Report of the BERAC Subcommittee Reviewing The FACE and OTC Elevated CO_2 Projects in DOE

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1.0 Introduction

Atmospheric CO_2 concentration ([CO_2]) is higher today than it has been for at least the last 650,000 years[1]. During that time span, the Earth has oscillated in and out of more than six glacial cycles with [CO_2] varying between 180 and 290 ppm. Today's global average [CO_2] is 382 ppm[2], more than 30 percent higher than it was at the dawn of the pre-Industrial time period. Of great interest is that global [CO_2] would be higher than it is today given the rate of fossil fuel emissions; however enhanced photosynthetic CO_2 uptake by both terrestrial and marine photosynthetic organisms takes up about one-half of the emitted CO_2[3]. Two critical missions of the DOE relevant to these issues are to support the research necessary to understand the effects of rising CO_2 on ecosystem goods and services and also to understand the extent to which photosynthesis within terrestrial ecosystems today and on into the future can continue to partly offset the emissions of anthropogenic CO_2. To address these questions so critical to human societies and to life on Earth, the DOE has developed and maintained a series of long-term field experiments to understand how photosynthesis and carbon cycles within ecosystems will function under an elevated [CO_2] environment (eCO_2).

1.1 Elevated CO_2 studies at the ecosystem scale

Open-top chambers (OTC) were the first serious attempt to evaluate the functioning of intact ecosystems under field conditions[4]. While OTC can maintain an eCO_2 environment, their footprint is small and the sidewalls of the OTC constrain natural airflow, creating an artificial microclimate. Just over a decade ago, an improved experimental design was implemented for high-stature vegetation. Here the DOE launched a series of ecological experiments with reasonably large (25-30 m) diameter footprints to understand how intact ecosystems would function under the elevated [CO_2] that is anticipated in just 50 years from now[5]. These large-scale experiments were designed to investigate the functioning of whole intact ecosystems continuously exposed to elevated [CO_2][6]. The experimental systems were designed by the Brookhaven National Laboratory and are known as <u>F</u>ree-<u>A</u>ir <u>C</u>O_2 <u>E</u>nrichment (FACE) experimental systems. The elevated pipes in a ring structure of FACE experiments represent a significant engineering feat, because they are designed to maintain an eCO_2 environment undermost atmospheric and turbulence conditions[7]. The engineering design has worked well,

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[1] Siegenthaler U et al. 2005. Stable carbon-cycle-climate relationship during the late Pleistocene. Science 310: 1313-1317.

[2] http://www.cmdl.noaa.gov/ccgg/trends/, October 16, 2006

[3] Tans PP, Fung IY, Takahashi T 1990. Observational constraints on the global atmospheric CO_2 budget. Science 247:1431-1438.

[4] Drake BG, Leadley PW, Arp WJ, Nassiry D, Curtis PS 1989. An open top chamber for field studies of elevated atmospheric CO_2 on salt marsh vegetation. Functional Ecology 3:363-371.

[5] An Evaluation of the Department of Energy's Free-Air Carbon Dioxide Enrichment (FACE) Experiments as Scientific User Facilities. BERAC Report, December 2002.

[6] Long SP, Ainsworth EA, Rogers A, Ort DR 2004. Rising atmospheric carbon dioxide; plants FACE the future. Annual Review Plant Biology 55:591-628.

[7] Hendry GR, Ellsworth DS, Lewin KF, Nagy J 1999. A free-air enrichment system for exposing tall forest vegetation to elevated atmospheric CO_2. Global Change Biology 5:293-309.

allowing for the first time an opportunity to investigate the functioning of large intact ecosystems under an enriched CO_2 environment[8].

1.2 Charge to the BERAC Subcommittee

On August 14, 2006, Dr. Raymond Orbach, the Under Secretary for Science at the U.S. Department of Energy (DOE), charged the Biological and Environmental Research Advisory Committee (BERAC) with undertaking a review of the Free-Air CO_2 Enrichment (FACE) and open-top chamber (OTC) projects supported within the Office of Biological and Environmental Research Climate Change Research Division of the DOE (see charge letter in Appendix A). He specifically requested that the committee:

- Review the scientific information that has come from each of the DOE FACE experiments and assess their potential to yield new findings if the ongoing experiments are continued. BERAC is requested to provide its advice as to whether any or all of the ongoing FACE experiments supported by BER, which are relatively costly to maintain and operate, have reached or are reaching a point of diminished scientific return such that continuing them is, or shortly will be no longer justified;
- Provide a set of recommendations concerning which DOE FACE experiment sites, if any, should be maintained, which should be phased out, and where it would be appropriate to establish one or more new ones to address programmatic goals requiring such experiments;
- Review and provide an assessment of CO_2 enrichment experiments and approaches where a non-FACE type protocol (*e.g.*, open-top enclosures) is employed. Different approaches for CO_2 fumigations and field manipulations involving other variables may also be considered;
- Provide guidance on the broader range scientific question related to proposals under consideration for FACE-type experiments;
- Assess the escalating costs of conducting FACE experiments, and their impacts in a flat budget environment;
- The scientific need and technical feasibility of modifying FACE experimental approaches to consider additional greenhouse gas or climatic influences on carbon processes and terrestrial ecosystems;
- Alternative approaches for conducting FACE-type experiments that offer significant cost advantages relative to conventional FACE designs

A Subcommittee, chaired by James Ehleringer of the University of Utah (a BERAC member), was formed to address the charges. The other members of the committee included Richard Birdsey (U.S. Forest Service), Reinhart Ceulemans (University of Antwerp), Jerry Melillo (Marine Biological Laboratory), Josef Nösberger (ETH-Zürich), Walter Oechel (San Diego State University), and Susan Trumbore (UC Irvine) (see details in Appendix B). On October 9-10, 2006, the Subcommittee met with officials from the Climate Change Research Program at the

[8] McLeod AR, Long SP 1999. Free-air carbon dioxide enrichment (FACE) in global change research. Advances in Ecological Research 28:1-55.

DOE and reviewed documents provided by both DOE Program Managers and principal investigators from FACE and OTC projects.

