Recently, in a letter to four senators President Bush commented on "the incomplete state of scientific knowledge of the causes of, and solutions to, global climate change." He also said the administration intends to "develop technologies, market incentives, and other creative ways to address global climate change."

REVIEW OF THE GLOBAL CHANGE AND RELATED ENVIRONMENTAL PROGRAM

Summary

On March 26 and 27, 2001, the Global Change Research Subcommittee of the Department of Energy's Biological and Environmental Research Advisory Committee (BERAC) met to review the global change and related environmental programs of the DOE. We heard presentations by both the office that coordinates the United States Global Change Research Program (USGCRP) and by staff that manage the Biological and Environmental Research (BER) global change research programs.

The overall assessment of the DOE/BER's contribution to the Nation's USGCRP is that it is fulfilling a unique niche and important role in the overall objectives of the Program. Specifically, it makes contributions to improve the forecasts of global change by means of realistic modeling of the climate system; it is improving understanding of the complex interactions of the Earth's carbon cycle; it is a major contributor to understanding the role of clouds and radiation in the climate system; and it improves understanding of the vulnerability of natural and managed ecosystems to climate and atmosphere changes. The program also is playing a key role in providing useful knowledge to support decision-making on various options for enhancing resilience to global change.

The Subcommittee was unanimous in its opinion that the research supported by the DOE/BER is of high quality and rigorously peer reviewed.

In terms of research budgets, the BER budget is the third largest global change research program following NASA and the National Science Foundation (NSF). The BER program also contributes strongly to the energy and environmental mission of the DOE.

The subcommittee has concerns about staffing levels available to manage a diverse program with many interagency and international ties. Because of the important international aspects of global change research, there is a strong need to coordinate with many partners. The subcommittee is seeing strains on program managers being able to cope with the workload. Also, we see that the facilities aspects of the program (e.g., ARM, FACE, AmeriFlux, etc) continue to show signs of not being adequately funded. We urgently recommend that these two infrastructure issues be resolved in order to avoid negatively affecting the quality of the science in these programs. Both of these issues have been emphasized in early reports and reviews, but they still remain major problems.

The recently released Science Working Group's Third Assessment report of the Intergovernmental Panel on Climate Change (IPCC) has shown a significant

improvement in our knowledge about global change. The DOE's contribution to this major international effort has been significant as indicated by citations of research sponsored by BER. In a similar fashion the DOE has taken on a key role in the U. S. National Assessment activities. This activity addresses regional impacts of global change in an integrated manner with strong involvement of various stakeholders. Many workshops and meetings were held in various parts of the country to obtain broad community input to the National Assessment effort.

The BER program is to be commended for strong ties to other program offices within the Office of Science (SC) and the Department. Research on computer modeling of the climate system is done in collaboration with DOE's Office of Advanced Scientific Computing Research. The BER Carbon Sequestration Research is well coordinated with BER's Microbial Genome Research, the SC's Office of Basic Energy Science's carbon sequestration research, and the Department's Office of Fossil Energy (FE). The BER Atmospheric Sciences research has demonstrated solid connection to the needs of FE, particularly air quality and atmospheric visibility (haze).

Although, the DOE does not have a direct mandate in education, one of the initiatives of the new administration is education. The BER has a number of K-12, graduate, and postdoctoral programs that contribute to helping develop the next generation of scientists. The program is attempting to reach out to women and underrepresented groups. Many scientists and laboratories involved in global change research devote significant time and energy to improving the public understanding of global change issues.

We are very pleased that the DOE management has responded to all of the recommendations of the previous review by the subcommittee. The steps taken and rationale for changes to the program are well understood by the subcommittee. We concur with all of the adjustments in the budget and the programmatic changes that have occurred as a result of our recommendations.

BER Global Change Research Program Accomplishments

Climate Change Prediction Program

Application of the parallel climate model: The Parallel Climate Model (PCM), a state-of-the-science coupled atmosphere-ocean general circulation model, was developed specifically for climate variability and climatic change studies on multidecade to multicentury timescales, including the study of climatic changes that may result from increasing concentrations of greenhouse gases. This model resulted from a highly successful and unique collaboration between DOE National Laboratories, university researchers, and the National Center for Atmospheric Research (NCAR). Simulations from this model were a primary source of projections for the recently completed Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR). Because the model was designed to be portable among scaleable parallel computing systems, simulations have been run on the National Energy Research Supercomputing Center's (NERSC) T3E and IBM SP computers, and the SGI Origin computer at Los

Alamos National Laboratory (LANL). Since completion of the IPCC TAR, ensemble simulations of climate variability and change using PCM have continued, with the results made available to a broad research community.

Coupled model development: A second generation of the PCM has been completed. The PCM continues to be designed to work on highly parallel computer systems. The team of scientists at NCAR and universities working on the National Science Foundation-supported Community Climate System Model (CCSM) is working closely with the PCM community to develop next generation climate models. A multi-institution software engineering working group developed a common framework and improved the performance of several model components so that both communities would use the same components at several different resolutions with implementation on a variety of supercomputers. Cooperation with the CCSM provides added academic involvement in development of PCM enhancements. To enhance use of PCM model output for regional climatic change studies, horizontal resolution was doubled in both the ocean and atmosphere models. These higher resolution individual component models are being tested.

Ocean model development: Los Alamos National Laboratory developed the Parallel Ocean Program (POP) global ocean general circulation model for climate applications. Following the successful inclusion of POP in the PCM, this state-of-the-science model was adopted as the ocean component for the CCSM. The model was developed to execute efficiently on parallel, distributed memory high-end computers and has produced high fidelity eddy-resolving simulations of the ocean circulation that were previously impractical running on the LANL Connection Machine (CM-5). As a result, it is now possible to carry out global and regional ocean simulations at spatial resolutions previously unattainable.

Development of the U.S. Historical Climatological Network: Support by DOE and NOAA enabled the development and maintenance of the U.S. Historical Climatological Network (USHCN) data set, a robust set of instrumental measurements of surface temperature and precipitation for 1221 stations in the contiguous U.S. beginning in the early to mid-1800s and extending through December of 1994. Database development required extensive data and review and quality control. Analysis of the USHCN data set has been critical for detecting trends in long-term U.S. climatic change, such as the observed reduction in diurnal temperature range and the increase in severe precipitation events.

Climate change detection and attribution: BER has been a leader in climatic change detection and attribution research. Statistically robust comparisons of observed and simulated climatic change done at the Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory provided the first scientifically defensible link between observed global temperature changes and human-caused environmental changes, principally the increase in atmospheric carbon dioxide concentrations from fossil-fuel combustion. More recent comparisons of observed and modeled changes in ocean heat content, based on ensemble PCM simulations forced by

natural internal forcing alone and by observed and estimated anthropogenic forcing from aerosols and greenhouse gases, show that ocean temperature increases are consistent with increases expected to be caused by observed increases in atmospheric greenhouse gas concentrations.

