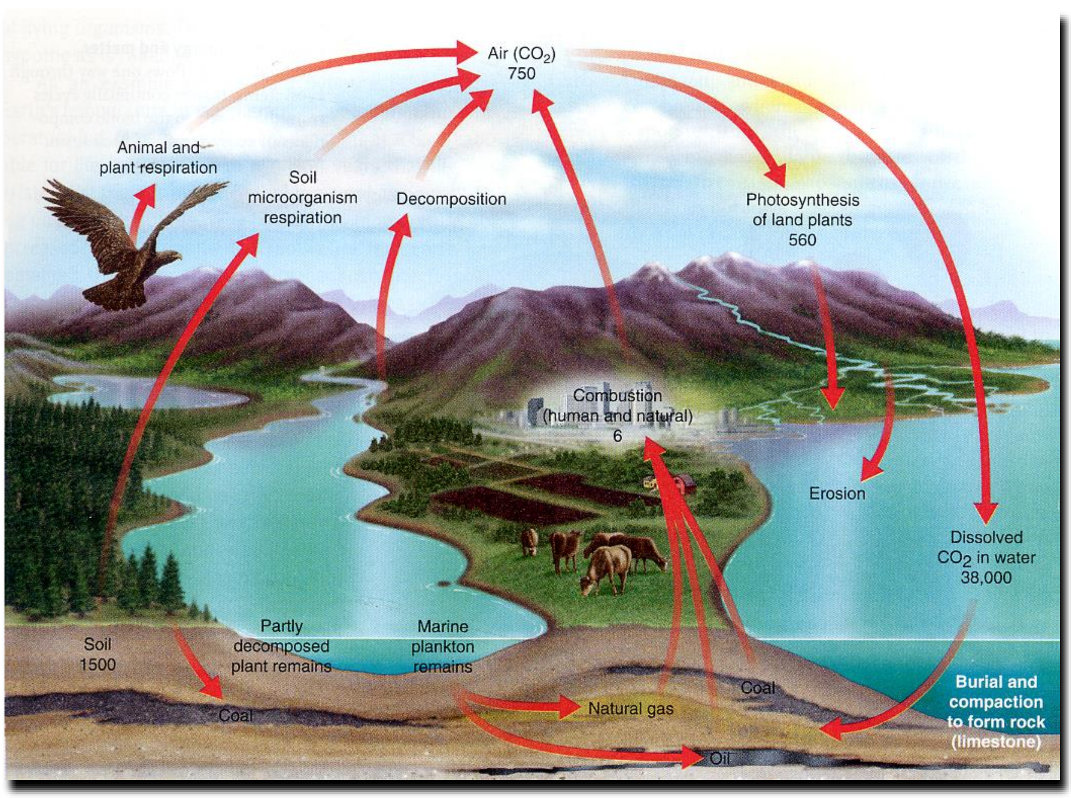
REDEMPTION OF THE BEAST

The Carbon Cycle and the Demonization of CO_2

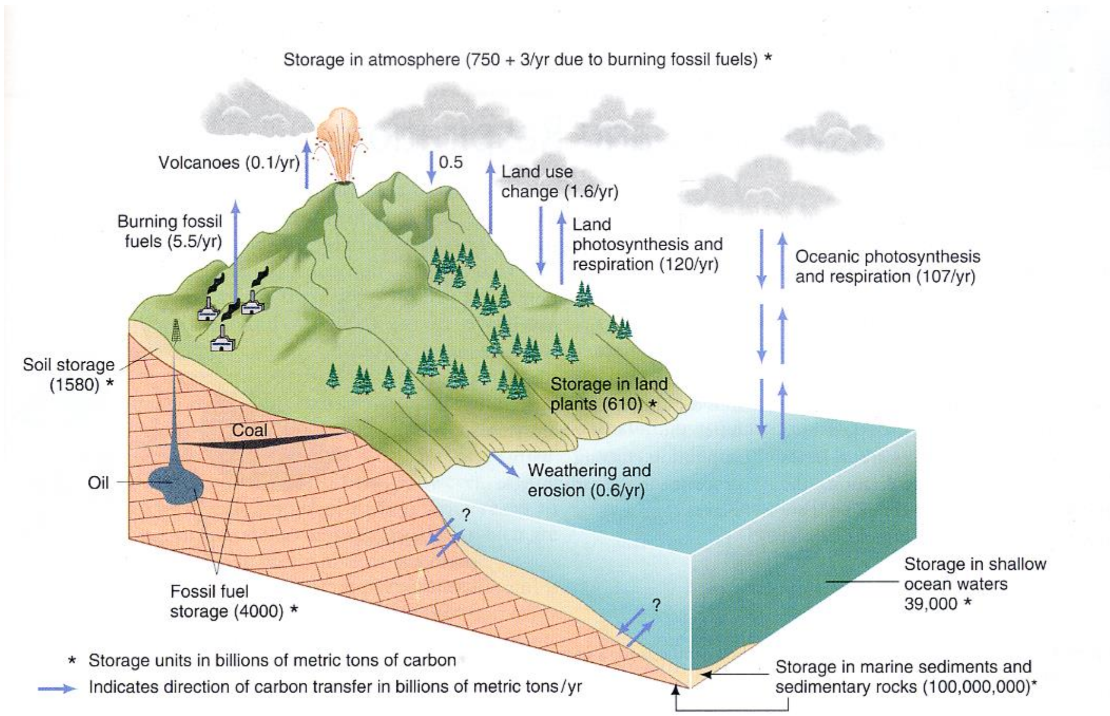
This essay and review of research into the carbon cycle and its effect upon the biosphere, more specifically upon the realm of plants and vegetation, is intended to provide a synopsis of evidence and information that is generally being neglected in mainstream discussions of Anthropogenic Global Warming (AGW) and to provide an enhanced and more realistic perspective on the effects of increasing concentrations of atmospheric of carbon dioxide upon the world of nature and the world of society, which, of course, are inextricably linked.

I will begin the review by introducing two graphs from relatively recent textbooks on Environmental Science that depict the Carbon Cycle throughout the various planetary sources and sinks. The basic numbers have not changed appreciably since the publication of these textbooks. The first chart is from Raven & Berg (2004) **Environment** 4/E; John Wiley & Sons, Inc. p. 106. Take note of the avenues of exchange from earth to atmosphere to ocean. The numbers are given in terms of "gigatons" of CO_2 with a gigaton being equal to one billion metric tons. The reservoir of the atmosphere is the one that is currently the cause for greatest concern due to the greenhouse effect being intensified by increasing concentrations of CO_2 resulting from the consumption of fossil fuels.



You will note that the amount of carbon dioxide in the atmosphere is given as 750 gigatons. You will also note that 560 gigatons are consumed in the process of photosynthesis by land plants. Take special note of the amount in the ocean: 38,000 gigatons, or 50 times the amount in the atmosphere. The soil at any time stores about 1500 gigatons. In the ocean the CO_2 is taken up by a variety of marine organisms that have the ability to precipitate calcium carbonate ($CaCO_3$) from seawater. This calcium carbonate forms the shells, or exoskeletons, of creatures such as scallops, bryozoans, foraminifera and coccolithophores. When these creatures expire their shells drift down and consolidate on the ocean floor where they are eventually lithified under pressure into limestone, chalk and marble, to become part of the lithosphere or rocky crust of the Earth. This is the greatest of all the reservoirs of carbon dioxide storage. This chart does not show the estimated amount of CO_2 stored in the lithosphere but it is enormous. Before going to the next graphic note that the amount generated through both human and natural combustion is 6 gigatons.

The next graphic also depicts the generalized global carbon cycle. It is reproduced from Botkin & Keller (2003) **Environmental Science – Earth as a Living Planet**; John Wiley & Sons, Inc. p. 63. It contains additional interesting details. Here fossil fuel burning accounts for 5.5 gigatons introduced into the atmosphere. This is ½ gigaton less than the preceding chart, presumably the ½ gigaton difference being the result of natural combustion and volcanism which is not included in this number. Storage in shallow ocean water is almost the same in both charts; fossil fuel deposits are shown to contain about 4000 gigatons of CO_2 while the sedimentary rock reservoir contains upward of 100 million gigatons! This is truly a staggering amount of carbon dioxide, and all of it at one time passed through the global atmosphere before it was taken up by the oceans, converted into biogenic calcium carbonate, and locked up in the Earth's crust. This is a clear implication that the ocean acts as a powerful pump, constantly extracting CO_2 from the atmosphere and ultimately sequestering it into carbonate sedimentary rocks, where it remains for a very long time. The natural process of oceanic uptake is constantly depleting the Earth's atmosphere of carbon dioxide, and if not replenished it would relatively quickly reduce the amount of CO_2 to a concentration too low for effective photosynthesis.



Finally, note that we have an additional interesting piece of information in the second graphic. The total amount of CO_2 residing in the atmosphere is given as 750 gigatons (same as the first chart) along with an additional +3 gigatons per year due to burning of fossil fuels. Hopefully the reader is paying attention to the extent that they will see that this +3 gigatons is about half the amount initially introduced into the atmosphere due to fossil fuel combustion, given as 5.5 gigatons in this chart and 6 gigatons in the Raven & Berg chart. A substantial portion of the difference between CO_2 released through combustion and the actual measured amount in the global atmosphere has been referred to as the "missing sink."

The Missing Sink

The idea of a missing carbon dioxide sink began showing up in the scientific literature in the early to mid- 1980s after several decades of air sampling and analysis. The program of atmospheric sampling dates back to 1968 when the National Oceanic and Atmospheric Administration (NOAA) began collecting air samples in Pyrex flasks, analyzing the contents and archiving the findings. Initially there were only two sampling sites but between 1971 and 1978 the number was expanded to 6 when NOAA launched the Geophysical Monitoring for Climatic Change (GMCC) program. In 1978 it was expanded again after the Department of Energy (DOE) started a program with the intention of looking at the longer term consequences of increased atmospheric CO_2 concentrations. One goal of this research effort was the development of models to determine the partitioning of fossil fuel derived CO_2 throughout the three principle global reservoirs: the oceans, the atmosphere and the biosphere. By 1982 a total of 23 sampling sites had been established. Samples at these sites were collected weekly and sent to the GMCC laboratory in Boulder Colorado for analysis. A full description of the sampling and analysis methodology can be found in [Komhyr, W. D. et al. (1985) **Global Atmospheric CO_2 Distribution and Variations From 1968-1982 NOAA/GMCC CO_2 Flask Sample Data**: *Journal of Geophysical Research*, Vol. 90, NO. D3, pp. 5567-5596, June 20.]

After 5 more years of sampling, 3 scientists from NOAA, NASA and Lamont-Doherty Geological Observatory, Columbia University performed an analysis on air samples collected from 1981 through 1987 and published their results in the journal *Science* in 1990. [See: Tans, Pieter P., Inez Y. Fung, & Taro Takahashi (1990) **Observational Constraints of the Global Atmospheric CO_2 Budget**: *Science*, vol. 247, No. 4949, March 23, pp. 1431 – 1438] By this time it had become well established that the amount of CO_2 in the atmosphere was increasing, however, as the authors of this paper comment "After 30 years of measurements in the atmosphere and the oceans, the global atmospheric CO_2 budget is still surprisingly uncertain." They acknowledge the contribution of fossil fuel combustion on the observed increase in atmospheric concentrations but point out that the measured rise was only somewhat over half of the fossil fuel derived contribution. In estimating the fate of this missing carbon dioxide they point out that the uptake of CO_2 attributed to the ocean was estimated to be between 26% and 44% of fossil CO_2. Disinclined to believe the ocean was consuming that much they speculated that there must be a substantial, but as of yet, unidentified terrestrial sink. In conclusion the authors comment that "Our analysis thus suggests that there must be a terrestrial sink at temperate latitudes to balance the carbon budget . . . The mechanism of this C sink in unknown; <u>its magnitude appears to be as large as 2.0 to 3.4 Gt of C per year</u> . . ." Given that the total anthropogenic contribution of CO_2 to the atmosphere is on the order of 6 Gt (gigatons) it is obvious that half of it is missing in action, so to speak.

In 1992, an article appeared in the *Australian Journal of Botany* by J.A. Taylor and J. Lloyd describing their analysis of global patterns of carbon sequestration. Their calculations and model runs indicated "the possibility that a significant net CO_2 uptake, a CO_2 'fertilization effect', may be occurring in tropical rainforests, effectively accounting for much of the 'missing sink.' [See: Taylor, J. A. and J. Lloyd (1992) **Sources and Sinks of Atmospheric CO_2**: *Australian Journal of Botany*, vol. 40, No. 5, pp. 407 – 418.] I will return to the question of the role of tropical rain forests in the uptake of carbon dioxide later in this review.

In 1995 a team of 5 scientists with NOAA and the Department of Geological Science at University of Colorado at Boulder, led by Phillippe Ciais, an atmospheric physicist with the *Laboratoire des Sciences du Climat et de l'Environment*, France, published the results of a study of weekly air samples taken from a global network of 43 sites by the Stable Isotope Laboratory at the Institute of Arctic and Alpine Research. These samples were measured for concentrations of Carbon 13, a stable isotope of carbon. In the words of the abstract to their paper, published in the journal *Science*, the concentrations and the isotopic ratios of carbon-13/carbon-12 in atmospheric carbon dioxide "can be used to quantify the net removal of carbon dioxide from the atmosphere by the oceans and terrestrial plants." Without getting into the details of their procedure, the result of their analysis, as the abstract goes on to describe, was that "A strong biospheric sink was found in the temperate latitudes of the Northern Hemisphere in 1992 and 1993, the magnitude of which is roughly half that of the global fossil fuel burning emissions for those years. The challenge now is to identify those processes that would cause the terrestrial biosphere to absorb carbon dioxide in such large quantities." [For more see: Ciaia, P. et al. (1995) **A Large Northern Hemisphere Terrestrial CO_2 Sink Indicated by the $^{13}C/^{12}C$ Ratio of Atmospheric CO_2**: *Science*, vol. 269, Aug. 25, pp. 1098 – 1101] Yes, here was the challenge – it turns out that something in the terrestrial biosphere was absorbing large quantities of carbon dioxide and no one was quite sure what it was.

Studies continued on the terrestrial carbon cycle through the 1990s and by the turn of the millennium the problem of the missing carbon had still not been resolved although progress was being made in determining the proportions attributed to the ocean and to the land biosphere. A small sample of some of the work follows.

[Bender, Michael L., Mark Battle & Ralph F. Keeling (1998) **The O_2 Balance of the Atmosphere: A Tool for Studying the Fate of Fossil-Fuel CO_2**: *Annual Review of Energy and Environment*, Vol. 23, pp. 207-223]

> "CO_2 is added to the atmosphere by biomass burning and the combustion of fossil fuels. So added CO_2 remains in the atmosphere. However, substantial amounts are taken up by the oceans and land biosphere, attenuating the atmospheric increase. . . Man is currently adding CO_2 to the atmosphere at the rate of about 6.4 Gt C/yr by combusting fossil fuels and (to a small extent) by making concrete. We are adding another ~1 Gt C/yr by deforestation, mostly in the tropics. If all this CO_2 remained in the atmosphere, the CO_2 concentration of air would rise by about 3.5 ppm/year, much more than the observed increase of about 1.5 ppm/year. The difference between fossil-fuel input and accumulation, today as in the past, is attributable to the CO_2 uptake by the oceans and by the growth of the land biosphere, as demonstrated by C. D. Keeling in a series of seminal publications."

Here we learn several things. We learn that in addition to fossil fuel combustion, carbon dioxide is added to the atmosphere through biomass burning. We are informed that the rise in carbon dioxide based solely on anthropogenic emissions should be occurring at 3.5 parts per million per year. The measured increase, however, is only 1.5 parts per million each year. In this study it was found that only 42.8% of total anthropogenic emissions of CO_2 was actually residing in the atmosphere. The remaining 57.2 % was, and is, being sequestered on land and in the oceans by natural processes. I should also point out that more recent studies suggest that cement production actually results in a net carbon dioxide sink rather than source, because, even though CO_2 is released during cement production, concrete, it turns out, reabsorbs even more of it over the long term.

Other studies followed:

> [Battle, M. et al. (2000) **Global Carbon Sinks and Their Variability Inferred from Atmospheric O_2 and δ13C**: *Science*, Vol. 287, No. 5462, Mar. 31, pp. 2467-2470] "Between 1991 and 1997, combustion of fossil fuels added roughly 6.2 gigatons of carbon per year (GtC/year) to the atmosphere in the form of CO_2. During this same period, the atmospheric burden of CO_2 increased by only 2.8 GtC/year. The balance of the CO_2 was taken up by the oceans and the land biosphere."

In this report we are given a somewhat different perspective on the same situation as discussed in the Bender, Battle and Keeling article. There the total annual amounts are given as 6.2 gigatons and 2.8 gigatons, or, in other words, 55% percent of human emissions of carbon dioxide are missing, gone, no longer part of the atmosphere, consumed by the biosphere.

An article by Steven C. Wofsy Abbott Lawrence Rotch Professor of Atmospheric and Environmental Science at Harvard University appeared in *Science* in 2001 [see: Wofsy, Steven C. (2001) **Where Has All the Carbon Gone?** *Science*, Vol. 292, June 22, pp. 2261 – 2263]
Wofsy writes:

> "Emission rates of CO_2 from combustion of fossil fuel have increased almost 40 percent in the past 20 years, but the amount of CO_2 accumulating in the atmosphere has stayed the same, or even declined slightly. The reason for this discrepancy is that <u>increasing amounts of anthropogenic CO_2 are being removed by forests and other components of the biosphere</u>. It is estimated that more than 2 billion metric tons of carbon – equivalent to 25 percent of the carbon emitted by fossil fuel combustion – <u>are sequestered by forests each year</u>."

Here is a remarkable fact. One quarter of the annual amount of fossil fuel sourced carbon dioxide was being consumed by forests alone. What effect could this process be having upon the forests of the world? I will come back to that question directly.

Liu, Zaihua, Wolfgang Dreybrodt, Haijing Wang (2010) **A new direction in effective accounting for the atmospheric CO_2 budget: Considering the combined action of carbonate dissolution, the global water cycle and photosynthetic uptake of DIC by aquatic organisms**: *Earth Science Reviews*, vol. 99, pp. 162-172

> "One of the most important challenges in the science of global change is effective accounting of the global budget for atmospheric CO_2. Anthropogenic activities have clearly altered the global carbon cycle and significant gaps exist in our understanding of this cycle. Roughly half of the CO_2 emitted by burning fossil fuels remains in the atmosphere, and the other half is absorbed by the oceans and the terrestrial biosphere. The partitioning between these two sinks is the subject of considerable debate. Without robust accounting for the fate of CO_2 leaving the atmosphere predictions of future CO_2 concentrations will remain uncertain."

Consider well the use of the term "uncertain" in this context. If the future CO_2 concentrations are uncertain, how can any projections as to climatological effects be certain? As one learns more about the actual science involved in this debate about carbon dioxide driven climate change the more it becomes apparent that uncertainty is the preeminent trait of our present knowledge of global change on all levels, and the constant refrain that the science is settled are seen to be downright duplicitous.

Plants Love Carbon Dioxide

So, it is apparent that Nature has the ability to remove large amounts of carbon dioxide from the global atmosphere. It is this uptake of CO_2 that removes at least half the amount that is being emitted through fossil fuel combustion. Whatever the exact distribution of CO_2 into the various sinks it is clear that a substantial portion of it is being consumed by the biosphere in the process of photosynthesis. It is also apparent to many researchers that if not continuously replenished the ocean alone would relatively quickly sequester so much carbon dioxide from the atmosphere that it would severely affect photosynthetic processes. Many workers in the field have, over the years, commented on the paucity of CO_2 in the atmosphere and the positive role it plays in biological processes. A couple of examples will serve to demonstrate the attitude about carbon dioxide before its demonization as the driver of global warming disaster. Near the end of the 19^{th} Century T. C. Chamberlin, one of the most influential geologists of that era and founder of the *Journal of Geology*, wrote:

> "The virtues of carbon dioxide are in inverse ratio to the sinister reputation which "a little knowledge" and a narrow homocentric point of view have given it. As a constituent of the atmosphere it is as necessary to the maintenance of life as oxygen because it is the food of plants and they in turn are the food of animals. Its peculiar competency to retain the heat of the sun renders it a decisive factor in the maintenance of that measurable constancy and geniality of temperature upon which the existence of life depends. It is a leading agency in the disintegration of crystalline rock and is a necessary factor in other geologic changes. It is an essential link in a chain of vital processes which involve all the constituents of the atmosphere."

> ". . . It is the least chemical constituent of a mixture that determines the amount of reaction. A loss of nitrogen or oxygen equal to .0003 of the atmosphere would doubtless be wholly inconsequential, while that amount of loss of carbon dioxide would be fatal to

life and to many important geological processes." [see: Chamberlin, T. C. (1898) **The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere**: *The Journal of Geology*, vol. 6, No. 6, (Sept.—Oct.) pp. 609 – 621]

Here Chamberlin points out the fact that even a miniscule decline in the relative concentration of atmospheric CO_2 would have serious consequences for global plant life. I would suggest that today we have a large group, who for various reasons – political, economic or philosophical, have chosen to take the "narrow homocentric point of view" by now attributing all climate change to the activities of mankind.

64 years after T.C. Chamberlin's remarks on the importance of carbon dioxide, soil scientist A. G. Norman, who studied the relationship between photosynthesis and carbon dioxide, publishing dozens of papers from the 1930s through the 1960s. In a 1962 article published in the journal *American Scientist* he commented on the vitally important role of CO_2 in global biological processes. In this article he addressed the paucity of atmospheric carbon dioxide relative to its importance as an essential plant nutrient.

> "It is somewhat unfortunate that we have allowed the phrase "plant nutrients" to mean those inorganic elements that are essential for plant growth, because this causes us to forget the real substances from which the bulk of the stuff of plants is synthesized. The chemical engineer of whom we spoke earlier might be a little taken aback at being told that his only raw materials would be carbon dioxide and water . . . If one added, however, that the carbon dioxide would be available only at a concentration of 3 parts in 10,000 by volume, diluted with an excess of nitrogen and oxygen, he might appear troubled, because to him that would mean the handling of vast quantities of air to extract the carbon dioxide needed. The plant can do this. Let us not underestimate the stupendous quantities of carbon dioxide that are incorporated into vegetation. Figures of the order of 1.5×10^{10} tons [15 billion tons] annually have been quoted for incorporation into terrestrial plants (excluding the oceans). Perhaps one-thirtieth to one-fiftieth of this may be accounted for by economic crops, or plants used by man . . . even the last figure for crop plants exceeds several fold the yearly carbon dioxide output of all industrial operations on earth."

Norman goes on to point out that:

> "Perhaps it is easier to grasp figures based on an acre. To grow a good field of corn which will yield 100 bushels, about 20,000 pounds carbon dioxide is needed to provide about 5500 pounds for the organic structures of the crop. During the growing season, therefore, the corn plants on one acre must deplete an enormous volume of air to meet their needs for carbon dioxide. No less than 21,000 tons of air are needed to supply 20,000 pounds of carbon dioxide. This is a startling calculation because it points up the astonishing ability of plants to do what an engineer might describe as "processing" these many tons of air to recover and utilize about two and one-half tons of carbon." [see: Norman, A. G. (1962) **The Uniqueness of Plants**: *American Scientist*, Vol. 50, No. 3, Sept., pp. 436 – 449]

The amount of carbon dioxide in the atmosphere since Norman wrote this article has increased to where it is now close to 4 parts in 10,000, by volume. This is still a miniscule amount when considered as a portion of the total atmosphere. If the amount of carbon dioxide in the atmosphere were to become diminished by a mere 2 parts out of 10,000 there would be serious detrimental repercussions to the process of photosynthesis, hence to the health of Earth's plant life and to the entire biosphere as a consequence. One conclusion to be drawn from Norman's comments is apparent: It takes a truly enormous amount of carbon dioxide to stimulate photosynthesis in the world's vegetation. I will return to the question of the effects of reduced atmospheric concentrations later in this essay.

