of 2015, and unmanned aircraft system flights at Oliktok will complement ground-based measurements.

GOAmazon has now been launched to study how aerosols, along with changes to heat and energy at the surface, influence cloud cycles under clean conditions as well as how aerosol and cloud lifecycles are influenced by the pollutant outflow from a tropical megacity. A similar experiment was initiated in Hyytiälä, Finland, with partners across northern Europe for measuring ecosystem–atmosphere relations.

The carbon and water cycles are not currently linked to nitrogen limitation in the Integrated Global System Modeling framework (IGSM); when nitrogen limitation *is* considered, simulations show growth still increases as $CO_2$ increases, but the global mean increase in growth is 18.3% less than when nitrogen limitation is not considered, meaning that more water enters ecosystems as runoff than was previously thought.

A study of the roles of fungi in $CO_2$ uptake and storage show that there are two types of fungi: one that is sufficient and one that is not efficient in enzymatic nitrogen degradation.

A study showed that, in a drought environment, one has to consider the hydraulic lift of soil water and its raising of nutrients from the deep soil; in general, models (from the ecosystem to global scales) have only begun to include the effects of hydraulic lift.

The subsurface sediments at the Rifle, Colorado site yielded subsurface microbial communities that consisted of many bacteria and archaea from classes and orders that had not been previously recognized or sampled. Researchers were able to completely reconstruct the genome of a dominant organism that turned out to be a member of a new phylum. Analysis of the complete microbial genome led to a detailed metabolic model with evidence for multiple new enzymes and pathways.

Currently at EMSL, there are calls for proposals for the 2014 science theme and for the 2014 EMSL–JGI collaboration.

The path forward for data management in BER and SC includes unifying current databases and including others in a federated system. The next step to be taken is to conduct a town hall meeting to solicit information; it will be announced the week after this meeting. This path would build on and be the first step in the BER virtual laboratory that was proposed a year ago.

Discussion

Wall asked how the informatics interacted with KBase. Geernaert replied that it was expected that KBase would be brought into this workflow.

Joachimiak asked Geernaert if he could elaborate on the term "molecular science." Geernaert responded that it gets into the bacteriology of subsurface environments and atmospheric aerosols. It will contribute to land modeling.

Zhang asked for clarification about the sites and whether funding constraints had an effect on the closing of the South Pacific site. Geernaert answered that the Azores site went live and took the burden off the Pacific site as a marine site. There is no decrease in interest in the tropics; the site of observation is simply being shifted. Zhang asked if it would happen right away. Geernaert said that the tropical West Pacific Site of ARM will be closed by the end of 2014, and a lot of that capability will be redeployed to the Southern Great Plains Site. This shift will result in more measurement capability and higher-resolution climate models.

Weyant asked if there were training in climate and computational statistics for people in data and informatics. Geernaert replied, probably, yes. There is a proposal to move the current climate model to the next level, and those advanced models will probably be run on computers at universities. The other question is how to share data from different sources.

Leung noted that collaboration among the DOE programs is important and asked if there could be a mechanism for facilitating such collaboration. Geernaert replied that there had been some discussions of other programs' interests and needs. BER has been looking at gaps in climate projections. Many programs have a big interest in ARM capabilities. It has not been determined how costs could be handled.

Robertson asked if the "7 out of 235" proposals funded in the NASA ROSES (Research Opportunities in Space and Earth Sciences) call referred to successful proposals for BER only. Geernaert responded that it *is* for BER only. BER is a minor player.

A break for lunch was declared at 11:51 a.m.

**Monday, March 3, 2014**
**Afternoon session**

The meeting was called back into session at 1:30 p.m., and **James Hack** presented a BERAC member science talk describing climate and computing challenges and opportunities on the path to the exascale.

Simulation science has begun to master deterministic time scales and is getting a handle on deterministic forecasts at regional scales. This capability was demonstrated by the European Weather Center's prediction of the wandering path of Hurricane Sandy a week in advance. As a result of that prediction, there is a political awareness that this modeling is real, and politicians will look at climate change harder because of its many consequences on water resources, agricultural and food security, human health, terrestrial ecosystems, coastal-zone and marine ecosystems, and human-engineered systems.

The multiscale turbulent phase change of water drives the entire climate system, and one needs to use greater computer power to deal with the complexity of the modeled system. Historically, as computer power has improved, the resolution and system complexity of modeling have improved. Today, the scale capabilities critical to enabling the treatment of eddy processes are required to characterize regional climate. In taking the current modeling frameworks forward, the systematic errors will not go away. Not only larger computers but also more sophisticated algorithms and parameterizations will be needed to deal with unresolved processes and upscale energy transport in models.

The parameterized physics behavior varies with the horizontal and vertical resolution, and decoding of parameterized processes is reaching formulation limits. A new approach is needed to move these problems forward. A lot of tasks are in the high-resolution-simulation workflow, and the hardware and software are not there. The computer architecture needs to be changed because the best machines now have a peak performance of 27.1 petaflops and 18,688 compute nodes, each with 16-core AMD Opteron central processing units (CPUs) and NVIDIA Tesla K20X graphic processing units (GPUs). High-resolution simulations will require exascale computers, ones that are 1000 times bigger and faster than the current biggest and fastest machines. The tools to employ this architecture do not exist, but 10 times the performance will be gotten out of a machine with the same footprint. That benefit will carry forward in time to affect all computing.

