An Evaluation of the Department of Energy's Free-Air Carbon Dioxide Enrichment (FACE) Experiments as Scientific User Facilities

U.S. Department of Energy
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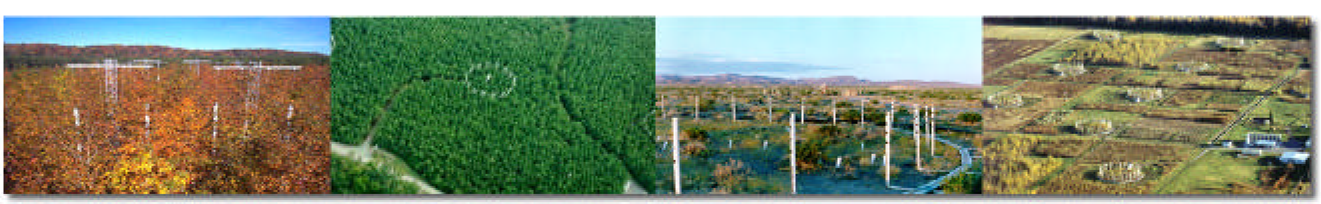

This evaluation and report was prepared by David Reichle for the U.S. Department of Energy's Biological and Environmental Research Advisory Committee. This report benefited significantly from the cooperation and contributions from the FACE facilities at Duke University, the Nevada Test Site, Oak Ridge National Laboratory, and the Rhinelander Research Station. DOE's BER/SC provided singular support throughout the review.

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It is critical to understand not only how ecosystems may respond to changes in atmospheric chemistry and climate, but also how ecosystems regulate the global carbon cycle now, and how they will regulate it in the future as conditions change.

FACE Web Sites

Department of Energy
http://cdiac.esd.ornl.gov

Brookhaven National Laboratory
http://www.face.bnl.gov

Oak Ridge National Laboratory
http://www.esd.ornl.gov/facilities/ORNL-FACE/

Duke University
http://c-h2oecology.env.duke.edu/Duke-FACE

Rhinelander, Aspen FACE Facility
http://oden.nrri.umn.edu/factsii/

Nevada Desert FACE Facility
http://www.unlv.edu/Climate_Change_Research

Executive Summary

The fate and effects of anthropogenic releases of CO_2 from fossil-fuel energy systems is an important component of the Department of Energy's (DOE) environmental research mission. The National Research Council (NRC) *(1)* and the United States Global Change Research Program (USGCRP) *(2)* have developed national research plans for carbon cycle science. Both reports identify a series of critical issues concerning the impacts of energy use on the terrestrial biosphere and the potential for effects on human society. These issues are central to the DOE mission. For the terrestrial biosphere, the overarching science questions are

- What are the magnitudes and distributions of the contemporary ecosystem sources and sinks of CO_2 and how are they changing over time?
- How do the processes in the terrestrial biosphere modulate the rate of increase in atmospheric CO_2 concentration and control the dynamics of sources and sinks?
- How will changes in atmospheric composition and climate affect the functions and structures of terrestrial ecosystems?
- How will changes in terrestrial systems induced by altered climate, atmospheric chemistry, and land use feedback on regulation of atmospheric CO_2 concentration?
- How will the ecological systems respond to carbon management options and what information is needed to evaluate these options?

These issues, and their underlying scientific questions, require the kinds of scientific information that cannot be obtained without large outdoor experimental facilities. User facilities, such as FACE (Free-Air Carbon Dioxide Enrichment), are needed to address the many natural, interacting variables that affect ecological processes.

Free-Air CO_2 Enrichment (FACE) user facilities support these research needs by providing the capability to conduct controlled CO_2 enrichment experiments in permanently sited locations in intact ecosystems. The facilities use the FACE Technology *(3,4,5)* to perform systematic observations on these ecological systems under as realistic conditions as possible. The FACE technology enables researchers to experimentally expose areas of intact ecosystems to elevated concentrations of trace gases, such as CO_2, in a controlled and controllable way *(Appendix A)*, to access components of the experimental and reference systems for sampling and

FACE user facilities represent excellent opportunities for ecologists to perform interdisciplinary, explanatory research on ecological processes and intact ecosystems under natural environmental conditions.

analyses, and to measure and monitor continuously key processes and system responses in real time without compromising the integrity of the ecosystems being observed. Face facilities provide the supporting infrastructure to maintain the experimental conditions and to systematically monitor processes and responses in the ecosystems being studied and observed.

This report was prepared on behalf of the DOE Biological and Environmental Research Advisory Committee (BERAC) based upon a request to analyze the operation, use, and value of the four BER-funded FACE facilities. The DOE/BER initiated an analysis of the BER-funded FACE facilities to assess both their current operation and use as scientific user facilities for environmental research, and how the operation and use of these facilities could be improved and enhanced in the future to increase their scientific value.

The major findings and recommendations in this report are:

The FACE facilities are attracting users.

- Research participation by off-site personnel is increasing.
- More than 368 research users have produced more than 250 peer-reviewed publications during the past 5 years.

FACE sites are evolving as effective user facilities.

- Publications are being tracked; scientific outcomes need to be evaluated.
- Records keeping is needed of user satisfaction and feedback.
- QA, data management and availability need to be strengthened.

The FACE facility network offers opportunity for additional users.

- A coordinating committee should be established to assure consistency among facilities.
- Staffing of core operations and the user interface needs to be strengthened.
- Standardized user policies and procedures are needed to promote accessibility by users.

Enhancements in research opportunities at FACE facilities can be made.

- The value of facilities should be enhanced for comparative ecosystem studies.
- Responsiveness to the user communities' needs would be improved by separately funding the facilities' core operations.

A basic mission of the Department of Energy has been the construction and operation of leading-edge facilities for world-class scientific research.

Increasingly larger and more complex experiments have become necessary to address the long-term, large-scale environmental questions.

Introduction

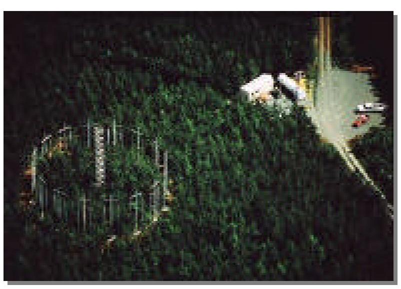
Carbon dioxide is the primary greenhouse gas affecting global climate change. The fate of releases of fossil carbon leads to the fundamental scientific question of the carbon metabolism of ecosystems, with the ultimate goal of predicting the impacts of global change on ecosystems and the impact of ecosystems on the future atmospheric content of CO_2.

The terrestrial biosphere is a major regulator of the atmospheric concentration of CO_2. Knowing the relationship of terrestrial carbon and CO_2 in the atmosphere is necessary to understand the interactions between climate and ecosystems that may occur during future climate changes. Knowing current and future fluxes of carbon is essential to managing radiative forcing by the atmosphere. A critical need is to understand how ecosystems may respond to changes in atmospheric chemistry and climate, how ecosystems regulate the global carbon cycle now, and how they will regulate it in the future as conditions change.

FACE facilities offer the potential for conducting a broad spectrum of controlled, manipulative experiments to examine the combined, interactive effects of selected human-induced and natural environmental changes on major types of selected ecosystems in the terrestrial biosphere. They also enable a broad spectrum of observations of ecosystem functioning and change resulting from manipulative experiments. They enable both remote and onsite access by multiple researchers to analyze and use the data to parameterize and test ecological response models, to measure additional response variables of ecosystem components, and to conduct process studies in the context of an intact ecosystem exposed to controlled environmental changes. These opportunities would not be possible if such facilities did not exist.

DOE initially funded the FACE sites as R&D experiments and they only later evolved into environmental research user facilities. BER currently operates four distributed research facilities referred to as FACE facilities the C-H_2O Research Site at Duke University *(6,7)*, Oak Ridge National Laboratory (ORNL) *(8,9,10)*, the Rhinelander U.S. Department of Agriculture (USDA) Forest Service (USFS) Research Station *(11,12)*, and the Nevada Desert FACE Facility (NDFF) *(13,14,15)*. In addition, FACE has a central operations support unit at Brookhaven National Laboratory (BNL).