1.3 FACE and OTC Projects in the DOE

Six FACE and OTC experimental projects were jointly reviewed:

- Coniferous forest FACE, operated by Duke University
- Mixed hardwood forest FACE, operated by Michigan Technological University
- Salt marsh OTC, operated by the Smithsonian Institution
- Oak scrubland OTC, operated by the Smithsonian Institution
- Deciduous temperate forest FACE, operated by the Oak Ridge National Laboratory
- Desert Shrub FACE, operated by the University of Nevada

2.0 What has been learned from FACE/OTC studies supported by the DOE?

2.1 The lead role of the DOE in pioneering long-term climate change research

Finding 1. *The DOE has been the lead federal agency in ecosystem climate change experiments, pioneering the required technology necessary to predict how ecosystems will respond to future CO_2 environments. The continued DOE role as the leader in this area is absolutely critical if we are to develop the knowledge base and models of how ecosystems will respond to future environments and to the release of anthropogenic CO_2.*

While climate change research can now be found in almost all of the major federal agencies conducting research, the DOE stands alone as the lead agency in funding climate change research experiments. The DOE has made significant investments in developing climate change experimental facilities, such as FACE for the study of elevated [CO_2] on intact ecosystems and the Through-Fall Displacement Experiment (TDE) to study the effects of both reduced and enhanced precipitation regimes on intact ecosystems. The DOE Program recognizes that ecosystem research requires longer-term support more than the typical 2-3 year research grants offered by many federal agencies that support such research. The DOE's long-term commitment to experimental climate change research is applauded by Subcommittee members as demonstrating the required long-term commitment to study ecosystem-scale response and their lags and feedbacks. The DOE is encouraged to continue support of pioneering experimental ecosystem-scale research and to expand the DOE's role in experimental research on climate change impacts on ecosystem. Of major significance will be those long-term studies that address questions of how multiple interacting climatic and biological drivers influence ecosystem processes and the ability of ecosystems to sequester anthropogenic CO_2.

2.2 FACE technology has demonstrated the capacity to create future CO_2 environments for ecosystem studies and had a significant impact on climate change research

Finding 2. *FACE studies have achieved the most realistic elevated CO_2 (eCO_2) environment for ecosystem studies of all experimental approaches to date without significant changes to microclimate; properly implemented OTCs have also been used to elevate CO_2 concentrations for small plot studies.*

Finding 3. *FACE-scale studies of ecosystem processes have been quite productive by any metric, and have produced fundamental new insights into carbon dynamics that were not predictable from pot- and greenhouse-scale studies.*

Finding 4. *In many cases, generalities about processes relevant to the ecosystem scale have emerged, allowing for progress in the development of models to predict carbon dynamics at multiple scales. Applications of the models are important to forming climate policy at national and global scales.*

Finding 5. *Results from FACE studies emphasized the overall importance of belowground processes to elevated CO_2, as well as the interaction between CO_2, surface energy balance, and climate response at the ecosystem scale.*

While it is clear that there are initial short-term responses of vegetation exposed to elevated carbon dioxide environments, there appear to be sustained enhancements of net primary production under elevated carbon dioxide environments across a wide range of young temperate plantation forest ecosystems[9] as shown in Figure 1 (top left). This sustained enhancement in net primary production has ultimate implications for the capacity of intact ecosystems to sequester carbon. FACE studies have also improved our understanding of belowground carbon cycling and how that changes with eCO_2. For example, the isotope tracer associated with the added CO_2 in FACE or OTC treatments provides a unique tool for investigating the dynamics of carbon allocation and turnover on a key timescale (weeks to years) that is longer than short-term flux measurements, but too short for the bomb radiocarbon tracer (associated with elevated $^{14}CO_2$ from aboveground nuclear testing that ended in the early 1960's). An example of the utility of the isotope tracer is the confirmation that fine tree roots can live on the order of 3-9 years[10 11], longer than previously thought by ecologists (Figure 1 bottom left). Overall, eCO_2 tends to be associated with enhanced allocation of carbon belowground, and the appearance of the stable isotope tracer in soil respiration has allowed partitioning of respiration increases into enhancements of root respiration versus microbial sources. At the same time, from Figure 1 (top right) ecologists are learning that the enhanced leaf litter production associated with an elevated

[9] Norby RJ et al. 2005. Forest response to elevated CO_2 is conserved across a broad range of productivity. Proceedings of the USA National Academy of Sciences 102:18052-18056.

[10] Gaudinski J et al. 2001. The age of fine-root carbon in three forests of the eastern United States measured by radiocarbon. Oecologia 129:420-429.

[11] Matamala R et al. 2003. Impacts of fine root turnover on forest NPP and soil C sequestration potential. Science 302:1385-1387.

carbon dioxide experiment does not initially slow soil nitrogen availability and produce a negative feedback on net primary production[12].

2.3 Surprises: the unanticipated effects of interacting climate and biological factors

Finding 6. *One "surprise" is the interactive importance other factors, such as moisture, other trace gases, and nutrients in moderating, enhancing, or diminishing the effects of eCO_2 on enhancing carbon fixation and altering phenology.*

The initial studies of a single factor (elevated carbon dioxide) have given way to subplot designs to address the interactions of multiple environmental and biological parameters on carbon cycling in a FACE experiment. Ecologists are learning that year-to-year variations in the environment (*e.g.*, drought on the physical side and soil nitrogen on the soil side) can significantly impact carbon sequestration capacity. One project (Rhinelander FACE) was designed from the beginning to study the interactions of multiple trace gas and biotic interactions. Here ecologists have learned that there are sustainable differential species responses to elevated carbon dioxide. After 6 years of growth under elevated carbon dioxide, trees have accumulated 35-74 percent more biomass than under control treatments, with sustainable and significantly different species responses (Figure 2) In addition, phenological responses such as the timing of leaf senescence vary markedly with eCO_2. In contrast, the presence of ozone reduces aboveground growth rates. In combination, ozone can nearly offset the growth enhancement effect associated with elevated carbon dioxide (Figure 2). One of the surprises is that the effects of trace gas species on aboveground and belowground processes are not additive, suggesting that much is to be learned from future investments in microbial and plant ecology, plant physiology, and the multiple interactions between microbes and plant roots and their exudates. These current results emphasize the importance of shifts in allocation and in particular the links between plants and microbial communities for determining how ecosystems will respond to environmental changes associated with atmospheric composition and climate change.

