2008 Advisory Committee Report – Biological and Environmental Sciences Divisions, Oak Ridge National Laboratory

The advisory committees to the Biological and Environmental Sciences Divisions at Oak Ridge National Laboratory (ORNL) met at Oak Ridge the evening of May 14th through the morning of May 16th, 2008. We were asked to provide input on the divisions' plans and visions for the future in four subject areas: *Climate Change Research, Remediation Science, Bioenergy,* and *Genomes-To-Life (GTL) Fundamental Science*. ORNL requested specific input on:

1) the scientific success of each program, including productivity, collaborative projects, national and international planning roles, and proposal success, and
2) the quality of future research plans for the four programs, such as the importance and relevance of the plans to both science and US needs, the boldness and appropriateness of the plans for a world-leading national laboratory, strategic partnerships, and staffing, equipment, and infrastructure.

The members of the joint advisory committee were Jean Bahr (ES), Dennis Baldocchi (ES), Jill Banfield (B), Rob Jackson (ES, and chair), Roger Lasken (B), Patricia Maurice (ES), Roger Pielke Sr. (ES), Jeff Steiner (ES), and Karl Stetter (B).

During our informative visit, which was well organized by ORNL, we heard presentations in each of the four subject areas, two to three hours per group. We also attended a poster session that allowed us to see many examples of the diverse biological and environmental research underway at ORNL. The review committee wishes to thank ORNL scientists and staff for the efforts they made in preparing for our visit and in providing informative sessions.

Overall Impressions

Both divisions have strong records in scientific publication and grantsmanship. In addition to the excellent productivities of the many ORNL scientists we know personally, the overall level of productivity in both divisions impressed us. Based on the data that we saw, ORNL scientists are at or near the top of their fields in many publication metrics (e.g., citation rates) compared to scientists in all other DOE national labs. They also show comparable publication and citation rates to accomplished scientists in academia, industry, and other institutions.

Based on these overall favorable impressions, the primary goal of this report is to help both divisions think about their strategic priorities and potential partnerships. The need for planning is particularly important with the large number of retirements that are pending at ORNL during the next five years. We also hope that this report will help the divisions brainstorm and prioritize for the future. Ultimately, the many decisions ORNL faces about staffing and future research should be made internally and with broad support from ONRL staff.

Our committee did not get a chance to visit labs or field facilities during our meeting and thus cannot comment on ORNL's needs for additional equipment or infrastructure support. We look forward to the chance to become more familiar with these facilities during individual visits and at the next Advisory Committee meeting.

Broad Recommendations across Divisions and Groups:

In the sections that follow we provide specific thoughts and recommendations for each of the four subject areas individually. In this section, we comment and make recommendations that are cross-cutting across all four subject areas in the Biological and Environmental Sciences Divisions as reviewed by our committee:

(1) First, we commend the ORNL staff scientists for the excellence of their research and we thank them for their informative presentations and hospitality during our visit.
(2) The laboratory faces a numerous pending retirements, and laboratory leadership recognizes the challenges posed by these retirements. We recommend that the Divisions set guidelines for how new hires will be prioritized, with emphasis on building strengths within and across groups and looking towards potential grand challenges for the coming decade.
(3) Relative to (2), hiring of junior staff scientists is essential, and supporting these junior scientists will be crucial to the short- and long-term productivity of the laboratory. DOE should support junior staff hires and ensure knowledge transfer (e.g., hiring new staff enough in advance to allow knowledge transfer from more senior staff).
(4) Interconnectedness and interdisciplinary approaches are key to the success of all four subject areas. Group leaders should work together in prioritizing hires, etc., to ensure that interdisciplinary strengths are fostered.
(5) In addition to building interdisciplinary strengths within ORNL, the laboratory should continue to increase collaborations with researchers in academia, at other laboratories and institutes, and in industry. The divisions need to assess other activities underway at national labs, universities, etc. to identify the most effective partnerships for current projects and for potential future grand challenges. To this end, increased workshops and other outreach activities should be beneficial.
(6) Across the four groups, there is a common need to focus on issues of sustainability and developing approaches that are environmentally sound as well as of fiscal and security benefit to the nation. The ORNL staff have valuable expertise that can help lead the way to building security in terms of energy, water, and other needs in a sustainable manner.
(7) We recommend that laboratory staff work to integrate emerging environmental sensor technologies more fully into their programs, either increasing sensor development through new hiring at ORNL or through enhanced collaborations with universities, other laboratories and institutes, and industrial partnerships.
(8) The GTL activities need to be better integrated with the other groups to ensure that genomic and associated research is relevant to the DOE's core missions and that the other groups are receiving maximum benefit from GTL capabilities and enhancements. In doing this, it is essential for the GTL to remain well connected to the Joint Genome Institute and to ensure emphasis on annotation.
(9) Finally, while we recognize that there are unique challenges to working within DOE, we recommend that ORNL scientists be stronger advocates across DOE and to the public for the nation's research needs. Part of this role should be to help the DOE and the U.S. to identify grand challenges for research, as ORNL scientists

are already doing. The ORNL administration needs to take full advantage of the expertise of its staff to help ensure that the scientific leadership of ORNL scientists is utilized fully in the future.

Climate Change

Overview

Our committee applauds the way that the Environmental Science Division is studying climate and ecosystems with a multi-faceted and multi-scale approach from genes to the globe. A variety of tools are being used, both experiments (field studies/monitoring, process studies, and ecosystem manipulation) and modeling (biogeochemical and climate system). This interconnected approach is exemplary for how science should be conducted when studying complex systems such as ecosystems and the atmosphere. Measurements provide data for parameterizing and validating models and for identifying processes at emergent scales. Models are used to generate and test hypotheses, integrate information in time and space, and to assess predictability, planning, and management, as is being done in ESD.