Atmospheric Radiation Measurement (ARM) Program

Site development and operations: The ARM Program developed, built, and managed Cloud and Radiation Testbed facilities in three climatic regions: the Southern Great Plains (SGP), the Tropical Western Pacific (TWP), and the North Slope of Alaska (NSA). The SGP is the largest of the three and produces a data stream of radiation and atmospheric column properties unmatched in terms of measurement completeness and temporal extent. Over 10 years of continuous millimeter (mm) radar data and lidar (LIght Detection And Ranging) data, in conjunction with various radiation and imager data, have been acquired by the Program, providing the science community with the best cloud and radiation data set (quality controlled and in a uniform format) available for analysis and model parameterization. This data set exceeds in length all other joint radar and lidar data sets by more than an order of magnitude.

Instrument development: In response to the need for continuous observations, the ARM Program developed continuously operating versions of research instruments, such as the mm-wavelength cloud radar and Raman lidar, and new commercial instruments such as the Yankee Total Sky Imager and the Science and Engineering Services, Inc. Micropulse Lidar. The addition of these instruments provided a unique measurement capability for parameters such as water vapor and cloud properties that are critical to improving climate models.

Data analysis and fundamental physics: The ARM Program pioneered the development of cloud microphysical property retrieval algorithms using multiple sensors. These algorithms are now applied routinely to ARM data to provide statistical descriptions of cloud bulk and microphysical properties and surface radiative forcing of clouds. The Program demonstrated for the first time that instantaneous clear sky measured and modeled solar irradiance in carefully controlled experiments agree to better than 10 W/m^2 (less than 2% of the daily average solar irradiance at the top of the atmosphere). The Program also demonstrated that instantaneous clear sky measured and modeled infrared (>700 nm) fluxes agree to 5 W/m^2 (less than 2% of the average radiation emitted from the top of the atmosphere). These improvements represent a factor-of-four reduction in measurement uncertainty, which was made possible by instrument improvements made by ARM. Further reductions in uncertainty will require additional advances in instrumentation. The small differences between detailed model calculations and observations established a new standard for the level of accuracy for the performance of climate model radiation codes. The Program conducted detailed measurements of anomalous solar absorption in atmospheric layers containing clouds. These measurements narrowed the uncertainty between models and measurements to less than about 4% of the

incident solar energy and 15-20% of the solar energy absorbed in cloud-containing layers of the atmosphere.

Model development, parameterization, and testing: The Program carried out the most extensive comparisons ever conducted of numerical weather models with actual cloud, radiation, and surface energy fluxes for both the U.S. Eta model and the European Center for Medium range Weather Forecasting (ECMWF) model. Those comparisons documented both model successes and failures and led to model improvements. The ARM Program pioneered the single column modeling approach to testing climate model parameterizations and turned this approach into an operational testbed. This included conducting the first detailed comparisons of observations, cloud resolving model simulations, and single column model results. They resulted in the first detailed look at how climate model cloud parameterizations actually perform in real atmospheric situations. The Program also developed new parameterizations for cirrus clouds (at least three competing versions), convective wakes, and mixed phase clouds, and a substantial modification of an existing convective cloud parameterization. These parameterizations are being tested and used in current climate models.

ARM Unmanned Aerial Vehicle (UAV) Program

Operations: The ARM UAV program conducted the first unescorted flight of a UAV in class A airspace and the first science measurements from a UAV were taken on station continuously for more than 24 hours. The Program also made the first science measurements from a UAV above 16 km. (The UAV platforms deployed under the auspices of the program are the Gnat-750, the Altus and Altus-II UAVs provided by General Atomics Aeronautical Systems, Inc.) The UAV Program developed a mature data system that provides direct real-time downlink of the data to the instrument mentor during flight and an archive that provides access of the data by the general science community. The Program developed aircraft operational systems that allow for the formation flying of multiple aircraft, which enables close coordination of cloud observations from two (or more) aircraft.

Instrument development: The UAV Program developed a versatile and powerful payload capability that includes active systems such as mm radar and lidar as well as passive spectrometer and radiometer systems. The addition of these instruments provides the capability to measure parameters such as water vapor and cloud properties at previously unattainable *in situ* resolutions.

Campaigns and fundamental physics: The Program conducted several campaigns with findings important for testing and improving model parameterizations. In the two ARM Enhanced Short-wave Experiments, the program measured absorption by liquid water clouds using unique flight and sampling plans. These experiments led to: (a) a better appreciation of the role of clouds and radiative processes, (b) new approaches to

experimental design, (c) improved instrumentation for measuring broadband and spectral radiation quantities, (d) unique datasets describing radiation absorption in clouds and other physical properties of clouds, and (e) advanced tests of the ability of climate models to calculate radiation absorption in clouds. Flights involving the Altus resulted in (a) improved calibration of instrumentation on geostationary and polar orbiting satellites used for estimating the top of atmosphere radiation budgets, (b) enhanced measurements of spectral albedo of several different surface types at a wide range of solar zenith angles, and (c) new techniques for the sensing of cloud optical properties, all of which are important to reducing uncertainty in climate models.

Atmospheric Science Program

Oxidant production above urbanized areas in the U.S.: The relative importance of seasonally and geographically varying processes affecting oxidant production and fate was evaluated quantitatively for several metropolitan areas in the U.S., providing vital information on the likely success of various possible control strategies. The importance of the hydrocarbon to nitrogen oxides (NO_x) emissions ratio was particularly evident in the Southern Oxidants Study (SOS) experiments conducted mainly in Tennessee. Results indicate that any southeastern ozone (O_3) control strategy based on further reduction in anthropogenic hydrocarbon emissions is likely to fail because biogenic hydrocarbon emissions from forests in the region are so large. In the Northeast, however, a different situation was encountered during the North American Research Strategy for Tropospheric Ozone (NARSTO) study. Ozone production downwind of very large metropolitan areas such as New York City and its environs was determined mostly by anthropogenic hydrocarbons emissions, indicating that control of those emissions would be more effective than control of NO_x emissions in reducing O_3. The Phoenix 1998 field campaign showed that very dry conditions slow radical production rates, which suppresses O_3 production rates by a factor of 3-4 compared to the SOS studies.

Quantitative evaluation of oxidant "background" and sources: Horizontal transport by winds over distances up to about 1000 km can influence oxidant concentrations in U.S. metropolitan areas. For example, numerical modeling studies associated with the 1998 BER Phoenix air chemistry field campaign showed that O_3 and its precursors produced in southern California can be carried to the Phoenix area, altering the effectiveness of potential local controls on energy-related emissions that contribute to oxidant formation. According to BER studies, surface O_3 concentrations produced by human activities could be elevated by 5 to 25 parts per billion by volume (ppbv), usually in episodic events, by this regional-scale transport from outside the Phoenix area.

Mexico City air quality study: Combined chemical and meteorological measurements supported by BER allowed the complex Mexico City system to be evaluated in detail for the first time. Transport of pollutants from this megacity is of major significance in regional air quality; but because of local and regional meteorological influences, the airborne chemicals found in the Mexico City basin had rarely been studied for more than one day, which is insufficient to understand production of local secondary aerosols. It

was found that primary carbonaceous soot and organic aerosols accounted for about half the particulate matter smaller than 2.5 micrometers in diameter (PM-2.5). It was also discovered that use of methyl tertiary butyl ether (MTBE) as an octane enhancer and lead replacement in fuels was linked to increased formation of formaldehyde, peroxyacyl nitrates (PAN), and O_3.