Another 'surprise' is the remarkable tolerance of coniferous forests under eCO_2 at the Duke forest to withstand an episodic event, such as an ice storm, which would normally cause extensive structural damage aboveground. Trees exposed to eCO_2 treatments did not suffer as much stem breakage as control trees when an unusual ice storm came through the site. At present, the basis of this increased stress tolerance is unexplained. Such results reinforce the importance of indirect responses that impact the resilience of ecosystems to future change.

2.4 Creating opportunities: links between DOE's Terrestrial Carbon Processes and Genomics: GTL Programs

Finding 7. *Given the significance of microbial processes under elevated CO_2, DOE's Terrestrial Carbon Processes and Genomics: GTL Programs would benefit from more significant interactions with FACE studies.*

[12] Zak DR et al 2003. Soil nitrogen cycling under elevated CO_2: a synthesis of forest FACE experiments. Ecological Applications 13:1508-1514.

The Genomics: GTL program has developed plans for several new research centers over the next several years. The sizeable investment in infrastructure of one of these new facilities should be associated and linked with the development of the next generation of FACE-type experiments (discussed later). As it appears that many of the surprises emerging from FACE studies relate to belowground processes and microbial ecology, the Subcommittee recommends that the DOE find ways to promote stronger interactions between the genetic and molecular biology techniques emerging through Genomics: GTL and the needs for a better understanding of microbial ecology in FACE studies. The melding of genomics, microbial ecology, and eCO_2 ecology will likely yield new and interesting data that will enhance our understanding of how ecosystem structure and functioning are modified under eCO_2. Such information will be extremely valuable to policy makers as they seek to understand how much terrestrial ecosystems will respond to future environments affected by the release of anthropogenic carbon dioxide.

3.0 The Life Cycle of a FACE Project

Three of the greatest challenges facing any eCO_2 FACE project are a determination of when an experiment has been successfully completed, determination of the useful life expectancy of that project, and determination of the capacity of that same experiment (biological setting and material, a small footprint ecosystem) to serve as a robust site for additional FACE research. The Subcommittee views these as among the greatest challenges because investigators close to their projects may not see their project as at the stage of development and maturity as perceived by others external to the project. Given the charge to this BERAC Subcommittee, we see no option other than to provide a series of criteria that the DOE can apply in making its decisions on future FACE activities. The Subcommittee developed a series of impartial guidelines for program managers and other officials at the DOE and these relate to the natural life cycle of a long-term FACE project.

3.1 What factors contribute to a limited lifetime for any eCO_2 project?

Three factors contribute to a limited lifetime for any eCO_2 project. The first and most logical reason is that the scientific purpose for which the experiment was designed has been completed. The other two reasons relate to technical issues. First among these is that the vegetation has become sufficiently tall that the pipes delivering the carbon dioxide cannot remain above the vegetation. This results in the integrity of the experiment being compromised because parts of the vegetation that grow above or outside of the FACE rings are no longer exposed to the same level of CO_2 as the vegetation growing within the confines of the FACE rings. A variation on this theme is that the buffer vegetation surrounding the FACE site has not kept pace and that there is a height gap between the treatment and buffer vegetation. The Subcommittee was informed that one or more of the current FACE facilities were impacted by this concern now and that the others would be impacted within 2-3 years. The second technical issue is the over sampling and trampling of the soil surface within the FACE ring. It appears that in all but the Mohave Desert FACE experiment there has been too much trampling of the soil surface and extraction of large soil samples, creating a Swiss cheese effect within the FACE rings. The consequences are that the FACE ring becomes progressively less useful for the investigation of both above- and belowground processes.

3.2 What are the phases in the life cycle of an eCO_2 experiment?

Finding 8. *The current FACE design and plot sizes appears to impose constraints on the experimental sampling of aboveground and belowground materials, leading to a useful life expectancy of only 10-12 years per experiment.*

Finding 9. *Harvesting plans of an eCO_2 project were not described nor explicitly defined in any of the provided documents for FACE or OTC projects.*

Finding 10. *Harvesting of eCO_2 sites is a critical and productive phase of an eCO_2 experiment life cycle; harvesting of the above- and below-ground components will yield some of the most useful samples for future research, analyses, and insights.*

Finding 11. *Earlier recommendations from the last review regarding data sharing policies, data archiving protocols, and modeling protocols should be more fully implemented; they have not been addressed in the present FACE projects.*

Although at the beginning, it was not clear that FACE technology could fully maintain a fixed elevated carbon dioxide level surrounding a natural ecosystem, that engineering feat has been accomplished and FACE studies have been able to address the role of elevated carbon dioxide on the functioning of ecosystems. A FACE project must be viewed in terms of a life cycle, where eventually the project scientists can harvest their ecosystem (Figure 3). Follow-up studies on a FACE ecosystem after the eCO_2 has been turned off may also be of interest to the DOE because of the opportunity to investigate short-term carbon dynamics of soils.

Experiments must eventually stop for several reasons, and they are unlikely to be able to persist throughout the entire life cycle of long-lived vegetation such as trees. Reasons for topping such experiments include: (1) the current limited ring size of FACE studies results in an over sampling of the soils within FACE rings that undoubtedly affect belowground processes, thus resulting in life expectancies for a project that are far shorter than the life expectancy of the tree; (2) the vegetation within the FACE ring grows much faster than the surrounding buffer vegetation or the capacity of the engineered pipes to be stable and provide the necessary carbon dioxide gases to maintain the elevated carbon dioxide environment inside the ring. These factors ultimately lead to the need to terminate the ‘gas-on’ phase of the experiment and to enter the ‘harvesting the ecosystem’ phase of the experiment.