The Climate Change Group is targeting critical aspects of the climate system that will play a role in future IPCC assessments and in meeting DOE and additional national objectives. These aspects include: How is the carbon cycle coupled within the climate system? How does climate respond to changes in biogeochemical cycles? Such efforts require the integrated efforts of climate, ecological and biogeo-scientists. Many of the pieces are already in place successfully at ORNL, but the 'proof of the pudding' will be in how effective the group continues to be in working across disciplines.

Staff

ORNL has an excellent staff with diverse skills to contribute to DOE's grand challenges. Most important is ORNL's attempt to maintain core senior staff and to re-invigorate the staff with new junior and senior hires. This approach should bring new input and ideas to the lab. The younger scientists are energizing senior scientists, and the senior scientists are providing the mentorship and leadership that the newer scientists will need to grow intellectually and professionally.

Many retirements are anticipated in the next five years, and ORNL recognizes the challenges associated with this fact. Management is considering strategic hires to fill future roles. One area that was not clear to us is the process by which these new positions are identified and prioritized. We make some suggestions for possible hires throughout this report that we hope will be helpful as ORNL considers this critical topic.

The Climate Change Group has many senior scientists who are playing key leadership roles at national and international levels. For example, several staff are editors of leading journals such as New Phytologist and Environmental Management. Key ESD personnel also took leadership roles in writing the *State of Carbon Cycling Report* (SOCCR) to DOE. Many also serve on important committees for the National Research Council and Department of Energy.

Science Impact

Division scientists have a strong and consistent publication record. Lead scientists are producing a total of ~130 papers per year at a rate of 2 to 3 papers per scientist annually. This is an appropriate and notable level of productivity in ecosystem sciences, especially considering the long-term and integrative aspect of the research. Over the past 15 years a number of widely cited papers have been published that are relevant to current and future DOE goals. Furthermore, many scientists are among the upper 10-20% of cited scientists overall. The division is highly productive intellectually.

Quality of Plans:
Continuing Experiments

Because many of the long-term, environmental studies at ORNL are nearing the end of their lifetimes, planning the next generation of manipulative experiments is extremely important. ORNL scientists recognize this need and are considering many new directions for future experiments.

ORNL scientists have pioneered studies linking molecular ecology with ecosystem attributes. Starting from the consequences of single-gene manipulations, these growth chamber studies are providing fundamental ecological insights. We fully support this research thrust. Based on the presentations we saw, we do feel that greater thought could be given to how these experiments link to GTL efforts at ORNL. Furthermore, there are opportunities to apply such tools in current and future ecosystem experiments, such as FACE. Strengthening those links could yield considerable benefits for ORNL.

Strong consideration needs to be given to the trade-offs of maintaining long-term studies and starting new experiments. The dilemma with ecosystem studies is that ecosystems operate on long time scales of decades to centuries. Long-term studies enable scientists to observe emerging processes needed to validate models. On the other hand, the argument against continuing long-term studies is the cost and perception of incremental findings. For example, there may be better opportunities and greater impact with new studies in different ecosystems or with a different suite of environmental manipulations.

We believe there are strong arguments for enhancing monitoring at the Walker Branch Watershed and continuing the FACE and old-field studies. At Walker Branch >30 years of data have been collected, starting with the International Biological Project in 1974. This ecosystem has an extensive baseline and an evolving dataset on how the forest watershed is responding to climate variability and change and natural succession (the forest started from abandoned fields in the 1940s). There is tremendous opportunity to continue such datasets to understand how the forest responds to climate change. Furthermore, Walker Branch Watershed is slated to become one of the 20 core sites for the National Ecological Observatory Network (NEON). Monitoring should continue during this important transition to the NEON mission.

The FACE study has been active for nearly a decade and appears well poised to answer many important questions. Based on results from 2006 and 2007, a few more years of operation could answer the fundamental question of if and when nitrogen limitation reduces the growth response of trees to elevated CO_2. This parameter is a critical one for land-surface models and for predicting CO_2 concentrations based on emission scenarios for the 21st century. The next few years are also critical because until now the ORNL forest has also neither produced seeds nor had substantial mortality. Long-term data are needed for how future CO_2 concentrations will influence tree reproduction, including the vitality and chemical composition of seeds, seed fecundity, and seedling establishment and recruitment. There are similar unanswered questions for mortality, such as how high CO_2 levels will affect C:N ratios of the dead wood and decomposition. Closing the FACE system now means that another experiment will have to run for more than a decade to answer such questions. The old-field study may be a lower priority, but it is producing new information on recruitment and regeneration that needs to be incorporated into dynamic vegetation models that are being coupled with climate models.

One of the highest costs in elevated CO_2 experiments is the CO_2 lost to the atmosphere, typically hundreds of thousands of dollars per year. We think that ORNL could lead studies that examine how to reduce this cost for the broader research community. For instance, the group could examine the role of porous fences surrounding plots that minimize advective losses yet still allow ventilation and increased CO_2. Modeling studies could test the efficacy of this approach. Such cost savings would help offset the price of raising the towers at ORNL (and in other experiments) as the forest grows.

If such experiments are to continue, ORNL scientists need to be stronger advocates for their continuation. This is especially true for the FACE experiment.

Future Experiments

Plans are being developed for manipulative ecosystem experiments in the arctic/boreal, tropical, coastal and spruce/fir zones. The arctic/boreal system has a huge store of carbon in a region that is already responding to climate variability and change. Furthermore, few nations are studying this system in detail, even nearby countries such as Canada. The tropics are of great interest because there is such uncertainty in how systems such as the Amazon will respond to climate variability and change. Coastal systems are another ecological hot spot. Based on the geological record we know that wetlands have the greatest potential to store carbon and water per unit area. Spruce/fir are of also interest because of their elevational and latitudinal limits; we don't yet know what could cause them to disappear and what ecosystems could potentially replace them. These are important ecosystem problems whose study is appropriate. But there is also considerable risk because these areas are not in the traditional core competency of the ORNL group and because such sites are remote. *We suggest that ORNL needs to prioritize one or two of these systems on which to focus its efforts. It will also need to identify key partnerships to increase the likelihood of success*.