Environmental research user facilities include specialized ecosystems, well-characterized and highly instrumented and often duplicated in different environments, to address large-scale scientific problems.



Important new scientific findings have derived from FACE facilities.

Scientific User Facilities

Conceiving of and constructing the machinery of scientific research is at least as challenging as developing or proving a scientific theory. A distinctive contribution of the Department of Energy has been the construction and operation of leading-edge facilities for world-class scientific research. The DOE Office of Science's mission includes planning, developing, building, and operating specialized facilities for use by the research community, including biological and environmental research *(16)*.

Scientific user facilities come in many different sizes and shapes, each designed to meet the specialized data needs required to answer major scientific questions; they are not simply bricks and mortar. Some physical science user facilities, such as the Advanced Photon Source, National Synchrotron Light Source, and High-Flux Isotope Reactor (HFIR), provide beam lines and sophisticated instrumentation for scientists to take a variety of measurements. Environmental facilities, such as ARM, measure many ambient environmental parameters for users, while FACE facilities provide controlled and controllable environments in which continuous core data measurements are taken on ecosystem and environmental variables and where users may access specialized instrumentation for specific measurements of ecosystem response.

DOE-Biological and Environmental Research (BER) funds two types of distributed (replicated in different environments) scientific user facilities for environmental research, both of which are "laboratory-without-walls" field facilities. The first type, represented by the FACE facilities, consist of controlled and controllable field CO_2 and O_3 exposure experiments that create and maintain environmental conditions for investigating the response of intact ecological systems to environmental changes. The second type consists of field observatories of instrumented sites that allow continuous, long-term measurements of a particular terrestrial ecosystem or column of the atmosphere. Examples of this latter type of distributed field facilities for users are the network of trace gas flux measurement facilities (AmeriFlux) and the Atmospheric Radiation Program (ARM) Cloud and Radiation Testbed (CART) facilities.

FACE user facilities study intact ecosystems, well-characterized and highly instrumented, to address large-scale comparative scientific problems. Environmental user facilities, as exemplified by the FACE facilities, are indeed a different user facility concept than that commonly accepted in the physical sciences. The basis of the FACE experiment is an

Excellent Web sites exist for each FACE facility and the DOE FACE network. All the facilities use an active presence at scientific meetings and scientific publications to communicate to the scientific community.

exposure system that controls atmospheric CO_2 levels without otherwise disrupting the environment or the ecosystem at the site. In reality, the "facility" is (1) an intact ecosystem being studied, (2) its experimental manipulation (e.g., CO_2 enrichment), and (3) the instrumentation measuring the ecosystem's response. The experimental treatments and measurement systems may change with time, but the important factors are the calibrated natural ecosystems, the collaboration inherent in scientific inquiry, and the integrity of the experiment. Those qualities and characteristics must endure.

User facilities are accessible and valuable to the user community, providing facility and infrastructure support, security and quality assurance for the experiments, long-term continuity in measurements, and data availability. This review evaluated the FACE facilities for their effectiveness in each of these categories.

Scientific Background

There are compelling scientific hypotheses to be tested at FACE facilities, such as

- Ecosystem regulation of carbon sources and sinks is affected by atmospheric CO_2 levels
- Fundamental mechanisms govern the commonality in the primary responses of terrestrial ecosystems to elevated CO_2 and
- Differences in forest ecosystem responses across the FACE facilities can be attributed to environmental interactions or ecosystem development.

The FACE facilities have enabled experiments to be performed on unaltered ecosystems. The scientific results are compelling and have been published in premier scientific journals. The results are both quantifying and changing understanding of how ecosystems, and their component mechanistic processes, function naturally and in response to global change.

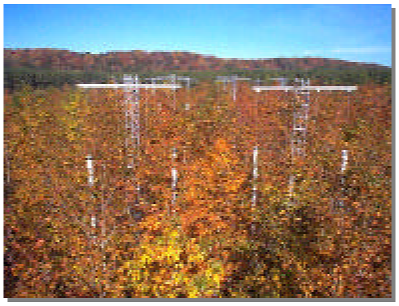
Some examples of these findings are

<u>In a southwestern desert ecosystem</u>

- While there is increased growth with increased CO_2 in forests, there are dramatic increases only in wet years in the desert.
- Wet-dry cycles in desert ecosystems affect CO_2 assimilation and nitrogen interactions.
- No significant increases in stomatal conductance and plant transpiration occur at elevated CO_2 in the desert ecosystem.
- Long-term (four years) changes in soil organisms involved in the nitrogen cycle occur in elevated CO_2.
- Abundance of desert invasive plant species (*Bromus*) increases in elevated CO_2.

<u>In a southeastern pine plantation</u>

- Net primary production, litter fall, and fine root production are enhanced in pine forests with enriched atmospheric CO_2.
- Increased soil moisture under pine forest with enriched CO_2 atmosphere is due to decreased evaporation with increased forest floor litter.
- Soil fertility limits carbon sequestration in this pine plantation with an enriched CO_2 atmosphere.



In a southern sweetgum stand

- Enhancement of net primary productivity has been sustained in a closed-canopy deciduous forest without a concomitant increase in leaf area index, but the additional carbon is allocated to fast-turnover pools, especially fine roots, rather than to aboveground woody increment.
- Photosynthetic enhancement is sustained throughout the sweetgum canopy with no indication of down regulation.
- Reductions in sweetgum stomatal conductance do not scale to similar reductions in whole-tree transpiration or annual stand-level evapotranspiration.

In a northern aspen/birch forest

- Forest pest incidence levels increased under atmospheric conditions with elevated CO_2 and O_3.
- Soil invertebrates declined with increased CO_2.
- Cold hardiness (birch and aspen) and insect pest resistance (birch) decreased with increased CO_2.
- Moderate levels of O_3 in the atmosphere offset growth enhancement caused by elevated CO_2.
- Elevated CO_2 and O_3 can caused significant changes in community dynamics and forest stand development.
- Impacts of elevated atmospheric CO_2 and O_3 rapidly cascade through the ecosystem, showing up in several trophic levels.

Most analyses of terrestrial ecosystem response to atmospheric and climatic perturbations inevitably conclude that belowground processes are key to predicting the trajectory and effects of global change. Belowground processes remain poorly understood because antiquated and cumbersome methodologies have been applied to highly complex and heterogeneous biological and geochemical systems. FACE facilities will offer new opportunities for research in these areas.

Are the BER-funded FACE facilities considered to be and recognized as scientific user facilities?

?

Are the BER-funded FACE facilities effectively operated?

?

Do the FACE sites offer significant research opportunities to scientists?

?

Can the FACE facilities be enhanced to attract more users?

?

Can FACE sites be enhanced as a distributed user network?

Review Approach

BER posed five questions that were to be addressed in the review, and these were communicated to the FACE facilities in advance, along with an explanation of the intent of the site visit. *(Appendix B)*

1. Are the BER-funded FACE facilities considered to be and recognized as scientific user facilities, and are they attracting scientists to use them as such? Users, in this case, are defined as scientists who receive their funding from a source other than [the core grant from] BER [that serves as the primary source of funding to operate the facility], but conduct research at one or more FACE facilities or utilize them for research remotely by, for example, accessing and analyzing data collected at these facilities.

2. Are the BER-funded FACE facilities effectively operated and advertised to attract scientific users, and do the facilities, or host institutions that operate them, keep track of the number of users and the products and outcomes of the research conducted at the facilities?

3. Do the FACE facilities individually and collectively offer significant opportunities for additional scientists to use them for research and, if so, what are they and how many additional users could they reasonably accommodate? If these facilities are underutilized, why?

4. How could the operation and advertising of research opportunities at the FACE facilities be enhanced to attract more users and increase their scientific value and utility?