So, to summarize: Each year anthropogenic fossil fuel combustion releases roughly 6 gigatons of carbon dioxide into the atmosphere. Of this amount nature is rapidly consuming, or sequestering, about half, leaving only about 3 gigatons of residual human sourced CO_2 remaining in the atmosphere.

The proportion of carbon dioxide in the atmosphere is measured in parts per million and at present stands at about 400 parts per million. (4 parts out of 10,000) Here is one way to look at the matter: For every 1 million molecules of air, (made up of primarily nitrogen and oxygen) there are 400 molecules of carbon dioxide. For comparison, of oxygen there would be 209,500 molecules, of nitrogen 780,900 with about 9300 remaining for argon gas and a few other gases. In other words, the total mass of the atmosphere is over 2500 times greater than the carbon dioxide within it and some 625,000 times greater than the total amount of anthropogenically sourced atmospheric CO_2. The mass of this 400 parts per million of CO_2 taken altogether makes up the total of about 753 gigatons residing in or transiting through the atmosphere at any given time. 3 of these 753 gigatons, then, are the consequence of human activity, the rest is the result of the natural activity of the carbon cycle, a difference of 250 to 1. Let's take a moment to do a bit of math. Dividing 400 by 1 million gives us the figure of .0004, the decimal fraction for the total amount of CO_2 in the atmosphere. To see the amount of atmospheric CO_2 resulting from human activity divide this number in turn by 250. The result is the decimal fraction .0000016. This is a very small number, not much greater than nothing at all when compared to the whole atmosphere.

Are we then supposed to accept the conclusion, without question or debate, that this miniscule additional amount of CO_2 to the atmosphere is going to provoke such a horrendous planetary catastrophe that we must completely overhaul our energy system, in effect, according to some of the more extreme proposals, dismantle our industrial infrastructure altogether? I am not making an argument for any one kind of energy technology over another here, I am simply trying to put things into perspective. I am totally in favor of making the conversion to a post carbon future. But if we seriously circumscribe the productivity of industrial society by over-regulating, over-taxing, or hamstringing vital industries in the energy sector we will actually delay the day when that conversion comes to pass. If we base our actions upon an exaggerated threat we will end up squandering our resources and natural capital on diversions and distractions from the truly critical concerns and problems that should head our list of priorities as an evolving, planetary civilization.

Let's return to the other side of the issue, the one that manages to be neglected in most mainstream discussions of climate change − the positive, *yes positive*, role of carbon dioxide in critical biological processes. As pointed out above, in the work of T. C. Chamberlin and A. G. Norman, the concentration of CO_2 in the atmosphere is very low relative to its importance for the health of the biosphere because of its fundamental role in photosynthesis. Reduce the amount of atmospheric carbon dioxide by even a small amount and plant life suffers, and hence, the entire chain of life. In fact, the amount of reduction that would begin to have serious effects on plant life is a mere 2 parts out of 10 thousand. So, given that a small decrease in the amount of carbon dioxide in the global atmosphere would be detrimental to plant life, what about the biological and environmental effects of <u>increasing</u> the amount available to plants? As it turns out there exists an enormous body of research into this question and to that important matter we will now turn.

Studies going back decades have demonstrated conclusively that carbon dioxide is indispensable to a healthy biosphere, having remarkable effects on plants of all types. I could not possibly go into detail on the hundreds of studies performed throughout the 20th century making the case that enhanced carbon dioxide concentrations have a positive effect on the biosphere, but I will discuss enough of them to make the point.

Awareness of the beneficial botanical effects of carbon dioxide enhancement goes back centuries. In the early 1600s a citizen of Brussels, Jean-Baptiste van Helmont, planted a 5 pound willow tree in a container in which he placed 200 pounds of soil. For five years van Helmont carefully monitored the amount of water provided and at the end of 5 years the tree weighed over 169 pounds but the soil was diminished in weight by only 2 ounces. While some of this increased tree mass was the result of small quantities of mineral nutrients supplied by the soil, two horticultural scientists referencing the work of van Helmont, remarked in 1964, that "More forcibly it should remind us that the primary nutrient from which the bulk of the plant originates is the carbon dioxide from the atmosphere." [See: Wittwer, S. H. and Wm. Robb (1964) **Carbon Dioxide Enrichment of Greenhouse Atmospheres for Food Crop Production**: *Economic Botany*, Vol. 18, No. 1 (Jan. – Mar.) pp. 34 – 56] I will return to the work of Wittwer and Robb directly.

The United States Department of Agriculture has, since its inception, published annual summaries of research and work relevant to agriculture. In the *Experiment Station Record* for 1904-1905, the Department provided a summary and translation of the experimental work of M. E. Demoussy, originally published in French in 1904. In the early 20th century Demoussy performed an experiment in France demonstrating the effects of carbon dioxide on a variety of plants. These experiments were an early demonstration of the benefits of carbon dioxide enrichment. The summary of the article in the Experimental Station Record was entitled "**The growth of plants in atmospheres enriched in carbon dioxide.**" The translation of Demoussy's article reads as follows:

> "The results of the author's investigations in growing lettuce in an atmosphere enriched in carbon dioxide have been questioned as being too limited to permit of generalizations.

The author has repeated his experiments with 16 species of plants, representing a wide range of families.

Duplicate series were grown, one in normal atmosphere containing about 3 parts of carbon dioxide in 10,000, and the other series in an atmosphere enriched daily by about five times the normal quantity of carbon dioxide. The experiments were continued for about 2 months, after which several portions of the plants were weighed. Among the species studied were coleus, lettuce, geraniums, centaury, mint, tobacco, balsam, fuchsias, etc. In all except the fuscias there was a decided increase in the weight of the plants, the average amounting to over 60 percent increase. In addition the geraniums, begonias, mints, etc. were hastened in their flowering and flowered more abundantly in the atmosphere enriched in carbon dioxide than was the case with the plants grown under normal conditions." [See: U. S. Dept. of Agriculture (1904-1905) *Experiment Station Record*, vol. XVI, p. 847. For the original article in French see Demoussy, M. E. (1904) **Sur la vegétation dans des atmosphères riches en acide carbonique**: *Comptes Rendus de l'Académie des Sciences*, vol. 139, No. 21, pp. 883-885]

Before moving on let's ponder the results of this experiment over 100 years ago. The control group of plants was exposed to the ambient CO_2 concentration, at that time measuring about 300 parts per million. The experimental group was exposed to 5 times that amount, or about 1500 parts per million. At the end of two months the average increase in the weights of the various species of plants exposed to CO_2 enrichment as compared with control groups was over 60 percent. In other words the plants responded exuberantly to the increase in their food supply and thrived strikingly.

Wittwer and Robb, referenced above, discuss an early experiment that demonstrated the positive effects on plants of carbon dioxide enrichment, citing the work of M. B. Cummings and C. H. Jones in 1918, published in the Vermont Station Bulletin. The title of their report was "**The aerial fertilization of plants with carbon dioxide**." Cummings and Jones initiated a series of trials in 1909 that extended over 7 years. Augmented supplies of carbon dioxide were supplied for 8 hours each day to plants growing in open boxes. Wittwer and Robb summarized the findings of Cummings and Jones: "Favorable yield increases were obtained with many crops. Yields of pods and seeds were enhanced in peas and beans. Potatoes produced more leaves and tubers. Large and heavier leaves were formed by foliage crops. Lettuce was very responsive. Flower crops produced blossoms earlier and in great profusion. Strawberries yield fruit far in excess of the controls."

Wittwer and Robb also mention that extensive experimentation was being conducted in Europe as well. They note that some of these experiments showed that the yield of some food plants such as tomatoes and cucumbers was doubled, or even tripled, by the addition of CO_2.

In the 1920s botanists with the Department of Plant Physiology and Pathology, Imperial College of Science and Technology, London, designed and constructed apparatus to improve standardization of testing, which prior to this time lacked sufficient controls to perform a reliable statistical analysis. [see: Bolas, B. D. & Henderson, F. Y. (1928) **The Effect of Increased**

Atmospheric Carbon Dioxide on the Growth of Plants. 1: *Annals of Botany*, Vol. XLII, No. COLXVI, April, 1928. pp. 509 – 523]

The results of their initial testing were published in 1928. Reporting on some of their earliest efforts they explain, "In this apparatus, seedlings of white mustard grown for eighteen days during the early summer of 1923 yielded a dry-weight increase of 68 per cent. ±7.7 per cent. over the controls." In regards to an extensive experiment performed on cucumber seeds they report that "in one of the experiments in the series now being performed the dry-weight ratio of the experimental plants to the control plants was 225 : 100 after fourteen days' growth in air containing increased carbon dioxide." They also comment on the work of German botanist H. Fischer published the year before: "Fischer in a recently published paper notes that plants grown in atmospheres rich in carbon dioxide are richer in chlorophyll than those grown in ordinary air. Increased greenness has been observed throughout the above series of experiments." The authors' final concluding remark describes the results on cucumber plants, "It is found that in all experiments the artificial enrichment of the air with carbon dioxide results in a large increase in the dry weight of cucumber plants as compared with the results obtained in normal air. An increase is evident within two or three days from the beginning of the experiment."

These results are quite extraordinary. Contemplate the fact that the weight of the experimentally enriched plants was 2 ¼ times greater than the control plants.

Turning back to the experimental work of agronomists Wittwer and Robb, we will consider their 1964 study **Carbon Dioxide Enrichment of Greenhouse Atmospheres for Food Crop Production.** This report described a series of experiments conducted from 1962 to 1963 at the Plant Science Greenhouses at Michigan State University with a variety of crops grown in containers. In this study they remark that:

> "The great demand of green plants for carbon dioxide, suggests that levels of this gas in the ambient air of a heavy crop stand, and particularly in enclosed greenhouse atmospheres, might become sufficiently depleted, that growth is reduced. Alternatively, carbon dioxide levels in plant growing atmospheres maintained substantially above the normal should favor growth."

Two points should be emphasized here. First – the authors advise that, because of the great demand by plants for carbon dioxide, it is likely that in a greenhouse environment the atmosphere might quickly become depleted in this essential gas to the extent that it begins to impede plant growth, supporting the idea that ambient atmospheric amounts of CO_2 are, in point of fact, precariously low relative to the requirements of the biosphere, a point I will come back to later in this essay. Second – plant growth could be stimulated through enrichment of carbon dioxide in the greenhouse atmosphere with potential economic benefit. The authors go on to describe the results of experiments in the tank culture of algae in which it was found that

> ". . . it is possible to increase, by as much as 50 to 100 percent or more, the rate of photosynthesis under natural conditions by 'carbon dioxide fertilization' . . . In fact,

carefully controlled experiments, the results of which for many plant species have now accumulated, show that neither the normal carbon dioxide concentration of the air, nor this gas in water . . . is sufficient for saturating photosynthesis in moderate or strong light." Here is a phrase we will encounter again: "carbon dioxide fertilization."

The authors are here pointing out that normal carbon dioxide amounts in both air and water are not sufficient for maximizing photosynthesis. In other words, the plants could readily consume a great deal more carbon dioxide than they presently are under ambient conditions. There is an important implication here. From this perspective one could surmise that the world's plants might actually, under current conditions, be suffering from a carbon dioxide deficit.

The following photographs from Wittwer and Robbs report dramatically demonstrate the remarkable effects of CO_2 enrichment on a variety of plants. These show only a few of the many similar experimental results but are typical.

Figure 1. Tomatoes grown in a controlled environment with CO2 concentrations varying between 125 and 500 ppm. Present global atmospheric concentrations are right at 400 ppm. Compare with the next image. From Wittwer & Robb (1964)

Figure 2 Tomato plants grown in an environment with CO_2 concentrations varying between 800 and 2000 ppm, that is, 2x and 5x the current atmospheric concentration. From Wittwer and Robb (1964).

In the image below Wittwer and Robb show results of carbon dioxide enrichment on several plant varieties after 30 days. The plants in the top row are leaf lettuce, second from the top is bibb lettuce, second from the bottom are tomato plants and the bottom is cucumber. The column on the left are plants grown in an environment with approximately 400 parts per million carbon dioxide, similar to the present concentration, and the column on the right shows plants grown with ambient CO_2 concentrations of 1000 ppm. The difference in growth is obvious and impressive.

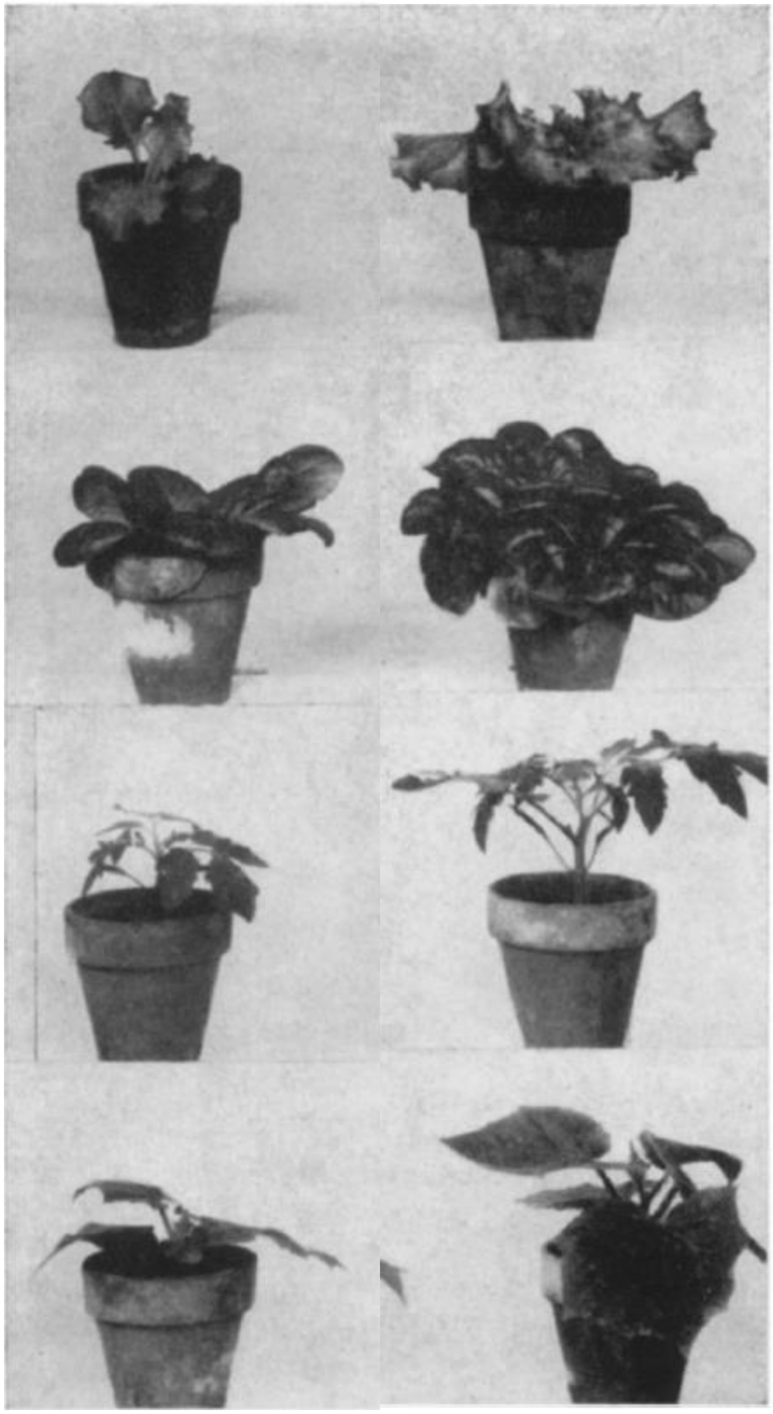


Table 1 below from Wittwer and Robb displays the effects on 8 varieties of lettuce. In every case the weight of the lettuce variety grown in an enriched environment was substantially greater.

TABLE 1
THE EFFECTS OF ADDED CARBON DIOXIDE ON THE YIELD OF GREENHOUSE GROWN LETTUCE (JANUARY 18-FEBRUARY 26, 1961*

Variety	Weight in Pounds per 10 Heads $-CO_2$	Weight in Pounds per 10 Heads $+CO_2$
Bibb	1.5	2.0
Cheshunt No. 5B	2.1	2.6
Proeftuins Blackpool	1.9	2.2
Simone	1.8	2.6
Kardot	2.0	2.7
Klack	1.8	2.5
Kurik	2.2	2.9
Mean (all varieties)	1.9	2.5

*Levels of CO_2 ranged from 200-350 p.p.m. in $-CO_2$ and from 300-600 p.p.m. in the $+CO_2$ during the daylight hours.

Experiments were also performed on a variety of tomatoes with the results shown below in Table 4 from Wittwer and Robb. Again, the remarkable effect on yield is impressive.

TABLE 4
EFFECTS OF CARBON DIOXIDE ENRICHMENT OF A GREENHOUSE ATMOSPHERE ON YIELDS OF SEVERAL VARIETIES OF TOMATOES*
(Accumulative yields in pounds per plant of marketable fruit from February 15-June 1)

Variety	$-CO_2$	$+CO_2$	Increase with $+CO$
	(lbs. marketable	fruit/plant)	(percent)
Michigan-Ohio hybrid	9.6	13.6	42
WR-7 Globe	9.3	15.9	71
Spartan Red 8	7.5	11.8	57
Spartan Pink 10	11.3	15.0	33
Ohio Hybrid 1	9.2	13.5	47
Ohio Hybrid 0	11.1	13.9	25
R-25	8.4	13.3	58
Tuckcross O	12.2	15.7	29
Tuckcross M	9.3	13.2	42
Mean (all varieties)	9.8	14.0	43

*Levels of CO_2 ranged from 125-500 p.p.m. in $-CO_2$ and from 800-2000 p.p.m. in $+CO_2$ during daylight hours, except when ventilators were open.

In summarizing their experiments, conducted at the Plant Science Greenhouses at Michigan State University, Wittwer and Robb discussed the effects on growth and development they observed during their experiments:

> "The effects of above normal levels of carbon dioxide are even more pronounced on reproductive development than on vegetative growth. Tomato fruit yields were significantly increased . . . Fruit harvest was more consistent and less subject to fluctuating outdoor weather. Size and fruity quality were enhanced . . . Our data for cucumbers are supported by those of Daunicht where percent increases in fruit production were several fold greater than those for vegetative growth. . . More rapid growth rates, from carbon dioxide enrichment of a greenhouse atmosphere, have resulted in earlier maturity and higher yields of lettuce. Three crops of lettuce in place of two during fall, winter, and spring production are possible . . . Other benefits from growing crops in high levels of carbon dioxide in a greenhouse atmosphere have been reported. The percent dry matter is increased. The essential oil content has been enhanced. Rooting of cuttings was favored. Tomatoes had a higher vitamin C and sugar content, and plants were more resistant to some fungus and virus diseases and insects."

In the conclusions to their report Wittwer and Robb confirm that their findings were similar to previous studies that found a substantial enhancement of plant growth. They made reference to Dutch botanist C. J. Briejer who published the results of his studies on plant responses to increased carbon dioxide concentrations in 1959 with the title *Een verlaten goudmijn: koolzuurbemesting* translated as "An abandoned gold mine: carbon dioxide fertilization". Wittwer and Robb concur with the comment "Our findings lead us to agree."

The authors conclude by emphasizing the benefits to be realized by commercial greenhouse operators with the employment of carbon dioxide enrichment:

> "the grower of greenhouse vegetables has an unprecedented opportunity to strengthen his competitive position through substantial yield increases, a marked improvement of quality, and year around production by enrichment of greenhouse atmospheres with carbon dioxide . . . The production potential for greenhouse grown vegetable crops of the future is comparable to that which appeared a century ago when the agronomic benefits of chemical fertilizers were first realized. The ultimate possible rewards are so great that growers of greenhouse vegetables can begin immediately to use and to benefit from the results of the research findings herein reported . . ."

Is it possible that this "production potential" could be realized on the scale of the planetary biosphere? I will return to that question.

After 21 more years of study, one of these authors, the late Sylvan Wittwer, (who passed away in 2012 at the age of 95) reiterated the fact that there were benefits to the increase in atmospheric carbon dioxide. But then he went on to say something else very interesting. He, along with co-author Emeritus Professor of Biology, Boyd R. Strain pondered the effect of the increasing supply of CO_2 on the planetary vegetation realm and speculated that

> “An increase in plant growth due to ‘fertilization’ of extra CO_2 has not been measured, but a 5 to 10% increase may already have occurred. Current data indicate that plants growing at higher than normal CO_2 levels are more tolerant of water, temperature, light, and atmospheric pollutant stresses. There are effects on carbon metabolism, plant growth and development, microbial activity, and terrestrial and aquatic plant communities.” [see: Wittwer, Sylvan H. & Boyd R. Strain (1985) **Carbon dioxide levels in the biosphere: Effects on plant productivity**: *Critical Reviews in Plant Sciences*, vol. 2, No. 3, pp. 171 – 198]

Here we see that by 1985 these scientists were speculating that there may have already occurred as much as a 5 to 10% increase in plant growth due to carbon dioxide fertilization, but at that time did not have sufficient data available to confidently make such a claim. We will come back to this question directly, and see that now, in 2017, we do have enough data to draw some conclusions.

Returning to the subject of carbon dioxide utilization in greenhouses we will turn to a 1973 report by the Economic Research Service with the U. S. Department of Agriculture. In this report, titled “**Global Review of Greenhouse Food Production**” the authors presented a brief exposition of early studies relating to the effects of controlled increases of carbon dioxide on plants. I will quote at length from that report:

> “Carbon dioxide, along with water, is one of the two major ingredients in the process of photosynthesis. Below-normal levels of CO_2, often found in unventilated greenhouses, can reduce the rate of photosynthesis, while above-normal levels can hasten photosynthetic activity.”

To repeat: The reason below-normal levels of carbon dioxide occur in unventilated greenhouses is that the plants will quickly consume all available CO_2 as they grow and unless the supply is replenished it will then diminish to levels insufficient for continued photosynthesis, thereby stunting further plant growth. The Review goes on to discuss the upsurge in CO_2 utilization in greenhouses in the 1960s due to development of safe and economical combustion sources of CO_2 along with monitoring devices and plastic tubing for distribution and circulation. These innovations led to a major increase of testing and experimentation. The Review describes the situation in Europe at the time:

> “The expansion first took place in Holland. It started in February 1961 when a grower used a small paraffin (kerosene) oil warming stove during the daytime hours on lettuce and obtained exceptional quality and weight: the effect was traced to CO_2. Followup work at the Glasshouse Experimental Station in Naaldwijk showed outstanding results on lettuce and strawberries and good results on tomatoes, endive, spinach and radishes. The weight of the lettuce was increased and growth accelerated by 20 to 30 percent. During the 1962/63 season, the area of treated lettuce expanded into thousands of acres and 25 percent of the early greenhouse tomato growers used CO_2. By 1972, the total area treated in Holland was about 7,000 acres . . .”

"The most recent wave of experimental work with CO_2 in the United States began during the winter of 1961/62 at Michigan State University. Increases of 30 percent in lettuce yields were obtained; the following winter the figure rose to 70 percent . . . Increases in tomato yields ranged from 25 to 70 percent, depending on variety, and average 43 percent. CO_2 proved to be especially effective in midwinter because crops in non-ventilated houses quickly utilize most of the available CO_2 during the early morning hours and thereafter receive little benefit from sunlight."[see: Dalrymple, Dana G. (1973) **A Global Review of Greenhouse Food Production** (Foreign Agricultural Economic Report No. 89) Washington D.C.]

A 1983 study on four plant species was conducted using transparent open-topped chambers placed in fields. Carbon dioxide was fed into the chambers by means of a ¾ horsepower fan and metered day and night. A high-pressure manifold allowed control of the ventilation airstream to generate 3 different CO_2 concentrations. The tests were conducted by 3 botanists and the report describing the tests and their results appeared in the journal *Science*.