Ozone in coastal environments: Laboratory studies showed for the first time that O_3 production in coastal environments can be augmented by reactions involving chlorine. Molecular chlorine, Cl_2, can be formed by reaction of OH with wet sea salt particles above the deliquescence point, which in turn can lead to chorine atoms. Field observations by Atmospheric Science Program scientists documented Cl_2 mixing ratios in marine air as large as 150 parts per trillion by volume (pptv), exceeding those generally predicted for marine air by more than an order of magnitude. Unique, chorine-containing organic products from the reactions of chorine atoms with isoprene and 1,3-butadiene were measured and may serve as "markers" of this chemistry in the field. These markers might be used to study the importance of anthropogenic and natural chlorine sources in the tropospheric oxidant budget.

Texas air quality study (TexAQS 2000): TexAQS 2000 was conducted during late summer, 2000 to understand the relative roles of emissions from refineries and other sources on O_3 and aerosols in the Houston area, with the additional complication of land and sea breezes causing recirculation of polluted air over the area. That field campaign, one of the largest and most comprehensive air quality studies ever conducted in the U.S., included over 250 scientists and technicians, five aircraft, and a comprehensive set of meteorological and chemical measurements deployed throughout the Houston area. The BER Atmospheric Science Program initiated the study, arranged partnerships with key state and federal organizations, and had a major role in defining the scientific goals of the study. In addition, Atmospheric Science Program scientists chaired the Science Team; participated in the Aircraft Planning Committee; instrumented a tall building site; co-chaired the Boundary Layer Dynamics Committee; instrumented and flew the G-1 research aircraft; provided meteorological support; and instrumented a site for examination of chlorine chemistry. Preliminary results reveal a unique combination of extremely high O_3 formation rates from local precursor sources, air quality variations compounded by land-sea breeze circulation, and high pollutant concentrations in the boundary layer that appear to have been transported long distances.

Carbon Cycle Research Program

Cause of interannual variation in atmospheric carbon dioxide (CO_2) increase: Long-term measurements of atmospheric CO_2 concentration and the ratio of stable carbon isotopes ($^{13}C/^{12}C$) in atmospheric CO_2 supported by BER at the Scripps Institution of Oceanography, University of California, San Diego (C.D. Keeling) have shown wide variation in seasonal and annual changes, with the largest annual rates of atmospheric CO_2 increase associated with El Niño events. During these events, exchange of atmospheric CO_2 with the terrestrial biosphere is the dominant cause of variation in both

the CO_2 concentration and the $^{13}C/^{12}C$ ratio. Exchange of CO_2 between the atmosphere and oceans is opposite in phase to the terrestrial exchange, and of smaller intraannual amplitude. These data provide the best available estimates of the relative role of terrestrial ecosystems and oceans in regulating seasonal and interannual changes in atmospheric CO_2. The knowledge gained is needed to reduce uncertainty about future changes in atmospheric CO_2.

Terrestrial carbon cycle modeling: BER supported development of a high spatial and temporal resolution global terrestrial carbon cycle model (GTEC, Global Terrestrial Ecosystem Carbon) based on first principles of photosynthesis, allocation of photoassimilate among plant organs, and decomposition of organic matter in combination with energy balance and water fluxes in terrestrial ecosystems. By employing high-performance computing methods, this model is the first global terrestrial ecosystem carbon cycle model to complete long-term simulations without loss of temporal resolution. This preserves important feedback processes associated with changing environmental conditions that must be approximated in other models. By working closely with experimenters, the model was used to explore the global scale consequences of ecosystem responses to environmental changes associated with energy production and use. The model was used to estimate the enhanced uptake of carbon resulting from CO_2 fertilization of plants, potential reductions in plant respiration due to rising atmospheric CO_2 concentrations, and interannual and long term changes in CO_2 exchange resulting from climatic variations and change. Model results contributed to the US National Assessment through the VEMAP program. Current developments include incorporation of terrestrial carbon cycle and hydrology dynamics into the Parallel Climate Model (PCM) for the integration of climate-carbon cycle dynamics in future global change analyses.

AmeriFlux network of terrestrial ecosystem CO_2 exchange measurement facilities: BER established a network (AmeriFlux) of 35 tower sites that make continuous measurements of whole-ecosystem exchanges of CO_2, water vapor, and energy using the eddy covariance method. When integrated over an annual cycle, the CO_2 exchange measurements represent the fundamental variable called net ecosystem production (NEP), which is more difficult to obtain by other methods. Common measurement protocols and intercalibration of instrumentation makes it possible to compare measured fluxes across all locations, which include most major North American ecosystem types. In this way, AmeriFlux is building a powerful quantitative database on how CO_2 cycles between the atmosphere and ecosystems of the Americas (the network is expanding into Central and South Americas, and AmeriFlux coordinates activities with similar networks in Europe and Australasia). The NEP data collected by AmeriFlux are advancing fundamental understanding of basic ecosystem functions (the areal extent and duration of the measurements is unprecedented) and forms a national/continental database needed to evaluate terrestrial ecosystem carbon cycle models. Top of canopy radiation and meteorological data from AmeriFlux sites are combined with satellite platform data streams (NASA-TERRA) to calculate ecosystem carbon balance with a diverse group of models. AmeriFlux results contribute significant information to the mission of other

agencies involved in the U.S. Global Change Research Program, such as the NASA TERRA mission.

Free-Air CO_2 Enrichment (FACE) technology development and implementation for study of terrestrial ecosystem responses to rising atmospheric CO_2: BER pioneered field experiments as the approach for understanding and quantifying biological cause and effect relationships associated with rising atmospheric CO_2. Two issues are critical: (1) how will changes in atmospheric composition affect terrestrial ecosystems and (2) how might terrestrial ecosystems affect the rate of atmospheric CO_2 increase? While it is known that elevated CO_2 stimulates plant photosynthesis and affects water use, significant limitations exist with respect to traditional approaches (e.g., greenhouses, growth chambers, and open-top chambers) to treating plants and ecosystems with controlled levels of CO_2. Limitations are especially important for large/tall vegetation such as trees. In response to needs for new technology, BER developed an innovative chamberless method of controlling CO_2 concentration in the field (i.e., FACE). This technology was a fundamental advance, and opened the door for a range of ecosystem-scale experiments needed to both test ecosystem models and answer key research questions. The first FACE experiments were carried out in crops in collaboration with the USDA, but have since been expanded to include several forest, grassland, and desert sites. Each FACE site is a unique user facility available to agency and university scientists. Because of their large physical dimensions, FACE facilities have allowed the size of research teams associated with individual experiments to expand by as much as an order of magnitude, representing a breakthrough in the quality and quantity of data that can be gathered and analyzed. FACE experiments can be used to evaluate other methods of conducting experiments, to evaluate models, and to carry out previously impossible experiments. Combinations of factors studied with FACE technology include CO_2 and O_3, CO_2 and soil water availability, CO_2 and soil nutrients, and interspecies responses to CO_2.