As a result, 1 million lines of code need to be redesigned in a smart way that improves the quality of the simulations. Later in the week of this meeting, an initiative will be launched, an Earth-system model that will run efficiently on DOE computing systems by 2017 (5 simulated years per day). It will be designed to meet the needs for building an end-to-end climate and Earth-system prediction capability. This initiative is being carried out by seven national laboratories and six academic partners. It will be funded at $21 million per year, with $19 million in funding at the national laboratories that will be redirected from current foundational projects.

The rate of scientific progress is increasingly dependent on the ability to efficiently capture, integrate, analyze, and provide access to large volumes of diverse data. However, many facilities and research programs across SC are not prepared for this challenge. A national dialogue on scientific data has indicated that

- DOE SC facilities and research teams have increasing storage and analysis needs that outstrip their management abilities.
- Research teams are increasingly geographically distributed and require collaborative tools and shared access to data and analysis infrastructure.
- Consolidating resources would provide economies of scale.

- Easy and long-term access to data would increase the value of and productivity from existing facilities.
- The value and importance for improved data management and data curation are increasingly being recognized.
- Investments in infrastructure and expertise are being leveraged significantly.

The ORNL Data Science Center will provide these capabilities with a rich data-analysis environment; the coupling of simulation, experiment, and observational data; a flexible compute and data environment that can be curtailed to specific needs; the cataloging and long-term stewardship of scientific datasets; and long-term allocations for major facilities and projects. The ORNL Data Science Center will leverage significant investments: 65,000 square feet of space, 40 MW of power, 6 kilotons of cooling, connectivity, and expertise. Such data science centers will provide core integrated services and a federated services catalog, providing the ability to construct complex multisite workflows.

The mission of the Oak Ridge Leadership Computing Facility is fielding the most powerful computers for scientific research. Titan was fielded last year. What is next is an extreme-scale (exascale) machine with 1- to 10-billion-way parallelism that requires hierarchical parallelism to manage and uses a message-passing interface (MPI) between nodes. Power usage will dominate the architectures; it cannot be more than 20 or 30 MW. Traditional "balance ratios" are eroding: neither memory size nor memory bandwidth is growing; floating-point operations are cheap; and memory access and data movement are the rate limiters.

Some lessons have been learned:

- Identifying the opportunities to parallelize code is often straightforward.
- Making changes to exploit parallelism is hard work.
- Developers can quickly learn.
- A directives-based approach offers a straightforward path to portable performance.
- For those codes that already make effective use of scientific libraries, the possibility of continued use is important; they can be made hardware-aware and help overlap computation with device communication.
- Ensuring that changes are communicated back and remain in the production "trunk" is important.

All codes will need rework to run at the exascale. Up to four person-years were required to port each code from the Jaguar to the Titan, which increased performance by a factor of 1.5 to 2.0. Experience shows that 70 to 80% of development time is spent in code restructuring. Each code team must make its own choice of programming language. The user community and sponsors must plan for this expense.

All codes will need error recovery at scale: at a minimum, simple checkpointing or restarting. More advanced error-detection and recovery techniques will be required as parallelism increases. Investments in good tools are critical to success; one cannot debug with print statements anymore. The fundamental algorithmic approach needs to be rethought. Heterogeneous architectures can make previously intractable or inefficient models and implementations viable and can increase run rates by more than a factor of 100.

The science drivers for larger, faster computers have been identified by the communities (i.e., material science, fusion, biology, and climate).

CORAL is a Collaboration of Oak Ridge, Argonne, and Lawrence Livermore National Laboratories to acquire three leadership-computer systems for delivery in 2017. DOE's SC and National Nuclear Security Administration (NNSA) signed a memorandum of understanding agreeing to collaborate on high-performance computing research and acquisitions. The collaboration grouping of these national

laboratories was based on common-acquisition timings. Collaboration is a win-win for all parties: it reduces the number of requests for proposals that vendors have to respond to, improves the number and quality of proposals, and allows pooling of R&D funds. This process is commonly referred to as codesign; NNSA has done this for a long time. There is a CORAL management structure in which the top three levels of management (executives, directors, and acquisition leads) work together. The request for proposals was written two weeks before this meeting, with R&D contracts to be awarded to two vendors to make sure that DOE ends up with a machine that will serve the scientific community well.

Discussion

Zhang asked if there were any advanced climate modeling outside the United States. Hack replied that there is invaluable work being done in other countries. Randall said that many programs are being carried out. Japan and the Max Planck Institute have been doing innovative work, and China is emerging. Hack emphasized that they are very aggressive.

Randall noted that there was the managerial side and the physics side and asked how one maintains a balance, especially on the physics side. Hack said that the United States needs to make investments in the whole-Earth system and in small-scale physics. These topics are spread across stovepipes. One needs to have a broad perspective and bridge those stovepipes. The physics is a very important part; he did not know how many students are being turned out to deal with those hard problems.

Joachimiak noted that there is the perception of a computational explosion and asked if the really good hardware, exascale architecture, and more-effective algorithms will bring about a new way to solve scientific problems. Hack responded, yes. The question, though, is not how big a computer is delivered but what type of science can be delivered. The computer scientists have to partner with the scientists to make big impacts; otherwise, a lot of the potential of this new hardware would go unrealized.

Leung asked if there was coordination with other agencies on these computational resources so they can be used by researchers with a broad array of hardware. Hack answered that what is wanted is a standard or performance portability or interoperability so infrastructure can be moved from one environment to another without a lot of training and other distractions. Right now, the architecture is heterogeneous; a standard is needed to converge on. That is goal that will never go away.

Washington noted that some companies (like Intel) want to put GPUs on the chip and reduce latency. Hack said that industry is working on that. They have a path forward. That is where the long-term contracts could have a big impact, to help move in a direction that will have the biggest return.