"The essential role of plants in the carbon cycle makes them a logical starting point for assessing the impact of elevated CO_2 on living systems. Through photosynthesis, plants form the support system for the rest of the biosphere. Since carbon is a chief input in the food producing process, any appreciable response of plants to changing CO_2 concentrations could have far-reaching implications." [see: Rogers, Hugo H., Judith F. Thomas & Gail E. Bingham (1983) **Response of Agronomic and Forest Species to Elevated Carbon Dioxide**: *Science*, Vol. 220 (April 22) pp. 428 – 429

The four species upon which the tests were conducted were corn, soybeans, loblolly pine and sweetgum trees. The plants were grown in pots and exposed to the different levels of CO_2 for a period of 3 months. All plant treatment protocols such as watering, fertilizing and light exposure were controlled and kept consistent. The carbon dioxide concentrations varied between 340 and 910 ppm. The results of the test was that

"Growth was enhanced in all four species. Yield increased for the two crop species and wood volume increased for the tree species. . ."

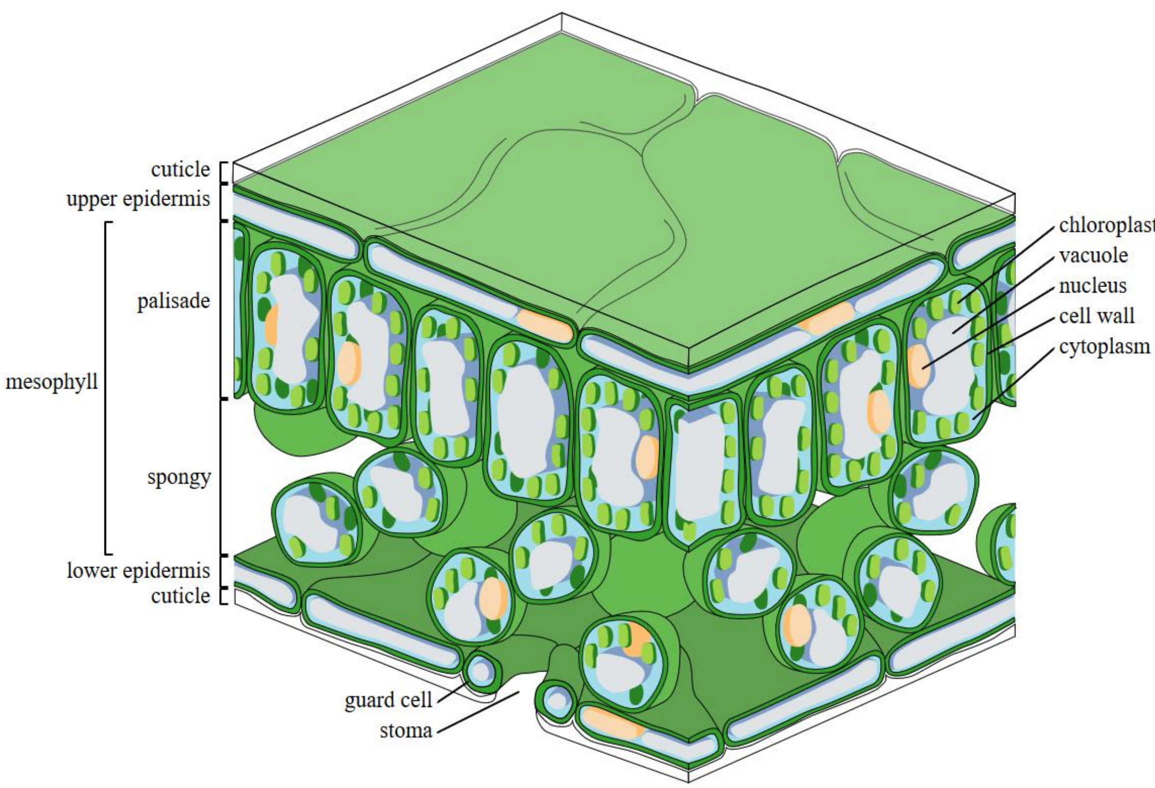
And in addition:

"Plants growing in atmospheres containing 520 to 910 ppm CO_2 did not undergo the wilting that we commonly observed for control plants on hot summer afternoons, when the rate of water uptake was exceeded by the rate of water loss. Wilting on hot afternoons inhibits leaf expansion and photosynthesis at a time when other environmental factors are most favorable for rapid carbon fixation. Thus a corn plant growing in an atmosphere with a high level of CO_2 was able to continue fixing carbon and avoided wilting even though it had a greater leaf area."

Some of the specific effects included:

"The leaves of soybeans, pine, and sweetgum thickened steadily as CO_2 levels rose. At 910 ppm CO2, leaf thickness in these three species was 131, 110 and 121 percent of the control values, respectively. Thickness increased in all of the cell layers of pine and sweetgum leaves. In soybeans the greatest effect was the appearance of a well-developed third layer of palisade cells."

The appearance of a third layer of palisade cells is quite remarkable. Observe the image below from Wikileaks Common. The palisade is the vertically oriented row of cells containing the chloroplasts that is situated just below the upper epidermis of the plant. It is one of two layers comprising the mesophyll layer of the leaf which serves as the primary zone of photosynthesis due to the high concentration of chloroplasts. The main function of the palisade cells is the absorption of light by means of their chloroplasts, which are chlorophyll containing organelles, or subunits, that absorb carbon dioxide and light energy during photosynthesis. The palisade cells containing the chloroplasts is typically one to two layers thick and is arranged in rows from one up to five in number. So now consider how remarkable it is that under a CO_2 enhanced atmosphere the leaves of soybeans will construct a whole additional palisade layer of chloroplast containing cells allowing for enhanced light absorption.



In conclusion the author's state:

> “These findings suggest positive growth responses to CO_2 enrichment for the agronomic and forest species studied.”

To reiterate: By 1985 scientists were beginning to suspect the possibility that enhanced concentrations of CO_2 may have been stimulating photosynthesis on a global level. But there is another point they make, one which reveals the remarkably important relationship of carbon dioxide to the health of plants, for by this time studies were revealing that in addition to growth stimulation, plants growing in a CO_2 enriched atmosphere were more able to tolerate a variety of stresses, including water deprivation, light deprivation, temperature changes and pollution, which I will discuss further.

Another important study published in 1983 with a summary of research up to that date. The author was Bruce A. Kimball, a soil scientist with the U. S. Water Conservation Laboratory, Phoenix. His primary interest in this study was the effect of increasing CO_2 concentration on agricultural yields. To that end he painstakingly compiled 430 observations on 37 different plant species grown under an enriched CO_2 environment. The results of these 430 observations, conducted over 64 years, were published in 70 different reports evaluated by Kimball. He points out that most of the studies were performed in greenhouses and growth chambers. In regards to this circumstance he comments that “Open fields might respond less than greenhouses or growth chambers to increased CO_2.” At this time in 1983 there had not been any serious effort to quantify the effects of carbon dioxide enrichment in an open field environment.

Extracting the data from these 70 reports Kimball included extensive appendices with his report. In reference to these Kimball remarks “As one scans the Appendices, it is apparent that CO_2 enrichment has had an overwhelmingly positive effect on yield.” P. 780

“An overwhelmingly positive effect on yield.” This was the consistent message of 70 reports published over 64 years describing the results of 430 observations on the effect of a carbon dioxide enriched environment on plants. So, in quantitative terms, what does this overwhelmingly positive effect on yield translate into? Kimball elucidates:

> “Plants are complex organisms, and undoubtedly there will be species differences and specific environmental differences affecting the amount by which the increased carbohydrate supply from increased CO_2 is transformed into marketable yield. Certainly more data are needed for the major crops . . . Considering the variability inherent in such work, however, the large body of prior experimental data is sufficiently representative to provide a more reliable prediction of future CO_2 effects . . . Thus, it appears from the analysis of prior data that agricultural yields will increase overall by about 33% with a doubling of the earth’s CO_2 concentration.” [See: Kimball, B. A. (1983) **Carbon Dioxide and Agricultural Yield: An Assemblage and Analysis of 430 Prior Observations**; *Agronomy Journal*, Vol. 75, Sept.-Oct., pp. 779-788]

A 33% increase in agricultural yields would have a potent effect on the global economy. Food would become significantly more abundant. It is likely that Earth’s population will stabilize between 9 and 10 billion over the next half century, assuming no natural extinction level event or nuclear war occurs in the meantime. More yield per acre could be achieved, meaning more food from less land to feed the global population.

In the same year that he published **Carbon Dioxide and Agricultural Yield**, Kimball coauthored another valuable paper with Sherwood B. Idso. Idso has been associated with Arizona State University as Adjunct Professor in the Departments of Geology, Geography, Botany and Microbiology but his primary work was as Research Physicist with the U.S. Department of Agriculture at the Agricultural Research Service in Phoenix, Arizona. He has authored, or co-authored, over 500 scientific papers, has performed numerous experiments and has conducted extensive research into the biospheric and atmospheric effects of carbon dioxide. Professor Idso is still active and has become a provocative figure in the climate change controversies because of his willingness to acknowledge a beneficial aspect to carbon dioxide enrichment along with his belief that increasing carbon dioxide is not going to have a dangerous effect on the climate. He is one of the foremost experts in the world on carbon dioxide's role in nature. Yet, here is an example of a brilliant scientist who has been demonized by the global warming establishment for simply pointing out the truth about carbon dioxide's beneficial role in life processes. His research is worth delving into further and directly I will review an important experiment he performed in the late 1980s.

Following upon Kimball's earlier work, the authors summarize the conclusions derived from this comprehensive survey of experimental accomplishments up to that time:

> "Probable effects of increasing global atmospheric CO_2 concentration on crop yield, crop water use, and world climate are discussed. About 430 observations of the yields of 37 plant species grown with CO_2 enrichment were extracted from the literature and analyzed. CO_2 enrichment increased agricultural weight yields by 36%. Additional analysis of 81 experiments which had controlled CO_2 concentrations showed that yields will probably increase by 33% with a doubling of atmospheric CO_2 concentration. Another 46 observations of the effects of CO_2 enrichment on transpiration were extracted and averaged. These data showed that a doubling of CO_2 concentration could reduce transpiration by 34%, which combined with the yield increase, indicates that water use efficiency may double." [see: Kimball B. A. & Idso, Sherwood B. (1983) **Increasing Atmospheric CO_2: Effects on Crop Yield, Water Use and Climate:** A*gricultural Water Management*, vol. 7, pp. 55 – 72].
>
> "Coupled with the increase in yield, the increases in water use efficiency are likely to be dramatic and probably will have a significant beneficial impact on irrigated and dry-land agriculture." P. 61

Such findings in a depoliticized environment might be welcomed, but, as it is, almost no one outside of scientifically trained dissenters and "climate change deniers" even knows, or cares about this research, most especially is this true in the general public. It has also become apparent that efforts are being made to downplay the positive effects of carbon dioxide by arguing that there are limits to the fertilization effect upon plants. It is certainly true that when plants, particularly trees, reach maturity their need for carbon dioxide declines. It would be surprising if they did not consume less carbon dioxide in their senescence. The most vigorous uptake of carbon dioxide is during the growing phase of the plant's life cycle. The fact that at some point there may be a limit to the botanical benefits of carbon dioxide enrichment does not negate the potent benefits that do accrue in the meantime.

A study of the effects of CO_2 enrichment on trees in a controlled environment was published in 1985 and its findings were consistent with earlier experiments.

> "Seedlings of two tree species from the Atlantic lowlands of Costa Rica, *Ochroma lagopus* Swartz, a fast growing pioneer species, and *Pentaclethra macroloba* (Willd.) Kuntze, a slower-growing climax species, were grown under enriched atmospheric CO_2 in controlled environment chambers. Carbon dioxide concentrations were maintained at 350 and 675 [ppm] . . . Total biomass of both species increased significantly in the elevated CO_2 treatment; the increase in biomass was greatest for the pioneer species, *O. lagopus*. Both species had greater leaf areas and specific leaf weights with increased atmospheric CO_2. . . Stomatal conductances of both species decreased with CO_2-enrichment resulting in <u>significant increases in water use efficiency</u>." [see: Oberbauer, Steven F., Boyd R. Strain & Ned Fetcher (1985) **Effect of CO_2-enrichment on seedling physiology and growth of two tropical tree species**: *Physiologia Plantarum*, vol. 65, Issue 4 (Dec.) pp. 352-356.]

In a report appearing in 1987, coauthored by none other than Roger Revelle, to whom Al Gore attributes his interest in climate change (as described in *An Inconvenient Truth*) there was an acknowledgement of the positive side of carbon dioxide effects:

> "A large number of CO_2 stimulation experiments with selected plant communities in controlled or semi controlled environments suggest that the annual production and biomass accumulation is increased at elevated CO_2 concentrations . . . If CO_2 stimulation of net primary production is a real effect in natural ecosystems as well, the dynamics of the presented models suggest that <u>there may be an increase in standing biomass</u> as well as in litter and humus carbon . . ." [see: Kohlmaier, Gundolf H; Bröhl, Horst; Siré, Ernst Olof; Plöchl, Matthias; & Revelle, Roger (1987) **Modelling stimulation of plants and ecosystem response to present levels of excess atmospheric CO_2**: *Tellus*, Vol. 39B, pp. 155 – 170]

The term 'net primary production' refers to the fundamental processes driving the activity of the biosphere. One of the textbooks to which I referred in the early days of my studies into global change was **The Economy of Nature: A Textbook in Basic Ecology** by Robert E. Ricklefs, [2nd ed. 1983, Chiron Press, Inc.] The author presents a succinct and clear explanation of primary production:

> "Organisms need energy to move, grow, and maintain the functions of their bodies. Energy to support these activities enters the ecosystem as light, which plants convert to chemical energy during photosynthesis. The rate at which plants assimilate the energy of sunlight is called *primary productivity*. It is important to realize that primary production underlies the entire trophic structure of the community. The energy made available by photosynthesis drives the machinery of the ecosystem. The flux of energy through populations of herbivores, carnivores, and detritus feeders, and the biological cycling of nutrients through the ecosystem are ultimately tied to the primary productivity of plants." P. 124

In other words, the health of the whole system depends upon the health of the plant kingdom, and the health of the plant kingdom is substantially enhanced with an increased supply of carbon dioxide.

"The energy made available by photosynthesis drives the machinery of the ecosystem."

And what drives photosynthesis? CARBON DIOXIDE + LIGHT. With an input of light energy plants perform a miracle of transformation, converting the incoming light energy into chemical energy and in the process combining carbon dioxide with water to form organic compounds out of two inorganic compounds. These organic compounds take the form of a simple glucose sugar that can store energy for later release as it is needed by living things.

The chemical equation for this remarkable process is:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

This equation tells us that 6 molecules of carbon dioxide added to 6 molecules of water yields one molecule of glucose sugar plus 6 molecules of oxygen. This glucose is the fuel that drives biological processes in almost all living things from bacteria to humans. Living organisms employ glucose for the synthesis of various polymers such as starch, cellulose and glycogen. These polymers serve several functions that are indispensable for biological processes such as energy storage and the creation of structural components out of which organisms are built.

The authors discuss the role of changing atmospheric moisture content in relation to photosynthesis and rates of transpiration:

> "Because photosynthesis requires gas exchange across the surface of the leaf, productivity also parallels the rate of transpiration of water from the leaf surface. As the moisture content of soil decreases, plants have greater difficulty removing water from the soil and leaves must close their stomata to reduce water loss. When soil moisture is reduced to the wilting point, leaves are effectively shut off from the surrounding air and photosynthesis slows to a standstill. Rate of photosynthesis is, therefore, closely tied to

> the plant's ability to tolerate water loss, to the availability of moisture in the soil, and to the influence of air temperature and solar radiation on rate of evaporation. Humid environments favor high rates of photosynthesis by reducing transpiration from leaves." pp. 132 – 133

Stomata are pores in the leaves of plants through which carbon dioxide is taken in and water vapor is released. Transpiration is the conveyance of water up from the roots throughout the structure of the plant and its ultimate evaporation from the aerial portions such as the stems, flowers and leaves. Of the total amount of water drawn in by the plant roots as much as 98 or 99%, even more, is lost to the atmosphere through transpiration. It has been found that the size of stomatal apertures is directly related to the amount of carbon dioxide in the atmosphere. When the stomatal apertures contract, less water is lost through transpiration. This fact has interesting implications with regards to the use of "stomatal density" as a tool for the purpose of determining paleoatmospheric CO_2 concentrations. Because many fossil leaves have preserved their stomatal size and density, it allows them to be used as an accurate and effective proxy measure of ancient atmospheric carbon dioxide concentrations, one perhaps more accurate than entrained air bubbles extracted from glacial ice. But that is a topic for another discussion. For now all I will mention is that there is, in some cases, a considerable divergence between CO_2 concentrations in air bubbles trapped in glacial ice and that which is indicated by fossilized leaves of the same time period.

In another study published in 1989, 3 horticultural researchers conducted tests to determine the combined effects of carbon dioxide enrichment and dehydration induced stress on winter wheat. The authors describe their protocol and the results:

> "Seedlings (one per pot) were grown in growth chambers maintained at 350 (ambient) or 700 [ppm] . . . and subjected to three levels of soil moisture (well-watered, medium stress, and severe stress). . . The ratio of dry wt. to leaf area . . . and water use efficiency were significantly higher in plants grown under CO_2 enrichment."

In other words the bulk mass of the wheat plants was greater in the CO_2 enriched environment, as well as their ability to withstand the stress of water deprivation, as would occur in the real world during times of drought. [See: Schonfeld, Manette; Richard C. Johnson & Davis M. Ferris (1989) **Development of Winter Wheat under Increased Atmospheric CO_2 and Water Limitation at Tillering:** *Crop Science*, vol. 29, no. 4, pp. 1083-1086]

A commissioned review was published in the peer reviewed journal *Plant, Cell and Environment* in 1991, authored by D.W. Lawlor and A.C. Mitchell with the Institute of Arable Crops Research, Biochemistry and Physiology Department. The Institute of Arable Crops Research, now known as Rothamsted Experimental Station, in Harpenden, England was founded in 1843 and has been doing continuous agricultural research since that time. The article was entitled **The effects of increasing CO_2 on crop photosynthesis and productivity: a review of field studies**. The research reported in this paper was part of the increasing effort to understand the effects of carbon dioxide enrichment on the field environment as compared with the more controlled environment of the laboratory or greenhouse. Lawlor and Mitchell report that "Only a small proportion of elevated CO_2 studies on crops have taken place in the field. They generally confirm results obtained in controlled environments: CO_2 increases photosynthesis, dry matter production and yield, substantially in C_3 species . . . and greatly improves water-use efficiency in all plants." They mention several earlier reviews such as the one by Kimball discussed above and point out that these reviews "of experiments done under a wide range of conditions, show that doubling of atmospheric CO_2 concentrations from ca. 330 to 650 cm^3 CO_2 m^{-3} (330 to 650 ppm) increases the productivity of a large number of C_3 crop plants on average by 33%." They follow that remark with a prescient observation: "Given the increasing ambient CO_2 concentrations over the last *ca*. 250 years, an increase in the productivity of vegetation, either natural or agricultural, would be expected." [See: Lawlor, D.W. & Mitchell, A. C. (1991) **The effects of increasing CO_2 on crop photosynthesis and productivity: a review of field studies**: *Plant, Cell and Environment*, Vol. 14, pp. 807 – 818]

Another interesting report appeared in 1993 authored by H. H. Rogers with the National Soil Dynamics Laboratory and R. C. Dahlman with the Environmental Sciences Research Division, U.S. Department of Energy. In regards to the increasing amounts of atmospheric carbon dioxide the authors state that "The fixation and release of this compound by plants is a two-way bridge linking the atmosphere and biosphere. Regardless of whether there are accompanying climate shifts, as have been predicted, CO_2 increases will directly affect growing plants. Not only is CO_2 essential for plant life but it also enhances growth and yield. Thus CO_2 is of pivotal significance to both natural and plant communities and agro-ecosystems." [see: Rogers, H. H. & R. C. Dahlman (1993) **Crop responses to CO_2 enrichment**: *Vegetatio*, vols. 104/105, pp. 117-131.]

To restate the observation of Rogers and Dahlman: "Not only is CO_2 essential for plant life but it also enhances growth and yield."

Botanists have known this for at least a century. It is the consistent and relentless message of many hundreds of tests, experiments, studies and observations going back as much as two centuries. It is the 800 pound gorilla in the room that proponents of anthropogenically induced catastrophic greenhouse warming refuse to admit or to talk about.

Rogers and Dahlman continue:

> "What physical climates will prevail and what interactions will occur in a future world are not known. What we can be sure of, however, is that as CO_2 levels climb higher and higher, the growth of vegetation will be stimulated, some plant species more than others. Most experimental probing's have revealed two main responses: (1) increased rates of photosynthesis, i.e. carbon fixation, and (2) enhanced water use efficiency. The proper function of these two vital plant processes can spell the difference between feast and famine. So the potential of elevated CO_2 to positively impact plants – our primary producers of food and fiber – is great. Virtually all works to date have shown enhanced crop growth, the alleviation of some stresses, and substantial boosts of yields."

This statement bears repeating: "The potential of elevated CO_2 to positively impact plants . . . is great." Here in the work of these scientists is demonstrated the remarkable relationship between the plant kingdom and carbon dioxide, showing enhanced crop growth, stress reduction and substantial boosts of yields. In any kind of economic or cost/benefit analysis of the effects of the continued introduction of carbon dioxide from fossil fuel consumption on the global climate and environment these factors absolutely must not be neglected. I will say again, in any discussion relating to carbon dioxide or climate change this aspect of the matter should not be ignored, yet somehow, belaboring a point, it is conveniently and entirely disregarded.

One is motivated to ask: Who are the real "denialists" in this debate.

Note also that here are a pair of scientists who are experts in the effects of CO_2 and they, like many others, are expressing uncertainty with regards to the supposed settled conclusion that the increase in atmospheric carbon dioxide is going to trigger a global warming catastrophe. It would behoove us to examine in more detail the process by which carbon dioxide is presumed to lead to a substantial increase in the global average temperature. And that I will do in another place. Here we are focusing on the relationship between carbon dioxide and the world of vegetation, and by implication, the biosphere.

The graph below, from the work of Rogers and Dahlman (1993) shows the effect of rising CO_2 levels on the efficiency with which corn, soybeans and sweetgum trees use water in the course of transpiration. The x-axis ranges from 300 parts per million up to 900 parts per million of atmospheric $CO_{2,}$ or about 2.26 times greater than the present atmospheric concentration. The y-axis shows the milligrams of carbon dioxide fixed per gram of water as the concentration of CO_2 rises. The higher the amount of carbon fixed the greater is the efficiency with which plants use water, the other indispensable element for biological processes. This increased WUE, or water use efficiency, has extremely important implications.

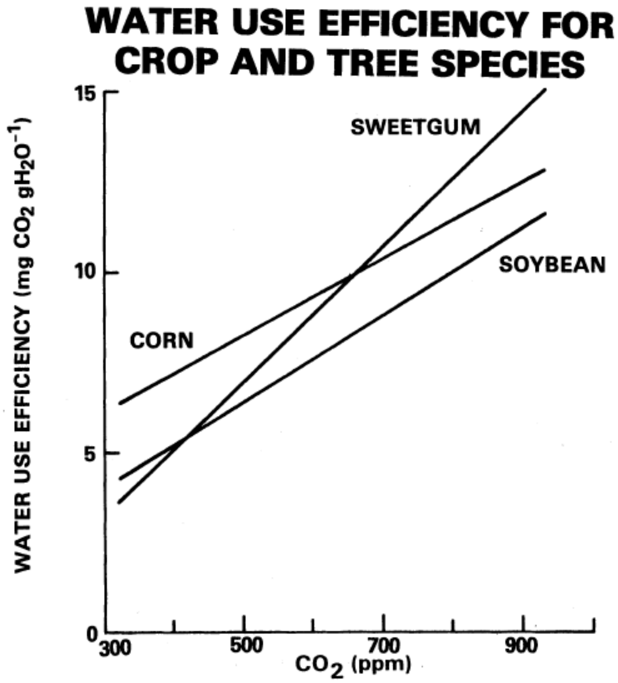


Figure 3. The caption to this graph that appeared in the original article reads as follows: "Typical gains of water use efficiency. . . Many experiments suggest that WUE may increase by as much as 100% as CO concentration doubles".