Results to date show that vegetation can respond strongly, and for many years, to elevated CO_2. With a 200 part per million by volume (ppmv) increase in CO_2 (over a background value of 350-370 ppmv), crop and tree growth is stimulated 15-30%. To date, there is no indication that the growth stimulation will decline with time. Unique and recent results, published in *Nature* and *Science*, include (1) large stimulation of growth by elevated CO_2 in pine trees growing in the field in the southeast, (2) greater growth stimulation of invasive weed species compared to native vegetation with elevated CO_2 in the arid southwest, (3) disproportionate allocation of carbon assimilated during photosynthesis to reproduction versus wood growth in pines, and (4) greater productivity of grasslands with higher plant community diversity when exposed to elevated CO_2 compare to CO_2-enriched grasslands with lower community diversity.

Ecological Processes Research -- Program for Ecosystem Research (PER)

Expanding the frontiers of soil microbial research: The most extensive analysis of diversity and composition of soil bacteria, including the discovery of at least four previously unknown bacterial divisions, was recently conducted within the PER. At least

17 bacterial divisions, representing nearly half the known divisions, were identified in just two soil samples. This showed that soil bacterial communities are more complex than previously thought, which has critical implications for studying soil bacteria and indicates that soil responses to environmental change may be more plastic than previously realized. This discovery of the vast soil bacterial diversity necessitated new technology to study soil bacteria, and in response, PER-supported scientists developed a fingerprinting technique that can be used with whole bacterial communities or specific bacterial divisions or groups. It allows both surveys of soil bacteria at the landscape scale and comparative studies of the response of entire bacterial communities to changes in climate and other environmental factors. Thus, PER research both significantly enhanced present knowledge of soil bacterial diversity and composition, and provided tools needed for future advances.

Benefits of increasing carbon dioxide (CO_2) may be balanced by detriments of rising tropospheric ozone (O_3) in forest ecosystems: By exposing young deciduous tree communities to the combination of elevated CO_2 and elevated O_3 for the first time using the BER-developed free-air CO_2 enrichment (FACE) technology, PER-sponsored research determined that elevated O_3 can completely negate the positive effects of elevated CO_2 on tree growth. This result is especially significant because energy production and use are driving an increase in *both* tropospheric CO_2 and O_3, and at comparable rates. This research is significantly reducing uncertainty about tree community-level responses to changes in atmospheric composition, and is also revealing important new questions about how forest ecosystems may respond to environmental change during coming decades by considering multiple factors in a field experiment. For example, the project made the important discovery that leaf physicochemical properties were markedly altered by exposure to elevated CO_2 and/or O_3. In one case, O_3-induced changes in leaf epicuticular waxes resulted in a 3- to 5-fold increase in *Melampsora* leaf rust. These and similar novel results have critical implications for long-term ecosystem productivity and nutrient cycling and for understanding the causal mechanisms of observed responses of trees to elevated CO_2 and O_3.

Surprising resilience of large trees to changes in precipitation: The largest and longest environmental manipulation of the amount of precipitation entering a forest ecosystem indicates that wood and leaf growth of *existing* large trees in the eastern deciduous forest is largely unaffected by changes in the amount of annual and summer precipitation of +/- 30%. This lack of effect of systematically reduced precipitation on tree growth results from a temporal disconnect between periods of active growth (spring and early summer) and typical occurrence of drought (mid to late summer). This discovery by the PER based on field data is in contrast to model predictions that temperate forest productivity is immediately and highly sensitive to modest changes in summer precipitation. These results indicate that reliable predictions of growth responses of forests to future climatic changes will depend on having accurate forecasts of both the magnitude and seasonal timing of precipitation changes. In the same large-scale forest experiment, PER-sponsored scientists documented that changes in the mean annual precipitation may cause chronic disruptions in ecosystem nutrient cycling and seedling and sapling survival, and this could alter the composition and productivity of the future

forest. The good news is that because changes caused by altered precipitation are likely to be gradual, society may have time to develop and implement proactive responses to changes in the eastern deciduous forest resulting from any future changes in precipitation.

New insights into effects of warming in combination with rising CO_2 on tree growth: A newly designed open-top chamber (OTC) system was used to study effects of warming ($+4^oC$) in combination with elevated CO_2 concentration (double ambient level) on physiology and growth of sugar maple and red maple. A significant insight that emerged from this BER research was that warming could simultaneously elicit both negative and positive responses in trees, making predictions of net effects of global warming on tree growth more difficult than previously assumed. Positive effects of warming on aboveground growth rates brought about through phenological (seasonal timing of growth) and photosynthetic responses did not compensate for the negative stress-related effect that occurred during a particularly hot, dry period during the multiyear experiment. In addition, the net negative effect on growth of warming was completely compensated by the CO_2 enrichment used in the study. Hypotheses predicting differential responses of the two species based on their physiologic and ecologic attributes were rejected.

Integrated Assessment Program

Benefits of reducing greenhouse gases other than CO_2: Analyses funded by BER showed that reducing emissions of non-CO_2 greenhouse gases, which may be less expensive than equivalent reductions in CO_2 emissions, might create important options for altering energy production and other (e.g., land-use) strategies aimed at slowing climatic change. Just as integrated assessment analysis has revealed large potential overall cost reductions by allowing the optimization of where and when CO_2 reductions are implemented, this new research projects reductions in cost through the trade-off of other greenhouse gases for CO_2. Although more research remains to be done, cost curves for emissions of non-CO_2 greenhouse gases in various sectors (e.g., U.S. agriculture) are being developed and included in the integrated assessment analyses.

Consequences of the connection between reducing greenhouse gas and aerosol emissions: BER-sponsored integrated assessment highlighted and quantified critical links between greenhouse gas emissions, aerosol emissions, and global warming. Depending on assumptions made, the perverse prediction that reduced CO_2 emissions might increase short term global warming through the concomitant reduction of aerosol emission can arise. This is related to the "cooling" effect of some aerosols. The connection between CO_2 and aerosol emissions influences the prediction of global climatic change and emphasizes the importance of better quantifying the radiative effects of aerosols. It also ties economic analysis of the mitigation of climatic change to impacts on regional air pollution, for example, by providing partial estimates of potential ancillary benefits of reducing CO_2 production.

Importance of carbon sequestration as a strategy for "buying time": BER-sponsored integrated assessments provided a basis for quantifying the potential significance of enhancing carbon sequestration in terrestrial ecosystems, oceans, and/or geologic

formations as a strategy for "buying time" with respect to reducing CO_2 emissions. Sequestration strategies that have limited lifetimes, either because of constraints on the amount of carbon sequestered or on the expected residence time before re-release, can be compared economically with other strategies that may be more expensive, such as premature replacement of capital stock.

Program Publications - Summary

The Subcommittee requested a list of open literature, peer reviewed publications resultant from research funded by BER's global change research programs from 1996 to date.

A report listing peer reviewed publications of research funded in whole or in part by the BER global change programs for the period, 1996-April 2001, is included as a separate appendix to this Subcommittee report.