Stacey noted that there is confusion between climate and weather. Climate is what can be modeled in the long-term. Weather is what you see out the window. He asked if that were a viable use of those terms. Hack replied that climate is a statistical description of weather. A single event does not define climate. The picture is bigger. Attribution of a single event as being indicative or typical of climate is difficult. One would get a split decision from climate scientists about any given definition of the terms. Climate and weather are not the same, but they are the same in that climate is the statistical distribution of weather events. Stacey noted that Gov. Cuomo has equated weather and climate in his characterization of Hurricane Sandy as a 100-year storm occurring every 2 years and asked whether, in the long run, that will work against climate scientists? Hack said that the statement of the frequency of events is a statement about climate trends.

Zhang asked whether, at the exascale, the failure of a node will cause a model to stop running. Hack replied that these faults are rare today, but with so many cores in an exascale machine, something will go

wrong more frequently. Several solutions are being looked into, such as ghost memory and checkpointing.

**Gary Geernaert** was asked to present the CESD response to the COV findings and recommendations.

The COV that was charged to review the operations of the CESD made five general recommendations and a series of program-specific recommendations.

The first general recommendation focused on SFAs and the burdens put on SFA teams by multiple reviews. This is a good recommendation. The review process is fair; some teams included too much detail. SFAs are dynamic funding mechanisms, able to include exploratory research. BER will continue to encourage the national laboratories to take full advantage of SFA goals. BER will work to minimize the burdens while maintaining the integrity of the review process.

The second general recommendation urged that the current, appropriate overall balance of laboratory and university research be maintained. This recommendation indicates that the Division is on the right track.

The third general recommendation pushed for increased travel funding to allow program managers (PMs) to attend scientific meetings. Travel funding comes up time and again in these reviews, but there is not much that BER can do about it. It is a decision that is made at higher levels of management.

The fourth general recommendation called for DOE to improve its electronic grant information system to better assist the program managers and support staff. The Portfolio Analysis and Management System (PAMS) was just getting up and running when the COV review occurred, and improvements will be incorporated in the next year.

The fifth general recommendation encouraged PMs to develop program-wide metrics of performance and progress in addition to the quantitative measure of publications. This is an extremely good recommendation. The issue of harmonizing metrics will be addressed by a team of PMs from across BER.

For the ASR, ESM, and RGCM programs, the COV strongly recommended that DOE maintain its proactive collaborations with the modeling community and its investments in ESM activities. BER acknowledges the diversity of expertise in national laboratories and universities that is required to advance the community models. BER will continue to develop strategies to best use the vast resources of the national laboratories and within the universities to rapidly advance the development of climate modeling in support of DOE and national needs. It will be proposing a new modeling framework announced soon.

For the Integrated Assessment Research Program (IARP), the COV recommended the consideration of a formal cooperative agreement in meeting its objectives. BER acknowledges the maturity of the IAR project at MIT, and recognizes the value of converting this project to a cooperative agreement, so it has initiated steps to convert the MIT project from a grant to a cooperative agreement.

For the TES program, the COV recommended engaging with other federal agencies to address how voids in ecosystem and carbon-cycle research at DOE can be filled and information about these elements of the Earth system be included in DOE modeling efforts. This is an important recommendation and elicited an important response. This is not a standalone program, and is not the only ecosystem program in the federal government. There is a working group to coordinate and collaborate efforts government-wide. BER will continue to coordinate its research activities and leverage opportunities with other

agencies through formal mechanisms, such as legislated committees, the Office of Science and Technology Policy, and interagency working groups.

For the SBR program, the COV recommended that the program be maintained with appropriate funding to retain key expertise in activities in radionuclide research. The SBR program is valuable to other programs across BER. BER recognizes the key role that SBR has played in the science of subsurface radionuclide fate and transport and that much of the traditional SBR research can also benefit research on subsurface nutrients and carbon. BER will maintain expertise and research on subsurface fate and transport of radionuclides as it works in parallel to explore synergies with challenges facing the subsurface science of climate change.

The COV had three recommendations for the ARM program, and the Division had respective replies:

- The PMs should continue the ARM Climate Research Facility management's proactive role in the development of the "best estimate" data sets. Yes, BER will continue to develop these data sets as part of the ARM Climate Research Facility.
- Scientific input from the Science and Infrastructure Steering Committee (SISC) and the Infrastructure Management Board (IMB) should be better documented. BER welcomes and agrees with these suggestions to improve the management processes applicable to the ARM facility. BER will improve its documentation of scientific input as part of the operation and management of the ARM Climate Research Facility.
- ARM proposals should have a succinct summary of previous activities to recount critical events and achievements to build institutional memory. BER will request that future ARM proposals include a summary of previous activities with a focus on critical events and achievements.

For the EMSL program, the COV recommended the continuation of the increase in the user pool, especially new investigators. BER will continue to work with EMSL to encourage the expansion of its pool of users, especially new users. This is already a metric of EMSL performance. EMSL.

For the facilities program, the COV recommended that PMs continue to gauge the science community to set priorities and maintain the proper balance of protecting legacy data sets and acquiring new instruments. The timing of this recommendation is excellent. In 2009–2010, there was a major acquisition of new instruments. At this point, there is a need to identify what new instruments should be acquired.

Discussion

Zhang, Chair of the COV, appreciated the response, which, he said, was very good. He suggested a strong effort be made to get more travel funding for program managers. Geernaert agreed that program managers should be visible at the reviews, but sending the whole management team to the field for review is not practical. There have been reverse visits, where program managers can be present. Wall noted that reverse-site visits result in fewer young researchers getting to meet with program managers. The past two COVs have pointed out the need for program manager visits to research sites. Merchant agreed; program managers get to appreciate the staff support and infrastructure present at the laboratories when they visit there.

