Free Air CO2 Enrichment Technology (FACE Technology)

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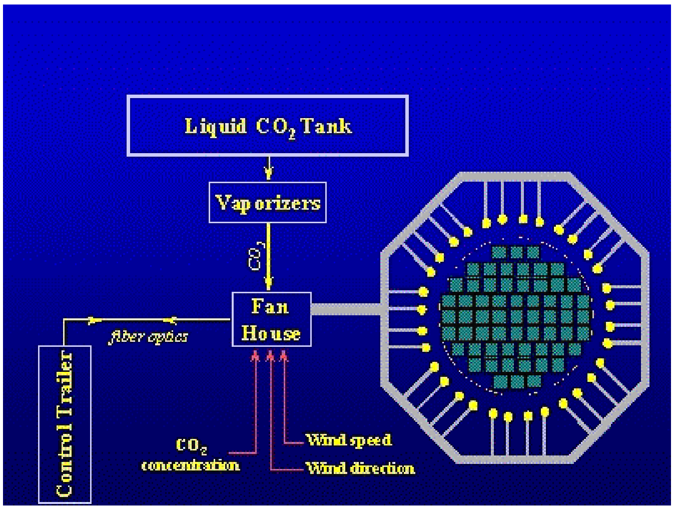
The atmospheric carbon dioxide concentration ([CO_2]) has risen by 35% since the start of the industrial revolution; it is higher now than at any time in the past 25 million years and is predicted to increase an additional 50% by 2050. Plants respond to rising [CO_2] through increased photosynthesis and reduced transpiration. Photosynthesis removes CO_2 from the atmosphere and respiration by plants and heterotrophs add it back.

Therefore, the terrestrial biosphere is not just a passive respondent to rising [CO_2] but can play a fundamental role in determining the rate of global change. Before FACE, much of what we knew about plant and ecosystem responses to rising [CO_2] came from studies conducted in enclosures where the response of plants is modified by their growth conditions. FACE was developed as a means to grow plants in the field at a controlled elevation of [CO_2] under fully open-air conditions. Results from FACE experiments provide perhaps the best estimate of how plants and ecosystems will respond in a future high CO_2 world.

What is FACE?

A typical FACE plot is approximately circular and surrounded by a ring of pipes that release CO_2 or air enriched with CO_2, at vertical intervals from just above the ground to just above the top of the plant canopy. Wind direction, wind velocity, and [CO_2] are measured at the center of each plot and this information is used by a computer-controlled system to adjust CO_2 flow rate to maintain the target elevated [CO_2].

Only pipes on the upwind side of the plots release CO_2, unless wind velocity is very low, at that time CO_2 is released alternately from adjacent release points. For vegetation of low stature, only one or two vertical release points are necessary, whereas for tall vegetation several vertical release points are needed to enrich the whole canopy.
Fast feedback algorithms avoid large overshoots in response to fluctuations in [CO_2] and provide a stable elevation of



[CO_2]. This basic design has been utilized with some variations and technical developments in over ten experiments in plots that are as large as 30m diameter that can accommodate vegetation as tall as 25 meters.

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What are the advantages of FACE?

FACE studies are fully open air and have many benefits over controlled environment and open-top chamber (OTC) experiments. FACE allows the investigation of an undisturbed ecosystem and does not modify the vegetation's interaction with light, temperature, wind, precipitation, pathogens and insects.

This, in combination with the large size of FACE plots, allows the integrated measurement of many plant and ecosystem processes simultaneously in the same plot, avoids many of the problems associated with edge effects prevalent in OTCs, enables significantly more plant material to be harvested without compromising the experiment, and allows plants to be studied throughout their life cycle, including trees that have enough space to develop to canopy closure.