5. Are the FACE facilities operated as a network of facilities involving the use of, for example, uniform experimental protocols and methods of measurement across the network and synthesis and intercomparison of results among facilities? If so, can their value as a network be enhanced and, if so, how? If not, what operational changes, if any, are needed and what is their existing and potential value of being operated as a network of facilities?

Each FACE facility was visited to gather information about site operations. These site visits conducted for this review were not scientific program reviews, although understanding the scientific objectives and operational protocols was necessary. The focus of discussions was placed on site operations and the actual and potential user facility functions. The reviewer met with the principal investigator(s) and/or the site operator and some scientific investigators.

The following attributes were identified in this review as important for an effective environmental research user facility:

- User outreach and communication
- Steering committee
- Site director
- A research management plan
- Experimental facility
- Measurement instrumentation
- Facility use review
- Data collection and storage
- Operations QA
- Data analysis and interpretation
- Publication and information exchange

Important attributes for distributed facility functions are

- Cross-cutting, scientific objectives
- Cross-site coordination
- Uniformity of measurements and QA
- Availability and exchange of information

The FACE facilities were evaluated using these criteria, and the results summarized in the Findings Section *(Table 3)* of this report.

Findings

The FACE facilities are becoming increasingly recognized as excellent user facilities that provide unique opportunities for environmental research. They have been established at four premier sites or institutions — the Duke Forest at Duke University, the Aspen FACE Project at Harshaw Experimental Farm at the USDA Forest Service North Central Research Station, the Sweetgum Plantation at ORNL, and the desert ecosystem at the Nevada Desert Research Center on the Nevada Test Site. All four FACE facilities have excellent experimental and measurement instrumentation and are well-recognized in the scientific community. They already have many attributes of user facilities and are beginning to coordinate their activities. Some, such as Duke University and the Aspen Site at Rhinelander, host annual FACE investigator meetings. In the future, closer coordination of experimental protocols, quality assurance, data management, and user interactions will help to ensure their performance as a distributed user facility with even a better interface with the scientific community.

More than 368 research users have worked at FACE facilities during the past five years.

Below are the five questions posed by the review and the findings associated with each site.

1. **Are the BER-funded FACE facilities recognized as user facilities and are they attracting users?**

   Users and their affiliated institutions have been documented at each of the FACE facilities, and reasonably good records are available of the research funding obtained by scientists to do research at these facilities. For the roughly five years during which FACE facilities have been operational, more than 368 researchers have used the facilities *(Table 1)*. In addition, 270 undergraduate students and visitors from across the United States and internationally have had the opportunity to learn about and, in some cases, participate in environmental research at these facilities. More than 250 peer-reviewed publications, symposia contributions, and theses have been produced *(Table 2)*. Judged against these criteria, the FACE facilities have been successful user facilities.

Table 1

Scientific Users at the FACE Facilities

Site	Scientist PIs	Tech. & RAs	Postdoc-torals	Grad Stud.	Total Research Users
Duke[a]	65	5	20	34	124
Nevada[b]	33	19	15	29	96
Oak Ridge[c]	35	10	3	11	59
Rhinelander[d]	50	11	6	7	74

Scientific users are those doing research and excludes those responsible for core operations.

(a) 1994 – June 2002, (b) April 1996 – May 2002, (c) 1997 – May 2002, and (d) data for 1997 – October 2002

<u>*Recommendation 1*</u>*.* BER program managers should meet regularly with their counterparts at other federal agencies, reinforce the relationship on interagency cooperation at DOE user facilities, and communicate the research opportunities and accomplishments at the FACE facilities.

The diversity and numbers of users *(Table 1)* and the scientific productivity of the FACE facilities *(Table 2)* demonstrate the value of the FACE facilities as research facilities. The uniqueness of these facilities is reflected both by these statistics and also by the many new scientific findings that heretofore could not have been accomplished without these facilities. But to ascertain how well these facilities are, or could be, operating as user facilities, another set of criteria were examined *(Table 3)*. These criteria examine site administration, user facilitation, data management and availability, and scientific communication and facility "advertisement."

FACE facilities are funded as part of DOE's contribution to combined inter-agency U.S. Global Program and Climate Change Science Program (USGCRP). While DOE has well-established user facility relationships in the physical sciences with other federal agencies (e.g., with the National Institutes of Health for research in structural biology research at light sources), this relationship is very new in the environmental sciences. DOE needs to ascertain the positions that other federal agencies take on funding environmental research at DOE FACE user facilities. Significant cost-sharing is already occurring by the institutions and other federal agencies sponsoring research at FACE facilities.

Table 2

Publication Productivity from the FACE Facilities

Site	Peer-Reviewed Publications [a]	Symposia/ Book Chap.	Books	Technical Reports	Theses	TOTAL	Presentations
Duke (1994-2002)	125[b]	16	0	0	12	153	240
Nevada (1996-2002)	32[c]	3	0	0	4	39	57
Oak Ridge (1997-2002)	20[d]	2	0	0	1	23	37
Rhinelander (1997-2002)	42[e]	17	2	4	2	67	16

(a) published and in press, (b) 1994 – June 2002, (c) April 1996 – May 2002, (d) 1997 – May 2002, and (e) 1997 – October 2002

2. Are the FACE facilities effectively operated and advertised to attract users (records kept, products tracked, outcomes evaluated)?

(a) User Satisfaction Feedback. While FACE facilities do not use user satisfaction forms and user feedback is not actively solicited, records have been kept of unsolicited user feedback at some facilities. Preliminary information suggests that user feedback is positive. The FACE facilities should solicit user feedback and use it in their administration of and planning for the user facilities.

Recommendation 2a. A consistent protocol for user feedback at DOE-BER FACE facilities should be established.

(b) Products Tracked and Outcomes Evaluated. Scientific publications by resident staff and visiting scientists are tracked very closely by the facilities. The FACE facilities record publications, which are annually summarized and provided to DOE-BER program managers, although there is little consistency across sites as to what constitutes a FACE publication. It ought to be simply defined as any, and all, publications resulting from research conducted at the FACE facility or using data from the FACE facility.

Recommendation 2b. DOE should provide guidance on what measures of scientific outcomes should be tracked to evaluate scientific impact.

Table 3

Evaluation of the FACE Facilities as User Facilities

	Duke	Oak Ridge	Nevada	Rhinelander
Is there a steering committee of users for the site?	?	?	?	?
Are there mechanisms for inter-site operational and scientific collaboration?	?	?	?	?
Is there a clear point-of-contact for the site for users?	?	?	?	?
Is there review of the facility's operation and performance?	?	?	?	?
Is there evaluation of the site's scientific products and outcomes?	?	?	?	?
Is there a responsible person for measurements and QA?	?	?	?	?
Is the data management and QA program documented?	?	?	?	?
Does the site archive and share data with potential users?	?	?	?	?
Is there a data use policy?	?	?	?	?
A publication credit acknowledgement procedure?	?	?	?	?
Does the site "advertise" and/or encourage users?	?	?	?	?
How do users interact with the site?				
• access to the site?	?	?	?	?
• proposals evaluated?	?	?	?	?
• user satisfaction feedback?	?	?	?	?
Is there an annual site progress report?	?	?	?	?

? = Yes ? = No ? = Partially accomplished

The user facilities are beginning to think in terms of scientific outcomes, as well as just publication numbers, and could very easily incorporate such measures into their annual reporting. There is no doubt that important new scientific findings have derived from FACE facilities that might otherwise have been unobtainable. Some FACE facilities include the following items in their annual reports:

- Web of Science and Science Citation indices
- Topics of symposia at meetings of scientific societies
- Covers and dedicated issues of scientific journals
- National news media coverage
- New research findings heretofore unreported
- Training of undergraduate and graduate students
- Evaluations by DOE advisory committee(s)
- Use of data in national and international scientific assessments
- Congressional testimony, National Academy reports, and other studies on future science directions

Recommendation 2c. A consistent QA plan and protocol for core data across all sites should be a goal of a distributed network of user facilities.