Weyant asked if part of the review considered coordination of international cooperation. Geernaert responded that, in ARM, about 1.5 years ago, a joint workshop was held with DOE's European counterparts. That workshop spun off into a series of United States–Europe workshops. The Office has talked with Scandinavia and with Russia about permafrost research. There is currently a joint project with Brazil.

Shaver asked if it were DOE's mission to cover all systems. Geernaert said, no. The agencies should coordinate with other federal agencies to avoid gaps in research. Zhang noted that the COV was referring to the earth-sea ecosystems. Shaver pointed out that there was a re-emergent concern in Alaska and in the press about the migration of radionuclides from remnants of Project Plowshare in Point Hope, Alaska, and that might be something that the radionuclide-migration effort might want to consider.

A break was declared at 3:06 p.m. The meeting was reconvened at 3:22 p.m.

Stacey initiated a discussion of the new charge on STEM [science, technology, engineering, and mathematics] education (workforce development). A subcommittee could write a draft, circulate it to the entire Committee, and gain acceptance of it in a formal BERAC meeting conference call.

Zhang said that a one-day workshop for using high-performance computing had been held about 10 months ago at Stony Brook University. There were only 20 seats, but the room was packed, and there was a long waiting list for the workshop. People who do climate modeling need to know about high-performance computing, but there is no course to take on that subject. Online education modules may be helpful. Students got a working knowledge of how to write programs from the one-day workshop.

Wall pointed out that one variable is the level at which a workshop is offered. Such workshops and online tutorials need to be matched with the skill set of the users.

Robertson said that this is a welcome charge. The sustainable-energy workshop discussed this problem last fall. It identified plant ecosystem physiology and multiscale mechanistic modeling as topics that are not covered in academic programs. Faculty recruitment would be difficult because of the lack of programs. More broadly, there is a need for cross-training, which was also mentioned in the grand challenges report, so students would have both depth and breadth to their knowledge.

Joachimiak noted that the generation of big data has been observed; these data sets are beyond an individual's ability to deal with. Tools and supercomputing are needed to extract meaning from big data. But not everybody knows how to use supercomputers; a training program is needed on using supercomputers to extract data from big data and to analyze for errors. Multi-scale problems need different approaches than those traditionally provided by academia. Teamwork is another skill that needs to be taught to early-career researchers.

Ehleringer said that value is derived when national laboratories and universities combine to train people to meet DOE missions, such as on the carbon cycle and the Next-Generation Ecosystem Experiments concepts.

Shaver pointed out that there are few whole-system ecosystem analysts. That capability needs to be rebuilt.

Stahl said that other areas with training needs are microbial physiology as well as plant ecosystem physiology. It is not feasible to go from genotype to physiology. Techniques and methods are needed.

Merchant said that people need to be trained in the old-fashioned techniques and methodologies and in research design along with the new computational techniques. At the University of California at Los Angeles (UCLA), a 12-week workshop was held on pure and applied mathematics so one could understand informatics. Several hundred people attended.

Stacey commented that whole-plant physiology and other areas are dying out because the funding is not there to support them. Some topics may need to be packaged with workshops on the underlying science, also.

Stahl suggested scientific communication as an area that needs to be expounded on.

Shaver noted that, 40 years ago, plant physiology was important because of adaptation and evolution. But it became perceived that the evolution of adaptation became a list of *Just So* S*tories* [a reference to Rudyard Kipling's work] and boring. Now one needs to understand how these processes apply to the whole system and how they scale across that system. Stacey pointed out that there is also coupling of ecophysiology with genetics.

Robertson said that, in order to understand multiscale modeling, one needs to understand all the underlying subsystems.

Stacey asked if atmospheric physics would be a good topic. Randall replied that one needs to understand radiation transfer and a lot of mechanisms. About 20 people in the nation teach the subject.

Leung stated that there is a need to look at things with a systems perspective, especially climate modeling. Without that perspective, even with the best physics, one will not get a meaningful model.

Washington said that, at the National Center for Atmospheric Research (NCAR), every other year there is a week-long workshop on models where the students can use a model at a workstation with mentors around. These workshops have been very successful. DOE and NSF could use those workshops as a model.

Randerson said that training is invaluable and there is a potential to strengthen such workshops in climate science, both for individual model components and the coupled model as a whole. He agreed with the various comments on the need for a multiscale modeling systems approach; the National Aeronautics and Space Administration and the Environmental Protection Agency have very successful fellowship programs; DOE could sponsor a similar fellowship program that provided links to a laboratory and mentors. DOE could also fund workshops in climate science. Universities and national laboratories could collaborate to make up a long-term series of workshops.

Weyant pointed out that there are other approaches, like interdisciplinary fellowships and postdoctoral programs. One has to get people acculturated to multiple disciplines. DOE should put resources in those places where there are gaps between disciplines.

Robertson said that (1) predoctoral fellowships and workshop training and (2) user workshops for DOE user facilities are possible ways to bridge those gaps.

Wall asked Weatherwax about whether these workshops would be done outside the NSF, Smithsonian, and Department of Education's STEM education. Weatherwax said that BER was not minimizing the importance of K–12 education for science; if there was any training required for K–12, the Subcommittee should bring that up. Otherwise, it should focus on what the national laboratories need for workshop training.

Merchant called attention to the many workshops that are available for postdoctoral students at Cold Spring Harbor Laboratory; they are very rewarding. The faculty members are very competent. Weatherwax said that DOE has funded such workshops.