The group is encouraged to continue efforts related to ecosystem gradients. There are great opportunities to bring additional ecosystem measurements to the AmeriFlux network, especially at sites that are currently not intensively studied. Adding process measurements of soil respiration, photosynthetic capacity, and canopy structure, for instance, will provide useful information as inputs to climate and biogeochemical models.

Our committee was surprised by the lack of any proposed experiments in monitoring or manipulating water availability. A primary emphasis on ecosystem warming experiments at ORNL seems appropriate, especially given DOE's current funding emphasis in this area. However, water issues will be as or more important in the coming decades as warming issues will be. Furthermore, ORNL has decades of expertise in thinking about water and carbon interactions. We would hate to see this expertise lost from the lab.

Modeling and Data Management

Building on its considerable strengths, the climate change group is planning to construct an Integrated Terrestrial Carbon Model (ITCM). Given ORNL's existing expertise in this area and its recent hires, including Peter Thornton, the opportunity to bridge ORNL's expertise in ecosystem experiments and land and climate modeling makes the goal a top priority in our view.

One shortcoming in the plan for integrating carbon cycle work from ecosystems to the globe is the lack of remote-sensing expertise at ORNL. ORNL lags the broader scientific community in examining the earth at scales larger than the watershed. To make the most of its integrated approach, we believe that ORNL needs an investment in scientists using satellite-based technology. Alternatively, the group could forge long-term partnerships with other groups that possess this expertise. Without it, ORNL will miss a critical opportunity to bridge the mechanistic understanding provided by its ecosystem experiments and the large-scale responses simulated through the ITCM. The need for remote sensing expertise is also critical if ORNL is to develop its understanding of land-use interactions.

Through such databases as the Distributed Active Archive Center (DAAC), ORNL has played an extremely important role in data archiving and availability. This role meshes well with ORNL's strength in linking field studies and modeling. We wholeheartedly support the group's database efforts.

Data systems serve as the glue that connects field studies and modeling. These data systems need to evolve and to grow and expand in the tools that they employ. By adding more value-added products to its databases, this service can be an even greater resource to the scientific community. Examples include the production of gap-filled data from raw data for AmeriFlux, the computation of photosynthetic and respiratory products, and MODIS cutouts. The data team is adding a new phenology network to ORNL's online resource, an extremely important addition because phenology is a key metric for evaluating global change. Many new data sources are emerging such as video images, remote sensing, eddy flux data and phenology gardens that can be used. ORNL should be creative in adding these new data streams to its databases.

Focus of Work

Most aspects of the targeted work we saw are broad in scope and highly relevant to DOE's missions. By developing experimental infrastructures and data capabilities, the team is addressing such topics as: 1) carbon cycle and lands; 2) impact adaptation and mitigation; 3) human dimensions; 4) regional aspects using process level work on the carbon cycle, and 5) ecosystem responses to global change. While this scope is broad (possibly too broad?), it is worthwhile. Furthermore, ESD is not extending beyond its core competency by branching into the fields of oceans and atmospheric chemistry/aerosols. Such fields are probably better treated at other labs.

The Management team may consider modifying the topic emphasis from "Ecosystems and Climate Change" to "Ecosystems and Environmental Variability and Change". This would better encompass the topics being studied. There is a low level of emphasis on land use change and fire. These are two major changes in the Earth system and feedback on to the climate system and state of the atmosphere. Land use affects albedo, evaporation potential and surface temperature. Fires have huge impacts on carbon fluxes and the successional state of ecosystems.

Strengths need to be added in the areas of land, land use change and fires. Expanding efforts in land use are encouraged because they are important drivers of the climate system and will affect the impacts of expanding or converting lands to biofuels. Land use change has gotten short shrift in terms of dedicated funding. Scientists are in house who are interested in these areas and have the skills to study these problems. But these areas could also be viewed as areas for future and targeted hires too.

We encourage new efforts to revisit and revise dynamic vegetation and gap dynamic models. The future of ecosystem models that are coupled within climate models will rely on links to DGVMs. Yet, there are many uncertainties in how these models simulate recruitment, colonization, competition, mortality, etc. (see discussion of long-term experiments above). Over the past decade there has been a stronger focus on biogeochemical cycling. The time is ripe to merge biogeochemical modeling with new generation DGVMs.

The need to incorporate ecosystem processes within the climate system was recognized by the National Research Council (2005). The Division should use this report to document to DOE leadership the essential contribution in this area that the Division is making. The hiring of Dr. Jim Hack was an excellent choice to lead this study.

The 2005 National Research Council reported in its Executive summary, under the topic "Determine the Importance of Nonradiative Forcings", that
" Several types of forcings—most notably aerosols, land-use and land-cover change, and modifications to biogeochemistry—impact the climate system in nonradiative ways, in particular by modifying the hydrological cycle and vegetation dynamics……Other nonradiative forcings modify the biological components of the climate system by changing the fluxes of trace gases and heat between vegetation, soils, and the atmosphere and by modifying the amount and types of vegetation. No metrics for quantifying such nonradiative forcings have been accepted."

This broadening of focus by the NRC report documents that climate change is much broader than global warming alone. While it was stated in one of the presentations that climate policy is energy policy, they could also be viewed as distinct issues. Climate policy would be needed regardless of how humans are altering the climate, and energy policy has issues that are not directly related to climate (e.g. energy independence). However, energy policy is clearly an important lever for addressing some aspects of climate change. The group may choose to separate the energy and climate foci, remembering the important links between them.