Let us recall the comment by Bruce Kimball quoted above from **Carbon Dioxide and Agricultural Yield: An Assemblage and Analysis of 430 Prior Observations.** Pointing out that most of the 430 observations were performed on plants in greenhouses or growth chambers he concedes that "Open fields might respond less than greenhouses or growth chambers to increased CO_2." By 1993 the question of CO_2 effect on open fields had been answered, for in that year the same Roger C. Dahlman, who was at that time with the U.S. Department of Energy - Office of Science, Biological and Environmental Research, reported on a decade long series of tests on field environments with controlled CO_2 enrichment on vegetation. [see: Dahlman, Roger C. (1993) **CO_2 and Plants: revisited**: *Vegetatio*, vol. 104/105, pp. 339 – 355] Dahlman reported that:

> "The decade-long USA research program on the direct results of CO_2 enrichment on vegetation has achieved important milestones and has produced a number of interesting and exciting findings. Research beginning in 1980 focused on field experiments to determine whether phenomena observed in the laboratory indeed occurred in natural environments. The answer is yes . . . Nearly all experiments demonstrate that plants exhibit positive gain when grown at elevated CO_2 . . . Most crop responses range from 30 to 50% increase in yield . . . Huge growth responses (100 to nearly 300% relative to controls) are reported from several tree experiments."

These are truly extraordinary results. Think for a moment about the implications of these findings: crops responding with a 30 to 50 percent increase in yield, and an almost unbelievable growth response from several tree species of 100 to 300 percent occurring as a result of CO_2 enrichment. Dahlman goes on to say that

> "The global rise of atmospheric CO_2 is well-established from numerous measurements beginning in the mid-1950s . . . A great many studies have confirmed that plants will respond to this increase, and it is important to obtain a good measure of the myriad of responses in order to understand implications for food and fiber productions systems . . . Moreover, there is a growing recognition that increasing atmospheric CO_2 represents a resource to be tapped by the earth's mantle of vegetation."

Describing CO_2 as "a resource to be tapped by the earth's mantle of vegetation" is certainly not in accord with the viewpoint of global warming advocates who now regularly refer to carbon dioxide as a "pollutant" and have even managed to pressure the EPA into declaring it a pollutant as well. As absurd as this is it is important to realize that this confers upon the EPA, a thoroughly politicized bureaucracy, considerable power over the private sector and the economy.

The author continues with his analysis of the increasing amount of data culled from field studies in addition to more controlled experiments in the laboratory:

> "Some of the most significant accomplishments of the past decade derive from field experiments, which have demonstrated that field observation of the effects of CO_2 on plant growth and physiology is consistent with findings from laboratory studies. Carbon dioxide-induced increases in photosynthesis, and the growth and yield responses are of the same sign and magnitude for both laboratory and field experiments. In some case field responses may even exceed those from the laboratory such as the striking increase of root growth and production associated with some field studies." P. 345

So not only do the positive field results equal those of the laboratory and controlled environment, in some cases they actually exceed it! The increased growth in root mass confers upon the plants enhanced ability to withstand a variety of catastrophes from flood to fire, and also allows the plant to draw deeper into the soil for water and nutrients during times rain deficit or stress.

> "Experiments on the interaction of CO_2 with other factors continue to produce interesting and exciting results. With some experiments the effect of elevated CO_2 tends to alleviate stress, and in other cases the combined effects of CO_2 and other factors are additive, such as temperature enhancement of the response to CO_2 . . . One striking set of experiments illustrates the combined effect of increased CO_2 and temperature on growth. Plants with C_3 type metabolisms typically show a 30 to 40 % growth response at doubled CO_2 concentrations." However when the plants were grown at doubled CO_2 concentrations AND higher temperatures "the CO_2- induced growth response was doubled to 60 to 80 % more than the controls. The final result is a substantial gain in productivity for the combined increase of CO_2 and temperature." P. 346

So whatever other effects may be attributed to increasing amounts of carbon dioxide and temperature, as far as plants are concerned they create a "substantial gain in productivity," almost unbelievably up to 80% in some cases when accompanied by a modest rise in temperature of perhaps a degree or two. C_3 plants, by the way, are the most common type of plants, comprising up to about 85% of all plants. They include all tree species, both evergreen and deciduous; many cereal grains such as rye, oats, wheat, barley, and rice; beans, potatoes, grapes, oranges and lemons, carrots, peaches, apples, pears, mango, coffee, peanuts and other nuts, spinach; many species of flowers and grasses and the list goes on. The subscript 3 refers to the type of photosynthetic pathway by which the carbon dioxide molecule is introduced into the plant.

The authors reconfirm the effect of elevated CO_2 concentrations with respect to water use efficiency:

> "Plants grown at elevated CO_2 often reduce conductance of water vapor. Field experiments continue to show this effect for a wide variety of plant types, including herbaceous and woody species . . . Lowered conductance translates into increased WUE, (water use efficiency) which appears to be a ubiquitous response of vascular plants. Mounting experimental evidence is confirming that <u>CO_2 enrichment improves plant water use efficiency</u>."

To once again belabor a point: Improved water use efficiency has important implications. It means that in times of drought plants that have otherwise been thriving in a carbon dioxide rich environment are also more able to withstand the effects of water deprivation. In regards to this effect Norman J. Rosenberg, a Professor of Agricultural Meteorology with the Center for Agricultural Meteorology and Climatology, University of Nebraska, pointed out that "This predicted effect on water use efficiency may be of particular importance in the semiarid and arid regions where limitations in natural rainfall limit current agricultural productivity."[See: Rosenberg, Norman J. (1981) **The increasing CO_2 concentration in the atmosphere and its implication on agricultural productivity**: *Climatic Change*, Vol. 3, pp. 265-279]

In other words, it is entirely possible that, to express this idea is less prosaic terms, with a carbon dioxide enriched environment Earth's deserts might begin to bloom.

In 1993 a six member team drawn from The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts and the Complex Systems Research Center, Institute for the Study of Earth, Oceans and Space at the University of New Hampshire, published the results of their estimate of global patterns of net primary production and soil nitrogen cycling under current environmental conditions. In their study they employed a process-based ecosystem simulation model that referenced information on climate, soils, land elevation, vegetation type and availability of water. This terrestrial ecosystem model (TEM) was applied to vegetation spatially referenced to a grid of 0.5 degrees latitude by 0.5 degrees longitude. These grid cells were programmed with appropriate regional climatic and hydrological data and vegetation parameters.

As do the majority of researchers into the role of carbon dioxide and climate change since the early 1990s, the authors first cite the IPCC projections of temperature rise over the next century. Remarking that climate changes of the magnitude predicted by IPCC models are certain to have an effect on net primary production (NPP) of the world's land ecosystems, that is, the ability of land plants to capture carbon each year through the process of photosynthesis, the authors emphasize that NPP "is of fundamental importance to humans because the largest portion of our food supply is from productivity of plant life on land, as is wood for construction and fuel." [See: Melillo, Jerry M. et al. (1993) **Global climate change and terrestrial net primary production**: *Nature*, vol. 363, May 20, pp. 234 – 240]

In considering the factors that can limit net primary production, the authors point out that:

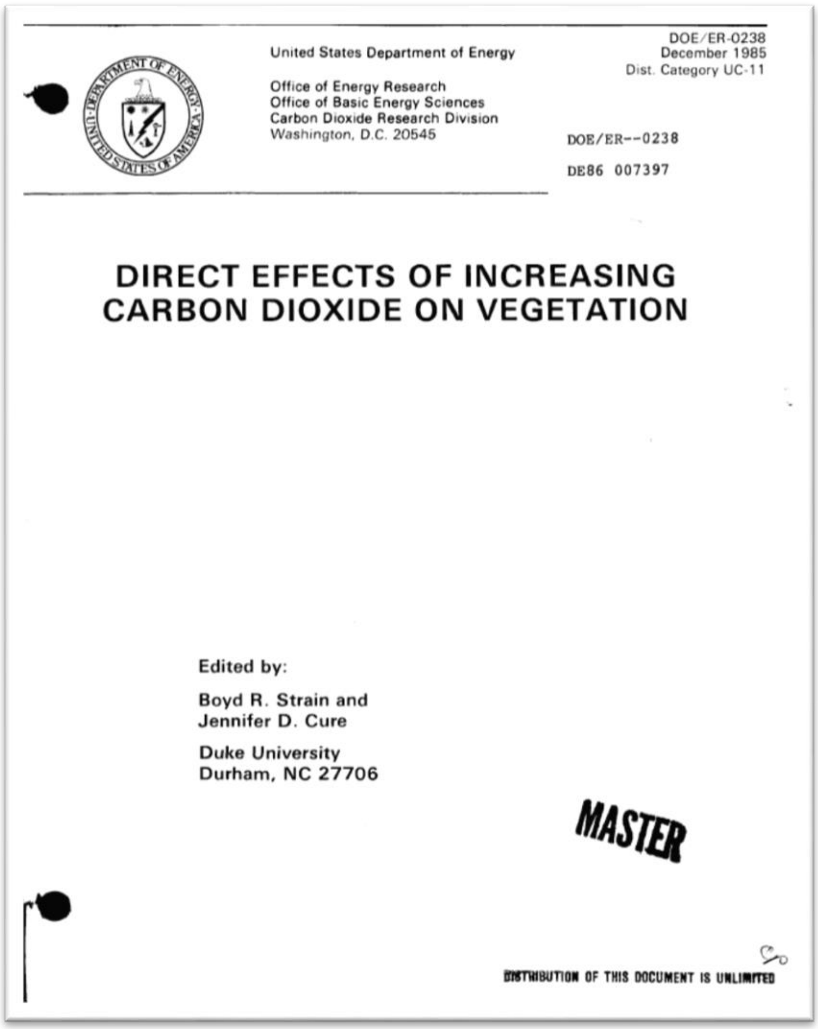
> "In many northern and temperate ecosystems, NPP is known to be limited by the availability of inorganic nitrogen in the soil. . . Under contemporary climate conditions in dry regions, TEM (Terrestrial Ecosystem Model) generally predicts that water availability limits productivity more than nitrogen availability. With a doubling of atmospheric CO_2 TEM predicts that the water-use efficiency of vegetation increases in these regions; that is, there will be an increase in production per amount of water used. These predictions are consistent with research findings that increases in water-use efficiency with elevated CO_2 are generally greatest in water-stressed systems."

In other words, carbon dioxide confers upon plants in arid climates a means of conserving water use, and, as the amount of carbon dioxide in the air increases, so does the ability of the plant to thrive in a water deficient environment. Carbon dioxide acts as a sort of safety valve for plants, in that its power to improve water use efficiency becomes stronger as water supply diminishes. This increased water use efficiency is brought about because the stomatal apertures of the affected plants decrease in size and density, limiting the amount of water lost from the plant through transpiration.

There are other benefits that accompany this physiological change in the plants. In 1978 a varied group of experts were assembled by the U.S. Department of Energy to review "what is known and not known about the response of plants to CO_2 enrichment." The report produced by this group, called the Quail Roost Study, made 10 recommendations for research. One conclusion of the study was that little to no field data existed by which to determine the consequences outside of controlled laboratory or greenhouse conditions. Field experimentation was highly recommended. Subsequently this deficiency was partially rectified by the work discussed above from Dahlman, "**CO_2 and Plants: Revisited**." This report served to encourage several other research projects.

One of these was the most comprehensive study up to that date on the effects of increasing carbon dioxide on plants. It was sponsored by the American Association for the Advancement of Science (AAAS) who convened a series of panels in the late 1970s and early 1980s to make recommendations to the Department of Energy (DOE) for a wide-ranging research program to further understand the consequences of rising atmospheric CO_2. Especially urged by the AAAS, following the recommendations of the Quail Roost Study, was research into the effects on plants with respect to such things as photosynthetic responses, nitrogen fixation, transpiration, reproductive biology, water use efficiency, microbial activity and biochemistry. As a result of this lobbying an international conference was convened in 1982 with the objective of investigating 'Rising Atmospheric Carbon Dioxide and Plant Productivity'. While there were many findings and new insights gained from the work of this conference a number of them were particularly useful in understanding the benefits of increased carbon dioxide to the planetary biosphere, and this led to further studies.

Evidence for the beneficial role of carbon dioxide was supported and confirmed by a followup report appearing in 1985 that was also conducted by the Department of Energy. The full report consisted of seven scientific reviews of various aspects of CO_2, climate change and biospheric responses. Results relative to plant, vegetation and crop responses were presented in a 286 page report entitled "**Direct Effects of Increasing Carbon Dioxide on Vegetation**" edited by botanists Boyd R. Strain and Jennifer D. Cure. This particular work was fully peer reviewed by the Committee on Climate of the American Association for the Advancement of Science, whose chairman at the time was none other than the aforementioned Roger Revelle, mentor to Al Gore, who, in writing a forward to the volume praised its careful and thorough review of the relevant research up to that date. He also stressed the uncertainty and the embryonic state of knowledge regarding the effects of rising CO_2 concentrations on other environmental aspects, especially atmospheric effects.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DIRECT EFFECTS OF INCREASING CARBON DIOXIDE ON VEGETATION

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In the preface to this volume the program manager, Roger C. Dahlman again, elaborates upon the role of CO_2 in the biosphere.

> "Carbon dioxide enhancement of plant growth is one important direct effect of rising atmospheric CO_2. Through photosynthesis, plants produce food and fiber from light and carbon assimilated as CO_2 and for the foundation of the Earth's life support system. Rising atmospheric CO_2 is thus an essential input to the food producing process, and effects of CO_2 enrichment described in this document have far-reaching implications for agricultural and ecological productivity. . . Enhanced plant growth and yield from more CO_2 is now widely recognized in different scientific and public sectors as an important element of the CO_2 problem."

Dahlman goes on to say that

> "Although it is not currently possible to accurately state magnitudes of many effects of CO_2 enrichment, there are strong indications from the work that has been done for this

SOA (State of the Art) volume that rising atmospheric CO_2 represents a resource for agriculture and food production rather than a conventional air pollutant. There are potentially beneficial consequences for crop productivity . . ."

How far we have come since 1985 in our revisionist science where the EPA, responding to political pressure, has now redefined carbon dioxide as a pollutant! No more talk about carbon dioxide as a resource for agriculture and food production, or talk about potentially beneficial consequences allowed! Carbon dioxide has been dishonestly transformed from a life-giving trace gas into a demonic poison that is going to provoke global catastrophe. Hundreds of millions of dollars have gone into promoting anti-carbon dioxide propaganda and a manufactured consensus on climate change and millions of people have fallen for it. Could there be any mechanism of social control more effective than that of exploiting carbon dioxide, a gas that every living thing produces through respiration? In other words, the implication of this politically contrived model of global warming is that you are guilty simply by virtue of breathing, and, being part of the problem, must, therefore, subject all of your activities to regulatory control! If you think I exaggerate you haven't been paying attention to the relentless direction of environmental policy since certain factions realized the advantages to be gained from demonizing carbon dioxide. Some of this I have addressed here.

I mentioned earlier an experiment by Sherwood Idso that was particularly compelling and worthy of consideration. In July of 1987 Professor Idso undertook a study of orange trees grown in a carbon dioxide enriched environment. He began by planting 30 cm tall (12") sour orange tree seedlings in open-top containers with clear plastic walls and carefully monitored all variables for consistency except for the concentration of carbon dioxide. In this experiment air was fed in through tubes at the bottom and allowed to exit through openings in the top. The trees were planted in pairs, one receiving the ambient CO_2 and the other enriched 300 ppm above ambient concentration.

The results shown in the next image speak for themselves. The orange tree on the right was grown in the CO_2 enriched enclosure. In remarking upon these results Idso says: "The net result of these differences in physiological response has been dramatic. After two full years of growth, an assessment of the volumes of the trees' trunks and branches revealed that the CO_2-enriched trees contained 2.8 times more above-ground sequestered carbon than did the ambient-treatment trees. Six months later a similar assessment of below-ground growth revealed that the CO_2 enriched trees also contained 2.8 times more root-sequestered carbon than did the trees grown in ambient air. [see: Idso, Sherwood B. (1991) **The Aerial Fertilization Effect of CO2 and Its Implications for Global Carbon Cycling and Maximum Greenhouse Warming**: *Bulletin of the American Meteorological Society*, vol. 72, no. 7 (July) pp. 962 – 965]

Figure 4. The original caption reads: At the conclusion of two full years of growth under ambient and CO2 enriched conditions, when this photo was taken, the CO2-enriched trees on the right were 2.8 times larger. In terms of both above- and below-ground biomass than the ambient trees on the left.

What we see happening, in effect, is the tree consuming the carbon dioxide from the atmosphere and transmuting it into organic, living substance out of which it creates itself as a mature plant.

A 1991 study by plant physiologist Bert G. Drake and ecologist Paul Leadley reviewed 7 experiments on canopy photosynthesis that had been conducted up to that time. A plant canopy is the assemblage of leaves by which the plant is able to intercept sunlight in order to uses its energy in the assimilation of carbon dioxide. [see: Drake, B. G. & P.W. Leadley (1991) **Canopy photosynthesis of crops and native plant communities exposed to long-term elevate CO_2**: *Plant, Cell and Environment*, vol. 14, pp. 853 – 860]

The review examined two studies of canopy photosynthesis in soybeans; one study of rice; one study of ryegrass; a study of meadow fescue and red clover; a study of Arctic tussock tundra; and a study of a salt marsh. In all 7 experiments by separate teams closed chambers were constructed in which temperature, humidity and carbon dioxide concentration were controlled. The authors begin by asking a critical question: "Will rising atmospheric CO_2 increase ecosystem carbon assimilations?" They then comment that while biomass production typically increased in plants with greater CO_2 availability when compared with those grown in ambient CO_2, in some experiments there was a gradual decline in photosynthetic capacity after long-term exposure. This led to the assumption that nutrient availability was the critical factor that would lead to reduced photosynthetic capacity. But, the authors of this review point out, the data was drawn from plants grown in controlled environments or greenhouses, and that many of the experiments were performed on annual plants with low carbon storage capacity. To rectify this bias the authors turned to studies that had been performed "on swards or small sections of the whole ecosystem exposed to long-term elevated CO_2 treatment." The crux of Drake and Leadley's review of these experiments were succinctly expressed in the abstract to their paper:

> Abs. "There have been seven studies of canopy photosynthesis of plants grown in elevated atmospheric CO_2: three of seed crops, two of forage crops and two of native plant ecosystems. Growth in elevated CO_2 increased canopy photosynthesis in all cases."

Specifically, the authors explain that:

> "The studies of canopy photosynthesis reviewed in this paper indicate that elevated atmospheric CO_2 increases CO_2 assimilation by 25—50%. This appears to be slightly higher than anticipated from laboratory studies. There is no evidence to support the notion that the effects of rising CO_2 would not be sustained."

In 1993 Bruce Kimball, Sherwood Idso along with colleagues J. R. Mauney and F. S. Nakayama updated their researches and reported their findings in an article in *Vegetatio* entitled "**Effects of increasing atmospheric CO_2 on vegetation**." At the very outset they state that "The increasing atmospheric CO_2 concentration probably will have significant direct effects on vegetation whether the predicted changes in climate occur or not." Paraphrasing: Whether the climate changes due to the increasing CO_2 or not, the effect on plants is still expected to occur. As to the nature of these "direct effects" Kimball et al. explain that "The main purpose of this paper is to describe these direct effects of increased CO_2 on plants and also to discuss some interactions between CO_2 and climate variables that are likely to have important consequences for the growth of vegetation. . ." The first graph in their paper shows how net photosynthesis is increased by an increase in CO_2. They comment that "Of crucial importance is whether the actual growth of plants will be similarly increased, because there are numerous intermediate steps before the carbohydrates produced in the leaves are transformed into root, stem, flower, fruit, seed, or additional leaf tissue. For the most part, the answer appears to be 'yes, growth and yield are also increased'. Figure 2 in their paper shows the results of several years of experiments conducted by the authors using open-top carbon dioxide enrichment chambers on seed cotton. The results of their experiments were that "In spite of the year to year variability and the influence of other treatments, CO_2 obviously stimulated cotton yields, amounting to a 64% increase at 650 µL/L (650 ppm) averaging over all the data. Thus, cotton is highly responsive to additional CO2, but what about other species of vegetation." [see: Kimball, B. A. et al. (1993) **Effects of increasing atmospheric CO_2 on vegetation**: *Vegetatio*, vol. 104/105, pp. 65 – 75]

The following photo from their article shows the authors CO_2 enrichment chambers at the USDA Agricultural Research Service, US Water Conservation Laboratory at Phoenix, Arizona. Photo taken June 9, 1987 by Bruce Kimball.

A 64% increase in cotton yield for the same amount of land is remarkable and has important implications for future conservation measures. So, what about other species of vegetation? The authors of this paper refer back to Kimball's 1883 study from which I quoted earlier.

> "Kimball assembled and analyzed much of the existing data available in the literature in 1983 about the yield or growth response of 37 species of plants to CO_2 amounting to 430 prior observations. The average response was a yield increase of about 33%. . . Cure (1985) assembled the available data about the carbon exchange rate (net photosynthesis), biomass accumulation, yield, and other physiological parameters of 10 major crops – wheat, barley, rice, corn, sorghum, soybean, alfalfa, cotton, potato, and sweet potato . . .the results of her analysis were close to the 33% reported by Kimball."

Kimball, Idso and their co-authors mention a review by L. H. Allen Jr. in 1991 in which he "tabulated the response of C_3 soybean to elevated CO_2. He concluded that a doubling of CO_2 concentration causes photosynthesis to increase about 50%, biomass accumulation to increase about 40%, and marketable seed yields to increase about 30%."

The authors also confirm that if temperature does increase it will have the corresponding effect on plant growth of amplifying the effect of carbon dioxide, pointing out that if temperatures do continue to mildly increase (which is not a certainty) then

> ". . . the growth stimulation may be closer to 56%, rather than the mean 32% presented earlier. Therefore, a present-day cool climate like that of Canada, Northern Europe, or the Soviet Union conceivably could get a triple benefit from the predicted CO_2 increase and global warming . . . (1) The increase in air temperature raises crop temperature closer to optimum and growing seasons may be longer. (2) The crop grows faster because of stimulation due to CO_2. (3) And it grows faster yet because of the interaction between CO_2 and temperature."

In their concluding remarks the authors reconfirm that "There appears to be a strong positive interaction between CO_2 concentration and temperature, which would greatly increase the CO_2 growth stimulation under some conditions. . . The growth response to elevated CO_2 is large, even under water-stress conditions . . . Plants growing in nutrient-poor soil also respond to elevated CO_2 . . ."

So, to the extent that temperature does rise even more carbon dioxide will be converted to biomass through photosynthetic uptake, thus reducing the amount in the atmosphere in the process.

The realization that increasing biomass would consume ever greater amounts of anthropogenically sourced CO_2 was apparent by 2005. The work of a 19 person team published that year looked at Richard J. Norby with the Environmental Sciences Division, Oak Ridge National Laboratory and 18 others

> "Climate change predictions derived from coupled carbon-climate models are highly dependent on assumptions about feedbacks between the biosphere and atmosphere. One critical feedback occurs if C uptake by the biosphere increases in response to the fossil-fuel driven increase in atmospheric [CO_2] ('carbon fertilization'), thereby slowing the rate of increase in atmospheric [CO_2]. . . Exchanges between the terrestrial biosphere and atmosphere are represented in models using empirical and theoretical expressions of net primary productivity (NPP), the net fixation of C by green plants into organic matter, or the difference between photosynthesis and plant respiration. Because the photosynthetic uptake of carbon that drives NPP is not saturated at current atmospheric concentrations, NPP should increase as fossil fuel combustion adds to the atmospheric [CO_2] . . . Our analysis indicates a 23% increase in forest NPP as atmospheric [CO_2] increases to 550 ppm over the next few decades. . . The effect of CO_2 fertilization on forest

NPP is now firmly established, at least for young stands in the temperate zone. Recent observations of older and larger deciduous trees in a mature Swiss forest demonstrated that physiological responses were similar to those of younger trees, thereby increasing our confidence that our results are generally relevant." Norby, Richard J. et al. (2005) **Forest response to elevated CO2 is conserved across a broad range of productivity**: *Proceedings of the National Academy of Sciences*, Vol. 102, no. 50 (Dec. 13.) pp. 18052 – 18056

I will return again to this theme of positive feedbacks between carbon dioxide availability and biomass. While it is likely that at some point plants will become acclimatized to higher concentrations of atmospheric CO_2, this study and other demonstrate that trees continued to well into their mature stages.