Stacey summarized the discussions as dealing with

1. Pre-and postdoctoral fellowships
    a. Focus on situations on multi-disciplinary areas with multiple mentors
    b. Focus on physiology: eco-physiology, synthetic biology, and metagenomics
2. Multi-week workshops focused on integration and interdisciplinary areas
3. Short-term workshops on specific topics and ideas (e.g., a model)

Randerson stated that a fourth category would be larger grants for a cluster of universities and laboratories to address mission-specific needs.

Remington added that there is a need to get statisticians talking to the geneticists and to the scientists. These boundary areas are killing the field. Pipeline building at NIH was avoided because "someone else is doing K–12 education." The Office of Science and Technology Policy's call to consolidate may make this problem worse for the mission agencies.

Stacey said that the Office of Science (SC) wants ammunition so that it can talk about the uniqueness of its needs. Maybe the letter report should focus on these needs. Weatherwax said that no one is challenging the need for K–12 education reform. However, the mission agencies have developed tools to address others than postdocs. There is a need to point out essential training for K–12 students to get them into the DOE pipeline. She asked if there were any training that DOE and BER could provide. Remington responded that the unique thing about today's research is the combining of different disciplines in one study. Joachimiak added that a unique capability is light sources. Someone has to be trained in that technology. At the Advanced Light Source (ALS), researchers were able to save billions of dollars by learning how to run experiments remotely.

Stacey summed up the discussion once again as recommending four areas of instruction:

1. Pre-doctoral and postdoctoral fellowships
2. Multiweek workshops and post-workshop experiences
3. Short-term workshops and post-workshop experiences
4. University–national laboratory schools

Ehleringer mentioned two other concepts that should be considered: cohort development and post-workshop mentorship. Weatherwax noted that, in general, there are established mechanisms between national laboratories and universities.

Stacey asked for volunteers for a small subcommittee to produce the letter-report draft. Zhang, Remington, Ehleringer, Stahl, Joachimiak, and Stacey volunteered.

Susan Hubbard e-mailed a comment about the need for short-term training on enzymology for meticulous biochemical analysis. Wall said that it is difficult to find an expert on enzymology today, and students are not going into the field. A classical enzymology mentor would be important. One way to revitalize the field would be to focus on the design of enzymes. Having biochemical guidelines for going into synthetic biology would also be very effective.

The discussion was tabled until the next day of the meeting. Stacey opened the floor to other Committee business. There being none, the floor was opened to public comment. There being none, the meeting was adjourned for the day at 4:30 PM.

**Tuesday, March 4, 2014**

The meeting was reconvened at 8:30 a.m.

**Allison Campbell** was asked to present an update on the Environmental Molecular Sciences Laboratory (EMSL).

To make sure that EMSL is serving the BER and DOE communities well, it identified the BER and SC research priorities and grouped them into four science themes: atmospheric aerosol systems, biosystem dynamics and design, energy materials and processes, and terrestrial and subsurface ecosystems. These themes are then used as the basis for proposal calls and investments in instrumentation, as vetted by advisory committees, users, and stakeholders. EMSL has facilities that offer integrated services and computation, imaging, spectroscopy/diffraction, synthesis/microfabrication, -omics, and radiochemistry. These capabilities of ESML are evaluated against key criteria: impact, uniqueness, and operations.

In atmospheric-aerosol systems, ESML wants to understand the molecular-scale dynamics of aerosols to improve climate-model simulations and to enable predictive understanding. It has a special interest in biogenic organic aerosols, a key component in aerosol–cloud–precipitation–radiation processes. ESML is excited to be a part of the current GOAmazon campaign. It has deployed staff and mass spectrometers to link what is happening at the molecular level to the experimental level.

In biosystem dynamics and design, its focus is to understand biological processes (from individuals to communities) in time and space. Here, its special interest is metabolic compartmentalization and pathways to inform predictive models.

In terrestrial and subsurface ecosystems, its focus is to understand the nutrient, metabolite, and chemical signature flux at biogeochemical interfaces in heterogeneous environments across multiple scales from the molecular to the field. Here, its special interest is in a molecular-to-pore-scale understanding of hydro-biogeochemical elemental cycling to advance predictive understanding of the water cycle and ecosystem biogeochemistry feedbacks and to inform the biogeochemistry components of the ESM.

In energy materials and processes, its focus is to understand the physical and chemical phenomena (with special attention to interfaces) that are needed to design new materials and systems for sustainable energy applications (e.g., batteries). Here its special interest is solvent-mediated interfacial chemistry to predict the transformation mechanisms and physical and chemical properties needed to design advanced batteries and new catalysts.

Its capabilities in computation and data visualization are coupled with experiments. It has a breadth of computational components. One needs to translate data into knowledge and understanding. Its fourth-generation machine has just been put on the floor with accurate state-of-the-art algorithms for computational chemistry, spectroscopies, and excited-state dynamics. In the future, it expects to produce predictive models increasing in scale from nano- to meso-scale systems relevant to larger-scale scientific problems. ESML's Cascade computer is number 13 in the Top 500; it speeds up NWChem with heterogeneous computer architectures.

Imaging capabilities include dynamic transmission electron microscopy movies and tomography of plant materials to inform hydrologic modeling. A dynamic transmission electron microscope (TEM) is currently being built to probe dynamic systems. It will have aberration correction, be tunable, have near-atomic spatial resolution, and have *in situ* liquid compatibility. It is expected that this TEM will unite structure-based design with dynamic observations to enable the rational design of biosystems and to visualize protein motions in real time. Science challenges that it will address include (1) unraveling how weak organic acids mixed with sea salt modify particle properties related to climate and affect the balance

of oxidants in the atmosphere and (2) discovering the structure and function of multi-heme cytochromes and their cognate complex partners that facilitate electron transfer.