(c) Quality Assurance (QA). Quality assurance must be a cornerstone of any user facility. The scientific user must be able to access data with complete confidence in its veracity. BNL has designed a formal QA procedure for operational data (http://www.face.bnl.gov/quality.htm). At the sites it helps operate, BNL supports the site technicians in performing operational QA on the control and measurement of atmospheric CO_2 (and ozone at Rhinelander) and the performance of the exposure system. "Quick Looks" and "Live Looks" Web pages and "Daily Performance" reports are available to monitor operational performance. The DOE Carbon Dioxide Information and Analysis Center at ORNL provides QA for the Oak Ridge user facility.

Research data QA is less standardized across the sites. QA needs to be a standardized component of core operations of every FACE user facility.

Recommendation 2d. The FACE Coordinating Committee should establish a policy for operations and research data management, and data availability procedures should be established (see 3a recommending establishment of a FACE Steering Committee).

(d) Data Archiving and Availability. Data management and availability to users is a work in progress at all FACE facilities, and to date there is no uniform protocol across the facilities for data management, archiving, and use. This is a key function for a user facility. FACE researchers and their sponsors want to provide access to accurate (quality-assured) and well-documented data from all the FACE facilities in a uniform and consistent manner. The DOE Carbon Dioxide Information Analysis Center (CDIAC) Web site provides easy access to background information

on all the FACE facilities. Operational and experimental data are available directly from principal investigators (PIs) working at the FACE facilities, but there are considerable differences in philosophy and approach on data documentation and sharing across the sites.

The BNL FACE data manager provides data to scientific users on system performance (release rates of CO_2, uniformity of CO_2 across the study area) and selected experimental data (wind speed and direction, PAR, and temperature) for Duke, NTS, and Rhinelander. Operational data are archived by BNL in Microsoft Access database format, available for download from the Internet or as a CD. Individual researches at all FACE facilities can provide users with additional data, but this is not a uniform policy, and issues of data propriety exist. Improved standardization of data management for operational data and research results across all FACE facilities would improve their functioning as a distributed network.

ORNL uses the DOE CDIAC and its data managers to archive data for user dissemination, scanning data to ensure that operating data are within acceptable quality limits. All users are assured that they will be provided with all the necessary, quality-assured core data for their projects. Research data on ecosystem response parameters are quality assured by principle investigators and shared with users on an "as needed" basis. All users are assured access to all the information needed to conduct their research.

The Nevada Test Site facility is on the right path with a designated data manager, and their approach should be encouraged by DOE as the standard expectation for all sites. Nevada has a resident site data manager and has adopted many of the CDIAC protocols for data documentation and quality assurance (QA). It is the only site that has a policy and plan for data documentation by users; all data are required to be documented and submitted to the site by January 31 of the year following their collection. Failure to comply with this policy results in future restriction to site access. A three-tiered data structure is used to disseminate core data rapidly, while protecting proprietary data.

Operational data at Rhinelander are available on the BNL Web site. CO_2 and O_3 data are examined for QA and archived on CDs, which are distributed upon request to investigators. BNL and Rhinelander conduct QA checks and handle archiving of the CO_2 and O_3 data, respectively. Micrometeorology data is checked for QA, archived, and available on the web site run by the USFS (www.fs.fed.us/nc/face or climate.usfs.msu.edu/face/meteorology.html). The USFS has just released a document that specifies Forest Service information and data management policies, "Knowledge Management and Program Delivery" *(17)*, and the Rhinelander FACE facility will serve as the case study to improve their information management for individual users.

Operational data at Duke are available from the BNL Web site. At Duke, management of research data is supported by the individual research projects. Research data have initial QA performed by the site director's graduate students, using range limits and cross-correlations. The site director's data manager performs a second QA before research data are published on the Internet at http://152.16.58.129/site/resources.html. Duke has a clear-cut data use policy (much the same as that used by CDIAC) based upon the Fair Use Policy of Harvard.

Duke University has also developed an outstanding Web site interface for users that integrates applications for access, reviews experimental protocols, provides operating protocols and training, and performs subsequent tracking of scientific products and publications. This is a commendable management tool that should be adopted by all of the FACE facilities and supported by DOE as an administrative function of a distributed FACE network.

(e) FACE "Advertising." The FACE facilities are doing an excellent job of advertising themselves. Web sites exist for each FACE facility and the DOE FACE network. All use an active presence at scientific meetings and scientific publications to communicate to the scientific community. Sites also use brochures very effectively, and several have received airtime on National Public Radio, CBS, CNN, BBC, and public television. Covers of prominent scientific journals (*Science*, *BioScience*, *Global Change Biology*, *Nature*, *Environmental Pollution*, and *Plant, Cell and Environment*) and *National Geographic* magazine carry the message to both the scientific and general public. FACE experiments have appeared in local, national, and international newspapers, and corporate and airline flight magazines have highlighted this work. A formal annual report is not produced by all sites, but BNL has produced a FACE progress report for DOE *(18)*. DOE receives annual progress reports from the FACE facilities that are available on the internet.

(f) Safety at the Sites. All of the FACE facilities have performed hazard analyses and have documented safety regulations and procedures. The uniformity in safety analysis among sites could be enhanced if it were part of a centralized FACE Facility Management Plan. Lightning, electrical hazards, fire, elevated work stations, and hazardous chemicals (such as ozone at Rhinelander) are key concerns. Users of the FACE facilities on DOE and USFS lands seem to have been able to accommodate to DOE and USFS safety requirements of these agencies without undue difficulty.

(g) Site Accessibility. The FACE facilities are readily accessible to users. Designated points of contact and procedures for requesting user access are posted on the FACE Web sites. Staff responsible for user and visitor access to facilities on DOE lands have a one to two week lead time to process badges for U.S. citizens. Both sites have special requirements (ORNL – 30 days and NDFF – 8 weeks) for foreign nationals.

3. Does the distributed FACE network offer significant opportunities for additional scientific users (how many more, what areas, why underutilized)?

Recommendation 3a. A FACE Cross-Site Coordinating Committee should be established to ensure that the scientific directors of the FACE facilities are actively engaged in collaborative planning for future research that is integrated across the sites. Planning of research at each site should be a result of site-specific user advisory committees.

(a) Additional Opportunities for Users. Underutilization of FACE facilities potentially squanders a national scientific resource. All sites can accommodate additional users, but each of the sites has physical limitations and must coordinate user access closely to protect the integrity of the experimental facility. The impact of proposed research is a consideration at all sites. The site director at Duke, for instance, can approve proposals quickly if there is no physical site impact involved and has had to make only one declination in the past two years out of approximately 40 requests. Establishing FACE as a formal DOE user facility is a step toward meeting the operational recommendations in this report and for strengthening support for scientific users. Additional funding would be required to provide full-time site scientific directors, operational supervisors, and data managers to meet increased user requirements. This strategic reorganization would be expected to significantly enhance the scientific value of the facilities and, consequently, increase user participation. Prompt accessibility to data by users could become a limitation in the future if there are not increased investments in data management and quality assurance, and there is potentially unlimited user opportunity for nondestructive experiments and modelers, especially those who wish to develop and test models by remotely accessing either data that are already archived or are being routinely measured. Continued development and deployment of automated, remote measurement technologies will improve both the cost-effectiveness of measurements and the availability of data to users.

Closer coordination of FACE facilities would assure uniformity of operational and use policy and research results documentation across sites.

Recommendation 3b. A documented user policy and procedure should exist at each site. Evaluation of site user procedures could be an oversight responsibility of a FACE Steering Committee.

(b) Potential for Increased Numbers of Users. All FACE facilities reported that the research sites could accommodate at least a two- to three-fold increase in the number of users but that none were adequately staffed, even at present, to handle the user interface. Access equity between inside and outside users should exist. Guidelines to users as to their responsibilities to adhere to safety procedures, respect the integrity of equipment and the ongoing experiment, share data, and report publications would be useful. Wide disparity now exists among sites. Some sites give the approved visitor site access, but they must find their own way around. Other sites have more formal training and oversight of users. ORNL and Nevada Test Site have official user facility policies for the DOE laboratory or site that each FACE user must follow. Obviously, different user procedures place different levels of demand on the site personnel.