While some might initially view the termination of the elevated carbon dioxide treatment phase as unfortunate, it is instead the excellent, long awaited opportunity to finally explore the belowground ecosystem in full detail, since the soils could only have been probed in pieces before. The Subcommittee is convinced that the harvesting phase of a FACE project life cycle may yield some of the most exciting, unexpected results, particularly if the project scientists have adequately considered microbial genomic opportunities and modeling studies before the ‘gas-on’ phase is completed. It is also an excellent opportunity to be able to analyze the aboveground biomass that could only have been indirectly sampled before. Thus, turning off the carbon dioxide in a FACE or OTC experiment is a natural stage of an experimental life cycle that opens the door for the harvesting phase where we finally see in detail how ecosystem components have responded to that future environment (Figure 3). Within the current suite of DOE projects, the Subcommittee feels that for those projects the DOE decides to allow to move onto the harvesting phase now, these investigators will have the first opportunities to publish their results of the 'harvest' in high-profile journals. The DOE should not let all experiments terminate at the same time, but we are aware that there is a scientific advantage to those groups that move onto the harvest phase first. In the interest of equitable and timely analysis and publication of data during a harvesting phase, the DOE should consider a constrained timetable for ending current experiments.

3.3 Harvesting of an eCO_2 experiment

Recommendation 1. *During FY 2007 enter into the harvesting phase of an eCO_2 experiment life cycle for several current projects.*

Recommendation 2. *For the remaining, existing eCO_2 projects, they should enter into the harvesting phase by FY 2010 at the latest.*

Recommendation 3. *We recommend that funding for any new or renewal research proposals at FACE/OTC projects be considered in the context of the schedule for harvesting a site.*

Recommendation 4. *As soon as harvesting schedule is determined, we recommend workshops at FACE/OTC projects to plan for the harvesting phase of the project.*

Recommendation 5. *We recommend that funding be provided after "turning off the eCO_2" to conduct the harvest and its analysis, to allow publishing of original research, and to allow for within-site and cross-site syntheses.*

In order for DOE to maximize the value of research investment made at FACE/OTC sites, the transition from the 'gas-on' to 'harvesting' phases of a FACE/OTC project should be treated as a research effort with its own set of scientific goals and procedures. A high level of research activity is expected to continue for however long is justifiably needed to "harvest" or sample some or all of the vegetation and soils, analyze the harvested materials, and synthesize the results after the CO_2 is turned off. At this same time, it is expected that appropriate soil and aboveground samples will be preserved and archived for future analyses.

(1) Early in the process, decisions need to be made about the degree to which the sites will be harvested versus left intact for potential future research.

(2) Similarly, it is critical to identify the data sets that will be archived for the long term and implement a data management plan. Deciding on an archive format and data requirements must

be undertaken with cross-site comparisons in mind, and this should be done within the context of the eCO_2 experiments as whole (as recommended by previous BERAC advisory committees).

(3) To accomplish (1) and (2), we recommend that a workshop be convened well in advance of ending CO_2 treatments and moving to the harvesting phase, including participation from the experimentalist/modeling/data management communities. The purposes of the workshop would be to:

(i) decide on measurements to be undertaken as CO_2 (and ozone in the case of the Rhinelander FACE experiment) is turned off (when to turn off, what measurements should be made, etc)
(ii) identify key missing measurements needed to effectively run models, interpret results, and conduct cross-site comparisons
(iii) ensure that data management and data archiving are sufficient for future needs
(iv) complete a synthesis of ecosystem C flows to resolve C balance in control and treatment plots (if not already done)
(v) plan for the future use of the site (harvest vs. future experiments)

(4) Once treatment has ended and ancillary short-term (<1 year) measurements have been made, the site materials should be appropriately sampled for analysis and archiving. The samples from a FACE site provide a unique and valuable record. If archives are not being made through the course of the experiment, it is critical that samples be preserved for future investigations (for example, of isotope signatures). Archived materials should include vegetation and soil samples, in frozen as well as dried form; resources should be made available for the set up of archives and a plan developed for the long-term continued storage.

There are unique opportunities for a FACE site following the harvesting phase of the experiment (Figure 3). Follow-on experiments using FACE/OTC sites should be considered (*e.g.*, soil warming to determine the relative vulnerability of stored soil carbon, or simulation of disturbance to observe regeneration differences, etc.). These must be carefully planned in order to coordinate with the end of CO_2 treatments.

Funding should be planned so that project scientists have resources (salary, analysis costs, workshops) sufficient for producing the synthesis of their research and cross-site studies.

We propose a criterion against which to judge whether or not to continue future funding for DOE's FACE and OTC projects. These criteria can be stated as:

- An existing 'gas-on' FACE project should transition to the harvest phase after it has completed its research objectives, allowing an opportunity to conduct more thorough sampling of the above- and below-ground components. This is a logical conclusion to a successful experiment.

Questions that help identify the stage of completion in an ongoing FACE study are:

- Is the core research being proposed for continuation at a site likely to lead to **new scientific insights** that are directly relevant to the missions of Terrestrial Carbon Processes Program and the Ecosystem Functioning and Response Program?

- Are there **technical constraints** that will restrict the capacity of the site to support the science proposed?
- Will **modifications** designed to address new science questions permit the site's research team to carry out the proposed research in an optimal way?
- Has the site **outlived its useful lifetime** because previous research has altered it in ways that render it unsuitable for future studies (both above- and below-ground)?

Figure 4 provides our suggested criteria for the determination of whether an existing FACE/OTC project should move from the 'gas-on' to the 'harvesting' phase of its life cycle. We believe that the decision process is a logical, progressive approach to determine which experiments should remain in the 'gas-on' phase of the experiment and which should transition to the 'harvesting' phase. We provide here a straightforward and unbiased mechanism that will allow the DOE to decide which projects should be transitioned and which should not. We assume at all times that the individual reviews for each of these projects received positive reviews and were ranked as having high scientific and technical merit value. The Subcommittee had no access to this information. Nor did they have any information related to individual proposals. The Subcommittee based its recommendation on a logical sequence of how to best manage a FACE/OTC project through it natural life cycle. We make the assumption that the quality of the effort at all times within a FACE/OTC project is excellent and that the project has received very positive reviews.