Figure 5 Sherwood Idso showing a succession of pine trees of the same age and grown under identical conditions except for the addition of greater concentrations of carbon dioxide. The tree on the left is grown under ambient concentrations and the trees to the right with enrichment above ambient as shown. Source: Moore, Patrick (2016) ***The Positive Impact of Human CO2 Emissionson the survival of life on Earth****: Frontier Centre for Public Policy.*

One More Benefit: Carbon Dioxide and Ozone

There is another benefit to carbon dioxide enrichment that needs to be discussed. It relates to the effects of ozone pollution on plants. Ozone (O_3) is a molecule composed of three oxygen atoms that normally makes up only about 0.6 parts per million of the atmosphere. The greatest concentrations of ozone are found in the stratosphere between 6 and 30 miles above the Earth's surface. Stratospheric concentrations of ozone range between 2 and 8 parts per million, about 10 to 50 times greater than at the bottom of the atmosphere. At this height above the Earth's surface ozone provides the crucially important service of intercepting ultraviolet rays which are very damaging to living things. However, at low atmospheric levels near the Earth's surface ozone can become highly phytotoxic. Ozone can interfere with photosynthesis and a considerable amount of evidence demonstrates reduced crop yields when exposed to ozone pollution.

The website of the Missouri Botanical Garden discusses the damaging effects to plant life from too much ozone exposure.

> “Ozone is the most damaging air pollutant to plants. The action of sunlight (ultraviolet radiation) on molecular oxygen and oxides of nitrogen spontaneously generate ozone . . . Ozone can move across great distances to cause damage to plants far from its origin and is therefore classified as a non-pointsource pollutant. The extent of damage depends on the concentration of ozone, the duration of exposure, and plant sensitivity. Acute damage to deciduous trees causes marginal leaf burn and dot-like irregular-shaped lesions or spots that may be tan, white or dark brown. Symptoms may spread over entire leaves. Another common symptom is bleaching of the upper leaf surface . . . Acute damage to conifers causes browning at the same point on all needles in a bundle (needle cluster).

Figure 6. Ozone damage on leaves of American linden or basswood tree (tilia).

Accessed from http://www.missouribotanicalgarden.org

Figure 7. Muskmelon leaves showing damage from ozone pollution.

Accessed from http://www.missouribotanicalgarden.org

Due to the known damaging effect of ozone on plants, and knowing that atmospheric levels of CO_2 were rising, and would probably continue to rise, and, that many of the same industrial practices that added to the growing carbon pool also contributed ozone to the atmosphere, a number of scientists have looked at the interactive effects of carbon dioxide enrichment and high levels of ozone.

In one important, statistically rigorous study, the researchers sought to determine the interactive effect on plants in an environment of both elevated carbon dioxide and elevated ozone. [see: Volin, John C, Peter B. Reich & Thomas J Givnish (1998) **Elevated carbon dioxide ameliorates the effects of ozone on photosynthesis and growth: species respond similarly regardless of photosynthetic pathway or plant functional group**: *New Phytology*, Vol. 138, pp. 315 – 325]. To better understand this situation the authors selected 6 perennial species consisting of two types of trees, quaking aspens and red oaks; two species of grass from the C_3 group – western wheatgrass and prairie Junegrass; and two species from the C_4 group – "sideoats grama" and little bluestem. (The number in subscript refers to the type of photosynthetic pathway.) C_3 plants were discussed above. C_4 plants have a different method of extracting carbon from the carbon dioxide molecule than C_3 plants and are adapted generally to more arid environments. The idea in this study was to get a relatively diverse cross section of plants. To perform the experiment, conducted at the University of Wisconsin, 64 seedlings of each species were planted in two controlled environment growth rooms. Each room was divided into four individual chambers for the purpose of testing the different treatment regimes.

The authors describe the situation: "In industrial regions, current ambient levels of O_3 reduce photosynthesis in many, and probably most, plant species. Chronic O_3 pollution commonly results in increased respiration rates, shifts in C allocation, decreased leaf retention, and shortened leaf longevity, and current levels are known to be high enough to reduce the growth and yield of agricultural crops and trees."

After discussing their material and methods Volin and colleagues report on the results of their experiments, and the results proved to be quite remarkable. The first thing they noted was that "In all six species used in this experiment, plants grown at ambient CO_2 were smaller and had a lower RGR (relative growth rate) when exposed to an elevated level of O_3-induced reductions in in situ photosynthesis at ambient CO_2." In other words, under a concentration of CO_2 equal to present atmospheric concentrations the presence of ozone caused stunted growth in the test plants. However, and this is where it gets interesting "Examination of the interactive effects of CO_2 and O_3 revealed that elevated CO_2 reduced the deleterious effects of high O_3 on both photosynthesis and growth."

In conclusion they state: "An elevated CO_2 environment seems to ameliorate the adverse effects of elevated O_3 on both photosynthesis and growth, regardless of photosynthetic pathway or plant functional group." And, finally "The amelioration of O_3 by CO_2 concentrations forecasted for the next century may have important consequences for both individual and interactive species responses." Yes, important consequences indeed, potentially positive consequences that are ignored or dismissed by the proponents of AGW (anthropogenic global warming) without further consideration.

So, here we have evidence that the presence of elevated levels of carbon dioxide counteracts the detrimental effects of elevated ozone. We can add that benefit of carbon dioxide to the list.

Given what we now know about the power of carbon dioxide to stimulate plant growth it is time to address the question of what is happening on the global scale of terrestrial nature as a result of the enhancement of atmospheric carbon dioxide that is underway. To that end there is a considerable body of empirical evidence now available.

The Terrestrial Biosphere and Carbon Dioxide

By the early 1980s the first signs of what could potentially be a planetary scale response to carbon fertilization was becoming apparent. In 1984 the work of Valmore C. LaMarche, Jr. and his colleagues with the Laboratory of Tree-Ring Research, University of Arizona, on rates of tree ring growth in subalpine pine trees in New Mexico, Colorado and California, appeared in the journal *Science*. [see: LaMarche, Valmore C. et al. (1984) **Increasing Atmospheric Carbon Dioxide: Tree Ring Evidence for Growth Enhancement in Natural Vegetation**; *Science*, vol. 225, Sept. 7, pp. 1019-1021]

The two tree species studied for this research were specifically bristlecone pines that grew near the tree line at altitudes typically around 10 or 11 thousand feet above sea level. Earlier studies by LaMarche and others discovered that tree ring thickness, and hence tree growth rates, began accelerating after about 1840, coincident with the transition out of the Little Ice Age. It was assumed that this was due to the warming climate. However, later studies up to the 1980s showed continued accelerated growth rates in spite of the fact the climate began to cool during this period and continued to do so through the 1960s and 1970s.

In the abstract of their report the authors write: "A response of plant growth to increased atmospheric carbon dioxide, which has been anticipated from laboratory data, may now have been detected in the annual rings of subalpine conifers growing in the western United States. Experimental evidence shows that carbon dioxide can be an important limiting factor in the growth of plants in this high-altitude environment. The greatly increased tree growth rates observed since the mid-19th century exceed those expected from climatic trends but are consistent in magnitude with global trends in carbon dioxide, especially in recent decades."

The next two graphs depict this accelerated growth rate in high altitude bristlecone pines as documented by LaMarche, et al.

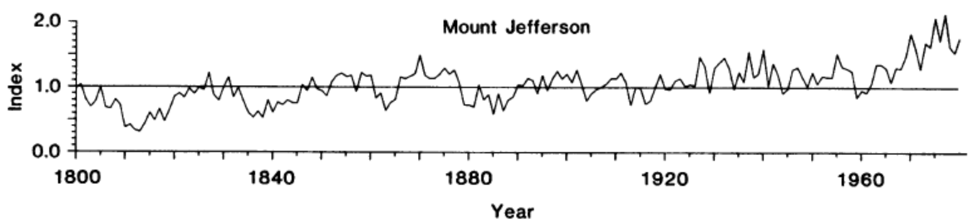


Fig. 1. Ring width indices for limber pine, Mount Jefferson, Nevada, showing rapidly increasing growth since the 1960's.

Figure 8. Tree width indices for limber pine, sampled at Mount Jefferson Nevada. Note rapid increase in growth rate since the 1960s. LaMarche, et al. p. 1019

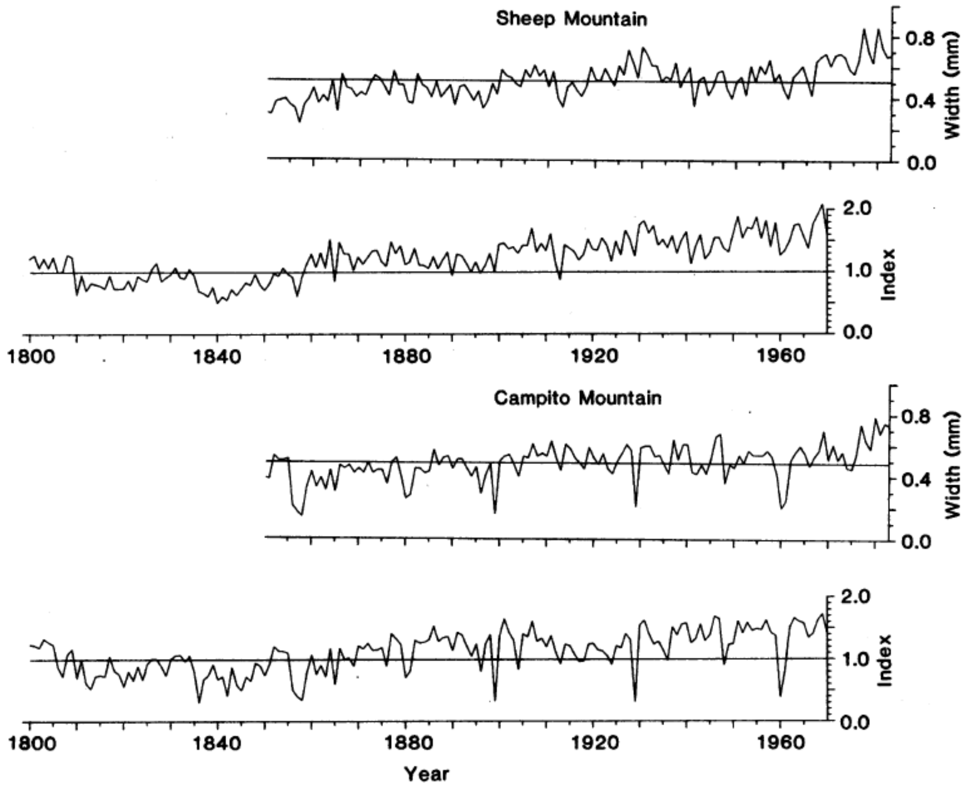


Figure 9. These are the growth records for bristle cone pines sampled from the White Mountains, California. They are typical of all samples gathered and studied by this team. Growth rates at the Sheep Mountain site increased by 106 percent between 1850 and 1983 and at the Campito Mountain site they increased by 73 percent during the same time interval. LaMarche et al. p. 1020.

After careful consideration of all possible explanations the authors' state: "We believe, from the evidence now available, that subalpine vegetation generally, and upper tree-line conifers in particular, could now be exhibiting enhanced growth as a direct response to increasing concentrations of atmospheric CO_2." They conclude by saying that: "Although high-altitude subalpine forests constitute only a small fraction of the earth's standing biomass, increased CO_2 uptake and storage could now be occurring in these habitats."

Three years later a paper was published by the Royal Society of London anticipating the potential effects of enhanced carbon dioxide on forest growth. The author, Paul Gordon Jarvis (1935 – 2013) was a forester and ecologist with the Department of Forestry and Natural Resources, University of Edinburgh. It was clear to Jarvis that plants and vegetation must be taking up increasing amounts of carbon dioxide.

> "Growth and partitioning to the roots of seedlings and young trees generally increases in response to a doubling in atmospheric CO_2 concentration. Experimental results are very variable, because of the differing length of the experiments, the artificial conditions and the artefactual constraints. At larger scales, direct measurements of responses to increase

> in atmospheric CO_2 are impractical but models of canopy processes suggest that significant increases in assimilation will result from the rise in atmospheric CO_2 concentrations." [see: Jarvis, P. G. (1989) **Atmospheric carbon dioxide and forests**: *Philosophical Transactions of the Royal Society of London*, vol. B 324, pp. 369 – 392]

"Larger scales" in this case could be regional, continental, or even global. Jarvis comments on an interesting fact. It is well known that there is a seasonal amplitude variation caused by the increased photosynthetic uptake of CO_2 in the spring, causing atmospheric concentrations to go down and its interruption during the winter when plants and leaves die-off. This oscillation is clearly shown in the Keeling Curve from Mauna Loa Observatory data upon which average global concentrations are inferred. Jarvis's comment is in reference to the fact that the amplitude of this oscillation has increased: "Inferences from the increase in amplitude of the seasonal oscillation in the global atmospheric CO_2 concentration at different latitudes suggest that forest is having a significant impact on the global atmospheric concentration." The amplitude of the seasonal oscillation is going to be a direct function of total biomass. In other words, if the amplitude increases it is because there is an increase in the amount of plants and forests taking up and releasing CO_2.

In discussing a possible temperature increase caused by increasing carbon dioxide levels, Jarvis admits that:

> "The detection of such an increase is difficult, not least because over the past 50 years the temperature in the temperate region of the Northern Hemisphere has been decreasing at a rate of about 0.15°C per year as a result of various superimposed climate cycles. There is not general agreement that an increase in temperature has so far been detected."

Yes, you read that right. For the half century prior to the writing of this article in 1989, the global temperature had been cooling from its 20th century high during the 1930s. This fact alone casts doubt upon scenarios in which carbon dioxide is the principal driver of global warming, for exactly at the time humankind began to substantially add to the atmospheric carbon dioxide pool, global temperature began to cool! Clearly there were other factors at work − the "various superimposed climate cycles" to which Jarvis refers − whatever those might be. In the late 1980s and early 1990s the global temperature began to rise, but with the onset of the 21st century the rise has been in a state of pause and global warming proponents have been attempting mightily to explain it away.

Jarvis conducted a number of first hand experiments on the effects of carbon dioxide enrichment on young trees, one of which involved approximately 30 each of both conifers and broadleaves. The experiments ranged in duration from a few weeks up to 2 ½ years. Jarvis comments on the results:

> "In all cases, the rate of growth of dry matter was increased at the higher CO_2 concentration, the increase being in the range of 20—120% with a median of about 40%.

In most of the experiments there were increases in the mass of leaves as a result of increases in the number, area or thickness. Masses of both fine and coarse roots were also increased . . . To a considerable extent, an increase in ambient CO_2 concentration was effective in compensating for lack of light, water or nutrients . . . Young trees growing in situations of low nitrogen or phosphorus, or on small volumes of nutrient-poor soils, none the less showed increased growth in response to a doubling in ambient CO_2 concentrations. A scarcity of nutrients does not prevent a growth response to increase in CO_2 concentration."

Jarvis then comments in regards to the carbon cycle that:

"Forests accumulate large amounts of carbon in woody branches, stems and litter. The standing crop of dry matter may typically vary from 100—500 t ha^{-1}. (tons per hectare, a hectare being 10,000 sq. meters, or 2.471 acres) A stand of 320 t ha^{-1} of dry matter of typical composition will have taken up approximately twice that amount of CO_2 during its period of growth, thus reducing the content of the atmosphere by that amount."

The notable lesson to be appreciated here is simply that as plants consume carbon dioxide in the process of photosynthesis, it is simultaneously being sequestered by becoming a part of the increasing plant matter and is therefore taken out of the atmosphere.

Jarvis realizes that this fact has potentially far reaching implications when considered on the planetary scale:

"If the atmospheric CO_2 concentration is so sensitive to the physiological activities of vegetation, particularly forest, proper consideration must be given to the possible role of vegetation in ameliorating the rise in atmospheric CO_2 concentration. A forest accumulating dry matter of average composition with respect to fats, proteins, carbohydrates and lignin at a rate of 5 tonne ha^{-1} per year, the approximate average for the U. K., would assimilate CO_2 at a rate of ca. 10 tonne ha^{-1} per year, removing carbon form the atmosphere at 2.7 t ha^{-1} per year. Consequently, an area of such forest of 2 Gha would be able to assimilate the 5—6 Gt per year of carbon currently being added to the global atmosphere annually by the burning of fossil fuels . . . The approximate area of Europe is 1 Gha (10×10^6 km^2). Thus a new, young, actively growing forest twice the area of Europe, could, in principle, assimilate all of the CO_2 produced through combustion and oxidation at the present rate."

Let's try to make this easier to comprehend. The area of Europe is about 3.931 million square miles. Twice this amount is 7.862 million sq. miles. The total land area of the Earth is about 57.308 sq. miles. So if an additional land area equal to about 1/15th the land area of Earth became forested, that forest would consume all of the carbon dioxide we humans are putting into it from the consumption of fossil fuels!

Consider that the total desert area of the Earth is about 19 million square miles and that the total area of land abandonment and degradation according to the estimates of the Global Assessment of Soil Degradation (GLASOD) commissioned by the United Nations Environment Program, is somewhere around 8 million square miles. Together the deserts of the world and the degraded land equal about 27 million square miles. If just a little over ¼ of this land area were to revert to forest it would, again, yearly consume all the carbon dioxide we humans put into the atmosphere.

Obviously this affect could not go on forever. However, what it does mean is that as the density of Earth's biomass increases, as larger areas of Earth's surface become green, the biospheric demand for carbon dioxide will increase as well. Jarvis estimates that at least 80 years would transpire before such new, additional forest mass would cease to assimilate carbon. The key here would be well-managed forests, with regular harvesting and replacement planting with new trees as well as full utilization of the timber in such a manner that oxidation is minimized. What this tells us is this: if the biomass of the Earth is, in fact, increasing due to stimulated photosynthesis and carbon uptake, we have at least a century to make the conversion to carbon neutral energy technologies.

The paper I referenced above by Sherwood Idso, describing in detail his experiments growing orange trees under conditions of CO_2 enrichment, addresses the issue of biospheric feedbacks.

> "Consider the fact that CO_2 is the primary raw material used by plants in producing organic matter via the process of photosynthesis, and that the more CO_2 there is in the air, the better plants can perform this vital function, even under conditions of limiting light, water and nutrients. This being the case, as literally hundreds of laboratory and field experiments have clearly demonstrated, the CO_2 sequestering ability of the world's plant life should rise right along with the CO_2 content of the atmosphere. And at some future date it may be possible that it will have risen high enough to offset man's perturbation of the global carbon cycle and yearly remove from the atmosphere all of the CO_2 that we yearly put into it, which would stabilize the CO_2 content of the air and prevent it from rising further."

After discussing the dramatic results obtained from his orange tree experiments Idso turns to the question of the effect on other trees comprising the total mix of Earth's forests. To address that question he invokes the phenomenon of the fluctuating annual cycle of atmospheric CO_2.

> "When the terrestrial vegetation of the Northern Hemisphere awakens from winter dormancy each year, it withdraws great quantities of CO_2 from the atmosphere as it begins a new season of growth, significantly lowering the CO_2 content of the air. Likewise, when it senesces in the fall, great quantities of CO_2 are liberated, raising the air's CO_2 content. The net result of these yearly recurring phenomena is a cyclic variation of the air's CO_2 concentration."

But, as Idso point out, something very interesting is going on with this process:

> "The peaks and troughs of this cycle are becoming more enhanced each year, something that every group of scientists that has ever studied the subject has concluded is due to the aerial 'fertilization effect' of the rising CO_2 content of earth's atmosphere. That is, as the CO_2 content of the air rises higher and higher each year, the plant life of the planet becomes more and more robust, so that each spring and summer it extracts more CO_2 from the atmosphere than it did the year before, and each fall and winter it releases more of it back to the atmosphere."

Recall that we learned that biospheric productivity increased at least 33% for a 300 parts per million increase of atmospheric CO_2 in order to appreciate the significance of what Idso says next:

> "What is particularly noteworthy about this observation is that the amplitude of the atmosphere's seasonal CO_2 cycle is increasing <u>at a rate that is four times greater than what would be expected</u> on the basis of what is known about the growth response of non-woody plants to atmospheric CO_2 enrichment. This fact implies that total biospheric productivity would increase by about 4 x 33% for a 300-ppm increase in the air's CO_2 content."

Based upon studies by Piers Sellers and James J. McCarthy in Planet Earth: Part III – Biosphere Interactions, Idso points out that land vegetation accounts for about 90% of the amplitude of the annual carbon dioxide cycle. [see: Sellers, Piers, and James J. McCarthy (1990) **Planet Earth: Part III: Biosphere interactions**. *Eos, Transactions American Geophysical Union,* vol. 71, no. 52 (Dec. 25) 1883-1884] As a percentage of the total planetary vegetation, trees account for about 75% of the land biospheric carbon exchange occurring in the process of photosynthesis. Therefore forests account for about 75% of 90% of the total global forest carbon uptake, or about 2/3. The rest of Earth's vegetation in the form of the non-woody plants account for about the remaining 1/3 of the response.

Based upon the rate of increase in the magnitude of the annual cyclic amplitude that is occurring 4 times greater than calculations would predict, Idso derives a very simple equation.

$$4(33\%) = 1/3(33\%) + 2/3GF$$

The term on the left represents the 4x net productivity enhancement of the entire biosphere as a consequence of a 300 ppm atmospheric enrichment. The first term on the right is the known response of non-woody plants and the second term is the mean response of the global forest to the same 300 ppm increase. Idso then solves the equation for GF.

$$132\% = 11\% + 2/3GF$$

$$132\% - 11\% = 2/3GF$$

$$3(121\%) = 3(2/3GF)$$

$$362\% = 2GF \text{ or } GF = 181\%$$

This number is consistent with Idso's empirical studies on orange trees. Regarding the same experiments discussed above, Idso and his colleague Bruce Kimball give additional details in the *Journal Agricultural and Forest Meteorology*. In describing the increase in biomass both above ground and below ground, they note that "although the fine root biomass density is enhanced by approximately 75% beneath the trees' canopy, the fact that the roots of the CO_2 enriched trees extend further out from their trunks than do the roots of the ambient trees results in a total biomass enhancement of 175%." Admitting that such an increase seemed hard to believe Idso and Kimball point out that "A 175% enhancement of fine root biomass produced by a 300 (ppm) enrichment of the air may seem inordinately large, but other measurements we have made on the trees would appear to confirm its reality. Idso et al. (1991), for example, found the CO_2 induced enhancement of total above-ground trunk plus branch volume to be 179%."

Here we note something very interesting and significant: Empirical studies in a microscale environment are consistent with the theoretical computations for the macroscale global environment, implying that an increase of 180% in the mean productivity of the world's forests is not farfetched at all. What does this imply with respect to climate change?

Simply this: Projections of future rise in carbon dioxide content would be limited by the fact of being consumed by the increase in global biomass. Idso refers to the work of G. Marland from 3 years earlier (1988). In a report prepared for the U.S. Department of Energy, Marland, who later became a contributing author for IPCC reports, calculated that the anthropogenic release of carbon dioxide into the global atmosphere could be balanced by a doubling of the growth rate of Earth's forests. Based upon the idea that forests account for 2/3 of total global photosynthesis, Idso calculates the amount of additional carbon dioxide necessary to stimulate a doubling of global photosynthesis. What he discovers is very interesting, for, as he explains

> "the maximum increase in atmospheric CO_2 predicted for the future is actually identical to the equivalent CO_2 increase of the past hundred or so years. Hence, we have already lived through an equivalent atmospheric CO_2 increase that is as large as the maximum additional CO_2 rise that could yet occur in conjunction with current CO_2 emission rates."