EMSL is widely known for its -omic and molecular-species characterization via metabolomics, bottom-up proteomics, top-down proteomics, and molecular-species characterization. In the future, this area will see the introduction of a high-field mass spectrometer to look at aerosols, biological mixtures, and genotype–phenotype links.

In radiochemistry, EMSL offers magnetic resonance, microscopy, X-ray photoelectron spectroscopy, and electron-microprobe analysis.

Many research projects couple these capabilities to explore metabolism, the dynamic processes in biogenic organic aerosols, and soil-carbon dynamics, for example.

EMSL's outreach activities include the sponsoring of focused user meetings, the placement of articles in news magazines, participation in congressional events, the publication of *Molecular Bond* magazine, the invitation of BER-funded PIs to EMSL, and the holding of "open houses" for researchers.

The Radiochemistry Annex is now open, and a virtual tour has been developed. EMSL has been invited to speak at the Plutonium Futures Meeting and to take part in the round-robin test in actinide spectroscopy. It has been meeting with Office of Environmental Management program managers.

EMSL has a Science Advisory Committee and a User Executive Committee.

In the FY13 science theme call, more than half of the proposal teams were entirely made up of personnel external to Pacific Northwest National Laboratory (PNNL), and almost one-quarter of the teams were new to EMSL. The call was very successful in attracting BER-funded participants. The FY14 science theme call closes March 3, 2014. The joint JGI–EMSL collaborative science call closes April 7, 2014, for research in biogeochemistry, carbon cycling, and biofuels. Another program is First Science, which is designed to explore what one could do that could not be done before.

Upcoming activities include an EMSL user meeting in May, a National User Facility Organization annual meeting in April, and a technical review in September.

Discussion

Robertson was impressed with the capabilities of EMSL and complimented the facility for making good inroads on outreach activities. He asked what activities there were for postdocs. Campbell replied that EMSL had activities for graduate students: Part of the user meetings is given over to tutorials, several eminent-postdoc positions are available, the facility is coupled with the educational activities of the PNNL program, and the organization is open to ideas. Robertson asked whether, if EMSL were given the opportunity to host workshops, it would be interested. Campbell answered, yes, it would jump at the opportunity of hosting workshops onsite; however, taking such workshops on the road is difficult.

Stacey asked if EMSL had addressed the uneven aspects of its resource usage. Campbell replied that management is constantly reviewing and dealing with that problem and trying to make instruments remotely operable to boost usage rates.

Zhang asked if EMSL had any encouragement for early-career researchers. Campbell replied that such people have been targeted with outreach activities but there is not an early career program as such.

Joachimiak emphasized that the collaboration with the JGI and links with KBase are very important. Campbell stated that the facility was trying to get data into KBase,

Ehleringer asked whether there was any interaction between EMSL and PNNL on isotopic-ratio mass spectrometry. Campbell said that there is some interaction.

Weatherwax welcomed **Victoria Orphan**, a Presidential Early Career Award for Scientists and Engineers recipient who is funded by BER, to speak on quantifying how uncultured cells experience their microbial neighborhood during cooperative methane oxidation.

This research investigates the molecular microbial ecology of anaerobic communities involved in carbon, nitrogen, and sulfur cycling and uses combined molecular, metagenomic, and isotopic methods to relate uncultured microorganisms to biogeochemical processes and to understand interspecies interactions.

Because cultured microorganisms may be adapting to the culture environment, fluorescence in situ hybridization (FISH) and secondary-ion mass spectrometry (nanoSIMS) are used to assess the metabolic potential of uncultured microorganisms by single-cell stable-isotope analysis to connect microbial diversity with metabolic function. Radio-labelled nitrogen is used to see what organisms are capable of taking up nitrogen. An ion microprobe is used to determine what cells are active in a given process (e.g., actively oxidizing methane in a lake-sediment community). One lesson learned is that the most abundant population does not necessarily correspond with the most active. Microbial interactions are assessed in terms of spatial distribution and how they interact.

Interactions between anaerobic methanotrophic (ANME) archaea and delta-proteobacteria have been investigated by working across the spectrum of mathematical simulations to engineered/default co-cultures to understand natural systems. Spatial structure balances the support of and competitive interactions within a multi-species community of bacteria, allowing them to grow together. Studies have focused on uncultured anaerobic methane-oxidizing microbial consortia found in methane hydrates at a depth of 500 to 1000 m in the ocean. Methane-oxidizing archaea share a lot of genetic information with methane producers. It is believed that what is going on is that methane is metabolized by archaea, producing an electron that is used by a sulfate reducing bacterium (SRB) that takes in sulfate and produces hydrogen sulfide.

Some of these methane-hydrate-impacted sediments support abundant methane-oxidizing archaeal–bacterial aggregates with a high level of taxonomic and morphological diversity and that form multiple associations. The goal is to bridge theoretical model predictions with in situ observations and quantitative single-cell measurements with FISH–nanoSIMS single-cell ion imaging and quantitative stable-isotope analysis to identify the location of specific cells and create an isotope-enrichment map.