Also, not all FACE facilities have documented user access policies and procedures. In a properly functioning set of FACE user facilities, especially a distributed network of such, scientific users ought to encounter a similar approach at each site. Presently, this is an obvious discrepancy for users attempting cross-site investigations. Having such a standardized policy is important not only to assist the potential user but also to protect the site facility in the event of denied site access, mistreatment of equipment or data, or other potential disputes. Both on-site and off-site scientific users should submit requests for facility access and be evaluated nonpreferentially.

4. How can the operation and advertising of research opportunities at FACE facilities be enhanced (attract more users, increase scientific value)?

Recommendation 4. Continue new R&D funding opportunities at FACE facilities for university and national laboratory researchers and include instructions to contact FACE facilities for R&D opportunities. This will continue to increase user numbers.

Many of the FACE facilities expressed some frustration with underutilization. This rate of utilization by users may be caused by (1) the newness of the user facility concept in the environmental research community, (2) lack of awareness of opportunities at FACE facilities, and (3) inadequate funding for meritorious proposals at FACE facilities. Continued evidence of exciting scientific accomplishments form compelling reasons for users to take advantage of the facilities. Enhancing the scientific opportunities of users should remain the site's primary goal.

The DOE FACE facilities are communicating well to the scientific community through FACE Web sites, the CDIAC Web site, scientific symposia at scientific society meetings, DOE Science Team meetings, international FACE conferences, International Geosphere-Biosphere Program (IGBP) committees and meetings, and most importantly a growing list of open literature publications. Scientific accomplishments are being communicated in the scientific literature. Publications and topical symposia at national scientific meetings continue advertising user research opportunities at FACE facilities.

In the community of ecologists and environmental biologists, many are inexperienced in designing and constructing large-scale experimental user facilities. DOE has exercised leadership in supporting large-scale, multi-disciplinary and multi-investigator research to advance the understanding of environmental phenomena.

5. Can FACE be enhanced as a distributed user network?

Recommendation 5a. All FACE facilities should be encouraged to participate in coordinated synthesis activities, including participation as a measure of site performance.

(a) Many FACE participants are enthusiastic to enhance their administration and operations to better function as a network of distributed user facilities. One technical result would be improved cross-site syntheses and comparative ecological interpretations. A distributed and integrated facility network will as a matter of cause

- Identify gaps in data sets and new approaches to data collection (e.g., automatic soil moisture and non-destructive vegetation measurements)
- Demonstrate the strength of using a common protocol for measurements (e.g., soil nitrogen dynamics and plant growth/productivity)

- Identify information gaps and the importance of the need for new data collection methods (e.g., for fine roots)
- Emphasize the value of centralized availability of core data.

Standardized variable selection and measurement techniques would allow comparison of responses across ecosystems.

DOE should continue to encourage synthesis proposals, workshops, etc. A FACE forest synthesis has been partially funded by DOE and the USFS; this was initiated with an emerging data workshop in May 2002 that assembled a series of comprehensive data sets across the FACE forest sites to enable subsequent analyses. This meeting will be followed by an analysis and synthesis workshop in early 2003, which will involve quantitative and conceptual analyses of data sets and preparation of a set of high-impact papers on forest response to elevated CO_2 (transpiration, soil respiration, and nitrogen mineralization). Future model-experiment interaction workshops are planned but, as yet, unscheduled. This is an excellent beginning at cross-site comparisons. The FACE facility at NTS should be included with the forest sites in synthesis activities of the DOE FACE facilities.

Recommendation 5b. The value of the FACE facilities as a network of distributed user facilities should be enhanced by DOE by

- Separating DOE budget lines for facility operations and research
- Defining and ensuring the minimal set of core measurements to be made at each site

(b) Enhancing the Value as a Network. While at some time in the future additional FACE facilities may be desirable, that is not necessarily the immediate priority. The operational performance of the existing FACE facilities needs to be enhanced. Variations in performance among sites to date largely result from funding levels and time in operation. BNL has played both an important science and support role (construction design, hardware, and software) necessary to successfully build and operate FACE facilities. ORNL had the internal capacity to build, operate, and maintain their facility from original BNL specifications, but the other sites without these resources stated that their facilities could not have been possible without BNL support and continuing collaboration. The site directors have been stretched from leading the science program to helping users and overseeing operations. Too much is expected of too few individuals. All sites need to strengthen their user interface and have support for full-time core operations supervisors and data managers.

New investments in automatic data collection (e.g., soil moisture, subsurface respiration and mineral fluxes, ^{13}C signal in CO_2 fluxes, and vegetation parameters) would minimize site impacts and accelerate data accessibility. All sites need to have high-speed data lines at the FACE facilities. Dedicated "always on" Internet access is needed for more frequent transfer of data and better remote access. Also, prompt transfer of data to data storage servers and then to data repositories for access by scientific users is important. The sites need to remain sensitive to the needs of onsite users who might require support laboratory facilities and improved canopy access (walkways, personnel lifts, and cranes).

Recommendation 5c. Each site should have a designated site director, whether called the principal investigator(s) or project manager. There are three important subordinate leadership positions: scientific director, operations manager, and site operator, one of which might be filled by a local PI or project manager.

(c) Operating as a Distributed Network. Enhancing the measurement programs at FACE facilities and improving users' accessibility to sites and data will place increasing strains upon site personnel. There should be clear delegation and separation of duties and common definition of core measurements across sites, not to needlessly bureaucratize the user facility but to ensure that adequate attention is given to site operations, user interactions, and scientific execution. The site operator should be a highly competent, full-time employee with primary responsibility for running FACE equipment.

The facilities need to adequately staff for administration and operations, with emphasis on satisfying the needs of the research user community. The user interface, convenient facility access, and easy data availability should not be compromised by the research activities of facility PIs. The role of the FACE operator, who may also be the site manager, is critical. There is a steep learning curve for this position, and replacement of a qualified FACE operator is difficult and time-consuming. BNL is called upon to fill in and assist various sites when local manpower needs are low. The FACE facilities are typically understaffed for optimal maintenance and operations, leaving the operator little time to assist facility users. Most sites felt that they need DOE direction in evolving into a distributed facility and that this would likely not occur without additional investments in administration and operations.

Benefits of operating as a distributed facility would be better coordination of operations procedures and costs, consistent tasks across sites, quantity purchases and pooled equipment inventories, continued improvement in operations software, and enhanced data archiving and QA. Annual costs for CO_2 vary considerably across sites

($250K/year in the desert and ~$640K-$700K/year at the forest sites). CO_2 quantities used at the FACE facility are large (over 20 tons of CO_2 per day at each of the forest sites and 100 g O_3 per day generated from O_2 at Rhinelander), and CO_2 remains a significant part of the operating costs (at least 30% of the core budgets).

BNL has two distinct FACE project tasks with similar funding levels. The first is entirely dedicated to operation of the FACE experiment at Duke Forest. The second, "FACE Facility Development," has four task areas. The first area is current operations at three of the DOE-supported FACE facilities (Duke, NDFF and Rhinelander). BNL monitors FACE operations directly by dial-up or Internet connection to quality-assure operational performance. For experiments that run throughout the year, as at the NDFF at the Nevada Test Site, BNL provides continuing engineering and problem solving support year-round. Another area is to develop infrastructure and improve performance of existing FACE facilities. This includes support and upgrades of control systems. A third area is continued development of the research platform concept for FACE facilities and development of data acquisition systems linked to the Internet that can be applied not only to FACE but also to other field programs, such as AmeriFlux, that have many common interests with the FACE facilities.

6. Other issues

In the course of the site reviews, other issues arose that are pertinent to DOE's charge but were not readily categorized under the five DOE questions. These issues are discussed below.