And then Idso poses the $64,000 dollar question: "If the past is prologue to the future, how much more CO_2-induced warming is likely to occur?" His answer to that question is what has earned him the animosity of global warming promoters:

> "Very little it would appear; for the most warming that is claimed for the globe over the course of the Industrial Revolution is about 0.5°C; and it can be effectively argued that only a portion of that warming may be attributed to CO_2 and other trace gas increases. Thus, warming yet to be faced cannot be much more than what has already occurred, which may not even be sufficient to return the earth to the relative mildness of the climatic optimum that made possible the colonizing voyages of the Vikings."

In regards to the question of the effect of a continued rise in the annual amount of CO_2 released into the atmosphere by human activities, Idso points out that

> "higher rates of CO_2 emissions would require relatively greater atmospheric CO_2 increases to sequester the additional carbon. But as the greenhouse effect of a CO_2 increase in this range is less than that of an equivalent CO_2 increase in the 300- to 600-ppm range, a near linearity would still be maintained . . ."

Idso does stress the importance of preserving Earth's forests since they function as such a powerful sink for atmospheric carbon dioxide, thereby significantly mitigating potential climatic consequences. In his closing remarks he puts the carbon cycle phenomenon into perspective:

> "In this regard, nature becomes our ally, as increases in atmospheric CO_2 result in growth rate increases of trees five times greater than growth rate increases on nonwoody plants. Hence, as the CO_2 content of the air continues to rise in the years ahead, woody species will begin to expand their ranges, as is already happening in many parts of the world. Also, as vegetative productivity increases simultaneously over the entire planet, man will harvest greater quantities of organic matter from each unit of land, thereby alleviating somewhat the pressures that currently lead to the felling of forests."

Finally, Idso points out that:

> "As the rising CO_2 content of the atmosphere thus provides a strong impetus for forest expansion, it likewise provides a solution to any problems its continued upward trend might produce, as it intensifies the major mechanism responsible for its removal from the air, operating in true Gaian fashion."

So we see that by 1991 Sherwood Idso is realizing that a small increase in atmospheric CO_2 concentrations is beginning to stimulate a response from the biosphere. We must now ask what evidence has accrued in the interim since Idso published his work, of an increase of terrestrial biomass, in other words, a greening of the Earth?

In an article published in the journal *Nature* in April of 1997 there appeared evidence portending things to come. The article was entitled **"Increased plant growth in the northern high latitudes from 1981 to 1991**." The lead author was Professor Ranga B. Myneni with the Department of Earth and Environment at Boston University. Among the other four authors was the late Charles David Keeling (1928 – 2005), then with the Scripps Institute of Oceanography. Keeling is well known in climate circles as the lead scientist responsible for establishing the carbon dioxide recording system at Mauna Loa Observatory that has documented the increase in atmospheric concentrations of CO_2. The other authors included C. J. Tucker with NASA Goddard Space Flight Center; G. Asrar with the Office of Mission to Planet Earth, NASA; and R. R. Nemani with the School of Forestry, University of Montana.

In the *Nature* article the authors present their analysis of data going back to 1981, collected by the Very High Resolution Radiometers (AVHRRs) carried on board NOAA meteorological satellites. These instruments can analyze the reflected wavelengths emanating from a variety of terrains, including desert, bare soil, inland water bodies, grasslands, forests and so on. Since each of these landscapes emits different wavelengths it is possible to draw conclusions about the relative abundance of each type of land surface and the extent of vegetation. Study of the global land data so produced led to the development of the "normalized difference vegetation index" or NDVI. The index is expressed as a scale from minus one to plus one and the greater the amount of vegetation the higher the number, with wavelengths in the range of 0.4 to 0.7 microns indicative of the photosynthetic activity of vegetation canopies. Studying 10 years' worth of data that started in 1981 the authors discern a very interesting trend. In the abstract to their article they state "Here we present evidence from satellite data that the photosynthetic activity of terrestrial vegetation increased from 1981 to 1991 in a manner suggestive of an increase in plant growth associated with a lengthening of the active growing season." They further observe that the regions exhibiting the greatest increase occur between latitudes 45 and 70 degrees north. [See: Myneni, R. B. et al. (1997) "**Increased plant growth in the northern high latitudes from 1981 to 1991**" *Nature*, vol. 386 (April 17) pp. 698 – 702.]

In the same issue of *Nature* an article introductory to the paper by Myneni et al., authored by Inez Fung with NASA Goddard Institute for Space Studies, puts their work into perspective.

> "Sustained long-term observations of photosynthesis are rare. Furthermore, the biosphere is notoriously heterogeneous. It is very difficult to extrapolate from field measurements at a few sites to behavior over a large region. . . Myneni *et al*. present satellite evidence that, on average, <u>the biosphere between 45° N and 70° N has been enjoying increased photosynthesis between 1981 and 1991</u> . . . The evidence presented by Myneni *at al*. is the first direct observation of the biosphere that photosynthesis has increased on such a broad scale for such a long time. The satellite observations are extremely provocative and, the authors argue, reveal specific areas where changes have occurred . . . It will be a challenge for ecologists to explain how photosynthesis could have increased by some 10% from 1981 to 1991." [See: Fung, Inez (1997) **Climate change: a greener north**. *Nature*, Vol. 386, April 17, pp. 659-660]

So here it is. By 1997 it had become apparent that because of the increased warmth since the late 19th century, coupled with increasing carbon dioxide amounts, the growing season had lengthened as had the degree of photosynthetic activity of the biosphere. This was manifesting as amplified vegetation biomass, hence the phrase "a greener north" in the articles title. The challenge to ecologists – to explain how photosynthesis could increase by 10% in a decade – is indeed provocative and implies the obligation to acknowledge a positive consequence to the increase in atmospheric carbon dioxide that is taking place, in contradistinction to the politically contrived view that seeks to demonize carbon dioxide as a "pollutant." With this attitude regarding carbon dioxide now dominating the discussion, an admission by workers in environmental and ecological fields of a positive effect would become a major liability, especially those seeking grant money from politically controlled or influenced sources.

The work of Myneni et al. examined forest response between the latitudes of 45 degrees to 70 degrees north. What about tropical regions?

A study appeared in *Trends in Ecology & Evolution* in the year 2000 that looked at the response of tropical forests to the increasing amounts of atmospheric carbon dioxide. The authors, Yadvinder Malhi and John Grace were with the Institute of Ecology and Resource Management, University of Edinburgh, Scotland. Their report, appearing in the Perspectives section of the journal, began by discussing what they presumed to be the inexorable future rise of atmospheric CO_2 concentrations due to fossil fuel burning and land clearing, and the implications of this increase to global climate change. They then qualify their statements by saying "However, these changes are meshed within an immense natural global carbon cycle that is still poorly understood and that will almost certainly provide new surprises." [see: Malhi, Yadvinder, and John Grace. "**Tropical forests and atmospheric carbon dioxide**." *Trends in Ecology & Evolution* Vol 15, No. 8 (2000): 332-337.]

The two things these authors emphasize should be kept in mind before continuing: the immensity of the natural carbon cycle relative to the contributions of humans and the fact that this immense natural phenomenon, which, in the authors' words, "is still poorly understood" is central to the question of climatic consequences. If the authors are right, that the immense natural carbon cycle is "still poorly understood," how is it possible to be so absolutely certain of outcomes that we can declare the debate over and the science settled with respect to the matter of climate change?

Mahli and Grace refer to a synopsis published in the journal *Tellus* a year earlier entitled **Current perspectives on the terrestrial carbon cycle** by Jon Lloyd. They discuss some of the findings presented in Lloyds' synopsis:

> "A recent review of experimental studies growing trees in open-top chambers indicates that a 300 ppm increase in atmospheric CO_2 concentration stimulates photosynthesis by 60%, the growth of young trees by 73% and wood growth per unit leaf area by 27%. It seems probable that there will be a similar response in natural forest ecosystems."

In the context of the notable findings of Jon Lloyd, Mahli and Grace proceed to discuss the implications for the tropics: "Because of their intrinsic high productivity, tropical forests are a prime candidate for such a C fertilization response, the crucial question has been to what extent such a response might be limited by nutrient availability, in particular by low nitrogen or low phosphorus." However, as they point out, studies referenced by Lloyd have shown that plants might "increase their nutrient acquisition process by investing in mycorrhizal colonization, and by mineralizing nutrient reserves in the soil by the production of surface enzyme systems and organic acid exudates." In other words, it is entirely possible, if not likely, that plants in a carbon dioxide enriched environment will develop the means to more effectively utilize available nutrient supplies.

Mycorrhiza are actually two different entities, a plant and a fungus, existing in a symbiotic or mutually beneficial relationship. Various kinds of fungus associate themselves with a particular plant through the root system. It has been found that the mycelium of the fungus can perform a number of functions beneficial to the plant, for example, accessing sources of phosphorous unavailable to the plant alone. It has been found that plants in association with mycorrhizal fungus are more resistant to diseases and the effects of drought. Mycorrhizal fungi are important in the colonization of barren or desolate landscapes that have been devastated by catastrophic floods, fires, or volcanic eruptions and provide greater protection for plants growing in soils with high metal or acid concentrations.

Mahli and Grace call attention to one of the important variables in the response of plants to rising CO_2: If plants become more efficient in the process of nutrient uptake, it mitigates one of the limiting factors of plant response to increased carbon dioxide concentrations. In many of the hundreds of studies conducted on plant response to increased carbon dioxide, nutrient availability, along with availability of light, was most frequently the limiting factor in the plants exploitation of carbon dioxide conferred advantages. If this turns out to be true, that plants gain improved means of accessing nutrients in the soil, thereby increasing their bulk mass available for carbon uptake, then, as Mahli and Grace point out "A small steady increase in forest productivity can produce a large net C sink." In other words the increase in biomass increases the ability of the forest to consume more carbon dioxide from the atmosphere transforming it into greater plant mass. The increased growth and plant mass then in turn consumes even more carbon dioxide in a positive feedback loop, removing it from the atmosphere in the process.

Mahli and Grace presented a table displaying the net biotic carbon sink in tropical regions based on the results of the Large Scale Biosphere-Atmosphere Experiment that not only looked at Amazonia but Costa Rica and Southeast Asia as well. However, the implications of the results of the LBA were considered problematic by the authors who state that "The total predicted tropical C sink is 4.5 Gt C year^{-1} (4.5 billion tons per year) . . . This seems implausible unless there are 'missing sources' in the global C budget that are currently neglected."

Once again, we have the problem of the disappearing carbon. Let's return to the question of carbon dioxide sources and sinks with which we began this essay.

4.5 Gt per year would amount to almost two thirds of all the CO_2 emitted annually through fossil fuel combustion. Is it possible that tropical forests are consuming this much carbon dioxide?

To understand this question better the authors suggested that an alternative approach to detecting carbon uptake was to examine long-term forestry plots to see if there was evidence for increased biomass. To this end they turned to the work of O.L. Phillips et al. whose research report was published in the journal *Science* in 1998. Quoting from Phillips et al.

> "A recent study compiled data from forest inventories across 68 sites in apparently undisturbed tropical forests. It found large variability between plots, but reached a remarkable conclusion – most South American forests have increased in biomass in recent decades and have been accumulating C in biomass at a rate of 0.71 ± 0.39 t C ha^{-1} year^{-1}." (71 ± .39 tons of carbon per hectare per year).

Over the whole area of tropical forests this translates into a total forest sink of some 2.0 gigatons of carbon per year of which at least half is in South America. So, according to these studies, tropical forests are taking up at about one third of the amount of the carbon being released through fossil fuel consumption and they are responding with increased growth and biomass accumulation. This does not include the mid-latitude forests that are consuming a substantial amount of CO_2 as well. In other words, Nature, with the help of Man, is initiating a rapid regeneration of tropical forests by exploiting the additional available carbon dioxide.

The Phillips et al. paper has some very interesting implications. They begin their paper by saying that "Tropical forests contain as much as 40% of the C stored as terrestrial biomass and account for 30 to 50% of terrestrial productivity. Therefore, a small perturbation in this biome could result in a significant change in the global C cycle." Their methodology involved compiling basal data on the cross sectional area of trees per unit of ground area in mature tropical forest plots. The data was drawn from four tropical regions involving over 600,000 tree measurements. The results of Phillips et al. are consistent with the work of many other researchers and "are therefore indicative of a widespread increase in the biomass of surviving Neotropical forests over recent decades." They come to no firm conclusions as to what factors, natural or anthropogenic, might be driving this increase in biomass but consider increasing carbon dioxide as a possibility saying "The biomass increase could also be a response to recent anthropogenic global change . . . Candidate factors for nutrient fertilization include increasing atmospheric CO_2. . ." Finally, in addressing the problem of the missing sink the authors put forward an idea that is laden with implications "Our results suggest that mature Neotropical forest biomass may account for ~40% of the so-called 'missing' terrestrial C sink. Hence, intact forests may be helping to buffer the rate of increase in atmospheric CO_2, thereby reducing the impacts of global climate change." [see: Philllips, O. L. et al. (1998) **Changes in the carbon balance of tropical forests: evidence from long term plots**: *Science*, vol. 282 (Oct.18) pp. 439 – 442]

The same issue of *Science* contained a second article by a seven member team describing a study of terrestrial carbon uptake in North America. The study utilized two atmospheric transport models incorporating data from 10 years' worth of carbon dioxide samples collected from an array of atmospheric sampling stations. Using this data spatial patterns indicative of the atmospheric distribution were developed and coupled with estimates of the ocean-atmosphere flux and the spatial distribution of fossil fuel carbon dioxide emissions. From this information it became possible to determine that spatial distribution of carbon uptake and ascertain an estimate of net annual terrestrial sources and sinks. Looking at variances in the pattern of carbon uptake the authors report that "A large North American terrestrial uptake was estimated consistently for a range of spatiotemporal patterns assumed for the terrestrial uptake." This large scale intake of carbon dioxide by North American vegetation is attributed to a number of factors including regrowth of abandoned farmland and previously logged forests with this process being enhanced by nitrogen deposition, CO_2 fertilization, and a mild increase in temperature. [see: Fan, S., M. Gloor, J. Mahlman, S. Pacala, J. Sarmiento, T Takahashi, P. Tans (1998) **A Large Terrestrial Carbon Sink in North America Implied by Atmospheric and Oceanic Carbon Dioxide and Models**: *Science*, vol. 282 (Oct. 16) pp. 442 – 446]

Both model simulations yielded more remarkable results. It was found that North America's contribution to the annual uptake of carbon dioxide was a 1.7 billion tons. Given that the estimate of the annual North American emissions of CO_2 by both the United States and Canada is about 1.6 billion tons, the implication is that North American vegetation is consuming each year more carbon dioxide than is being released through the burning of fossil fuel in North America!

A commentary on the findings of this team was included in the October 16 issue of *Science* to address this incredible and unexpected result:

> "As greenhouse warming experts try to predict how much of the world's climate may heat up in the next century, they keep bumping up against a mystery: Where does much of the carbon dioxide pumped into the air actually end up? . . . In what is shaping up as one of the most controversial findings yet to emerge in the greenhouse gas debate, a team of researchers . . . present evidence that North America sops up a whopping 1.7 petagrams (1.7 billion tons) of carbon a year – enough to suck up every ton of carbon discharged annually by fossil fuel burning in Canada and the United States."
>
> "The CMC team acknowledges that its results strain credibility. 'I have trouble quite believing' the size of the sink, says Tans, adding that 'We're pushing the data pretty far.' But, says Sarmiento, 'we've really carefully analyzed the data in a lot of different ways.' U.S. Geological Survey geochemist Eric Sundquist agrees: 'The paper is a credible and rigorous interpretation of the available data.' [see: Kaiser, Jocelyn (1998) **Possibly Vast Greenhouse Gas Sponge Ignites Controversy**: *Science*, vol. 282 (Oct. 16) pp. 386 – 387]

Obviously, these results have enormous implications relative to the whole global warming debate. And, obviously "greenhouse warming experts" are not as omniscient as the mainstream press and varied promoters of propaganda would have us believe. It is time to recognize that the IPCC is NOT infallible, that the so-called "consensus" is a complete fiction, and, that an effort to impose a global regulatory scheme based upon uncertain science would be a certain blunder.

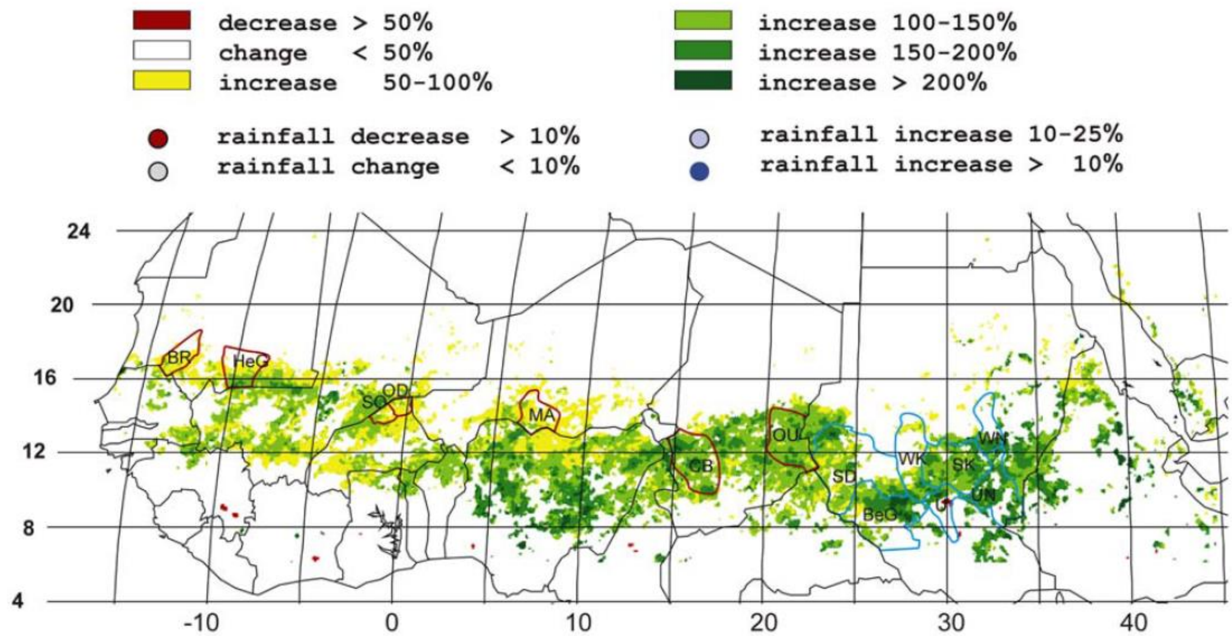
But let us proceed.

In 2005, a study of the Sahel region of sub-Saharan Africa utilizing the NOAA AVHRR (Advance Very High Resolution Radiometer) sensing system employing the Normalized Difference Vegetation Index (NDVI) was published in the peer reviewed *Journal of Arid Environments*. In their abstract the authors summarize the situation:

> "For the last four decades there has been sustained scientific interest in contemporary environmental change in the Sahel (the southern fringe of the Sahara). It suffered several devastating drought and famines between the late 1960s and early 1990s. Speculation about the climatology of these droughts is unresolved, as is speculation about the effects of land clearance on rainfall and about land degradation in this zone. However, recent findings suggest a consistent trend of increasing vegetation greenness in much of the region. Increasing rainfall over the last few years is certainly one reason, but does not fully explain the change." [see: Olsson, L.; L. Eklundh & J. Ardo (2005) **A recent greening of the**

Sahel—trends, patterns and potential causes: *Journal of Arid Environments*, vol. 63, pp. 556-566]

The figure below is reproduced from Olsson et al. It shows the results of trend analysis from 1982 to 1999 across the Sahel and southern Sahara region of north Africa. The data was derived from 40 climate observation stations and shows the percent change during that time frame. In regards to this figure the authors state "The increase shown in Fig. 1 is remarkable. . ." Reproduced below is Figure 1.



In the conclusion to their paper the authors state "the strong secular trend of increasing vegetation greenness over the last two decades across the Sahel cannot be explained by a single factor such as climate. Increasing rainfall does explain some of the changes but not conclusively."

So what other factors might remain to explain this greening of what has been desert through most of historical times?

As evidence continues to mount the answer to that question has become undeniable.

In 2005 the journal *Global Change Biology* carried a report on trends in the vegetation cover of Australia. The lead author Randall J. Donahue is a research scientist with CSIRO Land and Water, and the Research School of Biological Sciences, The Australian National University. The other authors Tim R. McVicar and Michael L. Roderick are affiliated with the same institutions. The papers abstract describes their method:

"Using Advanced Very High Resolution Radiometer data spanning 1981-2006 . . . we examine whether vegetation cover has increased across Australia . . . Results from an

Australia-wide analysis indicate that vegetation cover has increased, on average, by 0.0007 per year – and increase of ~8% over the 26 years . . . Over the same period, Australian average annual precipitation increased by 1.3 mm yr^{-2} (up 7%) . . . Interestingly, where vegetation cover increased at water-limited sites, precipitation trends were variable indicating that this is not the only factor driving vegetation response. As Australia is a generally highly water-limited environment, these findings indicate that the effective availability of water to plants has increased on average over the study period . . . Regardless of what has been driving these changes, the overall response of vegetation over the past 2—3 decades has resulted in an observable greening of the driest inhabited continent on Earth." [see: Donohue, Randall J.; Tim R. McVicar & Michael L. Roderick (2009**) Climate-related trends in Australian vegetation cover as inferred from satellite observations, 1981-2006**: *Global Change Biology*, vol. 15, pp. 1025-1039.]

By 2013 Randall Donahue and his colleagues had expanded the scope of their research from Australia to the globe. Their update was presented in *Geophysical Research Letters*. While they do not specifically name carbon dioxide as a culprit in their earlier work, by 2013 they are convinced that it is playing a dominant role in the observed greening.

"Satellite observations reveal a greening of the globe over recent decades. The role in this greening of the 'CO_2 fertilization' effect—the enhancement of photosynthesis due to rising CO_2 levels—is yet to be established. The direct CO_2 effect on vegetation should be most clearly expressed in warm, arid environments where water is the dominant limit to vegetation growth. Using gas exchange theory, we predict that the 14% increase in atmospheric CO_2 (1982—2010) led to a 5 to 10% increase in green foliage cover in warm, arid environments . . . Our results confirm that the anticipated CO_2 fertilization effect is occurring alongside ongoing anthropogenic perturbations to the carbon cycle . . ."

"The increase in water use efficiency of photosynthesis with rising C_a [carbon dioxide] has long been anticipated to lead to increased foliage cover in warm, arid environments, and both satellite and ground observations from the world's rangelands reveal widespread changes toward more densely vegetated and woodier landscapes. Our results suggest that C_a has played an important role in this greening trend and that, where water is the dominant limit to growth, cover has increased in direct proportion to the CO_2-driven rise in W_p [water use efficiency of photosynthesis] . . . The CO_2 fertilization cover effect warrants consideration as an important land surface process." [See: Donohue, Randall J. et al. (2013) **Impact of CO_2 fertilization on maximum foliage cover across the globe's warm, arid environments**: *Geophysical Research Letters*, vol. 40, pp. 3031 – 3035.]

The CO_2 fertilization effect certainly does warrant consideration as an important land surface process, one that is clearly a net positive within the global ecology. However, the reality is that among global warming promoters the subject of positive consequences is taboo, to even bring it up invites derision and condescension and charges of being a fossil fuel industry lackey. But such an attitude is, in reality, symptomatic of a combination of ignorance and arrogance and an unwillingness to think outside the confines of one's ideology.

Science Daily reported on the work of Donohue and his colleagues, quoted above, that was undertaken under the auspices of the Commonwealth Scientific and Industrial Research Organisation, a 101 year old Australian scientific and research body (CSIRO). Science Daily interviewed Donahue about his teams work on the carbon fertilization effect: Among his comments Donahue said this: "On the face of it, elevated CO_2 boosting the foliage in dry country is good news and could assist forestry and agriculture in such areas; however there will be secondary effects that are likely to influence water availability, the carbon cycle, fire regimes and biodiversity, for example," Dr. Donohue said. "Ongoing research is required if we are to fully comprehend the potential extent and severity of such secondary effects." [see: CSIRO Australia. "**Deserts 'greening' from rising carbon dioxide: Green foliage boosted across the world's arid regions.**" *Science Daily*, July 8, 2013.]