With respect to the studies of the climate system, we recommend that

- Quantitative assessments of the decadal global model should be developed and performed with new climate metrics to evaluate the relative importance of regional radiative and nonradiative climate forcings;
- The integration of the global model projections as an initial value problem, as summarized by Jim Hack, is strongly supported, and the development of ensemble simulations should be a priority;
- The effective grid spacing in the global model runs should be about 10km in order to capture mesoscale atmospheric systems that are significant components of the

climate system; this effort will require higher resolution data layers of land surface boundary conditions
- In the context of assessing the global and regional average radiative heating (or cooling), as projected by the models, other metrics besides global average surface temperature should be included. This includes global and regional upper ocean heat content and tropospheric temperature and water vapor variability and trends.
- Observational data are essential for validating model skill and should be a high priority for archiving and use in model comparisons.
- Model components should be developed such that different parameterizations and modules (e.g. the ocean component) can be inserted into the climate system model (i.e. "plug-compatibility").
- The water, carbon, other chemicals, and energy cycles should be assessed in an integrative framework.

The focus on sustainability should be strongly supported. This framework permits an effective bottom-up assessment of the spectrum of environmental and social influences on critical resources, in contrast to the top-down approach that arises from downscaling of global models. This approach (referred to as "vulnerability) was recommended in an IGBP book Kabat et al 2004.

We also recommend that

- The diverse range of landscape processes be included in the sustainability focus, including how changes in land cover and land use alter local, regional, and global climate
- The nexus of "energy-carbon-water" could be changed to "energy-food-water" [or a new one added] where these are resources rather than physical quantities. This then connects directly with the concept of sustainability.
- The spectrum of risks to critical energy, food and water resources should be identified, including how risks are altered by new technologies (e.g. biofuels, carbon sequestration). This approach includes how ecosystem processes within the climate system are altered. It also can be used to evaluate feedbacks to the spectrum of risks for a given technology. Instead of "projecting consequences" (a top-down view), the assessment of risks is a resource and location perspective (a bottom-up view).

Finally, peer reviewed papers and the documentation citations of these research papers should remain among the most important mechanisms used to evaluate the productivity and contributions of ORNL scientists.

Partnerships
The proposed ecosystem manipulation plans will rely strongly on partnerships. ORNL has the capacity and ability to train and transfer technology (e.g., FACE, warming facilities) to local partners. There is no guarantee such transfer will work, especially in harsh and remote environments.

Advances in the environmental sciences depend upon advances in new instrumentation. In the past decade there has been a revolution in instrumentation that is not well integrated into ESD research. For example advances in chemical sensors using proton transfer reaction mass spectrometry and tunable diode lasers enable users to measure a wider suite of greenhouse gases. Development of miniature sensors with distributed datalogging enable one to sample spatial heterogeneity of plants and soil environment much better. To remain at the cutting edge of science a better link with instrument groups should be fostered. ORNL has world-class instrument developers. Better partnerships within the institute are encouraged.

The need to examine terrestrial process at scales larger than watersheds highlights the importance of remote sensing technologies. New hires or partnerships are critical in this area for the lab to continue its leadership.

The Climate modeling effort has formed partnerships with the Community Climate Model through Warren Washington. For regional studies, which include influences from the global scale, the team is encouraged to seek out some new partners rather than re-invent efforts by leading modeling teams at NCAR, GFDL and NASA-GISS. As one example, Roni Avissar, at Duke, has developed the Ocean-Land-Atmosphere-Model (OLAM) with new generation numerics and grid structure. It and other models may be better adapted for addressing regional problems. So the climate modeling team is encouraged to seek such new partnerships, where and when relevant.

Remediation Sciences

Scientific Impact: Productivity

Building on a tradition of successful research within the ESD, the group participating in the Integrated Field-Scale Subsurface Research Challenge (IFC) led by Phil Jardine is publishing at an excellent rate in high-impact peer-reviewed journals,. The data sets generated by their field experiments at ORNL and elsewhere, plus the interpretations of these results, are clearly a resource for the broader remediation science community. The ORNL group has developed a unique set of approaches that contribute not only to process-level understanding but also to developing engineering solutions that serve as models for future best practices. Field and laboratory observations and experiments are being used to constrain conceptual models that are subsequently tested with quantitative computer models. Overall, their approach serves as an excellent example of merging laboratory and field experimentation and observations, conceptual modeling, and quantitative computer modeling in an iterative fashion.

In addition to evaluating “natural attenuation” processes, the group is testing active remediation strategies, demonstrating that their science has real-world applications. The group’s research is also being used in academic environments to train students in the integration of data at different scales and through the combination of data and modeling.

The Scientific Focus Area (SFA) in Environmental Remediation Science is fairly new as a focus area, but group members have good track records from previous projects at ORNL and strong publication records in their disciplines.

Collaborative projects:

The Remediation Science group has a long history of collaboration among scientists at ORNL, other national labs, and academic partners. The uniquely qualified staff of scientists and engineers at ORNL, and the unique field and laboratory facilities they have built, have attracted excellent researchers from other institutions. One important outcome of these collaborations is the numerous co-authored publications of the group. A challenge for the future is to expand on this strong tradition by continuing to bring in new collaborators and junior scientists.

The new funding structure has prompted the group to focus collaborations in two main areas: (1) integrated, field-scale subsurface research for radionuclides and (2) Hg transformation and environmental behavior. One advantage of the new funding structure is that it appears to have focused group efforts and strategic planning more than in the past. The committee members were uniformly impressed with the coherent vision presented the remediation science staff. They clearly outlined the specific science questions that motivate their agenda. They also described a general, integrative approach for improving the understanding of the fate and transport of contaminants across many environments and scales. This is an excellent example of how a group can develop a strategic plan of importance to DOE objectives and build multidisciplinary collaborations around it.