Number of Peer Reviewed Publications by Program or Program Area Resultant From Funding in Whole or in Part by BER's Global Change Research Programs for the period, 1996-April, 2001 are as follows:

Program or Program Area	**Number of Publications**
Climate Change Prediction Program	360
Atmospheric Radiation Measurement Program (ARM)	615
Atmospheric Science Program	328
Terrestrial Carbon Cycle	
AmeriFlux	166
FACE CO_2	273
Atmospheric & Terrestrial Carbon Measurements & Carbon Cycle Modeling	124
Ocean Carbon Cycle Research	
BIOMP	34
Terrestrial Carbon Sequestration Research (initiated 1999)	10
Ocean Carbon Sequestration Research (initiated 1999)	4
Program for Ecosystem Research	312
Human Dimensions Research	
Integrated Assessment	199
Carbon Dioxide Information and Analysis Center (CDIAC)	66
TOTAL	2491

Subcommittee Recommendations

The subcommittee has the following specific comments and recommendations for the following program elements of the DOE Global Change Program:

ATMOSPHERIC RADIATION MEASUREMENT PROGRAM (ARM)

It is interesting to note that in the first U.S. Global Change Research Program Plan (FY1990), the role of clouds was the highest priority element. The goal of addressing that element was (1) to improve understanding of cloud-radiation feedback mechanisms as they influence climate change on all time scales and (2) to properly represent cloud mechanisms in coupled general circulation models.

The ARM that DOE began in FY1990 is one way to undertake the responsibility to address that USGCRP goal. The initial objectives of ARM were to describe quantitatively the radiation balance from the surface to the top of the atmosphere and determine atmospheric characteristics responsible for this balance, including the formation and evolution of clouds. The focus of the research was to be the acquisition of high quality radiation measurements in the atmospheric column and atmospheric characteristics responsible for the radiative balance. What progress has been made to achieve that goal and objectives?

Details of the ARM Program regarding sites, instrumentation, data management, costs, scientists and institutions involved, etc. are available from many sources, including the ARM web site (www.arm.gov). Instrumentation had to be developed to make the necessary observations so the radiative balance in the atmospheric column could be measured. Thus the Unmanned Aerial Vehicle (UAV), Raman Lidar, and an mm cloud radar were developed. Long-term, continuous high quality data sets have been obtained and made available to the scientific community. These data as well as model parameterizations are now used in computer models for testing and development. The European Center for Medium Range Weather Forecasting (ECMWF) and the National Center for Environmental Prediction (NCEP) are using data and products from ARM. During the collection of data over the years and analyses of those data, the question of anomalous absorption of radiation has provoked a scientific controversy within the atmospheric community. The data from ARM are critical to a resolution of this question. The ARM facilities have been used as a test bed for algorithm testing and validation by NASA's EOS program, by USDA's hydrology experiment, and NOAA and Japan's island effects study.

Collaborations and partnerships have played a significant role in ARM. Internally at DOE, there have been several BER collaborations. Programs on climate prediction, tropospheric aerosols, and the carbon cycle depend on ARM observations to aid their work. At the Federal level, NASA has carried out level validation and calibration experiments using satellite and ARM ground based observations. USDA has used ARM to support their UV-B network. NOAA has used ARM data to support soil moisture, soil temperature and aerosol measurements. NSF's GPS network also has used ARM data to support their research. Internationally, ARM has been a major component in the design of a network of baseline water vapor measurement network carried out as a part of the Global Water Vapor Project (GVAP). Within the World Climate Research Program's Global Energy and Water Experiment/Continental Scale International Project (GEWEX/GCIP), ARM has provided support for soil moisture, temperature and aerosol

measurements as well as cloud systems studies. Of major importance is the cooperation between the Australian Bureau of Meteorology and the ARM Program to establish a fourth ARM site in Darwin, Australia.

Why have these collaborations taken place? The ARM Program has excellent instrumentation that provides relatively long records of cloud properties and atmospheric radiation components. There are no other programs in the world that have the capability or the data to do that. Scientists involved with ARM in these cooperative programs know the data are reliable and available.

ARM sites are truly distributed facilities where scientists can carry out their own experiments using ARM instrumentation and data that have been certified by the community as to their accuracy and reliability. In many cases, scientists do not even have to travel to the ARM sites, but can receive the information they need at their home institution via communication networks that already are in existence. The ARM Program has attracted many of the best atmospheric radiation scientists. Scientists from other disciplines who could profit from ARM data are drawn to such a program and feel comfortable becoming involved with the ARM Program and its scientists.

It is planned that the present ARM sites will continue to be operated, providing at least ten years of data from each site. A mobile facility also is planned that would make observations in regions that are important to future modeling efforts, but where there is no ARM site. Science activities will continue and expand that will provide better parameterizations and model development. Support of ARM Fellows at ECMWF and NCEP will continue to help build the future cadre of climate modelers. Collaborations are expected to increase as NASA launches AQUA and other environmental satellites and as new scientific programs are undertaken to fulfill the original goals and objectives of the USGCRP.

The ARM Program has made significant progress towards the goal and initial objectives that were set out by the USGCRP. DOE has played and continues to play a very important role in supporting and managing a program to understand cloud-radiation feedback and cloud mechanisms as they influence climate change on all time scales and their use in climate models. As stated above, there is no other program like this anywhere in the world. Most importantly, a program like ARM is still of highest scientific priority if the USGCRP is to be completely successful.

ARM Recommendation: The Subcommittee encourages BER to continue to fund ARM and if possible in the future, to increase that funding level.

ATMOSPHERIC SCIENCE PROGRAM

The subcommittee was given a draft Atmospheric Science Program Strategic Plan that covers the Atmospheric Chemistry Program, the Environmental Meteorology Program and the Tropospheric Aerosol Program. All of these interconnected programs address the

problem of control of the transport, transformation, and fate of energy related pollutants. Clearly, the policy driver for this set of programs is the societal concerns of air quality at urban, regional, and global scales, climate change, and atmospheric issues involving energy policy. The draft strategic plan states "the current objectives of the program are: (1) to improve understanding of chemical and physical processes that determine the concentration and distribution of energy related air pollutants such as sulfur and nitrogen oxides, tropospheric ozone, and aerosols; (2) to improve understanding of meteorological processes that control the dispersion and air chemistry of energy-related trace gases and particulate matter in the atmosphere; and (3) to develop and test predictive models for the above processes."

The Subcommittee agrees that these stated objectives are of high priority and is pleased that all programs have developed strong partnerships with energy production and energy consumption industries and the energy policy community. The Subcommittee was pleased to hear that many experiments are sponsored jointly by EPA and NOAA. BER also partners with other DOE offices such as the Office of Fossil Energy, the Office of Energy Efficiency and Renewable Energy, and the National Energy Technology Laboratory. The Atmospheric Science Program has been a long-standing program within BER and has established a record for unraveling many processes involved in air pollutants. There have been several successful field campaigns, such as Phoenix 1998, Nashville 1999, Philadelphia 1999, Central California Ozone Study 2000, and TexAQS 2000 that shed light on various regional and urban pollution problems. Five new experiments are being planned to be conducted over the next few years. The newest is the tropospheric aerosol program.