Based on the information that was provided to the BERAC Subcommittee by the DOE, we make the following recommendations:

- Coniferous forest FACE, operated by Duke University; transition to the harvesting phase no later than FY 2010
- Mixed hardwood forest FACE, operated by Michigan Technological University; transition to the harvesting phase no later than FY 2010
- Salt marsh OTC, operated by the Smithsonian Institution; transition to the harvesting phase no later than FY 2007
- Oak scrubland OTC, operated by the Smithsonian Institution; transition to the harvesting phase in FY 2007 or possibly as late as FY 2010
- Deciduous temperate forest, operated by the Oak Ridge National Laboratory; transition to the harvesting phase no later than FY 2010
- Desert Shrub, operated by the University of Nevada; transition to the harvesting phase in FY 2007

4.0 Plan and design the next generation of elevated CO_2 ecosystem experiments now

4.1 The next generation of climate change and elevated CO_2 ecosystem experiments

Recommendation 6. *Immediately plan and initiate a workshop(s) to plan the next generation of climate change and eCO_2 experiments, incorporating multiple interacting climate-change factors and potentially different eCO_2 designs and/or technologies.*

Recommendation 6a. *Convene a workshop(s) to plan for the next generation of climate change and eCO_2 ecosystem experiments that will incorporate multiple "drivers" of climate change (temperature, nutrients, soil type, moisture, and bio-complexity) and multiple-level [CO_2] treatments.*

Recommendation 6b. *Following the workshop(s), we recommend a pilot study(ies) of alternatives to the current FACE (ring) approach for future climate change experiments that would allow for consideration of*

- *operational CO_2 savings beyond diurnal control (design)*
- *site location as a factor in CO_2 cost savings(i.e., consider selecting sites that are close to a CO_2 source to reduce shipping costs)*
- *larger plot sizes*
- *soil carbon sequestration considerations*
- *subplot treatments*

Recommendation 7. *We recommend stronger linkages in studies of microbial process studies between DOE's Terrestrial Carbon Processes and Genomics: GTL Programs in future elevated CO_2 projects. For instance, development of a Genomics: GTL Program in carbon sequestration and belowground processes could be collocated with a future elevated CO_2 project so that ecology, structure-function relationships, and genomics are more fully integrated.*

There is consensus among the Subcommittee members that the FACE-type technology is a highly useful and unique way to study the responses of whole ecosystems to global change drivers. Originally designed to examine responses to elevated CO_2, there are already two FACE arrays that combine elevated CO_2 with increased tropospheric ozone levels. We now think that the approach can be further modified to include additional environmental drivers. Consideration of concurrent changes in multiple factors will allow us to predict and understand how terrestrial ecosystems will respond to a set of possible environmental futures. The capability to conduct multi-factor experiments on intact ecosystems of large stature (*e.g.*, forests) does not now exist. Developing such a capability will require investing in technology engineering research and development (Figure 5).

We think that the modeling community should be involved in all aspects of the FACE research from the design and establishment through the final data analysis and integration steps. One of the most powerful uses of modeling is to clearly state research questions based on an integrated understanding of extant information. It also helps to check the reasoning in the analysis and integration of data during and at the end of the study.

In terms of the foci of the next generation of climate change experiments, it is not the task of the Subcommittee to design or define those experiments but rather the task of the scientific community. No doubt changes in atmospheric CO_2 will not occur independent of other environmental change. It is also quite well documented that impacts of elevated CO_2 on carbon storage and ecosystem functioning can be influenced, in some cases markedly, by the state and change in other environmental variables. Considering the impact of other environmental factors on the response of ecosystems to elevated CO_2, and the likelihood of change in these variables, FACE and other elevated CO_2 experiments should take these factors into consideration. The following points will be useful as part of a workshop to define the next generation of climate change and eCO_2 experiments:

- A synthesis of results to date combined with modeling should be used to come up with explicit and testable hypotheses for the next generation of experiments; one major result would be to test our ability to predict what will happen based on extrapolations from existing knowledge, or specifically address the factors associated with the largest uncertainties in model predictions of response.
- More multifactorial studies are required to understand whether plant and ecosystem responses are additive or nonlinear.
- Advances in technology for observing soil processes (from genomic to *in situ*, nondestructive, automated measures) should allow for better incorporation of belowground studies in new experimental designs.
- Advances in the technology of controlling CO_2 in air should be considered (and perhaps new technologies solicited) to see if savings could be achieved.
- Consideration of the advantages and disadvantages associated with (a) a single, very large, multifactorial manipulation study versus (b) several smaller studies undertaken with different vegetation types. Which design addresses key model uncertainties better?
- Exposure of plants to multiple CO_2 levels, allowing a response curve and testing at higher CO_2 levels (above 'safe' levels) is desirable.
- Planning the experiments to combine multiple aspects of expected future change in atmospheric composition and climate.
- Balancing the need to measure responses of longer-lived vegetation with the need to observe the response to elevated CO_2 over more than one generation.
- Exploration of new questions, for example how eCO_2 affects resilience towards disturbances like fire, damage, or herbivory (disturbance may provide one mechanism for performing multigenerational experiments in some ecosystems).
- Careful selection of plant/soil systems for investigation so as to enhance the scalability of results to other plant and soil types. Selection of any new site should have involvement of modeling groups in the planning stages so that the experiments test specific hypotheses and/or address areas where model predictions are most sensitive and uncertain (*e.g.*, allocation, respiration).
- Experimental design will need to adjust to accommodate multiple experiments. For example, a great deal can be learned by explaining causes of temporal and spatial variation among replicates if those are located on identified gradients (*e.g.*, nutrient availability).

Although this project will be expensive by current standards, the answers are required by policy makers in order to know how ecosystems will respond to climate changes and the continued release of anthropogenic CO_2.