In the area of radionuclide transport, the group has been a leader in integrating science and engineering research, a key to successful remediation. One impediment to future success is the loss of some graduate fellowships in remediation. These fellowships are an example of interdisciplinary training that is essential for national security. They were also an excellent tool for recruiting new staff into the laboratory. Funding for enhanced education and outreach would help the community more broadly.

In the SFA project, the group is taking advantage of the end-member field site of mercury contamination at the ORNL reservation. In this area, the group needs to develop additional in-house expertise and a broad range of external collaborations. Additional laboratory facilities for methyl mercury and other analyses are also needed. With adequate funding and increased expertise, the group could become a center for mercury investigations that would serve a broad community, particularly current and future academic collaborators.

The new funding structure provides incentives to build new partnerships with academia, since such collaborations represent the primary opportunity to expand funding in the two focal areas. We see expanding the collaborative network as important not only for accomplishing project goals but also for improving education and outreach. However, we also believe that DOE should consider increasing its funding for these IFC and SFA projects based on research progress and new discoveries. Core funding for the remediation science group is anomalously low, having been set from a baseline year that was well below the running 5-year average.

National and international planning roles:
The group has developed a plan for testing remediation strategies and has disseminated that plan nationally and internationally. The current and proposed research is transferrable to environmental engineering and remediation throughout the world. For example, they have transferred knowledge and capabilities to military sites and other

DOE facilities. They have been proactive in seeking sources of external funding (DoD, EPRI, EPA, NOAA, etc.), providing additional transfer of knowledge and capabilities.

Proposal success

Funding success for the group in the past year was strong relative to other national labs (twice the average). However, this is within a context of overall decreased funding in the recent past. The previous funding structure made the group's funding levels particularly vulnerable to the loss of key staff. While this vulnerability remains, the new funding structure may help to limit large year-to-year fluctuations in support. As noted above, base funding was unfortunately set based on a single year's (low) funding level rather than on an average over multiple years. Given the recent staff turnover, the funding level needs to be high enough to support new hires as the group develops its research programs and to permit additional strategic hiring

Quality and Plans for Future Research

Overall the committee agreed that the remediation science group is addressing problems that are important to the needs of DOE and more broadly throughout industrialized nations that face similar contaminant challenges. The committee also agreed that the group is approaching these problems with novel strategies appropriate to a world-class laboratory. It has done and continues to do an excellent job of developing and articulating its vision in integrated field challenges (IFC) and is carrying through with this in the new scientific focus area on contaminant transformation and environmental behavior. The committee judged their planning and vision to be exemplary.

The group supplied our committee with specific suggestions for strategic investments that could enhance the existing research programs. In the IFC focus, two priority areas that warrant additional research investments were ground-water/surface-water interactions and numerical simulations, including further development of models that can take advantage of advancements in high performance computing. We strongly agree that these are important areas for their local field site and for the advancement of remediation science and practice.

The SFA is a newer program and is still developing its vision. The SFA's current vision includes both becoming a center of excellence for mercury studies and expanding the approach that they have initiated with mercury to address other contaminants, such as uranium.

Mercury is a contaminant present across the DOE complex. Within the Department of Energy, it makes sense to support Hg research at Oak Ridge because of the high level of contamination there and the developing expertise. Current expertise in the SFA group includes natural organic matter, geomicrobiology, colloid fate and transport, and other supporting disciplines. However, we foresee significant challenges in Hg as a research priority because of the lack of critical mass Hg (bio)geochemistry at ORNL. Many aspects of Hg (bio)geochemistry are unique, require specialized approaches, and benefit from long-term experience with the intricacies of the Hg system. The primary project member with Hg expertise is a senior laboratory scientist with long-term expertise. Loss of that staff member would generate a critical gap in expertise. *If ORNL is to be successful as a Hg center, our committee feels that ORNL needs to hire additional staff with expertise in Hg (bio) geochemistry fairly quickly.* Such hiring would greatly increase the chance of success in accomplishing the current project and in arguing for a center of excellence. Developing a center of excellence would require a flagship leader well known for Hg research, or a junior scientist coming from a well established Hg group.

In the area of environmental management, the group identified potential opportunities for future funding through the EM-20 program. An initial proposal to EM-20 was recently funded dealing with reducing methyl-Hg in streams. While the committee did not receive much information about the nature of other proposed projects in this area, the group should be commended for being pro-active in working with DOE to identify site-specific needs that could benefit from funding through this program.

The Integrated Facilities Disposition Program also provides an ideal opportunity to use the group's considerable expertise. Such research could anticipate and mitigate the risks of disposition activities that alter local land cover and hydrology, affecting the fate and mobility of legacy contaminants. *Support for scientific studies before disposition activities begin, including integrated monitoring, process studies, and modeling, should decrease both the risks and the costs of such projects*. Not to take advantage of ORNL's expertise in this area would be a shame.

Strategic Partnerships

The existing projects involve collaborations with a number of researchers at universities and at other national labs. As noted above in our discussion of collaborations, we encourage the group to continue to expand their network of university partners, particularly those who can help to fill critical gaps in expertise. *Within ORNL, strengthening partnerships with GTL researchers should provide avenues for fruitful collaborations motivated by practical remediation questions.*

The group has an excellent set of test-beds that could be used in evaluating novel environmental sensors and sensor systems. Its scientists are ideally suited to recommend which parameters are most critical for sensor development and to work with engineers to make new sensors field-deployable. *We particularly encourage collaborations in nanotechnology, electrical engineering, computer science and other key fields to promote sensor development.* The current ORNL field sites offer ideal opportunities for field testing of various sensors, wireless instruments and other means of data transfer, different methods of powering sensor beds, etc. We see great potential for developing new partners in industry who could assist with developing, deploying, testing, and eventually commercializing new sensors and other technologies appropriate for environmental monitoring and remediation. For instance, the new science and technology park that is being built adjacent to ORNL could open new partnerships with the private sector.