Recommendation 6a. A DOE FACE Steering Committee, which establishes the operational and research guidelines for all FACE facilities, should define standardized core measurements at each site. Such a steering committee might be composed of three to four outside, preeminent scientific experts plus the site directors, offering unbiased extramural perspective and internal knowledge and practicality.

(a) _Core scientific measurements._ The concept of "core" scientific measurements, versus scientific R&D measurements, must be clarified at each site. The original funding of FACE facilities as research projects and the continued lumping of site core functions and research in a single funding document confuse what are core vs research measurements. There is considerable variation across the FACE facilities as to what constitutes a core measurement. Is it CO_2 exposure levels and basic meteorological data? Does it include initial site characterization? Should basic ecosystem response parameters (e.g., measurements to calculate net primary production [NPP] and net ecosystem production [NEP]) be considered core data? Consequently, resources allocated to operation of the user facilities and core data collection vary across sites. Research data of common interest to most users might be considered as "core data." The important issue is that these data be measured and made available to users.

All FACE facilities were amenable to increased collaboration/coordination as a set of distributed user facilities, thus encouraging the sharing of new ideas and scientific synthesis. This might be accomplished by a DOE cross-site steering committee that included the FACE facility directors. Establishing separate, identifiable core budgets for each FACE facility could help encourage more open and effective operation of the sites as user facilities. DOE might consider FACE core operations as part of a single DOE/BER user facility budget. This would avoid meritorious research competing with operating funds.

Recommendation 6b. Existing funding for FACE facilities should be separated into core facility operations and R&D at all sites.

(b) Leveraging of Research Funding. It is difficult to assemble data on costs of core operations and research at the FACE facilities. Basic operational costs have not been expensive when CO_2 costs are excluded (less than $300K per site). The funding sources for core operations and research have been very diverse; besides DOE-BER (Terrestrial Carbon Program [TCP] and Program for Ecosystem Research [PER]), other DOE sources have included Experimental Program to Stimulate Competitive Research (EPSCoR), National Institute for Global Environmental Change (NIGEC), LDRD, Nevada Operations Office (NVO) site support and interagency TECO solicitations, with WFO from USGS, NSF, Desert Research Institute (DRI), USFS, Canadian Forestry, and federal agency and university cost-sharing. In reality, DOE-BER has stimulated significant outside investment in these user facilities. Two of the sites gave considerable credit to TECO funding as being instrumental in both shaping the research at their FACE facility and also in stimulating inter-site comparisons.

Recommendation 6c. Scientists at each of the sites should determine whether operating protocols result in consistencies across sites for inter-comparisons of results.

(c) Consistent Experimental Operating Procedures. The individual FACE facilities differ in a number of their exposure protocols, for example, whether there is fumigation at night (NTS and Duke) or not (ORNL and Rhinelander), and set points for CO_2 (Duke = ambient plus 200 $\mu mol\ mol^{-1}$, 24-7; ORNL = 560 ppmv). The NDFF uses a 550 ppmv set point. All sites except ORNL use the Brookhaven set point controls, and the same software for feedback control on CO_2, and operate at ± 20% of respective set points more than 84% of the time. Regardless of set point controls, actual CO_2 concentrations will vary. What is important is that investigators report actual CO_2 concentrations in their publications.

Recommendation 6d. The administrative and operational components of the FACE facilities should be responsive to the user community. Although one would expect some degree of flexibility for sites to organize in ways to capitalize upon their host institution(s) structure, key functions at each site (e.g., director, operations manager, chief technician, and data manager) should be recognized by the user facilities as essential staff positions.

(d) FACE Facility Management and Administration. The Nevada and Rhinelander sites use a steering committee consisting of PIs to administer the site and review user proposals. Nevada's Committee is comprised of several university and DRI representatives; Rhinelander's consists of university, USFS, and national laboratory scientists and is probably the most diverse; Oak Ridge's uses only ORNL PIs for its Steering Committee. The Nevada and Rhinelander sites delegate the responsibilities for site director, site operations, and science coordination to discrete individuals (Nevada also has a chief site ecologist and chief site technician). At Oak Ridge, most functions are the responsibility of the FACE facility PI. Oak Ridge, Duke, and Nevada have designated data managers. Nevada and Rhinelander have good operational structures that ought to be emulated by the other sites. All of the sites' staffing for operations is marginal and should be strengthened.

A minimal management structure for a FACE facility ought to include a senior site manager, a site operator and backup operator in training, and a site data manager funded as part of the user facility core operations.

All four sites report review and turnaround times of a user's request for site access of one to two weeks and appear to have clearly identified points of contact.

All of the FACE facilities have developed mechanisms to secure CO_2 from fossil sources that have a different, and unique, carbon-13 signature from that in ambient air (Nevada from a California gas supplier, Rhinelander from PRAXAIR in Iowa, ORNL from BOC, and Duke from PRAXAIR – Fertilizer Production Plant in Hopewell, Virginia). This variation in isotopic signatures permits exciting, breakthrough tracer experiments, leading to identifying and quantifying ecosystem pathways and feedbacks for carbon assimilation, transport, and allocation.

Site security at ORNL, NTS, Duke Forest, and the USFS Rhinelander experimental forest have been cited by users and all site managers as being invaluable for the integrity and protection of these long-term ecological experiments. In addition, Duke, Nevada, and Oak Ridge profited from historic site ecosystem data generated through the International Biological Program (IBP), and Rhinelander benefited from a long history of forest productivity experiments. Both Rhinelander and Oak Ridge parlayed previous DOE investments by the bio-energy programs. Duke also has a colocated AmeriFlux facility. All the sites now offer the advantage of the long-term continuity of key core personnel and the science management teams.

Recommendation 6e. The FACE Coordinating Committee should provide the requisite overall planning for strategic issues for the FACE network.

(e) Strategic Planning. Most of the sites would welcome greater DOE leadership and felt that planning by a FACE Steering Committee that included objectives and approaches would be very important in developing a more integrated distributed FACE network. One consideration is how the critical financial resources are allocated to maintenance of the FACE facilities. Better strategic and out-year planning would allow the user facilities to execute infrastructure improvements more efficiently and do advanced preparation for future ecological research. Other strategic issues include how to interface FACE facilities with international FACE experiments and other potential environmental user facilities.

Summary

The FACE Facilities are good examples of environmental user facilities.

While the FACE experiments are still new user facilities, they have demonstrated their importance to researchers in the scientific community, as well as to the mission of the DOE. DOE is in an enviable and important position, and it should aggressively support the FACE facilities; DOE's foresight and investment in environmental user facilities can affect the future of environmental research and progress in this scientific field.

While there remain opportunities to strengthen and improve the FACE facilities, the enthusiasm and caliber of the professional staff and the existing facilities are impressive.

FACE experimental facilities were not intended at the outset to be user facilities, but their broad scientific relevancy and diverse research participation have demonstrated their utility as environmental user facilities. DOE is now exploiting the potential of FACE facilities by funding them as user facilities and encouraging the sites to expand their scientific scope beyond CO_2 questions to also address the processes by which ecosystems respond to climate change.

The data summarized in this report represent the first five years of operation of the four FACE facilities. In the five years, from mid 1997 to 2002, more than 368 research users produced more than 250 scientific publications, reports, and theses. Users and scientific publications have been progressively increasing. The facilities operate with an "up time" greater than 95% above 4º C (uncommon during the growing season), making them dependable resources for scientific users.

FACE facilities are based upon sound scientific research.

The FACE facilities are good examples of environmental user facilities whose foundation is based upon sound scientific research plans. All of the FACE facilities can be characterized by enthusiastic research teams, good intra-site cooperation, and growing inter-site collaboration. They all have demonstrated considerable versatility in securing financial support from DOE and other federal agencies.

Most FACE researchers are eager for cross-site synthesis and comparative scientific interpretations.

Seeking better inter-site result comparability and interface consistency has lead to the concept of a network or "distributed user facility." This evolution has created "unfunded mandates" in data management, modeling, and inter-site syntheses recognized by all to be critical activities that are having to compete for resources with core operations requirements. The sites need to collectively identify for DOE the minimal set of core measurements and facility operations that should be consistent across all facility sites.