The Tropospheric Aerosol Program (TAP) is a fundamental one that has long been needed as a component of modeling studies. It should be funded as soon as possible and developed with other agencies that also have an interest in contributing to the goals of the program. The TAP has as its goal the development of the fundamental understanding necessary to provide tools for simulating the life cycle of tropospheric aerosols. That will involve processes controlling their mass loading, composition and microphysical properties, all as a function of time, location and altitude. The program will conduct field, modeling, and laboratory, and theoretical studies on processes controlling formation, growth, transport and deposition of aerosols. Evaluation of models that are constructed will be a major component of the TAP field activities. TAP will work closely with other DOE programs as well as programs in other Federal agencies, states, and the private sector. To ensure that the results of this research are translated into useful products for the community, a forum will be provided by a public/private partnership whose membership spans government, utilities, industry, and university researchers in Mexico, Canada, and the United States.

Atmospheric Sciences Program Recommendation: The Subcommittee is pleased with the newly drafted Atmospheric Science Program Strategic Plan and BER's management of the implementation of the plan. The scientific issues are fully addressed in the plan. These include air pollution and cloud processes, air pollution impact assessment, air toxics, dry deposition, regional haze, megacity impacts, inter-regional transport, trans-

boundary transport, 3-D characterization of atmospheric-chemical and meteorological fields, modeling, use of synchrotron radiation facilities for chemical identification, and instrument needs.

CLIMATE MODELING/CLIMATE CHANGE PREDICTION PROGRAM

The DOE has become a Federal leader in the development of state-of-the-art climate models focused on prediction of the climate system on time scales of decades to centuries. One of the highest priority areas of research in the strategic plan for the USGCRP is to investigate the "Changes in the natural and human-induced forces affecting the Earth System." Specifically, the USGCRP has a stated research objective "to fully develop coupled physical, chemical, and biological climate system models, including major forcing and feedbox from human systems that provide more accurate climate projections." Using the DOE's computational capabilities vested in the national laboratories and the scientific expertise of these labs plus that of the academic community, new and improved climate models are being developed and used to estimate energy related impacts on the environment. This activity must be enhanced and better coordinated to take advantage of new developments in computational science, especially with regard to using new generation high-performance supercomputers. The subcommittee is pleased that the BER is working closely with DOE's Office of Advanced Scientific Computing Research (ASCR). The recently released IPCC report states "Confidence in the ability of models to project future climate has increased." DOE- supported climate models have played a key role in the IPCC assessment. They have shown global and regional patterns of global surface warming from the 1870s to the present that follow observed temperature changes. These new generation climate models do not have artificial adjustments of fluxes of heat over the ocean that had been used in many past studies of global warming. The new models give realistic monsoon, El Niño-La Niña, and North Atlantic and Arctic Oscillation patterns. Thus, the models are capable of reproducing many of the observed patterns of global and regional natural climate variability. New research over the next 5 years will be conducted as a partnership with the Office of Science's "Science Discovery through Advanced Computing" plan that provides computational resources. With increased national and international concern about climate change and the need to understand the climate system, this program must be retained at a high priority level.

The BER presentation of the Climate Change Prediction Program demonstrated a focused activity on the development of improved models and their application to long-term climate change. BER management views this as a targeted activity for delivering climate change forecasts. The vision of this activity as a "virtual center" is correct. With improved communications, it is possible for researchers at laboratories and universities to interact effectively and use supercomputers at remote sites. There is no need for a single co-located center activity; however, there is need for an effective management mechanism. The BER management is well aware of these issues and is capable of dealing with them within the DOE structure as well across interagency boundaries. One of the areas that we are pleased to see is the grants program to the university community. This

should be kept as a high priority in order to keep the innovative aspects of this program alive and well. Without fresh ideas, the field would not advance. The roles of the laboratories and universities are now better defined so that both contribute to new generation climate models. The multi-agency support of the Community Climate System Model is a good idea from the standpoint of having a more coordinated effort. Each agency will have a different expectation in the cooperative arrangement. DOE's research, for example, must concentrate on relationships between energy use and climate change as its expectation.

Although, the Accelerated Climate Prediction Initiative (APCI) was highly reviewed and promoted by DOE management, it did not survive as a new major initiative in FY 2001. Nevertheless, two smaller pilot projects of the ACPI were funded. One pilot project will lead to improved computational efficiency for coupled climate models. The other will lead to improved methods for "initializing" the climate for the 1990s, allowing for an early test of the prediction of global and regional climate change. Both of these projects are already showing real promise. The April 2001 issue of Science featured a new climate modeling result showing that the heat content of the upper ocean was increasing globally and regionally in agreement with observations. This work was carried out by DOE-supported climate model studies. The importance of this new finding is that there is another independent measure of global warming other than the surface air temperature. DOE funding was crucial for this new finding.

The issue of historical and climate data was discussed. The DOE is developing a networked system of data between various laboratories and supercomputer centers. This virtual distributed data center will allow for more convenient access to the observed and model data. This will be especially helpful to researchers involved in detection and attribution of climate change. The latter is an area of research that is of great interest to policy makers. DOE has sponsored the Program for Climate Model Diagnostics and Intercomparison (PCMDI) that has taken on the world role of international climate model intercomparison. This activity started with atmospheric model intercomparisons and now other climate components are being compared. Over the last few years, the intercomparisons have included detailed analyses of fully coupled climate models. Another important research activity for PCMDI is to provide a test bed for various parameterizations of physical processes in climate model. Because the PCMDI does not conduct research on parameterization itself, it can provide independent judgment of positive and negative aspects of proposed methods. In cloud and radiation schemes, the PCMDI has important interactions with DOE's ARM program. Without question this activity is serving a unique and important role in the international community.

Climate Modeling Program Recommendations: The climate modeling aspects of the BER program should continue (1) the course of building improved models that are aimed at climate change simulations and prediction, (2) the data intercomparisons for the community, and (3) working with other agencies in a cooperative manner under the general guidance of the USGCRP.

1. In carrying out the charge from the Global Change Research Act that the research "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating and adapting to the effects of global change", the USGCRP must find ways to meet the difficult challenge of bringing the predictive global climate modeling capability to regional and local levels, where most of the impact assessment and policy making decisions are made. USGCRP has undertaken programs that integrate advances in high performance and massively parallel computation with climate modeling. We encourage management to continue these cross-disciplinary efforts. Techniques that emerge will lead to the construction of models with enough spatial resolution and numerical accuracy to be of use in regional climate prediction.

2. Effects of global change on ecosystems and consequently on a wide variety of goods and services required to sustain human life on Earth, are largely unknown, but potentially profound. Many interacting factors and the large space and time scales needed to address this issue, make comprehensive experimentation difficult. In the absence of such experiments, DOE is encouraged to pursue the development of predictive mathematical models and simulations complemented by field experimentation, collection of environmental data sets, and an understanding of ecological processes.