Staffing, equipment and infrastructure

The Remediation Science program has hired a group of junior chemists/geochemists who need to be well supported in terms of salary and laboratory facilities for career development and for accomplishing project goals. Additionally, a recent junior hire in modeling also needs to be well supported during the initial phase of her professional career. Additional mid-career hires in geochemistry (particularly isotope geochemistry) and hydrogeology would allow the group to expand their already excellent program to address key questions relevant to remediation at ORNL and other sites.

Summary of key recommendations:

(1) The IFC focus area is a leader in the field of remediation science and should continue to be strongly supported. We recommend the following:
   a. Continued broadening of university partnerships.
   b. Developing additional industry partners, perhaps through the new science center.
   c. Building collaborations with engineers to design novel environmental sensors.
   d. Emphasizing ground-water/surface water interactions as a priority for growth (as highlighted by the ORNL group), because of both the local need for remediation research at ORNL and the broader national need.
   e. Developing models that can take advantage of high performance computing advancements.
   f. Planning for strategic hires to maintain critical mass and leadership capability; plans for hiring of junior staff and perhaps another mid-career staff member should be ongoing.

(2) The SFA focus area is relatively new and developing.
   a. The overall strategy of linking field, laboratory, and molecular modeling and integrating processes from the molecular to the field scale seems appropriate.
   b. Continue to target mercury as a contaminant of primary interest, given the legacy of high-level Hg contamination at ORNL and throughout the weapons complex.
   c. Consider uranium as another key element of interest.
   d. One key concern is the lack of critical mass of Hg specialists at ORNL. The group needs to hire either a mid-career flagship leader in Hg or a junior hire from a well known Hg research program. This is important both for meeting current project objectives and for developing a center of excellence for Hg research at the ORNL. We recommend that this hiring need be quickly addressed.

(3) Broadly, the Remediation Science group should be commended for reaching out to other DOE programs and non-DOE sponsors (e.g., DoD) for research funding. This includes the base support activities.
   a. The program has faced budget challenges for over a decade, starting with the loss of the EM program in the late 1990s as well as losses of projects associated with resignations or retirements of key researchers. While the funding for field research activities and microbial ecology has increased significantly since 2002, this increase has not balanced the declines in funding for geochemistry projects. The group needs to continue to articulate its considerable strengths to DOE.
   b. One key need identified by our review committee is to support junior scientists for project and career development.

c. The Remediation Science group did an excellent job of articulating its strengths and vision, and appears to communicate well within the program. Continuing to communicate this vision is essential. The two primary focus areas overlap in objectives and should remain in good communication and work together towards strategic goals in facilities, hiring, etc.
d. The remediation science group could provide needed context for the GTL program, and we recommend enhanced dialog between these groups.

Bioenergy

Background

Oak Ridge National Laboratory maintains a high profile in national bioenergy research. Between 1976 and 2001, ORNL had a significant influence on the direction and institutional research infrastructure of bioenergy research in the U.S. that extends to today. In particular, these research activities encompassed cellulosic feedstock development (particularly the short-term woody rotation crop poplar, and perennial grass genetics and genomics research). Oak Ridge National Laboratory is also well known for its research into the impacts of energy crop production on environmental quality. Accomplishments during the 1976-2001 period were achieved by research conducted at ORNL, as well as through ORNL-administered funding to universities and to cooperators at federal research agencies, including Auburn University, University of Minnesota, Virginia Tech, Ohio State, Alabama A&M, Mississippi State, USDA-Agricultural Research Service, and USDA-Forest Service. Also, ORNL has collaborated with energy companies including Southern Company, and major timber companies including WestVaco, Union Camp, Boise Cascade, and Weyerhaeuser.

After a period of re-direction to other research priorities (2002-2006), bioenergy research at ORNL was re-emphasized in 2007, when funding increased from <$1-million per year to more than $10-million . The BioEnergy Science Center (BESC) was launched with a $25-million commitment, ~$7-million of which supports ORNL directly, to address biomass conversion. This conversion research is trying to enhance the breakdown of cellulosic biomass in poplars through germplasm exploration and gene discovery, genome manipulation. mapping of traits important to biological conversion, and methods development to screen feedstocks and microbes rapidly for conversion efficiency. Another $4-million per year is used to enhance biofuels resource assessments that include feedstock logistics and environmental impacts. The increase in emphasis on bioenergy research activities at ORNL is very appropriate at this time given the renewed interest for solutions to help relieve the world energy crisis and to enhance national energy independence and security.

Introductory presentations by Dr. Robin Graham, Group leader of Energy and Environmental Systems, and Dr. Martin Keller, BESC Director, provided an overview of the history of bioenergy research at ORNL and ongoing biological conversion research within the BESC. Our committee was asked to focus on four research areas:

- Bioproducts & Other Bioprocesses. Dr. Jonathan Mielenz briefly described ORNL accomplishments and new research in the areas of bioproducts. We learned about how knowledge of bioprocesses has been applied in the past for the conversion of synthesis gas to ethanol, succinic acid fermentation, microbial removal of mercury from coal, the use of microbial fuel cells for water clean-up, and the bioprocessing of cellulosic feedstocks;

- Biomass Resource Analysis. Dr. Tris West presented an overview of current research and the capabilities of ORNL in biomass resource analysis;
- Environmental Sustainability of Biomass Resources. Dr. Virginia Dale presented a summary of the history of research on land use and land management. She also discussed current collaborative research seeking to understand the causes and implications of land use changes, with an emphasis on sustainable land use; and
- Security of Bioenergy and the World Marketplace. Dr. Paul Leiby continued with a presentation of current and future research related to oil and biofuels for energy security.