Success of the FACE facilities as a network of user facilities will depend on a closer inter-site coordination (e.g., site directors functioning on a cross-site coordinating committee), well-conceived experimental designs, strategic location of facilities in key biomes representing important ecosystems, archival repository of data for future use, and incorporation of simulation modeling for interpretation and extrapolation of results. Data management needs to be strengthened at all FACE facilities. Among all the FACE facilities, Duke appears to have achieved the best synergy among experimentalists and modelers, with eight modeling groups accessing data during the past two years.

It is recommended that DOE/BER establish a cross-site FACE Coordinating Committee consisting of the FACE facilities science manager and selected experts from the scientific community. The purpose of this Coordinating Committee would be to:

- Encourage program integration and coordination
- Enhance the user interface with policies and procedures facilitating accessibility and use
- Establish a necessary and consistent set of core measurements
- Cross-site standardization of operations as appropriate
- Determine user satisfaction and obtain feedback for improvement
- Evaluate science productivity and outcomes

FACE user facilities have been very successful. While opportunities remain to strengthen and improve the FACE facilities, the enthusiasm and caliber of the professional staff and the existing facilities are impressive. The host institutions and other funding sources have provided considerable cost-sharing. The sites are operating extremely effectively. The scientific community abounds with innovative new ideas and experimental designs for examining pertinent future issues at FACE facilities.

DOE can take several actions which will enhance FACE performance as environmental research user facilities:

- Separate operational and research funding lines for the facilities
- Ensure adequate support staff for user facilitation – site director, operations manager, and data manager
- Encourage cross-site data comparisons and synthesis.
- Continue to share FACE accomplishments with other agency counterparts

The FACE user facilities might better be called "global change research sites." FACE is just one technology (instrumentation) applied to manipulating an ecosystem. Other approaches are likely to be developed. Independent of the experimental technology, the progressive development of measurement and understanding of basic ecological processes would be relevant to other user facility experiments. FACE user facilities can achieve even greater value with the addition of new measurement systems and experimental variables such as water, nutrients (nitrogen), and/or trace gases. Consideration should begin now on how results from FACE facilities will be scaled-up for regional problem solving through (a) modeling, (b) inclusion of additional environmental variables, (c) addition of measurement of new ecological processes, (d) gradients of FACE rings along moisture/growing season gradients, and (e) new experimental manipulations.

Many opportunities exist for enhancement of research at the FACE facilities.

FACE user facilities represent excellent opportunities for ecologists to perform interdisciplinary, explanatory research on ecological processes and intact ecosystems under natural environmental conditions. These facilities are providing both real-time and archived (quality-assured) data, heretofore unavailable, to the scientific community. The distributed network of FACE user facilities would permit comparison of results across ecosystems and serve to quantify fundamental ecological properties and mechanisms of ecological systems.

Appendix A

More information plus the relationship between the four DOE FACE projects and others is at http://www.face.bnl.gov/face3.htm.

FACE Facility Characterization

Site	Ecosystem Type	No. Rings	Experimental Variables
Duke	Loblolly Pine	7	CO_2 – ambient +200 µmol mol-1, daytime fumigation
Oak Ridge	Sweetgum	6	CO_2 – 560 ppm, daytime fumigation
Nevada	Desert	9	CO_2 – 550 ppm, 24-hr. fumigation
Rhinelander	Aspen, Birch	12	CO_2 – 560 ppm, daytime fumigation, variable O_3

More details can be found on the CDIAC Web site.

Core Data Measurements at the FACE Facilities

Core data measurements at the sites include

Duke Forest: carbon dioxide concentrations, storage fluxes, meteorology, soil fluxes, stand vegetation characteristics and physiology, and soil characteristics

Nevada Test Site: carbon dioxide concentrations, weather, micrometeorology, soil moisture, and species composition

Oak Ridge: stand characteristics, carbon dioxide concentrations, weather, micrometeorology and soil moisture

Rhinelander: carbon dioxide and ozone concentrations, meteorology, ring maps of vegetation and information on tree clones

Appendix B

Total Construction Costs and Present BER Funding of Four DOE FACE Facilities

Site	Construction Cost[a] ($M)	Fiscal Year 2002 BER Support for Research, Operation, and Maintenance of each FACE Facility[b] ($M)
Duke	1.67	3.48
Nevada	2.89	1.14
Oak Ridge	1.05	1.02
Rhinelander	1.70	1.77
Total	**7.31**	**7.41**

[a] Construction cost included the cost of (a) labor needed to prepare each site for the four experiments; (b) permanent equipment needed to conduct the experiments, including gas handling and mixing systems, CO_2 (and O_3 at Rhinelander) analyzers, CO_2 evaporators, CO_2 (and O_2 at Rhinelander) storage tanks, wiring, computers, meteorological sensors, and O_3 generators (at Rhinelander), etc.; (c) software and its installation required to monitor, analyze, and archive the CO_2 (and O_3 at Rhinelander) concentration measurements; (d) hardware infrastructure used by researchers to gain access to the facility, including walk-up towers and mechanical lifts for access to plant canopies, walkways to protect the soil surface, etc.; and (e) labor used to construct and install all hardware and software at each site. Construction cost varied among facilities because of differences in the number of treatment rings (ranging from six to 12), the number of gases controlled (CO_2 or CO_2 and O_3), the amount of site preparation (including propagation of 40,000 trees at Rhinelander; all other facilities used existing vegetation at the facility site), local labor and equipment cost differentials, and infrastructure requirements for researchers to gain access to the different ecosystems.

[b] BER does not differentiate funding for facility operation and maintenance from funding for research at the FACE facilities, but roughly 50% of the current BER funding for FACE is associated with operation and maintenance of the facilities. Some of the funds allocated to the Duke site, through funding of Brookhaven National Laboratory, support activities at the other three sites, especially software and hardware troubleshooting. The total annual BER support for all four facilities combined equaled approximately 39% of the combined Fiscal Year 2002 budget for BER's carbon cycle and ecological research programs.

Appendix C

DOE Charge Letter to Reviewer

Page 1

Department of Energy
Germantown, MD 20874-1290

FEB 0 6 2002

Dr. David E. Reichle
237 Mainsail Road
Kingston, TN 37763

Dear Dr. Reichle:

As you know, the Department of Energy's (DOE) Office of Biological and Environmental Research (BER) funds several Free-Air Carbon Dioxide Enrichment (FACE) facilities in the U.S. These are distributed experimental facilities located in different types of ecosystems. The DOE Office of Science considers these FACE facilities to be non-traditional in that they are not single-purpose, bricks-and-mortar kinds of facilities. Instead, they consist of hardware and instruments installed in the field to conduct controlled experiments on intact ecosystems. The experimental design, measurements, and observations at FACE facilities are diverse and can include multiple potential endpoints of interest to the scientific community.

As I indicated to you on the phone, I would like an evaluation of the operations of four BER-funded FACE facilities: (1) the loblolly pine forest facility at Duke Forest in North Carolina, (2) the aspen forest facility at Rhinelander, Wisconsin, (3) the Mohave Desert shrub facility at the Nevada Test Site in Nevada, and (4) the sweetgum plantation facility at the Oak Ridge National Laboratory in Tennessee. In particular, I am requesting an evaluation of their operations as user facilities, focusing on the following specific questions:

1. Are the BER-funded FACE facilities considered to be and recognized as scientific user facilities, and are they attracting scientists to use them as such? Users, in this case, are defined as scientists who receive their funding from a source other than BER, but conduct research at one or more FACE facilities or utilize them for research remotely by, for example, accessing and analyzing data collected at these facilities.
2. Are the BER-funded FACE facilities effectively operated and advertised to attract scientific users, and do the facilities or host institutions that operate them keep track of the number of users and the products and outcomes of the research conducted at the facilities?
3. Do the FACE facilities individually and collectively offer significant opportunities for additional scientists to use them for research; and if so, what are they and how many additional users could they reasonably accommodate? If these facilities are underutilized, why?
4. How could the operation and advertising of research opportunities at the FACE facilities be enhanced to attract more users and increase their scientific value and utility?
5. Are the FACE sites operated as a network of facilities involving the use of, for example, uniform experimental protocols and methods of measurement across the

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DOE Charge Letter to Reviewer (continued)

Page 2

network and synthesis and intercomparisions of results among the facilities? If so, can their value as a network be enhanced, and if so, how? If not, what operational changes, if any, are needed and what is their existing and potential value of being operated as a network of facilities?