Absolutely we need more research, but it is also the case, based upon what we now know, that negative consequences of some of those secondary effects will be mitigated under a carbon dioxide enhanced atmosphere. For example, greater root mass means that the plant can reach deeper for water and nutrients, that it can consolidate and retain the soil against erosion more effectively, that it can survive the effects of fires more effectively, and would be less likely to uproot during an intense storm.

Confirmation of a global biospheric recovery continues to mount up. Another study was published in *Nature Climate Change* in 2015 by a seven member team that employed satellite-based passive microwave observation to estimate above ground biomass, (ABC) whereas previous studies had utilized radar or optical observations. As the authors describe: "The intensity of natural microwave radiation from the Earth is a function of its temperature, soil moisture and the shielding effect of water in aboveground vegetation biomass." This new method supported earlier findings. From their investigations the team learned that

> "From 2003 onwards, forest in Russia and China expanded and tropical deforestation declined. Increased ABC associated with wetter conditions in the savannahs or northern Australia and southern Africa reversed global ABC loss, leading to an overall gain, consistent with trends in the global carbon sink reported in recent studies." [see: Liu, Yi Y. et al. (2015) **Recent reversal in loss of global terrestrial biomass**: *Nature Climate Change*, vol. 5 (May) pp. 470 – 474]

A 2016 study on carbon exchange fluxes in the Sahel region concluded that "A budget for the entire Sahel indicated a strong C sink <u>mitigating the global anthropogenic C emissions</u>." [see: Tagesson, Torbern, et al. (2016) **Spatiotemporal variability in carbon exchange fluxes across the Sahel**: *Agricultural and Forest Meteorology*, vol. 226-227 (Oct.) pp. 108-118] It should be noted that the idea that the biosphere is acting as an important carbon dioxide sink, thereby reducing the amount in the atmosphere substantially over the long term, has generally been excluded from IPCC computerized projections of the future. But, here again the evidence is mounting that as the density of the Earths vegetation increases so will the ongoing need for greater amounts of CO_2 to stimulate photosynthesis, resulting in a positive feedback cycle.

Reinforcing this probability is the work of Joseph M. Craine and Peter B. Reich, with the Department of Integrative Biology, University of California, Berkelely and the Department of Forest Resources, University of Minnesota respectively. Their work, published in 2001 in *New Phytologist*, looked at the longevity of leaves for 10 grassland species under varying carbon dioxide concentrations and demonstrated yet another positive effect. They write:

> "Although many plant traits affect C and N cycles in an ecosystem, leaf longevity has a central role in determining litterfall, standing biomass, and net primary productivity (NPP). For example, increases in leaf longevity could increase the carbon gain of individual leaves . . . and therefore increase stand NPP." [see: Craine, Joseph M. & Peter B. Reich (2001) **Elevated CO_2 and nitrogen supply alter leaf longevity of grassland species**: *New Phytologist*, vol. 150, pp. 397 – 403)

In other words, by living longer the leaves of these plants would consume even more carbon dioxide. As the authors say in their concluding discussion: "All other things equal, the increase in leaf longevity due to elevated CO_2 would lead to greater ecosystem carbon gain, assuming the leaves maintained positive net photosynthesis over the additional period."

A 2014 study looked at long-term experimental forestry plots that were established in 1872 in Central Europe, the same year as the founding of the International Union of Forest Research Organizations. From then until the present day, now over 140 years, these plots were surveyed between 10 and 20 times. The authors of this new study, Hans Pretzsch and four others used the data collected from these surveys to analyze growth trends. What they found was interesting.

"Based on the oldest existing experimental forest plots in Central Europe, we show that, currently, the dominant tree species Norway spruce and European beech exhibit significantly faster tree growth (+ 32 to 77%), stand volume growth (+ 10 to 30%) and standing stock accumulation (+ 6 to 7%) than in 1960 . . . Standing wood volume, mean diameter, dominant height and mean tree volume currently grow significantly faster than in the past . . . coinciding with an increase in resource supply (CO2, N), together with an extended growing season accompanied by changes in other climatic variables . . . present forest stands grow more rapidly, and accumulate a given standing volume earlier than comparable stands did a century ago." [see: Pretzsch, Hans, et al. (2014) **Forest stand growth dynamics in Central Europe have accelerated since 1870**: *NatureCommunications* 5 : 4967 | DOI: 10.1038 / ncomms 5967 | www. nature.Com /naturecommunications]

The authors of another 2016 study employ meta-analytic techniques to compare soil water content under both ambient and elevated CO_2 concentrations with varying conditions of climate, vegetation, soil and so on. The research was based upon 1705 field measurements sampled from 21 separate sites widely dispersed across 8 countries and published in 45 independent studies. In the abstract to this report the authors concede the now unavoidable conclusion:

> "While recent findings based on satellite records indicate a positive trend in vegetation greenness over global drylands, the reasons remain elusive. We hypothesize that

> enhanced levels of atmospheric CO_2 play an important role in the observed greening through the CO_2 effect on plant water savings and consequent available soil water increases."

The authors begin their paper by defining and describing the phenomenon of drylands.

> "Defined broadly as zones where mean annual precipitation is less than two-thirds of potential evaporation, drylands are critically important systems and represent the largest terrestrial biome on the planet. Climate change, increasing populations and resulting anthropogenic effects are all expected to impact dryland regions over the coming decades. Considering that approximately 90% of the more than 2 billion people living in drylands are geographically located within developing countries, improved understanding of these systems is an international imperative." [see: Lu, Xuefei; Lixin Wang & Matthew F. McCabe (2016) **Elevated CO_2 as a driver of global dryland greening**: *Nature.com/scientific reports* (Feb. 12)]

Certainly the reoccurrences of drought and famine over the decades, especially in sub-Saharan Africa, have repeatedly underscored the importance of improved understanding as an international imperative.

But then the authors go on to describe the extraordinary developments beginning to manifest on planet Earth that could change the entire equation in profound ways:

> "Recent regional scale analyses using satellite based vegetation indices such as the Normalized Difference Vegetation Index (NDVI), have found extensive areas of 'greening' in dryland areas of the Mediterranean, the Sahel, the Middle East and Northern China, as well as greening trends in Mongolia and South America. More recently, a global synthesis over the period 1982-2007 that used an integrated NDVI and annual rainfall, showed an overall 'greening-up' trend over the Sahel Belt, Mediterranean basin, China, Mongolia region and the drylands of South America."

Pause for a minute and ponder what this research is saying. After years of a presumptive expansion of Earth's deserts it is beginning to dawn upon researches that something has changed. Deserts are now contracting!

In various public forums and podcasts I have stated that the Earth's deserts are actually contracting. In response to presenting this information various "critics" have typically said something to the effect that everybody "knows" that deserts are expanding around the world, and therefore I don't know what I am talking about, and therefore anything else I might have to say can be dismissed or ignored as well!

The idea of popular misconceptions regarding the status of Earth's deserts was addressed recently in the *Proceedings of the National Academy of Sciences* in an article entitled "**On regreening and degradation of Sahelian watersheds.**" The study by Armel T. Kaptue and two collegues at the Geospatial Sciences Center of Excellence, South Dakota State University, used satellite-derived vegetation indices in Senegal, Mali, and Niger from 1983 to 2012 to determine net primary production. As a preface to their work the authors explain that "In the last 20 y, remote-sensing studies have documented an apparent increase in vegetation productivity in the Sahel using satellite measurements of vegetation greenness" (NDVI). But, while this has been going on, they further explain "Over many decades our understanding of the impacts of intermittent drought in water-limited environments like the West African Sahel has been influenced by a narrative of overgrazing and human-induced desertification. The desertification narrative has persisted in both scientific and popular conception, such that regional-recovery ("regreening") . . . following the severe droughts of the 1970s—1980s, are sometimes ignored." And further "in the popular press and often in the environmental and development literature, the reports are sometimes forgotten, to the extent that popular opinion . . . holds fast to pessimistic images of overgrazing, degradation, sand storms, and sand-dunes "marching" south from the Sahara towards the sea." [see: Kaptue, Armel; Lara Prihodka, and Niall P. Hanan (2015) **On regreening and degradation in Sahelian watersheds**: *Proceedings of the National Academy of Science*, vol. 112, no. 39 (Sept. 29) pp. 12133-12138]

As I am criticized by various individuals who find the information I bring to the table unpalatable because it goes against their assumptions and unexamined beliefs, it is persistently apparent that most of them are simply regurgitating something they have heard, or read in popular accounts and assume, therefore, that they have enough knowledge to express an opinion on the matter. The degree of ignorance, the amount of misinformation and lack of critical thinking skills manifest in many of the remarks directed towards me in some of these public forums is symptomatic, I believe, of the sorry state of modern liberal education in America today. But that is another discussion for another place.

Another report by a 19 member international scientific team was published in 2016 that utilized two 30 year remote-sensing based estimates of the northern hemisphere leaf area index (LAI) coupled with simulations from 19 Earth system models (ESMs). There is no ambiguity about the findings of this team:

> "Significant land greening in the northern extratropical latitudes (NEL) has been documented through satellite observations during the past three decades. This enhanced vegetation growth has broad implications for surface energy, water and carbon budgets and ecosystem services across multiple scales. . . Our findings reveal that the observed greening record is consistent with an assumption of anthropogenic forcings, where greenhouse gases play a dominant role . . ."

"Where greenhouse gases play a dominant role." In the conclusion to their report the authors state that

> "This study adds to an increasing body of evidence that the NEL has experienced an enhancement of vegetation activity, as reflected by increased trends in vegetation indices, aboveground vegetation biomass, and terrestrial carbon fluxes during the

> satellite era. Our analysis goes beyond previous studies . . . to establish that the trend of strengthened northern vegetation greening is clearly distinguishable from both IV and the IV (internal variability) and the response to natural forcings alone. It can be rigorously attributed, with high statistical confidence, to anthropogenic forcings, particularly to rising concentrations of greenhouse gases." [see: Mao, Jiafu; et al. (2016) **Human-induced greening of the northern extratropical land surface:** *Nature Climate Change*, Vol. 6 (Oct.) pp. 959 – 963]

And the results of yet another study, conducted by a multidisciplinary, international team of scientists was published in 2016 in the journal *Nature, Climate Change.* This research confirms what is becoming apparent to a growing number of researchers around the world concerning the terrestrial effects carbon dioxide enrichment. NASA's website featured an account of the work of this team under the heading "**Carbon Dioxide Fertilization Greening Earth, Study Finds**." The account proceeds to describe the work of the team:

> "From a quarter to half of Earth's vegetated lands has shown significant greening over the last 35 years largely due to rising levels of atmospheric carbon dioxide, according to a new study published in the journal *Nature Climate Change* on April 25. An international team of 32 authors from 24 institutions in eight countries led the effort, which involved using satellite data from NASA's Moderate Resolution Imaging Spectrometer and the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer instruments to help determine the leaf area index, or amount of leaf cover, over the planet's vegetated regions. See NASA's website at https://www.nasa.gov/ feature/ goddard/2016/carbon-dioxide-fertilization-greening-earth

The study involved computer simulations of each variable in turn that could be stimulating the observed greening. The team looked at global temperature change, land cover change, precipitation, sunlight, nitrogen and carbon dioxide. The conclusion reached after extensive analysis was that nitrogen was responsible for 9% of the effect while carbon dioxide contributed a whopping 70%. One of the lead authors of this study was Ranga Myneni whose work was discussed above. Lead author Zaichun Zhu, from Peking University, China, is quoted as saying that the greening "has the ability to fundamentally change the cycling of water and carbon in the climate system." Co-author Shilong Piao of the College of Urban and Environmental Sciences at Peking commented "While our study did not address the connection between greening and carbon storage in plants, other studies have reported an increasing carbon sink on land since the 1980s, which is entirely consistent with the idea of a greening Earth."

In any case the article concludes with a little perspective on the matter:

> "The greening represents an increase in leaves on plants and trees equivalent in area to two times the continental United States."

This incredible phenomenon of planetary greening is of such considerable interest and importance that it is worth referring to the original *Nature Climate Change* paper upon which

NASA based their report for additional insight. In the abstract of that paper the authors describe their procedure and results:

> "Global environmental change is rapidly altering the dynamics of terrestrial vegetation, with consequences for the functioning of the Earth system . . . Yet how global vegetation is responding to the changing environment is not well established. Here we use three long-term satellite leaf area index (LAI) records and ten global ecosystem models to investigate 4 key drivers of LAI trends during 1982-2009. We show a persistent and widespread increase of the growing season integrated LAI (greening) over 25% to 50% of the global vegetated area . . . Factorial simulations with multiple global ecosystem models suggest that CO_2 fertilization effects explain 70% of the observed greening trend, followed by nitrogen deposition (9%), climate change (8%) and land cover change (LCC) (4%). CO_2 fertilization effects explain most of the greening trends in the tropics, whereas climate change resulted in greening of the high latitudes and the Tibetan Plateau." [See: Zhu, Zaichun, et al. (2016) **Greening of the Earth and its drivers**: *Nature Climate Change*, Vol. 6, August, pp. 791 – 796]

By climate change the authors are referring to the global increase in average temperature of about one degree in the past 150 years. The authors conclude their milestone paper with this statement "Overall, the described LAI (leaf area index) trends represent a significant alteration of the productive capacity of terrestrial vegetation through anthropogenic influences."

Let's consider what this statement is saying. The alteration of the productive capacity of terrestrial vegetation is a positive alteration, meaning that it is leading to MORE productive capacity for Earth's vegetation, and this, as they readily admit, is happening as the result of anthropogenic influences. In other words, by consuming fossil fuel and releasing carbon dioxide into the atmosphere we humans are increasing the productive capacity of Earth's vegetation. When confronted with this reality the typical response of environmental ideologues is to shut their eyes and cover their ears, or, to roll their eyes and adopt an air of condescending authority while referring to some totally imaginary scientific consensus and then affecting the hastiest possible retreat from any further informed discussion.

NASA has found itself in somewhat of an awkward position with the results of this study. On the one hand they are subject to pressures emanating from the Executive branch of the U.S. Government, being considered an independent agency within that branch. What might be questionable at this point in time is the genuineness of NASA's independence. Several prominent NASA scientists have been in the forefront of promoting global warming fears and there can be no doubt that for 8 years the Obama administration was pushing global warming orthodoxy as promulgated by the Intergovernmental Panel on Climate Change − Summaries for Policymakers and by powerful, well-funded environmental groups. On the other hand, NASA certainly deserves credit for featuring a report that introduces a critically important dimension into the debate on climate change that is not consistent with the mainstream, government manufactured narrative, the debate that is, again, nowhere near being settled as proclaimed by those factions with political, economic or environmental agendas.

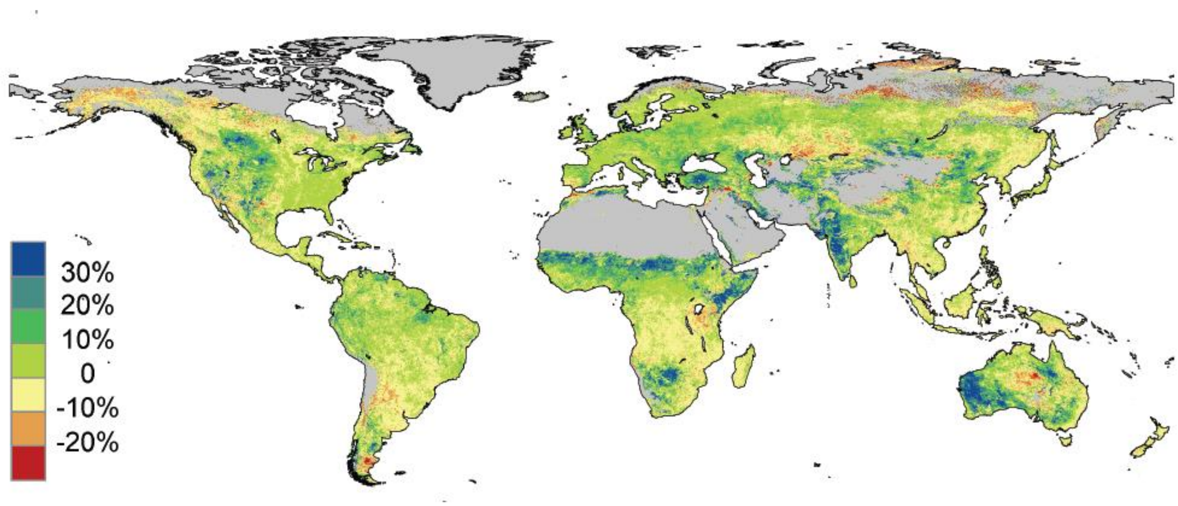


*Figure 10 Global net primary productivity increase as of 2010. The phenomenon of planetary greening has continued unabated since then. Source: CSIRO Australia. "**Deserts 'greening' from rising carbon dioxide: Green foliage boosted across the world's arid regions.**"* Science Daily*, July 8, 2013.*

All of this should lead one to ask: How is it that the promoters of catastrophic anthropogenic greenhouse warming (AGW) never talk about any of the research discussed in this essay?

Is it because it contradicts their narrative? Is it because it demonstrates that whatever may be the projected unfavorable consequences of increased atmospheric carbon dioxide there is unequivocally an upside. I think the answer is obvious.

Those heretics who stray from the hallowed dogmas of climate change, or to use the original term, greenhouse warming, whether they be dissenting scientists, congressmen or women, journalists, independents or others, will face being thoroughly pilloried, slandered, vilified, maligned and denigrated by various eco-fanatics and ideological partisans for simply pointing out that there is a positive side to the increase in carbon dioxide. Several websites exist for the sole or primary purpose of smearing and discrediting climate change heretics and dissenters through guilt by association. (Two of the most execrable examples are DeSmogBlog and "SkepticalScience" both of which subordinate the science of climate change to propagandistic ends.)

But this idea is so contrary to the official interpretation of "climate change" that all of those true believers and promoters of AGW, heavily invested in the belief of a carbon dioxide triggered global climate catastrophe, will avoid by any means necessary the responsibility of confronting facts that do not support their doctrinal narrative. Even a modest open minded scrutiny of mainstream and popular sources of information thoroughly confirms this.

However, one thing is absolutely certain. The world we live in is going to change. It has changed on all meaningful time scales which we are capable of measuring. It is going to continue to undergo a variety of changes no matter what we humans do, no matter what kind of regulations, legislation, taxes, subsidies or carbon remediation schemes are ordained by the high priests of climate change.

Sometimes those changes will be catastrophic.

It is also a fact that human activity is going to play a role in these changes, more pronounced in some areas and less in others. And, it is also a fact that all change requires adjustment and adaptation. This is unavoidable. The picture painted by the research discussed herein on the biological effects of enhanced CO_2 shows that there is an advantage and a benefit to the increase in atmospheric concentrations whatever else may occur as a consequence of a hypothetical and uncertain temperature rise.

In a realistic cost benefit analysis one would ask whether or not, or to what extent, the positive effects counterbalance the negative effects of CO_2 driven temperature increases. We can see that the intensified primary productivity of the biosphere could result in substantial gains in crop productivity, meaning more yield per acre, thus producing more food on less land. This would be an extremely valuable outcome, one the environmentalists should celebrate. In addition, the standing timber supply shows a powerful positive response to CO_2 enrichment. The increased resiliency of plants to environmental stresses such as drought, disease, insect invasion, pollution and so on would be an outcome whose value would be immense.

20 years ago a 1997 report in the *Annual Review of Plant Physiology and Plant Molecular Biology* by 3 plant physiologists summed up the understanding of carbon dioxides known benefits to the plant kingdom by that time quite succinctly. In their abstract the authors state:

> "The primary effect of the response of plants to rising atmospheric CO_2 is to increase resource use efficiency. Elevated CO_2 reduces stomatal conductance and transpiration and improves water use efficiency, and at the same time it stimulates higher rates of photosynthesis and increases light-use efficiency. Acclimation of photosynthesis during long-term exposure to elevated CO_2 reduces key enzymes of the photosynthetic carbon reduction cycle, and this increases nutrient use efficiency. Improved soil-water balance, increased carbon uptake in the shade, greater carbon to nitrogen ratio . . . are all possibilities that have been observed in field studies of the effects of elevated CO_2." Abs.[see: Drake, Bert G., Miqeul A. Gonzalez-Meler & Steve P. Long (1997) **More Efficient Plants: A Consequence of Rising Atmospheric CO_2?**: *Annual Review of Plant Physiology and Plant Molecular Biology,* Vol. 48, pp. 609 – 639]

Drake and Gonzalez-Meler were with the Smithsonian Environmental Research Center and Long was with the John Tabor Laboratories, The Department of Biological and Chemical Sciences, University of Essex, U.K.

Of course, against this astonishing display of positive effects of increasing carbon dioxide must be weighed potentially negative ones. However, it should be kept in mind that the positive effects are the result of hundreds of empirical studies, that is, real world studies on the effects of carbon dioxide on vegetation. Most of the negative consequences of increasing carbon dioxide concentrations at this point are conjectural, based upon projections accruing from computer simulations and are purely hypothetical, such as, for example, the speculated rise in temperature driving an increase in storm and hurricane activity, or an increase in the intensity and duration of drought, or the rising of sea level caused by the melting of Greenland and Antarctic ice sheets.

Each of these assumptions can and should be challenged and tested, not proclaimed and then insulated from all further discussion and debate. It is this effort to shut down debate, by calling anyone who questions the assumptions driving government sponsored computer models, a “climate change denier” that demonstrates there is a fundamental dishonesty involved and a major effort to stifle alternative points of view. Let us be clear: the use of terms like “climate change denier,” “denialist” and so on in response to legitimate questions and criticisms of computer based projections of future climate change is the certain indication that the individual employing such terms is the witting or unwitting purveyor of a fraudulent, manufactured consensus and the subjugation of science in the service of propaganda. The use of such name calling is intended to shut down the necessity of any further discussion or debate.

IN SCIENCE, THE DEBATE IS NEVER SETTLED!

And, especially is it never settled with respect to an issue as complex as climate change. The term “climate change denier” is a blatant absurdity. NO ONE denies that the climate changes. Those who throw this term are literally proclaiming their ignorance of the subject of climate change − or worse − they are revealing their dishonesty since, they are, to a greater or lesser extent, knowledgeable of these matters, but prefer to avoid honest discussion because of a commitment to political or economic agendas.

It is the purpose of this essay to inquire into the relationship between carbon dioxide and Earth’s biosphere and her plant kingdom specifically. Seeking to answer the question of whether or not, or to what extent, the addition of trace amounts of carbon dioxide to the global atmosphere is going to trigger a catastrophic global warming, or any detectable warming at all, or something in between, is not the objective. However, in spite of IPCC projections, it now appears that the global climate is not as sensitive to increased CO_2 concentrations as assumed in the early models that relied on introducing positive feedback processes to amplify the initial effect. On the other hand, as discussed above, the effect of an increase in carbon dioxide concentrations on plant primary productivity has been shown to be complemented by a modest temperature increase.

This is not to say that the role of carbon dioxide in provoking a warming of the global climate is in any way to be demoted from continued study or concern. However – again – the empirical evidence of actual global temperature and the IPCC’s computerized projections continue to diverge to the point that it is fair to question the assumptions regarding the effectiveness of increased CO_2 concentrations on the warming of the global climate. It is in the nature of the absorption of long wave radiation by carbon dioxide that its capacity to capture and re-radiate heat energy is mostly accomplished by the first 100 parts per million atmospheric concentration with diminishing effectiveness beyond that amount. This fact has important consequences regarding the efficacy of increased atmospheric carbon dioxide to actually provoke a significant warming of the global temperature and is a question that needs to be addressed in greater depth. This is not to say that there are not limitations on the benefits, and most likely contraindications of elevated atmospheric carbon dioxide, and these, of course, need to be addressed. Nevertheless, an honest discussion of the consequences of more carbon dioxide in the atmosphere needs to include all dimensions of the problem, and not be limited to only hypothetical negative effects.