Recommendations:

There has been a renaissance in bioenergy research activity at ORNL in the past two years, especially with the establishment of the new joint venture *BioEnergy Science Center* with the University of Tennessee. ORNL scientists have already obtained impressive and promising results in conversion science in a short period of time. The interdisciplinary effort focused on the conversion of woody cellulosic biomass to biofuels is excellent, with competent ORNL scientists teamed with selected off-site research groups. Appropriate and very innovative research strategies have already been designed.

We recommend that the team emphasize the whole-system approach for converting poplar woody biomass (and perennial grasses) to liquid fuels. Critical and unique to this whole-system perspective is the possibility of optimizing poplar genetics by both elite natural germplasm identification and by genetic manipulation for 1) feedstock disposition to pre-treatment, 2) the development of conversion-efficient microbes specific to each feedstock, and 3) technology development for high-throughput assessment of system processes. Applying advanced trait genetics to field production should help minimize future problems with disease and insect pests and other threats to production. The ORNL team should regularly assess their research identity and relative success compared to the many other groups working in biochemical conversion; this is a highly competitive arena and only the best technologies will survive in the marketplace.

ORNL can have a significant national impact by establishing a *Center for Bioenergy Sustainability* that builds on expertise from the earlier *Biofuels Feedstock Development Program*. Progress is especially needed in biomass resource analysis, the environmental effects of land use change, modelling of environmental impacts (particularly carbon cycle impacts), and broader modelling efforts analyzing the integration of biofuels into the oil economy for energy security. Given the DOE strategy that bioenergy, and in particular liquid biofuels, is the near term opportunity for a secure source of transportation fuel, ORNL can provide leadership and a unique perspective on the national bioenergy supply chain. The challenges of sustainability have rapidly surfaced in the national and international debate on biofuel viability as a solution to the transportation fuels crisis. There are many federal, state, industry, and NGO institutions contributing to this debate. ORNL should develop a clear plan for the kinds of unique technical and scientific contributions they can make for assessing the impacts of the bioenergy economy and the appropriate scales for that assessment. For instance, ORNL scientists should prioritize what portion of this effort should focus on international, national, and local issues. ORNL can provide leadership to bridge and synthesize information between the bio-based and petroleum-based transportation fuels sectors, particularly the integration of biofuels into the transportation fuels supply chain.

Bio-based energy can be viewed a sub-set of agricultural or forestry production. There are ongoing national assessments of U.S. agricultural and forest commodity production and economics, with numerous reports of the state of natural resources conditions in land use. The team should assess what similar or complementary efforts are underway, particularly within the federal government and other national laboratories, and determine their most effective partners in filling the gaps for technology and information needs. Also, it is important to determine who are the specific customers/users of any new information that is generated from ORNL studies, and to coordinate or provide context for study conclusions. A good example of this was the coordination of analyses using the USDA-ERS REAP and ORNL POLYSYS models in the recent updated biomass assessment report for the Biomass Research and Development Board.

Regarding the production of feedstocks, specific attention in the short-term should be given to how to provide the best information needed to meet the goals of the Renewable Fuel Standard. Also important is the need to provide the kinds of decision-making information that can be used by feedstock producers, bioenergy producers, and policy makers to help guide the development of the biofuels industry into the future. The scale limitations and local applicability of modelling efforts should be determined, particularly as related to the use of model results to assess or direct site-specific management decisions and their impacts. Field-validated modelling results will be especially important when trying to develop spatial assessments of resources at relatively fine scales. This will likely require partnerships with appropriate universities, USDA-ARS, and industry. Also, a continued emphasis on integrating different kinds of models and data appropriate to different scales will be needed.

Given the full-cycle approach to developing woody feedstocks for liquid fuel production, ORNL should apply its sustainability assessment technology to full life-cycle assessments of this emerging industry. The term sustainability is popularly used but not universally defined. There are specific government definitions for sustainability, and it would be helpful to communicate your research with these definitions. Science is needed to integrate the assessment of bioenergy system productivity, economic feasibility, and natural resource stewardship. The current research addressing the larger impacts of land-use change should be included in the assessment of bioenergy system sustainability, particularly as it relates to avoiding disruption of food supply changes and ecosystem services. There are federal inter-departmental efforts already underway addressing the issues related to sustainable biofuel production. For short-term contributions to the debate about bioenergy sustainability, ORNL needs to coordinate its efforts through US-DOE and to build on progress in other agencies and universities.

With the need to increase global resource availability while maintaining critical ecosystem services, ORNL can provide valuable contributions at this scale. Along with the emphasis on carbon accounting throughout the biofuels life cycle, other important indicators are water, land-use changes, and net energy balance. The specific analytical tools and integrated analysis platforms developed by ORNL will be of value to other investigators and would be an important extension of previous technology development research. A related example of potential synergies across divisions in this area could be an assessment of the sustainability of the Billion Tons study initiated by DOE nationally. Again, it is important to know what potential customers specifically need, and to design those needs into your technical products. Care should be given to avoid duplicating efforts, and to incorporate other widely accepted technologies such as those that available from other organizations, particularly federal agencies (e.g., National Institute of Standards and Technology, US-EPA, USDA-ERS, or USDA-ARS).

Genomes to Life

The Bioenergy Center-associated investment in proteomics and proteogenomics is highly appropriate and establishes unique capabilities with the likelihood for growing international leadership in the area of functional studies of organisms and consortia.