TERRESTRIAL CARBON RESEARCH, ECOLOGICAL PROCESSES RESEARCH, AND THE TERRESTRIAL PORTION OF CARBON SEQUESTRATION RESEARCH

The DOE has important research programs in the areas of terrestrial carbon and ecological research. The principal question addressed by DOE BER terrestrial carbon research concerns the capacity for natural and managed ecosystems to take up and store atmospheric CO_2. This is one of the fundamental policy-relevant issues concerning the carbon cycle and global change. The principal question addressed by BER's Ecological Processes Research is how climate and atmospheric changes affect terrestrial ecosystems and resources, including their ability to provide goods and services of value to humans. Terrestrial ecosystems are major sources of both food and fiber and currently remove from the atmosphere about 25% of the CO_2 emitted by anthropogenic activities such as fossil fuel combustion and deforestation. Were the sign of this uptake to be reversed, the annual increase in the concentration of CO_2 in the atmosphere would rise from the average of the last 20 years, 1.5 ppm/yr, to 2.5 or 3 ppm/yr.

Over the past decade, the BER has played a leading national and international role in supporting critical research to better understand the role of terrestrial ecosystems in the global carbon cycle, including the potential for such ecosystems to store additional carbon and thus reduce atmospheric levels. The AmeriFlux and Free Air Carbon Enrichment (FACE) networks are two current activities that are intended to answer questions such as: how much CO_2 is being removed from the atmosphere by terrestrial ecosystems of different types? What are the critical processes controlling the amount of

CO_2 taken up by these ecosystems? Will terrestrial ecosystems continue to take up CO_2 in the future and how will this affect future atmospheric concentration of CO_2? BER also supports a variety of other related activities, including modeling and atmospheric observations, focused on the same or similar questions. These are important science/policy questions.

The AmeriFlux network, currently with 15 sites, examines a range of natural and managed ecosystems by measuring the exchange of CO_2 between the ecosystem and the atmosphere every half hour within an area of several hundred hectares. The sites must be strictly comparable with each other, and current data must be strictly comparable with data acquired in prior years, requiring rigorous inter-calibration and network-wide QA/QC. A variety of supplementary activities occur at each site that is essential to the success of the program. These activities need to be standardized and reported in compatible formats. Most importantly, the measurements must span climatic time scales (years, to decades) and sites must be distributed in major ecosystem types and climate zones. Each system has unique ecological properties and within each type, land-use history plays an important role. Individual sites provide important information on processes controlling carbon exchange, especially when coupled with other ground-based measurements and experiments. The network as a whole is contributing to the development of a U.S. CO_2 budget for terrestrial ecosystems.

The FACE network and other experiments examine ecosystem responses to elevated atmospheric CO_2 concentrations and other changes in atmospheric composition and climate. Plants generally increase their growth rates in response to increases in the concentration of CO_2, but the long-term responses of entire ecosystems to CO_2 enrichment alone and in combination with other changes in atmospheric composition and climate are not well understood. This understanding is critical for predicting the response of ecosystems to increasing CO_2 concentration and the effectiveness of terrestrial systems in mitigating anthropogenic emissions. The experiments supported by BER address fundamental ecological issues such as effects of CO_2 enrichment on succession and competitive interactions in plant communities, combined effects of elevated CO_2 and ozone concentrations on terrestrial ecosystems, and the interactive effects of nitrogen loading, plant community diversity, and elevated CO_2. In FACE experiments, relatively large areas (e.g., 15-30 m diameter) of intact vegetation are exposed to elevated levels of one or two trace gases such as CO_2 and ozone. DOE's BER is the major federal supporter of FACE experiments. It currently provides primary support for 5 FACE sites in the U.S. Hundreds of scientists conduct research at these sites. The network has very similar requirements for long-term observations and site diversity as AmeriFlux, with higher costs (by a factor of 2-3) and similar issues for archiving, QA/QC, etc.

Experimental modifications of climate also demonstrate DOE's unique ability to perform large-scale manipulations necessary to advance the science on global change issues. The Throughfall-Displacement Experiment (TDE) manipulates the amount of precipitation in a stand of trees. Soil-warming experiments increase the temperature of soils in intact ecosystems. These types of experiments provide important insights on the sensitivity of terrestrial ecosystems to climate change and the causal mechanisms that account for

observed responses to the changes. They also provide information that would be difficult to obtain in other ways on how carbon cycling is affected by the experimental alterations.

Carbon Cycle and Ecological Processes Research Recommendations: Ongoing observational and manipulative experiments to understand the long-term responses of ecosystems to natural and simulated environmental change should be sustained. The need for additional long-term multi-factor experiments needs to be emphasized. Such experiments represent critical avenues for direct testing both our understanding of how ecosystems will respond to global change and the adequacy of models intended to simulate and predict the responses. Clearly, DOE has a critical niche in the global change arena by its ability to design and carry forth the large-scale coordinated observations and manipulative experiments necessary to address scientific underpinnings and implications of climate change. These large-scale experiments are user facilities in the sense that they are open to all users. As such, they serve as research platforms for university and government researchers and provide unique opportunities for higher education, continuing education, and the public.

Terrestrial model development and testing is a critical part of both DOE's carbon research and ecological processes research. These modeling efforts are targeted at improving the scientific basis for projecting ecosystem effects of human-induced changes in climate and atmospheric composition. Carbon cycle modeling is based on ecosystem processes and aggregated to the global scale. Model inter-comparisons are a key part of ensuring that models appropriately include key components. Steps to interface carbon cycle models with climate models are now receiving the attention needed to advance understanding. Nevertheless, the synthesis of model-experimental interactions needs further attention.

Given the urgent need to understand the role of terrestrial ecosystems in the global carbon cycle and how these systems are likely to respond to global change, it is important to point out the critical role of the BER program. BER has played the lead role in the U.S. in developing and supporting research networks and related modeling and atmospheric observations. The BER program also has provided leadership in both the national and international coordination of terrestrial carbon cycle and ecological processes research. Further efforts to exchange data and compare results need to be encouraged. Facilities can be most effective in addressing global change issues if the scientists involved are part of worldwide interactions. The BER terrestrial carbon research has filled a critical need with consistent, focused research intended to develop the "Big Picture". The types of integrated and large-scale experiments and research networks described here require the leadership, guidance and sustained support of DOE. No other agency appears capable of filling this need for studies on ecological processes and terrestrial carbon cycling.

In reviewing the BER terrestrial carbon research and ecological processes research, the BERAC Global Change Subcommittee was particularly impressed by the AmeriFlux and FACE networks, their accomplishments, and the effectiveness of their coordinated activities.

The Subcommittee urges DOE to strengthen the coordination activity, possibly by seeking Facilities funds, which would be absolutely appropriate (see below).