FACE is considered a consolidated technique to expose crops, forest plantations and natural vegetation to the conditions of elevated atmospheric **CO2** concentrations that are expected to occur in the next future. **FACE** technology has developed considerably since the first experiences made by Harper and co-workers in the **70th's** (Harper et al., 1973) and by van Mooi and co-workers in the **80th's** (Mooi, 1985). At present there are more than twenty operational FACE sites around the world in Northern and Central America, in Europe, Asia and Oceania. The size of the FACE plots varies from one meter diameter of the **MiniFACE** (Miglietta et al., 1996; Miglietta et al., 2001) to the **30 m** of the larger FACE systems that have been used to fumigate with **CO2** patches of forests plantations (Hendrey, 1999). FACE experiments are almost unanimously considered to provide the best opportunity to expose patches of managed or unmanaged vegetation to conditions of elevated atmospheric concentrations with minimal alteration of the natural environment where plants are growing. Nevertheless, FACE systems also suffer from some experimental limitations that have to do with the presence of substantial infrastructure, the unavoidable presence of CO2 concentration gradients along the wind direction and short-term fluctuations in CO2 concentration. The use of blowers has also some technical consequences on the FACE design that finally requires large pipes to allow the circulation of large quantities of air, higher power requirement and significant infrastructure. Moreover, the use of the blowers implies the construction of control rings where everything is operated in the same way than in the FACE, with the only exception of the injection of carbon dioxide. Recently different groups of scientists in the **USA** (Steve Roberts, personal communication), **Japan** (Okada et al., this issue) have attempted to modify the design of their FACE systems to introduce the release of pure carbon dioxide instead of an air-CO2 mixture. Such "pure-CO2" FACE was thought to be a possible alternative solution to the more conventional systems, providing some potential advantages.Data developed by Ibimet clearly indicate that Free Air CO2 Enrichment can be satisfactorily obtained by releasing pure CO2 instead of a pre-diluted air+CO2 mixture. The use of CO2 jets at sonic velocity greatly enhanced the air-CO2 mixing that occurred at the releasing points and this translated into an adequate air-CO2 mixing within the FACE area under both low and high-wind conditions. Power spectra analysis showed the relative merits of the pre-diluting effects of the sonic jets and plenums when compared to subsonic CO2 release. As we hypothesized the effect of the pre-dilution was evidenced in the Kolmogorov scale fluctuation. The advantages of this type of FACE design are clear. The so called "blower effect" is completely suppressed, the infrastructure is much lighter and less disturbing than in any other FACE system, the capital cost of the infrastructure is greatly reduced and the construction of the "control rings" is no longer required. More research is instead needed to evaluate the quality of the control under atmospheric stability and in particular at night. This aspect was not specifically considered for the **POPFACE** system as the fumigation was stopped during night. In this respect, the direct comparison of fast-frequency CO2 spectra for a pure-CO2 and a pre-diluted CO2 injection system, would be of importance to understand if pre-dilution operated by the blowers would improve the situation significantly, under those conditions (He et al., 1996). The possibility to continue satisfactory CO2 fumigation in a poplar plantation that is expected to grow very rapidly and to attain a significant height, is a big challenge ahead of us. Hopefully the POPFACE project will continue over the next seasons thus providing an opportunity to further test the quality of the CO2 control with the same free air CO2 enrichment system.

Unique Free Air CO2 Enrichment (FACE) technology to elevate the atmospheric concentration of CO2 in the experimental plots. Much research using elevated CO2 has been done in enclosed areas, such as growth chambers and greenhouses where it is relatively easy to control the levels of gasses. There are some limitations associated with these techniques, however. It is difficult to study plants under certain natural conditions, such as temperature, pollination, wind, humidity, and sunlight, within these enclosures. Size of the plant growth and experimental area is also constrained when using these technologies. It uses natural wind conditions to carry CO2 enriched air across the vegetation. Because the plants are outside in a more natural environment, the chamber effects normally created by enclosures such as greenhouses are reduced or eliminated.