Two types of sulfide-oxidizing organisms and the delta-proteobacteria probe were targeted. Analysis of 61 aggregates made up of more than 5000 cells showed that they formed two types of spatial arrangement. The population-level spread of the archaea and sulfur-oxidizing microorganisms were studied. Aggregate–aggregate interactions were separated and compared to look at individual cells. There is no significant difference in activities in the bulk analysis. When the population sets were paired, each ANME–SRB aggregate exhibited a unique pattern of anabolic activity and significant partitioning of activity. There is a metabolic coupling going on in the two aggregates.

The role of spacing was investigated with statistical tools. A metric for the degree of mixing within ANME–SRB aggregates was defined (the J value), allowing one to look at variation with the degree of mixing. As the aggregates became more separated, there was a drop-off in activity; with poor mixture,

there was a balance in activities. Partitioning of anabolic activity between syntrophic partners varies according to aggregate structure; however, the total aggregate activity is the same regardless of spatial structure. Hot-spot analysis is used to assess activity in neighborhoods of aggregates and to develop a network map and relate it to nitrogen-15 values to see how the cells are clustering within an aggregate. Local correlations in activity level are seen within and between neighboring ANME–SRB populations; therefore this looks like a promising approach.

In other work, consortia are being modeled *in silico* to predict the effects of spatial organization of different microbial interactions (i.e., bacterial and archaeal activities and their ratios). There is an interest in applying these techniques to other environments, organisms, and processes. These nondestructive techniques (FISH–nanoSIMS) can be used to look at immunofluorescence protein, mRNA transcript detection, and TEM and elemental-analysis data. It would be interesting to see how predictions hold up in two dimensions rather than three dimensions. It is also desired to understand the effects of spatial organization on functioning and activity of interacting microorganisms (e.g., in the cleanup of polluted environments).

In summary, high-resolution molecular, microscopy, and isotopic tools can be used to study the eco-physiological potential and interactions between environmental microorganisms in structured communities. Specifically, anabolic activity between associated ANME methanotrophs and delta-proteobacteria is correlated: spatial segregation promotes divergence in relative activity levels between partners. In addition, geostatistical analysis reveals spatial structure and activity within consortia with localized positive and negative zones of correlated cellular activity.

Discussion

Wall asked whether one sees pili or connections between cells when one looks at these organisms. Orphan replied that vesicles are sometimes seen, but it is unclear as yet whether all artifacts have been eliminated. Wall asked if peak number one was a higher-evolved association and can therefore make these mixed cultures. Orphan replied, yes; that is the assumption right now. It is a very specific group of organisms with about 97% similarity within that peak-1 group. It is world-wide distributed in association with ANME-2.

Robertson asked if these interactions of aggregates occurred in soils. Orphan answered that these nitrate aggregates and interactions have been found in terrestrial systems. The sulfate aggregates are more problematic, but they cannot be ruled out.

Joachimiak asked if there were a time correlation in these mutualistic interactions. Orphan replied that she did not have a lot of data on this wonderful question. It is not known where time zero is. The effects of nutrient dynamics are difficult to discern.

A break was declared at 10:30 a.m. The meeting was called back into session at 10:44 a.m.

**Jonathan Male** was introduced to describe the activities of the Bioenergy Technologies Office (BETO) of the DOE Office of Energy Efficiency and Renewable Energy (EERE).

More than 13 million barrels of petroleum distillates are required every day to fuel the U.S. transportation sector. Ethanol is blended up to 10% in current gasoline. Approximately 10% of U.S. crude-oil imports are used to make chemicals and products, such as plastics for industrial and consumer goods. Biomass-derived chemicals make up 4% of current chemical sales. Biomass is a leading renewable resource with the potential to provide, with existing infrastructure, drop-in replacements for the 11 million barrels/day of petroleum fuels consumed in vehicles on the road and the 1 million barrels/day required for

air transportation. The United States could produce more than 1 billion tons of sustainable biomass resources to provide transportation fuel, make chemicals, and produce power. By 2030, there is the potential to develop terrestrial-biomass resources to displace 30% of current U.S. petroleum usage, not counting the contributions of algae.

The mission of the BETO is to develop and transform U.S. renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted research, development, demonstration, and deployment supported through public–private partnerships. The goals are to make cellulosic biofuels competitive with petroleum-based fuels at a modeled cost for mature technology of $3 per gallon of gasoline equivalent (GGE); help create an environment conducive to maximizing the production and use of biofuels by 2022; and, by 2020, validate the technology and economics for the production of advanced biofuels that reduce GHG emissions by 50% or more compared to petroleum fuel.

A complete bioenergy supply chain is needed from growing to fuel-distribution infrastructure, requiring (1) R&D on feedstock supply and conversion and (2) demonstration at increasing scales. It also requires sustainability, optimal strategic analysis, and innovation, which must meet five criteria:

- Is this a high-impact problem?
- Will EERE funding make a large difference?
- Is the focus on the broad problem and open to new ideas, approaches, and performers?
- Will EERE funding result in enduring economic benefit to the United States?
- Is this a proper role of government, or should it be left to the private sector?

Innovation is challenging and involves risks, which deter financing. The risk associated with bioenergy needs to be reduced. R&D at DOE national laboratories is reducing that risk. In 2012, enzyme costs were reduced about 90%, new microbes that could use more sugars were developed, and methane conversion in several chemical processes was increased from 20 to 80%. Accomplishments have also been made in the algae program: stacking multiple traits throughout the genome with robust expression and targeted protein localization, improving strain through systems biology, and developing whole-algae hydrothermal liquefaction technology.

Currently, biofuels are only displacing gasoline in the marketplace; the market for biofuels needs to be extended to other petroleum derivatives.