The CMCS project on protein complexes of *Rhodopseudomonas palustris* has generated key technology that can potentially contribute significantly to other missions in bioenergy and bio-interface processes. The apparent difficulty in elucidating some key discoveries suggests that some careful thought will be needed to determine how to best apply this technology to future projects. It is vital to identify a way to optimize the value of this technology to new focus areas during the transition from a high throughput pipeline. A secondary facet is the opportunity to integrate discoveries from the protein complex and proteomics/functional gene efforts into parallel annotation efforts (e.g., inferred functions for proteins of unknown function by association with complexes of known function).

The *Shewanella* knowledgebase is a valuable resource that has begun to address a tremendous need across within and beyond DOE: the integration of diverse, complementary data forms in a useable and flexible format. This will be important for discovery of new phenomena and concepts, and also for data sharing and outreach to collaborating communities (e.g., geoscience). The project reflects a good mix of data gathering and tools/architecture development. A logical next step will be to add new components, specifically to address the challenges associated with dealing with data from new sources (especially expression data) and multiple coexisting organisms (communities). The best data rendering formats for this remain unclear. At present, the data are presented via Pathway Tools, KEGG maps and (to some extent) in genome context. (Are these formats appropriate for all organisms, e.g., archaea?) Some deep thinking about the challenge of communities is essential, as is input from researchers already addressing these challenges.

The relationship of ORNL to JGI remains a critical strength in DOE, although this point seemed to be lost under the pressure to rapidly pursue development of new energy sources. DOE should not lose sight of the requirement for continued basic research in microbial genomics and the need for new technologies for understanding organisms and analyzing complex environmental communities. The goal of developing annotation capabilities at ORNL is vital and is one of the clearest paths towards major improvement presented to our Advisory Committee. Large genomics centers have gained their capabilities largely through their own efforts to develop programs. Following the assignment and completion of chromosomes at the different sequencing centers for the human genome project, many centers dropped out of the elite ranks simply by not attending to the demands of the research and competitiveness of the field. The Advisory Committee has identified this as a major danger confronting DOE. It would be a serious blow to ORNL if it failed to maintain a strong program of growth and reinvention in the area of annotation services. This resource should be prioritized for growth, with some reconstruction. It is clear that for sequencing centers to remain at the forefront, they will need to make the jump from being primarily devoted to sequencing efficiency and throughput to being a biology-centered program. ORNL should view this as an exceptional opportunity to position itself for future innovation in the energy field as well as for microbiology in general and, combined with JGI, to remain a premier genomics resource within DOE. A key and immediate step is to complete the process of automation of the pipeline (both for routine isolate genomes and for draft genomes and sequence fragments from metagenomic projects) to free up staff time for developing new annotation methods and approaches and research support to the broader scientific community. A specific suggestion is to effectively and rapidly incorporate data inputs from other programs (e.g., proteomics, cDNA sequencing, making use of knowledgebase data sharing tools) to support development of new annotation tools (e.g., for archaea important in bioenergy applications, such as methanogens).

In the grand challenge area, ORNL is well suited to tackle science problems, including microbial communities in multiple contexts. There are already community projects underway, and these could leverage and contribute to the development of informatics tools, as noted above. The construction of artificial microbial consortia has made important progress, with some good discoveries. FACS sorting of antibody-labeled bacteria should enable the analysis of the community and may provide insights into metabolic interdependence. Specifically, the current approach seems to be a valuable model system for studying metabolic intermediates as they flow through members of a consortium.

While the project addresses vital scientific questions, there are components of the design that may need consideration if work aims to provide insights into how natural or engineered systems function. The recently observed response of the co-cultures to the imposed environmental conditions (biofilm formation) may suggest that the community is seeking alternative configurations to those chosen by design. If natural environments are not static (either due to external forcings or as a result of complex behavior), diversity may be key to community function. Natural communities are not assemblages of clones but are comprised of populations within which genomic heterogeneity is an inherent feature. Neglect of this fundamental characteristic may have unanticipated consequences. Viruses are certainly important both in shaping community membership and function. While incorporation of viruses may be possible in future designs, the community will likely crash without the natural population diversity that likely secures the survival of both hosts and viruses in natural systems.

The area of microbial interfaces is an important grand challenge area for which ORNL brings important expertise. However, the project appears to need some focusing, particularly with a view to efforts in this area at other institutions.

Collaborative projects with the Chemical and Materials Sciences Divisions were mentioned frequently. There appear to be multiple critical links within ORNL, and large new initiatives will certainly benefit from strengthening ties with researchers in these areas. Specifically, the nanoparticle-microbe project appeared to need better-defined inputs. The question of nanoparticle (especially manufactured nanomaterial) organism impacts and interactions is a key area of national need, given the general failure of the nanotechnology initiative to address this area until recently. The size-dependence of nanomaterial properties/reactivity was also mentioned, but the extent to which science in this area will be incorporated into the project is unclear (i.e., only nanoparticle synthesis collaborators and microscopists were mentioned). The committee suggests that this project may benefit from some focusing.

The Bioenergy Centers program combines several different technologies in a powerful multidisciplinary approach to identifying genes involved in cell wall formation. First results have been obtained in a very short period of time and appear promising. They are using an innovative approach that relies upon selecting for interesting strain variants with appropriate phenotypes. The search for microbial thermo-adapted microorganisms and their enzymes for cellulose degradation good progress has made made.

Gene discovery for biomass recalcitrance is done in a high throughput process that has good potential to identify the genes involved. The plans for HTP phenotype screening are an important contribution. This basic approach to understanding the genetics and biochemistry of the system also provides a targeted approach that could lead to improved poplar strains for use in bioenergy production. Analysis of cellulase complexes and also the effect of temperature on the enzymatic kinetics are also important components of the research. The long history of ORNL in the areas of poplar and switchgrass genetics and genomics are strengths of the program, as is the collaborative nature of the work which includes multiple institutions.