It would seem appropriate for the evaluation to be done by a small team consisting of individuals like you who have knowledge and experience with the operation, maintenance, and use of research facilities. The team would then report its findings and recommendations, as a subcommittee, to DOE's Biological and Environmental Research Advisory Committee (BERAC). Accordingly, I suggest a BERAC subcommittee of two to undertake the evaluation, consisting of you and Dr. Boyd Strain. Dr. Gene Bierly, who is a member of the BERAC, will be asked to serve as your BERAC point of contact.

As a first step, please contact Boyd to ask whether he is available and interested in serving as a member of this subcommittee. Secondly, I will arrange a briefing for the subcommittee on the FACE facilities funded by BER. The briefing will be held at DOE Headquarters in Germantown, Maryland or at some other location in the Washington, D.C. area on a date convenient for the subcommittee. Travel support for the briefing and for site visits to FACE facilities will be provided to the subcommittee by the Oak Ridge Institute for Science and Education (ORISE).

Enclosed is a March 2001 FACE Research Progress Report that includes summary information on the four BER-funded FACE facilities to be evaluated. Additional information on these and other FACE facilities is available on the FACE website: http://cdiac.esd.ornl.gov/program/FACE/face.html.

If you have questions about this request or need additional information, please let me know.

Yours sincerely,

Jerry W. Elwood, Ph.D.
Director, Environmental Sciences Division
Office of Biological and Environmental Research
Office of Science

Enclosure
cc:
Dr. Gene Bierly
Dr. Jeff Amthor (w/o enclosure)
Dr. Roger Dahlman (w/o enclosure)
Dr. Keith Hodgson
Dr. Ari Patrinos (w/o enclosure)

Letter to FACE Facility PI Before Visit

SAMPLE

The DOE Office of Biological and Environmental Research (BER) has asked me to help them collect information and evaluate four of its distributed research facilities, referred to as the Free-Air Carbon Dioxide Enrichment (FACE) facilities at Duke University, Oak Ridge National Laboratory, Rhinelander USFS Experiment Station, and the Nevada Test Site. The objective of this effort is to provide information to DOE to help them, and you, to develop and operate these experimental facilities as User Facilities. So, my visit is not a scientific program review; although understanding the scientific objectives and operational protocols will be helpful. I will focus on site operations and the actual/potential User Facility functions. Therefore, it is not necessary to treat my visit as a scientific program review nor to meet with scientific investigators. Instead, discussions with the Principal Investigator(s) and or Site Operator will probably be sufficient.

BER has already sent to you the five fundamental questions that they want addressed. I am attaching these as **Attachment # 1** for your convenience. This is not a pass/fail review, but rather a cooperative effort to improve the attractiveness of FACE sites as User Facilities.

To maximize the effectiveness of my one-day visit, it would be helpful if you could provide me with the background information outlined **in Attachment # 2** before my arrival. While some of this may take time for you to collect and organize, receiving this information from you before my visit, will allow me to obtain a better understanding of your site and its operations. It will also give us more time to discuss other issues when I visit. Please send information to my home address:

David E. Reichle
237 Mainsail Road
Kingston, Tennessee 37763

Some of these "other issues" I have listed in **Attachment # 3** as more specific questions about your facilities' operations in a broader user facility context. They are talking points and are not organized in any particular order. But, I hope that they provide you with adequate lead time to obtain some of the information asked for; in some cases the appropriate answer may simply be "yes" or "no."

I am scheduled to meet with you on July 18, 2002, and will be coming alone and will be available all day. I would encourage you to set up a schedule as you deem most appropriate, leaving ample time for discussion. The Oak Ridge Associated Universities (ORAU) is handling the logistics for me as I visit the FACE sites. Please advise Mike Wetzel at ORISE (e-mail: wetzelm@orau.gov) as to your hotel recommendation for the nights of July 17-18, 2002, directions/local transportation and meeting location.

If you have technical questions you can reach me by e-mail at drr4der@aol.com/.

Respectfully,
Dave Reichle

Attachment 1

1. Are the BER-funded FACE facilities considered to be and recognized as scientific user facilities, and are they attracting scientists to use them as such? Users, in this case, are defined as scientists who receive their funding from a source other than [the core grant from] BER [that serves as the primary source of funding to operate the facility], but conduct research at one or more FACE facilities or utilize them for research remotely by, for example, accessing and analyzing data collected at these facilities.

2. Are the BER-funded FACE facilities effectively operated and advertised to attract scientific users, and do the facilities, or host institutions that operate them, keep track of the number of users and the products and outcomes of the research conducted at the facilities?

3. Do the FACE facilities individually and collectively offer significant opportunities for additional scientists to use them for research and, if so, what are they and how many additional users could they reasonably accommodate? If these facilities are underutilized, why?

4. How could the operation and advertising of research opportunities at the FACE facilities be enhanced to attract more users and increase their scientific value and utility?

5. Are the FACE facilities operated as a network of facilities involving the use of, for example, uniform experimental protocols and methods of measurement across the network and synthesis and inter-comparison of results among facilities? If so, can their value as a network be enhanced and, if so, how? If not, what operational changes, if any, are needed and what is their existing and potential value of being operated as a network of facilities?

Attachment 2

In order to foster a better understanding of each site and its operations and allow more time to discuss other issues during the visit, the following background information was collected beforehand:

1. Names and institutional affiliations of users, dates of involvement, and nature of the collaboration (e.g., worked at site, modeled results, helped with databases, or advised students).

2. Information on user satisfaction and user feedback.

3. Statistics on proposals approved and/or declined; description of user policy and proposal review/approval procedure.

4. Listings of publications (only FACE, not earlier chamber or other studies), with user coauthors identified. Indicate what work was funded by DOE and what was funded by other sources.

5. A summary to date of DOE core funding and, as a separate figure, extramural funding (and sources) that supported users.

Attachment 3

During the site visits more specific questions were asked about the facilities' operations in a broader user facility context. The questions in Table 3 were distributed and the information thus obtained was incorporated into this report and summarized in Table 3.

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Acronyms

ARM – Atmospheric Radiation Measurements
BER – Office of Biological and Environmental Research
BES – Basic Energy Sciences, Office of Science
BNL – Brookhaven National Laboratory
CDIAC – Carbon Dioxide Information and Analysis Center
DOE – U. S. Department of Energy
DRI – Desert Research Institute
EPSCoR – Experimental Program to Stimulate Competitive Research
FACE – Free-Air Carbon Dioxide Enrichment
LDRD – Laboratory Directed Research and Development (DOE)
NEP – Net ecosystem production
NDFF – Nevada Desert FACE Facility
NIGEC – National Institute for Global Environmental Change
NPP – Net primary production
NRC – National Research Council
NTS – Nevada Test Site
NVO – Nevada Operations Office (DOE)
ORNL – Oak Ridge National Laboratory
PER – (DOE/BER) Program for Ecosystem Research
PI – principal investigator
ppmv – parts per million by volume
QA – Quality assurance
TCP – (DOE/BER) Terrestrial Carbon Program
TECO – Joint interagency solicitation by DOE, NSF, NASA, USDA, and EPA on Terrestrial Ecology and Global Change
USDA – United States Department of Agriculture
USFS – United States Forest Service
USGCRP – United States Global Change Research Program
USGS – United States Geological Survey
WFO – Work for Other Federal Agencies