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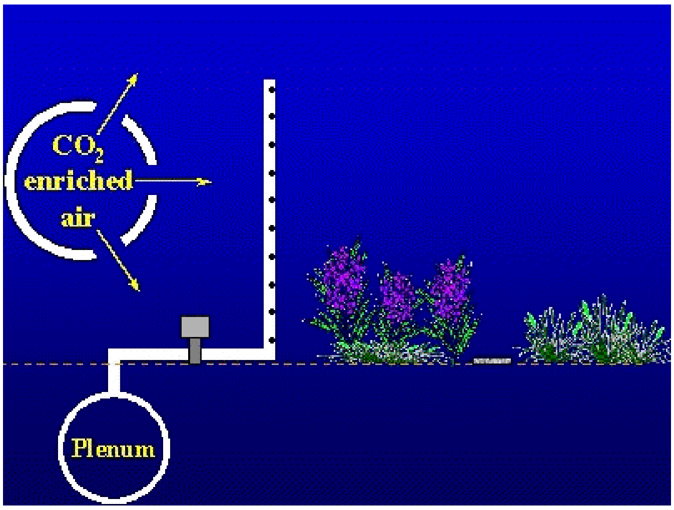
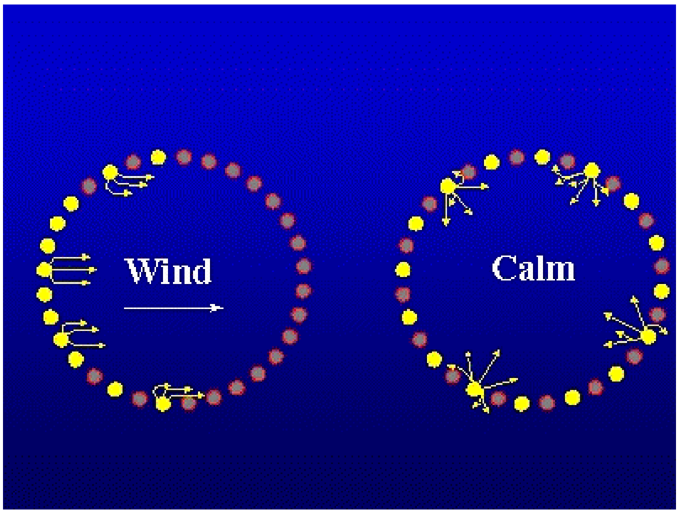
This is made up of six fumigation circles. Three of these circles are fumigated with CO2 enriched air. The FACE system is designed to maintain the level of
CO2 above the experimental planting at 550 parts per million (ppm), using sensors set up in and near the circles and a central control computer. The remaining 3 circles are 'fumigated' with ambient air (~360 ppm CO2) with no experimental CO2 addition in order to protect against erroneous results caused by the experimental equipment. Sensors at each circle continuously transmit information about wind speed and direction, as well as CO2 concentrations above the plots via fiber optics to a control computer. The computer, located in a centralized control trailer, uses this information to calculate the amount of CO2 to release, and which side of the circle to release it on. This information is sent to fan houses located at each circle that contain instruments, which adjust the CO2 fumigation equipment.

A valve inside the fan house controls the amount of pure CO2 added. The CO2 then is mixed with ambient air and a large fan blows this mixture into an underground pipe, called a plenum, which runs around the plot circle in the shape of an octagon. To conserve CO2, the enriched air is only emitted on the upwind side of the circles. Every 4 seconds, the control computer relays control instructions to the fan where a system of electronic components open and close large pneumatic valves on vertical emitter pipes installed around the plots (upwind pipes are opened, downwind pipes are closed). After passing through these valves, the CO2 enriched air travels up through the vertical pipes and is

Emitted through a series of small holes. Natural wind currents distribute the enriched air over and through the plots. When the wind speed is too low to carry the enriched air across the plots, alternating vertical





Pipes are opened so that small, shifting winds can still distribute the CO2 enriched air.
Because airflow is important to the distribution of the CO2, as much of the infrastructure at the site as possible is buried so as not to obstruct wind. This includes the plenums, CO2 piping, and utilities serving each circle. Any aboveground structure in the field is located at a distance great enough from any fumigation area to prevent disturbance of the airflow patterns.

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