4.2 Advice on new eCO_2 proposals under current consideration

Recommendation 8. *We recommend that no new eCO_2 projects be initiated until after workshop recommendations on the future design of eCO_2 experiments to address multiple interacting factors. It is clear now that single factor approaches are limited.*

Regarding the specific proposals under consideration, this is a decision for the DOE and its external review process, as guided by the principles outlined here. We wish to reiterate that this Subcommittee did not have access to individual proposals nor was it asked to review individual proposals. Our recommendations address programmatic issues and not specific proposals.

5.0 Cost savings considerations

The Subcommittee was not provided with sufficient, organized information to allow it to make recommendations about potential cost savings. However, the recommendation to enter the "harvesting" phase for several OTC and FACE sites will greatly reduce operational costs associated with the supply of CO_2 and the engineering and maintenance of the rings. In addition, implementation of **Recommendations 3 and 8** will generate extensive cost savings.

6.0 Appendix A. Charge letter from Under Secretary for Science Raymond Orbach

Under Secretary for Science
Washington, DC 20585

August 14, 2006

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Associate Vice Chancellor for Basic Biomedical Research,
and Director, Office of Research, Health Sciences
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Pittsburgh, P A 15261

Dear Dr. Broido:

By this letter, I am charging the Biological and Environmental Research Advisory Committee (BERAC) to undertake a review of the Free-Air:'$C0_2$ -Enrichment (FACE) and related experiments that are supported by the Biological and Environmental Research (BER) Climate Change Research Division. The October 2005 BERAC review of the BER Terrestrial Carbon Processes research recommended further evaluation of the FreeAir-C02 -Enrichment (FACE) experiments to provide guidance on "How long should a current site remain operational, and where might new sites best be established?" The BERAC report noted that" ... while long-term continuity of some FACE sites is clearly warranted, DOE should periodically evaluate when a site has reached a point of diminishing scientific returns." Accordingly, I am asking that a follow-on BERAC FACE Panel be convened to:

- Review the scientific information that has come from each of the DOE FACE experiments and assess their potential to yield new findings if the ongoing experiments are continued. BERAC is requested to provide its advice as to whether any or all of the ongoing FACE experiments supported by BER, which are relatively costly to maintain and operate, have reached or are reaching a point of diminished scientific return such that continuing them is, or shortly will be no longer justified;
- Provide a set of recommendations concerning which DOE FACE experiment sites, if any, should be maintained, which should be phased out, and where it would be appropriate to establish one or more new ones to address programmatic goals requiring such experiments;
- Review and provide an assessment of C02 enrichment experiments and approaches where a non-FACE type protocol (e.g., open-top enclosures) is employed. Different approaches for C02 fumigations and field manipulations involving other variables may also be considered.

A number of proposals for FACE-type CO_2 enrichment experiments and other types of carbon cycle research were submitted in response to a recent carbon cycle solicitation. The BERAC Panel is requested to provide guidance on the broader range scientific questions and ecosystem types that have been proposed for employing FACE-type of investigations of carbon cycle processes. Specifically, the Panel is also asked to assess additional issues of:

- Escalating costs of conducting FACE experiments, and their impacts on scientific studies in a flat budget environment;
- The scientific need and technical feasibility of modifying FACE experimental approaches to consider additional greenhouse gas or climatic influences on carbon processes and terrestrial ecosystems;
- Alternative approaches for conducting FACE-type experiments that offer significant cost advantages relative to conventional FACE designs.

Since the October BERAC review observed that there is broad interest in results from F ACE investigations, it would seem advisable to populate the FACE Panel with representatives from the scientific community that uses information and data from such experiments and from the community that is more involved in the design and technology requirements for such large-scale experiments. This should include user interests of other Federal Agencies (e.g., U.S. Dept of AgriculturelForest Service) and representatives from industry. From the scientific community, panelists might include a CO_2 experimentalist, a carbon cycle modeler, and others with knowledge of protocols and approaches for conducting large-scale field experiments. It is assumed, of course, that Panel members would be free of conflicts of interest with respect to current and past participation in
F ACE experiments. BER's staff can help identify conflicted and non-conflicted potential Panelists.

There is time urgency to implement this review because early FY 2007 funding decisions will be dependent on the outcome. It would be very helpful if the Panel could provide a preliminary report of its findings in September before the start of the FY 2007 fiscal year.

I recommend that Dr. James Ehleringer be asked to chair a subcommittee ofBERAC to undertake this review.

Sincerely,

Raymond L. Orbach

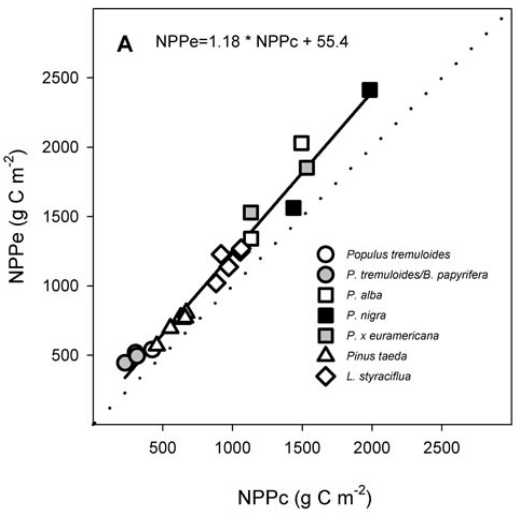
Raymond L. Orbach

Reference:
Recommendations on the DOE Terrestrial Carbon Cycle Research Program, a report prepared December 2005 (in response to the charge dated April 18, 2005) - see pp 4-5 for discussion and recommendations of the FACE component ofTCP review.

cc: Elwood, Jerry
Thomassen, David

7.0 Appendix B. Members of the BERAC Subcommittee to review FACE and OTC Projects in the DOE

Birdsey, Richard	Northern Global Change Research Program, USFS, 11 Campus Blvd., Newtotown Square, PA 19073-3294
Ceulemans, Reinhart	Department of Biology, University of Antwerp, Campus Drie Eiken, Universiteitsplein 1, Wilrijk, Belgium B-2610
Ehleringer, James (Chair)	Department of Biology, 257 S 1400 E, University of Utah, Salt Lake City, UT 84112-0840
Melillo, Jerry	Ecosystem Center, Marine Biological Laboratory, 7 MBL Street, Woods Hole, MA 02543
Nösberger, Josef	Institute for Plant Sciences, ETH, 8092 Zurich, Switzerland
Oechel, Walter	Department of Biology, San Diego State University, San Diego, CA 92182-0057
Trumbore, Susan	Department of Earth System Science, University of California at Irvine, Irvine, CA 92717-3100