The AmeriFlux and FACE networks are *defacto* "distributed facilities." They are characteristics of any large DOE facility, plus the unique attribute of being distributed sites. Both networks cost $5-20 million to put in place and require comparable operational and maintenance amounts annually. A significant fraction of the annual costs arises from operational expenses rather than scientific research. There is a continuous need for infusion of new and improved technology. The scientific and policy value of the networks would benefit from an enhanced infrastructure and from stronger coordination across sites. The networks need to be expanded and upgraded to meet their important scientific goals effectively. Scientific progress is severely limited by the need to construct and operate the facilities using funds from research programs. A dedicated facilities fund to cover operating and maintenance costs is essential. Without dedicated funds, these science initiatives will be jeopardized due to the need to provide infrastructure and/or operational support. Such consistency and stability in funding would allow the opportunity to take advantage of new technologies and to avoid compromises in experimental design, QA/QC, data management, or operations.

Terrestrial Carbon Sequestration Research:

Carbon sequestration is another important area of research in BER's program. Influences of both above-and below-ground storage of carbon as well as land-use are being explored. The Carbon Sequestration in Terrestrial Ecosystems (CSITE) research consortium leverages resources across the laboratories, universities, and research institutions. The ability to project future carbon sequestration potential is being advanced with a firm footing in science. Carbon sequestration is seen as an important link between the scientific understanding of the carbon cycle and carbon management strategies.

INTEGRATED ASSESSMENT OF GLOBAL CHANGE

The DOE Integrated Assessment of Global Change Program (IAP) sponsors research that integrates simplified representations of the climate, biogeochemical systems, and human activities into frameworks that can both help elucidate scientific uncertainties in system components and inform policy. (The attachment at the end of this report is an outline of how ongoing activities supported by BER's Integrated Assessment Program contribute to issues concerning climate change.) The DOE IAP program was a pioneer in bringing biophysical and social science aspects of climate science into a common framework. The IAP has been closely linked both to national and international goals in order to understand, model, and assess implications of observed and projected changes in atmospheric composition that can influence climate system dynamics.

The IAP has focused on research concerned with integrated model development and evaluation and the evolution of greenhouse gas emissions from human activities. This research has been principally conducted at universities and national laboratories. Many investigators funded by the IAP are leaders in the area of integrated assessment of climate variability and change.

The IAP has served as a catalyst for the highly interdisciplinary research required for the synthesis of the broad knowledge needed to make informed policy or decisions related to climate change. Research advances in the integration of earth system science, economics, and technology innovation and diffusion have been especially impressive. The Subcommittee commends the DOE BER for initiating and supporting the development of the IAP. The contributions both of the IAP research projects and funded researchers to the Intergovernmental Panel on Climate Change and the U. S. National Assessment of Climate Variability and Change have far exceeded what might have been expected from the modest program funding levels. Skilled leadership combined with a rigorous peer review process has resulted in a program that is a unique to the U.S. Global Change Research Program and to fundamental advances in climate assessment and policy.

Integrated Assessment Research Recommendations: The next phase of the IAP should include increased attention to a wider variety of demographic, social, political, and cultural driving forces that shape human interactions with the environment. The recent report by the Board on Sustainable Development of the National Research Council provides important guidance on critical research needed to guide a transition to sustainability. Research on understanding how complex societal factors influence patterns of environmentally significant consumption and trade, land use change, waste management, and how these activities couple to greenhouse gas and aerosol emissions is urgently needed. Research related to understanding past, present, and future emissions of non-CO_2 greenhouse gases and aerosols from sources other than fossil fuel energy systems is crucial to the evaluation of climate policy options.

Another important research area relevant to the IAP is the study of societal vulnerability, adaptation, and resilience to climate variability and change. Arguably, the weakest links in the current generation of integrated assessment frameworks are the characterizations of feedbacks related to human responses to environmental change. This area of research is not funded adequately by any USGCRP agency. This is another area that requires regional scale understanding. The DOE IAP research community will need to attract a wider range of social science expertise to move forward on this expanded integrated assessment research agenda.

The Subcommittee recommends increased funding for the IAP to support the important expansion of the research agenda discussed above. This element of the DOE Global Change Program provides a crucial bridge for linking fundamental scientific advances to societal needs. The societal value of advances in the basic disciplinary programs is limited currently to an inadequate capability for synthesis and integration of new knowledge into a usable decision support system framework.

OCEAN CARBON/ BIOTECHNOLOGICAL INVESTIGATIONS OF OCEANS MARGINS PROGRAM (BIOMP) and OCEAN CARBON SEQUESTRATION RESEARCH PROGRAM

The Biotechnological Investigations-Oceans Margins Program has two elements: molecular biological investigations of linkages between carbon and nitrogen cycles in ocean environments and the enhancement of minority participation in oceans science. Research is focused on the development and application of molecular tools that detect and evaluate the presence of genes associated with carbon fixation, denitrification, and nitrogen fixation, which are fundamental microbial processes in biogeochemical cycling. A goal is to correlate the presence of these genes with measured carbon and nitrogen transformation rates to develop new understanding of how these two biogeochemical cycles are related and influence each other. Future goals include correlation of these data with remotely sensed information on plume dynamics to investigate regional aspects of carbon-nitrogen cycling. Because of the clear significance of carbon cycling in models of climate change, in combination with the role of nitrogen in limiting carbon fixation, sophisticated analyses of carbon-nitrogen cycling in ocean environments has considerable potential for advancing the understanding of carbon sequestration in the world's oceans. With a very limited budget, this Program is making relevant advances in the development of useful molecular tools and in defining relationships between critical biogeochemical cycles. A novel aspect of the Program is the utilization of partnerships between institutions with strong marine research programs and those with historically underrepresented groups to increase participation of minorities in oceans research. The establishment of productive collaborations has occurred. From a group of 46 students trained to date, 38 represent minority groups. The contributions of this Program – both to oceans research and minority participation – are significant despite the very limited budget. The program adds a creative, biotechnological approach to problems of climate change.

Oceans research also is pursued through the Ocean Carbon Sequestration Program. Research is focused on rigorous evaluation of the potential application of CO_2 injection into the deep ocean, as well as enhancement of natural carbon sequestration in oceans. Experimental and modeling approaches address the potential of direct injection. A large-scale ocean experiment, which is jointly funded by NSF and planned for 2002, will assess the effect of iron fertilization on carbon export. Not only will the potential for carbon sequestration be assessed, but also the possibility of accessory environmental effects. As with the other "Oceans" program, the budget for Oceans Sequestration is meager. Nevertheless, it interfaces with numerous other DOE (BER-Terrestrial Carbon Sequestration and Genomics, Fossil Energy) and government agency (NOPP, NOAA, NSF) programs. These enhance the scientific return on the original investment.

Ocean Carbon Sequestration Research Recommendation: The Subcommittee recommends that an increasing focus be placed on determining how the information on carbon-nitrogen linkages can be utilized eventually in models of carbon cycling.

UNMANNED AERIAL VEHICLE (UAV)

The Subcommittee heard about the use of the unmanned aerial vehicles (UAV) as another tool to carry out special measures in conjunction with other ARM measurement systems. The UAV can perform measurements that cannot be obtained by satellite and ground based systems; however, the Subcommittee was not convinced that the same measurements could not be obtained using manned aircraft at possibly lower cost.

UAV Recommendations: The Subcommittee recommends that the DOE management conduct an independent review of the usefulness and uniqueness of the UAV compared with other methods of obtaining the same data.