In recent years, the budget for BETO has been $199 million enacted in FY12, $188 million in the final continuing resolution of FY13, $282 million requested for FY14, and $232 million enacted for FY14. The budget was boosted in FY14 by funding from the Defense Production Act.

In conversion technologies, three FOAs are currently on the street: one for renewable carbon fiber to reduce vehicle weight, one for bioenergy technology incubators, and one for biological and chemical upgrading for advanced biofuels and products. In thermochemistry, an FOA is on the street for carbon, hydrogen, and separation inefficiencies; a workshop will be held on refinery integration multiyear program planning to enable biofuels to leverage existing refinery infrastructure.

In algal biofuels, current commercial cultivation technologies are designed for production of high-value products rather than high-yielding commodities. More than 1500 strains were screened, and 30 high-yield algae were identified that showed marked improvement in productivity. Year-round algal production is needed; this problem can be addressed through combining strains or polycultures. A commercial-scale algae-production testbed has been established at Arizona State University, and projects are being carried out on advancements in algal biomass yield. The Office needs to increase portfolio

diversity and to support R&D breakthroughs. Two FOAs are currently on the street, one on process integration and one on synthetic biology.

The Office operates a user facility with 10- to 210-L reactors; 2- to 300-L fermentation systems; and continuous liquid-liquid separation, extraction, and analysis. There is also a Computational Pyrolysis Consortium to apply and integrate multiple approaches for modeling and improving the process steps and components on the basis of the latest chemical and physical information.

Five demonstration plants are online or coming online this year: Abengoa Bioenergy in Hugoton, Kansas (ethanol and green electricity), POET-DSM Project Liberty in Emmetsburg, Iowa (cellulosic ethanol), INEOS [INspec Ethylene Oxide and Specialities] in Vero Beach, Florida (cellulosic ethanol), Sapphire Energy in Columbus, New Mexico (algae to green fuels), and American Process in Alpena, Michigan.

Landscape analysis is being used to boost crop productivity and to minimize landscape-scale Environmental effects.

Currently, biofuels can produce a smaller carbon footprint in aviation fuels. This is a smaller market to expand into, and there are early adopters.

EERE is collaborating with SC on energy crops, systems biology, climate change and sustainability, photosynthesis, and catalysis. Under the Biomass R&D Act, all work is overseen by the Biomass R&D Board and working groups and the Biomass R&D Technical Advisory Committee.

BETO is conducting a number of workshops this year: Demonstration and Deployment Strategy on March 11–12, Biomass and Direct Liquefaction on March 20–21, Algal Biofuels Spring Strategy Workshop on March 26–27, Bio-oil Co-processing on April 3, Woody Feedstock on March 4–6, Herbaceous Feedstock on June 24–26, and Biomass 2014: Growing the Future Bioeconomy on July 29–30.

Discussion

Randerson asked what the pros and cons were of bio-electricity versus development of biofuels. Male replied that, in the United States, there is no power standard. Coal is expected to cost $30 per ton through 2030 and natural gas is expected to cost $4–6 per mmBtu. With biomass costing $80 per ton, that makes it a difficult economic case. If you come into power with biomass, there are many renewable-power options. Fuels, though, is a tough market. There will be electrification, but electrification works only in certain models, mostly in densely populated areas. Electricity of vehicles will occur, but not in a rural setting. Long-distance trucks cannot give up payload for batteries; similarly, airliners cannot give up seats. Those are their revenue streams. Not much work is being done in biopower in EERE. Margins will be greatest from fuels plus byproducts, then fuels, then power because of competitive pressures.

Weyant noted that California has the Low-Carbon Fuel Standard. That legislation assumed that electric cars would be developed and deployed and that natural gas and biofuels would produce carbon savings. The refining industry would like to survive. He asked how that industry can continue contributing and how timing will affect biofuel adoption. Male replied that, in corn ethanol, production took off after 2 years. The first-of-a-kind biofuel plants are being built now. Financiers have to see that the risk has been reduced. Then plants have to be scaled up and up. Pipelines cost $1 million per mile. Refineries have a good deal of the required infrastructure. They *are* looking at how they can participate in this market. There is a pipeline of products. Corn ethanol is at the end of the pipeline. Other drop-in fuels are farther down the pipeline. It takes time. The financial support is not there to hit the 2020 goals.

Weyant asked if legislators should be told to be patient and to stay the course. Male replied, yes; it can take some time.

Robertson asked if there were an optimal number of pilot plants. Male responded that it depends on whether one wants a centralized plant or a dispersed plant with hydrogen produced in one place, intermediates made in several other places, and one or more full refineries someplace else. With sugar, there could be cellulose destruction at many sites and a central conversion plant. At the moment, wood chips are being shipped to Europe from North America because of the logistics. He had no answer to Robertson's question because of the complexity of the space. Robertson asked if decentralized pyrolysis would work. Male replied, yes; blended feedstocks could be commoditized. Specifications could be developed, allowing purchases of specific grades, a blend, or mixtures that reflect trade-offs.

The Committee continued the STEM education and training discussion from the previous day. Stacey revisited the STEM education and training component. A summary of the previous day's discussion had been circulated to the Committee overnight. Wall said that the key points had been captured. Robertson suggested augmenting the term "workshops" with "short courses." Stacey said that the Subcommittee would submit a draft of the letter report to the Committee by e-mail. The uniqueness of DOE and BER need to be stressed. The report is due June 30, and the draft could be discussed at the June meeting of BERAC.

The floor was opened to public comment. There being none, the meeting was adjourned at 11:42 a.m. A date for the next meeting had not been set.

Respectfully submitted,
Frederick M. O'Hara, Jr.
Recording Secretary
March 14, 2014