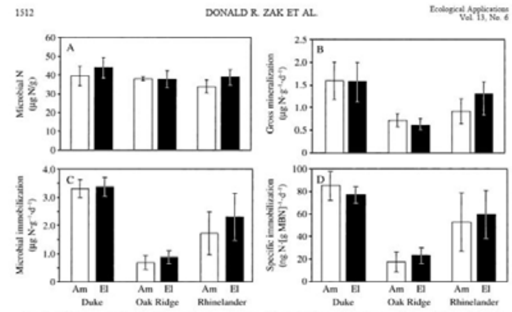


FIG. 2. (A) Mean microbial N, (B) gross N mineralization, (C) microbial immobilization, and (D) specific immobilization under ambient (Am) and elevated (El) CO_2. Bars indicate treatment means ± 1 SE for the Duke, Oak Ridge, and Rhinelander free-air CO_2 enrichment (FACE) experiments averaged across sampling dates (1999 and 2000). The interaction between experiment and CO_2 treatment was not significant for any microbial parameter illustrated in this figure.

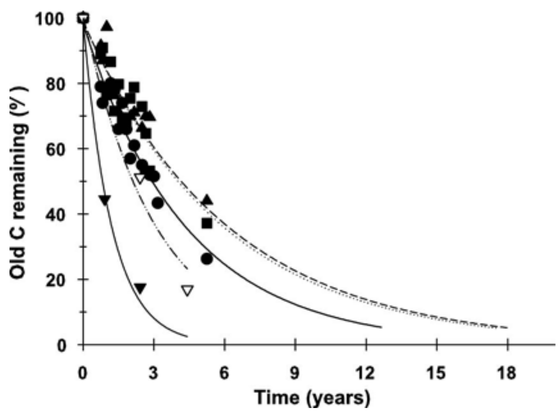


Figure 1. FACE studies have provided many new and often surprising results on the functioning of intact ecosystems under elevated carbon dioxide levels. Top left: Results from cross-site synthesis show that net primary production is enhanced 23±2% and is conserved across a broad range of sites (Norby et al., 2005). Top right: There is no evidence that changes in plant litter production under elevated CO_2 will initially slow soil N availability and produce a negative feedback on net primary production (Zak et al., 2003). Lower left: The turnovers rate of roots of different diameter size classes under elevated carbon dioxide show that fine roots live for 3-9 years or longer, far exceeding previous estimates (Matamala et al., 2003).

Standing biomass in Rhinelander FACE rings after 6 years.

Community↓ *Treatment →*	+ CO_2	+ O_3	+ CO_2 & + O_3
Aspen stands	+ 35 %	– 26 %	– 4 % (+ 4%)
Aspen-birch stands	+ 66 %	– 10 %	+ 24 % (+ 28%)
Aspen-maple stands	+ 74 %	– 8 %	+ 38 % (+ 33%)

Relative differences in soil respiration rates in Rhinelander FACE rings after 7 years.

Treatment	
+ CO_2	+ 26%
+ O_3	-8%
+ CO_2 + O_3	+39%

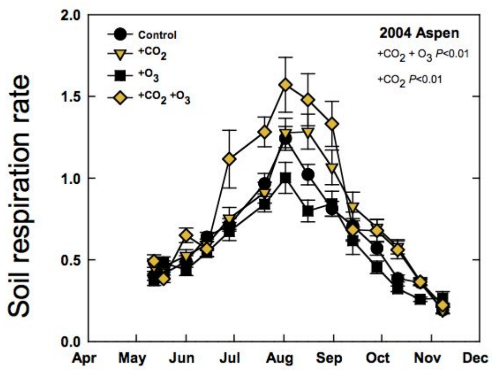


Figure 2. Patterns of biomass production and soil respiration at the Rhinelander FACE site, where treatments include multiple trace gas factors of carbon dioxide and ozone considered in combination with treatments that involve different natural dominant tree species combinations. Top left: Enhancement of aboveground biomass under elevated CO_2 is partly to completely offset by the increased O_3 levels expected in the future. Top right and bottom left: The effects of elevated CO_2 and O_3 are not additive.

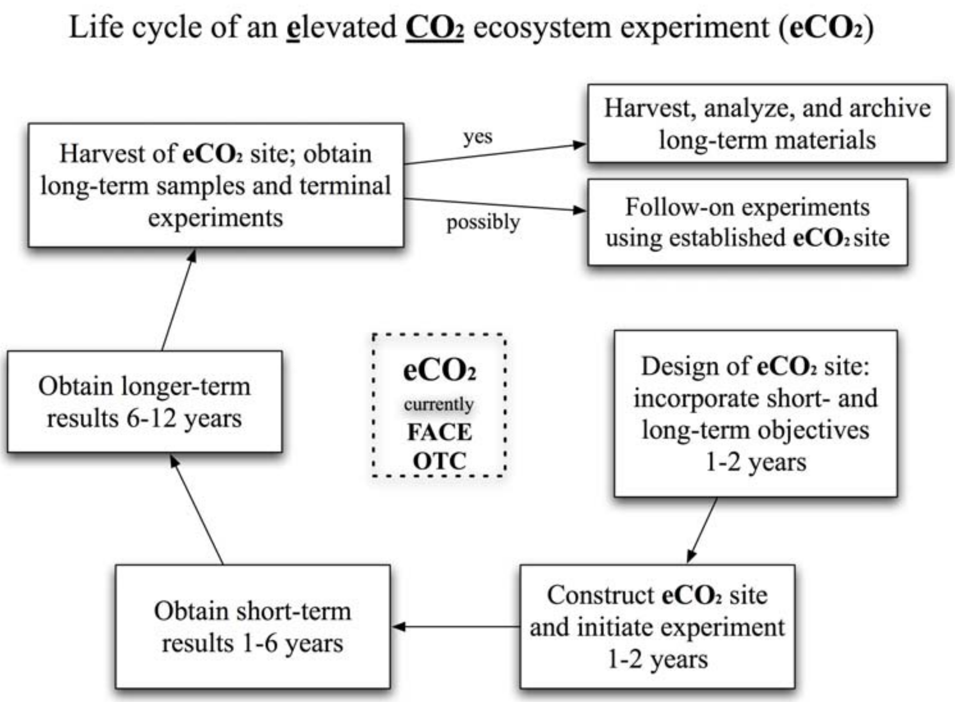


Figure 3. The life cycle of a FACE or OTC project.

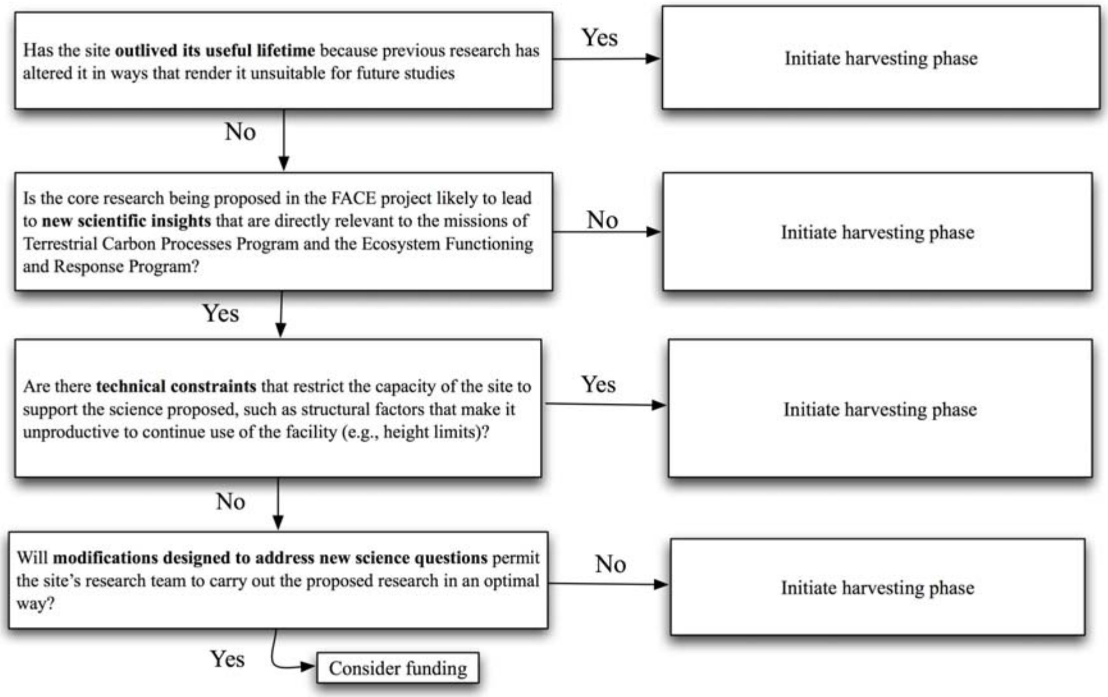


Figure 4. A sequential, decision-based flowchart to provide guidance on when a FACE or OTC project should transition from the experimental phase where the ecosystem is exposed to elevated carbon dioxide levels to the harvesting phase where the carbon dioxide is turned off and the below- and above-ground are fully harvested and analyzed.

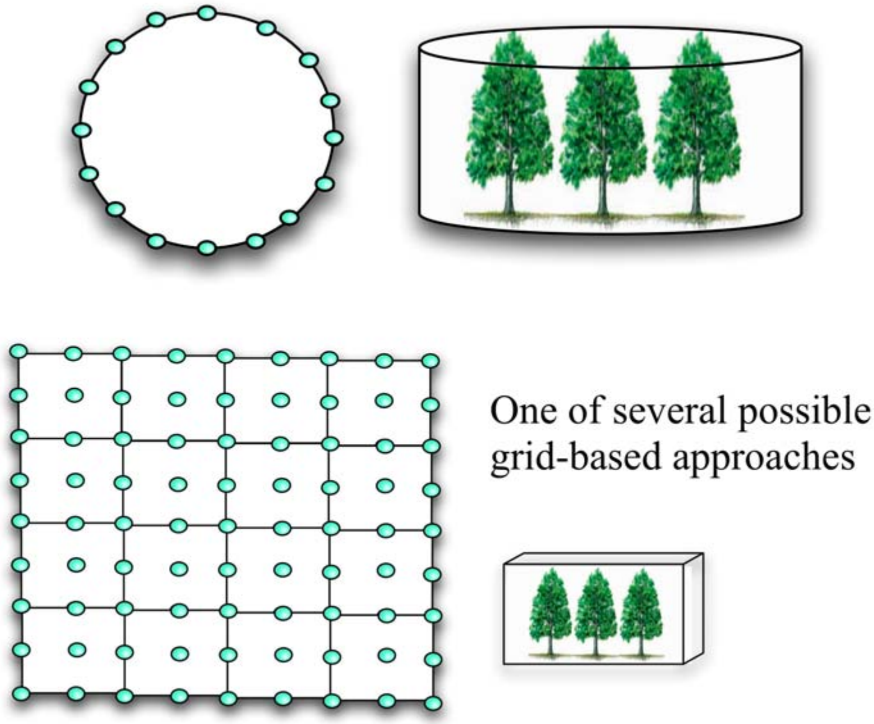


Figure 5. Planning is needed now to design the next generation of elevated carbon dioxide experiments that will allow for multiple treatment factors, sufficient space to accommodate sampling needs, and to protect some portions of the experiment from becoming overly sampled during the experiment treatment period. Shown above are the current FACE rings (top), which are limited in diameter by gas dispersion characteristics and one of several contrasting possibilities based on a gridded design (bottom) that might be considered in a future design.