The Little Ice Age

There is one more factor relative to the phenomenon of carbon cycling that needs to be addressed in regards to the matter of climate change. It is especially important to understand that the advent of our ability to technologically monitor changes in global temperature on any meaningful scale goes back barely more than a century and coincided with the termination of the Little Ice Age. The Little Ice Age was a period of global cooling that began in the early 14th century, and, with several interruptions, continued into the early and mid-19th century. Its cessation was not everywhere simultaneous, some regions warming earlier than others. It is considered by many paleoclimatologists to have included some of the coldest few centuries of the entire Holocene (the last 11 thousand years or so). The Little Ice Age was a time of glacier expansion worldwide, with many glaciers around the world growing more massive than they had been since the Great Ice Age ended at the beginning of the Holocene. The temporal coincidence between the end of the Little Ice Age, the scientific ability to record and monitor temperature changes on a large scale and the ability to measure atmospheric CO_2 concentrations means that the base line against which the degree of global warming is now being measured just happens to be one of the coldest periods of the entire Holocene. This raises a legitimate question: How much of the temperature rise since the mid-19th century is natural and how much is CO_2 driven? It is typical to plot data on temperature rise during the period from mid-19th century to the present as the dependent variable and plotting the time span on the x-axis only from the end of the LIA to the present, which is going to misleadingly exaggerate the appearance of the y-axis, making the temperature increase look more dramatic than it would appear if graphed with a longer time frame.

Since we have been discussing the positive consequences to vegetation and forest growth resulting from an increase in carbon dioxide concentrations and temperature, it would be valuable, by way of contrast, to look at the vegetation response to global cooling such as occurred during the Little Ice Age.

In November of 1993 *Science News* reported on the work of Ian D. Campbell of Forestry Canada in Alberta and John H. McAndrews, an ecologist and evolutionary biologist from the University of Toronto. These scientists studied how the Little Ice Age affected forests in southern Ontario. They designed a computer program that simulated forest succession over time by documenting the changing pollen record preserved in the soil and were thus able to obtain an estimate of associated changes in the biomass of regional forests. In summarizing the results of their research the authors report that “The biomass declined by 30 percent during the Little Ice Age, indicating that the cooling knocked the region's woodlands far out of equilibrium." [see: Monastersky, Richard (1993) **Minor climate change can unravel a forest**: *Science News*, vol. 144, no. 22 (Nov. 27) p. 359]

It should be noted before proceeding that given the rebranding of the term "global warming" to "climate change" as used in the title of this article could easily be misleading. Since the phrase "climate change" has now been re-defined to mean human driven global warming, unless one goes beyond the headline and reads the article one would not know that it is actually talking about entirely natural global cooling instead. Whether the title of the article was deliberately chosen to mislead I cannot say, but the potential for such deception is certainly obvious.

In any case, the work of Campbell and McAndrews points to a rather disquieting fact: Global cooling is ominously unfavorable to Earth's vegetation. A biomass decline of 30% is disturbing to contemplate. The real question now begging to be asked is this: What would be the comparable effects today of a global cooling similar to the Little Ice Age on the world's croplands and agricultural systems? While one cannot quantify with certainty, there is no doubt that a 30% *decrease* in food crops, similar to the estimated decrease of 30% forest biomass due to the onset of a global cooling cycle, would result in crop failures, major food shortages and subsequent famine. How much worse this would be than a 30 percent *increase* in the yield of food crops resulting from enhanced warming and CO_2 concentrations cannot even be gauged.

If the Little Ice Age could have detectable injurious effects on northern hemisphere forests what kind of effect would the Great Ice Age have? Several studies suggest the response was severe.

In 1997 a study was published in the journal Science on vegetation response to diminished CO_2 availability during the Late Pleistocene. The lead author for the 8 person team was Professor Alayne Street-Perrott with the Tropical Paleoenvironments Research Group at the University of Wales, Swansea. Other authors worked in geology, biogeochemistry, hydrodynamics, sedimentology, geography and radiocarbon dating. [see: Street-Perrott, F. et al. (1997) **Impact of Lower Atmospheric Carbon Dioxide on Tropical Mountain Ecosystems**: *Science*, vol. 278, No. 5342 (Nov. 21) pp. 1422 – 1426] The team examined pollen from piston cores extracted from the bottom of two high altitude lakes in East Africa. One of the things they looked at were changing carbon isotope values in organic matter. These shifts are a reflection of the kind of plants yielding the pollen that settled onto the lake bottoms. As briefly discussed earlier there are two dominant types of plants defined by the particular way they take up carbon dioxide, the C_3 and C_4 plants. C_3 plants constitute most of the global biomass including trees. C_4 plants have apparently evolved in response to environments of low carbon dioxide availability. They have not infrequently been referred to as "weeds." Isotopic analysis of leaf waxes and algal biomarkers were used by the team to reveal the type of plants growing in the nearby environment of the lake and hence to confer the ability to make inferences about the local climate at the time those plants were growing.

The authors summarize the conclusion of their research by stating: "Here we show that changes in the partial pressure of atmospheric CO_2 had a significant impact on tropical mountain ecosystems." Pointing out that concentrations had been reduced to as low as 180 parts per million, they refer to earlier work by others on changing tree line elevations due to presumed temperature changes. In particular they cite the work of geographer J. R. Flenley (1979 **The Late Quaternary vegetational history of the equatorial mountains:** *Progress in Physical Geography*, vol. 3, pp. 488 – 509) on tropical forestation of equatorial mountains. Flenley's conclusions are interesting to say the least. I will let Flenley explain: "Until a few years ago, most people believed that the vegetation of equatorial mountains was essentially stable. . ." However, as it turns out, that is not the case, as Flenley goes on to explain: "Since about 1960 several groups of enthusiasts have produced pollen diagrams purporting to show substantial changes in the vegetation of equatorial mountains during the late Pleistocene. Such diagrams became available for sites in South America, East Africa and New Guinea. Even after the publication of this work, many scientists preferred to remain unconvinced. It was always possible to find a reason why any particular site should be unrepresentative of a larger area."

In other words, many scientists and workers in relevant fields were reluctant to acknowledge the degree of change that was being documented in various environments around the world, preferring instead the comforting belief in the natural stability of ecosystems over time.

But, Flenley goes on to say that "There comes a time in any subject when enough evidence accumulates for a dramatic change in orthodoxy to be appropriate, and I believe now is the time in this case." The results of Flenleys 1979 updating and review of the more extensive evidence then available reveal what many scientists were loath to admit but which has been confirmed by numerous subsequent studies up to the time of Street-Perrott's 1997 paper. Flenley explains:

> "In general, although not in detail, the vegetation found at a given point in the Late Pleistocene was similar to that now found at a higher altitude in the same area. During the period 33,000—30,000 BP, forest limits were lower than at present by at least 700 m and perhaps much more. Between 30,000 and 27,500 BP the limits rose somewhat but then declined again reaching their lowest levels of the last 30,000 years during the period 18,000—15,000 BP, when they lay at least 1000 m and possibly as much as 1700 m below present values."

Up to 1700 m below present values! 1700 meters is almost 5600 feet, more than a mile. In other words, during the coldest part of the last phase of the Great Ice Age, tree lines on tropical mountains were depressed by as much as a mile from the present tree limit. This is an extraordinary fact, with profound implications for any conception of global change. Interestingly, As Flenley also points out, studies show that by around 8000 years ago tree lines had migrated to a somewhat higher elevation than at present, then declined back down to present elevations about 3000 years ago. None of this is in any way characteristic of a stable climate to which this planet can be returned with the implementation of politically contrived regulatory schemes.

Flenley concluded his report with a comment that stands in stark contrast to the prevailing environmental views of 1979 and of 2017: "The pollen diagrams show more or less continuous fluctuation in the composition of vegetation in the last 30,000 years. Even the Holocene forests have existed for only a few tree generations. This argues against the long-held ideas about the stability of equatorial vegetation."

Flenley's declaration that "There comes a time in any subject when enough evidence accumulates for a dramatic change in orthodoxy to be appropriate" is as relevant now as it was then, for as it was in 1979 so it is again, in 2017, time for a dramatic transformation in orthodoxy. The change for which more than ample evidence has accumulated has to do with a deeper understanding of the forces of global change and the realization that change on all scales has been a dominant factor in climatology, geology, biology, and in human history. However, vested interests have intervened in the scientific process to promote an agenda in which anthropogenic forces are now seen as the prevailing driver of global change to the virtual exclusion of natural factors that have been operational on all time scales since the world began. To bolster this agenda carbon dioxide has been portrayed as the purveyor of global doom, for carbon dioxide, being a byproduct of the energy industry that powers our emerging global civilization, provides an effective means to secure control over all aspects of society, industry and the resources of this planet. Add to that the quasi-religious belief on the part of certain environmental factions in an imaginary scenario of a pristine, unchanging world to which balance and harmony would be restored if only the influence of humans could be eliminated and industrial progress curtailed in the name of saving the Earth.

I would suggest that there are two things modern environmentalists fail to realize: First, they fail to comprehend the extent to which planet Earth has been subjected to frequent and brutal assaults as part of a larger cosmic environment, assaults that generate intense global upheavals, extreme environmental and climatological alterations, biospheric disruptions, and mass extinctions that far exceed anything mankind has yet visited upon the planet, and, that these catastrophic disruptions of the planetary natural order occur with alarming frequency. The second thing environmentalists fail to realize is that humankind is an integral part of the natural order, and that by creating a scientifically advanced, technological and industrial civilization on Earth, humans are performing the precise function for which God, Gaia, or Natural Selection − take your pick − created the species *homo sapiens sapiens.*

While Flenley attributed most of the dramatic transformation in forest distribution at the end of the ice age primarily to changing temperature, Street-Perrott et al. see a substantial role for carbon dioxide.

> "We conclude that the glacial-to-interglacial isotopic shift observed in lacustrine algae was driven by natural variations in dissolved CO_2 . . . In agreement with recent model results . . . our isotopic data suggest that glacial-to-interglacial variations in atmospheric pCO_2 had a significant impact on the distribution of tropical rain forests, thus contributing to the decrease in terrestrial biomass at the LGM." (Late Glacial Maximum)

The LGM coincides temporally with Flenley's period from 18,000 to 15,000 years ago when tree lines were depressed up to a mile, or more, from present elevations. This period is considered by most palaeoclimatologists to have been the period of most extreme cold during the final phase of the Wisconsin Ice Age, as it is called in North America. Street-Perrott go on to say that the data they studied "also reveal the existence of severe carbon limitation in high-altitude lakes during glacial times."

Severe carbon dioxide limitation in this case means 180 to 200 parts per million, about 1 molecule out of 10 thousand less than the amount in the atmosphere at the dawn of the 20th century. Since then the atmospheric concentration of carbon dioxide has increased by about one more molecule per 10,000 molecules of air, to where it is now 4 parts out of 10,000.

But think about this. If the atmospheric concentration of CO_2 is diminished by a mere 2 parts out of 10 thousand from where it now stands, it will have extremely detrimental consequences for the biosphere. Photosynthesis of C_3 plants would begin to shut down and this would have grave ramifications all the way to the top of the food chain. On the other hand, increasing the carbon dioxide content by a couple of additional molecules out of 10 thousand of air provokes an almost miraculous response from the plant kingdom.

In fact, plants have such a voracious appetite for carbon dioxide that one might argue at present atmospheric concentrations the global plant realm is actually starved of its most essential nutrient. A number of attempts have been made by global warming true believers to discount this interpretation and all that it implies but their efforts are proving increasingly futile against the tidal wave of new information and the overwhelming evidence unfolding in front of our eyes.

In the same issue of *Scienc*e in which the Street-Perrott et al. article appeared, Graham D. Farquhar with the Research School of Biological Sciences, Australian National University provided a valuable perspective on their work:

> "Street –Perrott and her colleagues have studied the paleoenvironmental history of high-altitude lakes and the surrounding vegetation in East Africa. They examined the lake sediments, the pollen and leaf waxes in them, and the carbon isotope composition of bulk organic matter and of specific biomarkers. They conclude that the increasing concentration of carbon dioxide in the atmosphere since the last glacial period has allowed trees to grow where vegetation was (before 13,000 years ago) restricted to an almost treeless, grassy heathland."
>
> "The findings offer an explanation for a paleoecological puzzle . . . During the glacial times, the trees were being starved of the substrate for photosynthesis. Along these lines, Sage has argued that agriculture became viable at several places around the world . . . only when the CO_2 concentration became sufficiently large to sustain decent yields for our first farmers." [see: Farquhar, Graham D. (1997) **Carbon Dioxide and Vegetation**: *Science*, vol. 278 (Nov. 21) pp. 1411]

Farquhar also provides an important perspective on the increase in water use efficiency.

> "For the individual plant, water-use efficiency is almost directly proportional to the level of CO_2 for a given regime of temperature and humidity. So concentrations of 180 parts per million (ppm) (such as occurred during the LGM), being half the current levels, would mean that plants had to transpire twice as much water then as now to achieve the same level of photosynthesis. Put another way, doubling the CO_2 concentration is almost like doublings the rainfall as far as plant water availability is concerned."

He mentions one other factor that is worth considering:

> "Further, increased greenhouse forcing also speeds up the global hydrological cycle, and so, on average rainfall increases with increasing CO_2 concentrations. Many of the paleo-records indicate arid conditions during the LGM."

Keep this in mind next time you are told in no uncertain terms that drought is going to increase with increased CO_2 concentrations. (Along with storms, hurricanes, mass extinctions, rising seas, disease, more extremes of hot and cold, etc. etc.)

A factor I mentioned earlier has to do with the thermal capture ability of carbon dioxide in the atmosphere relative to the concentration. Farquhar elaborates on this point when he says:

> "Both photosynthesis and the enhanced greenhouse effect are more sensitive to CO_2 levels when the concentrations are low. . . The effects of the 180-ppm increase to the present 360 ppm should be much greater than the effects of going from 360 to 540 ppm, the latter being twice the preindustrial level.

And in the same manner, the incremental thermal capture effects of going from 540 ppm to 720 ppm would be even less. Farquhar points out that:

> "The plants of today are much less water- and CO_2-limited than they were at the LGM. Nevertheless, one suspects that the direction of change in the near future will be the same as that following the LGM, of an increased 'effective rainfall,' with the agricultural and ecological consequences that follow. Given that the availability of water for agriculture is already becoming such a problem, this aspect, at least, of atmospheric change is a welcome one."

One would think. But how often do we hear this discussion in the mainstream media? I don't recall Al Gore discussing any of this in An Inconvenient Truth. To the extent that it IS discussed by proponents of AGW it is only for the purpose of discrediting and dismissing the positive benefits of carbon dioxide enhancement.

In regards to the matter of a deficit of atmospheric CO_2 during the ice age, Rowan F. Sage, mentioned by Farquhar above, with the Department of Botany at the University of Toronto, has developed a thought-provoking hypothesis that makes a great deal of sense given what we now know about the relationship between carbon dioxide and the biosphere. The title of his 1995 paper conveys the crux of his idea: "**Was low atmospheric CO_2 during the Pleistocene a limiting factor for the origin of agriculture?**" He lays out the case for carbon dioxide as the limiting factor in the evolution of agriculture during the late Pleistocene. I will quote extensively from his paper:

> "Agriculture originated independently in many distinct regions at approximately the same time in human history. This synchrony in agricultural origins indicates that a global factor may have controlled the timing of the transition from foraging to food producing economies. The global factor may have been a rise in atmospheric CO_2 from below 200 to near 270 μmol^{-1} (ppm) which occurred between 15,000 and 12,000 years ago. Atmospheric CO_2 directly affects photosynthesis and plant productivity . . . In the late Pleistocene, CO_2 levels near 200 μmol^{-1} may have been too low to support the level of productivity required for successful establishment of agriculture. Recent studies demonstrate that atmospheric CO_2 increase from 200 to 270 $\mu mol\ mol^{-1}$ stimulates photosynthesis and biomass productivity of C_3 plants by 25% to 50%, and greatly increases the performance of C_3 plants relative to weedy C_4 competitors. Rising CO_2 also stimulates biological fixation and enhances the capacity of plants to obtain limiting resources such as water and mineral nutrients. These results indicate that increases in productivity following the late Pleistocene rise in CO_2 may have been substantial enough to have affected subsistence patterns in ways that promoted the development of agriculture. Increasing CO_2 may have simply removed a productivity barrier to successful domestication and cultivation of plants." [see: Sage, Rowan F. (1995) **Was low atmospheric CO_2 during the Pleistocene a limiting factor for the origin of agriculture?** *Global Change Biology*, vol 1, pp. 93 – 106]

Sage points out that "An outstanding feature of the origin of agriculture is that it occurred independently in distinct cultural regions around the world at approximately the same time in human history." He then points out another extremely interesting statistic: "Assuming *Homo sapiens sapiens* appeared in Africa between 200 and 150 ka, (thousand yrs ago) the period of initial domestication between 11 and 6 ka represents approximately 3% of the time modern humans have occupied the planet." History, I might add, dating from the rise of Sumer 3000 BC, is barely 2% of the time of modern humans on Earth.

Sage then articulates an inescapable conclusion: "Synchrony in the independent occurrence of identical biological or cultural phenomenon implicates a common environmental catalyst: however, no such factor has been satisfactorily identified for the origin of agriculture." As Sage sees it the common environmental catalyst was the global rise in carbon dioxide that occurred at the end of the Great Ice Age. As he further explains:

> "Even in regions favorable to agriculture during the Pleistocene, poor stress tolerance of plants as a result of low CO_2 could have caused the frequency of crop failure to be too high. . . By increasing productivity, the end-Pleistocene rise in CO_2 could have led to greater crop density, thus allowing a surplus of food to be gathered with much less effort. Increased surplus would have compensated for poor harvest years, while improved stress tolerance and soil fertility would have reduced the frequency of crop failure. With

increased stability in the food supply, a continuity of agrarian experience between generations could have become established. . ."

After 4 or 5 millennia of such continuity the groundwork had been laid for the rise of civilization and the commencement of history and thus it blossomed in the Fertile Crescent.

But it must be emphasized that what has been confirmed in the past 22 years since the publication of Sage's paper is that the end of the Pleistocene was overwhelmingly catastrophic on multiple fronts. Whatever successful social adaptations to Pleistocene conditions may have evolved prior to terminal events, they may be difficult or even impossible to detect because of the widespread environmental destruction that accompanied the planetary shift out of the ice age into the early Holocene. For example, pervasive utilization of marine resources was a probable response to late glacial conditions, meaning that social and cultural groups would have occupied coastal areas that are now under 300 to 400 feet of ocean water. Too many modern academics in fields of ancient history and prehistory are too quick to dismiss the possibility of relatively sophisticated cultural adaptations to late ice age environments, primarily due to their failure to appreciate how profound and far reaching were the environmental changes accompanying the shift to the present interglacial period, changes that can, without exaggeration, be described as globally catastrophic. The synchronous rise in agriculture, of which Sage speaks, may be the consequence not only of the rise in CO_2 levels but also the post-catastrophe reestablishment of human population to numbers sufficient to undertake agriculture on a scale capable of leaving a discernable trace in the archaeological record.

As an interesting aside, in traditional and archaic traditions in which long range time is reckoned by the changing of the astronomical ages as marked by the passage of the vernal equinox through the constellations of the zodiacal wheel, Flenley's period of deepest cold and severe carbon dioxide limitation from ca. 18,000 to 15,000 years before present would have occurred during the "Age of Scorpio." Traditionally, Scorpio is the sign of death, which, somehow in this case, seems symbolically appropriate. It is entirely possible that during such a time the effort to merely survive may have been the dominant activity in which most humans were engaged.

Optimum Carbon Dioxide?

So let us now pose this question: What IS the right, perfect and optimum atmospheric carbon dioxide concentration for the global atmosphere? According to one faction it absolutely can't be over 350 parts per million. That's about what it was for a while during the middle of the 20th century. Prior to that, back in the 19th century it was lower, about 280 parts per million, had stayed pretty steady at this concentration for millennia, and had not been significantly altered until humans began consuming fossil fuel.

At least that is the currently accepted version of the matter.

To demonstrate the stability of the atmospheric carbon pool climatologists rely primarily on data from ice core proxies, which generally, although with some important exceptions, show roughly that concentrations remained more or less steady through time, at least over a couple of hundred thousand years. But, it must be mentioned here, without elaboration at this time, that a number of glaciologists have challenged the accuracy of ice core data, pointing out that there are many factors which can skew the results and that the concentration of carbon dioxide found in an ancient air bubble that was extracted from ice buried hundreds to thousands of feet down core in the glacier, stored for thousands of years under conditions of extreme pressure, is not necessarily an accurate representation of the entire planetary average of atmospheric carbon dioxide at the time the snow originally fell in that one particular place. If it did, by chance, turn out that there were significant inaccuracies in the ice core data as to ancient atmospheric CO_2 concentrations it would render all of the elaborate computer models of the IPCC meaningless. But that is a discussion for another place.

In regards to the appropriate concentration it all depends on what time period one is referring to. It should be pointed out that the amount of carbon dioxide in the atmosphere has been steadily declining through geological time. The work of geoscientists Mark Pagani and colleagues has demonstrated this phenomenon. This group, affiliated with Department of Geology and Geophysics, Yale University, the Earth Sciences Department at the University of California and the Department of Geosciences, Penn. State University, studied deep sea cores to ascertain ancient climate patterns. They specifically looked at sedimentary organic molecules called alkenones that are produced by certain species of algae. By studying the stable carbon isotopic compositions of these alkenones they are able to measure the CO_2 concentrations of the paleoatmosphere. For more on their methodology see [Pagani, Mark, et al. (2005) **Marked Decline in Atmospheric Carbon Dioxide Concentrations During the Paleogene**: *Science*, vol. 309 (22 July) pp. 600 – 603]

They describe the prevalent view of global climate change since early in the Eocene over 50 million years ago:

> "The early Eocene [~52 to 55 million years ago] climate was the warmest of the past 65 million years. Mean annual continental temperatures were considerably elevated relative to those of today, and high latitudes were ice-free, with polar winter temperatures ~10°C warmer than at present. After this climatic optimum, surface- and bottom- water temperatures steadily cooled over ~20 million of years . . . High-latitude cooling eventually sustained small Antarctic ice sheets by the late Eocene culminating in a striking climate shift across the Eocene/Oligocene boundary (E/O) at 33.7 Ma. The E/O climate transition, Earth's first clear step into "icehouse" conditions during the Cenozoic, is associated with a rapid expansion of large continental ice sheets on Antarctica in less than ~350,000 years."

In reference to ancient atmospheric carbon dioxide concentrations the author's state:

> "Changes in the partial pressure of atmospheric carbon dioxide (pCO_2) are largely credited for the evolution of global climates during the Cenozoic. However, the relation between pCO_2 and the extraordinary climate history of the Paleogene is poorly constrained."

The authors point out that various investigations have yielded conflicting results as far as tracking the relationship between changing carbon dioxide levels and changing global climate. They emphasize that "this deficiency in our understanding of the history of pCO_2 is critical, because the role of CO_2 in forcing long-term climate change during some intervals of Earth's history is equivocal." As an example they cite the Miocene Epoch, which lasted from about 25 to about 5 million years ago, in which there seemed to be no correlation between CO_2 and climate change, what they call a "decoupling." Pagani et al. point out the obvious when they state: "Clearly, a more complete understanding of the relation between pCO_2 and climate change requires the extension of paleo-pCO_2 records back into periods when Earth was substantially warmer and ice-free." In regards to the amount of CO_2 in the atmosphere back then they state:

> "On a broad scale, our results indicate that CO_2 concentrations during the middle to late Eocene ranged between 1000 and 1500 parts per million by volume (ppmv) and then rapidly decreased during the Oligocene, reaching modern levels by the latest Oligocene. In detail, a trend toward lower CO_2 concentrations is evident from the middle to late Eocene, reaching levels by the E/O boundary that could have triggered the rapid expansion of ice on east Antarctica."

1500 parts per million is almost 4 times higher than the present concentration. The following graph from Pagani et al. shows the trends in carbon dioxide levels up to the end of the Miocene (5.33 million years ago) and temperature from the early Eocene Epoch through to the present in the graph of oxygen isotope changes.

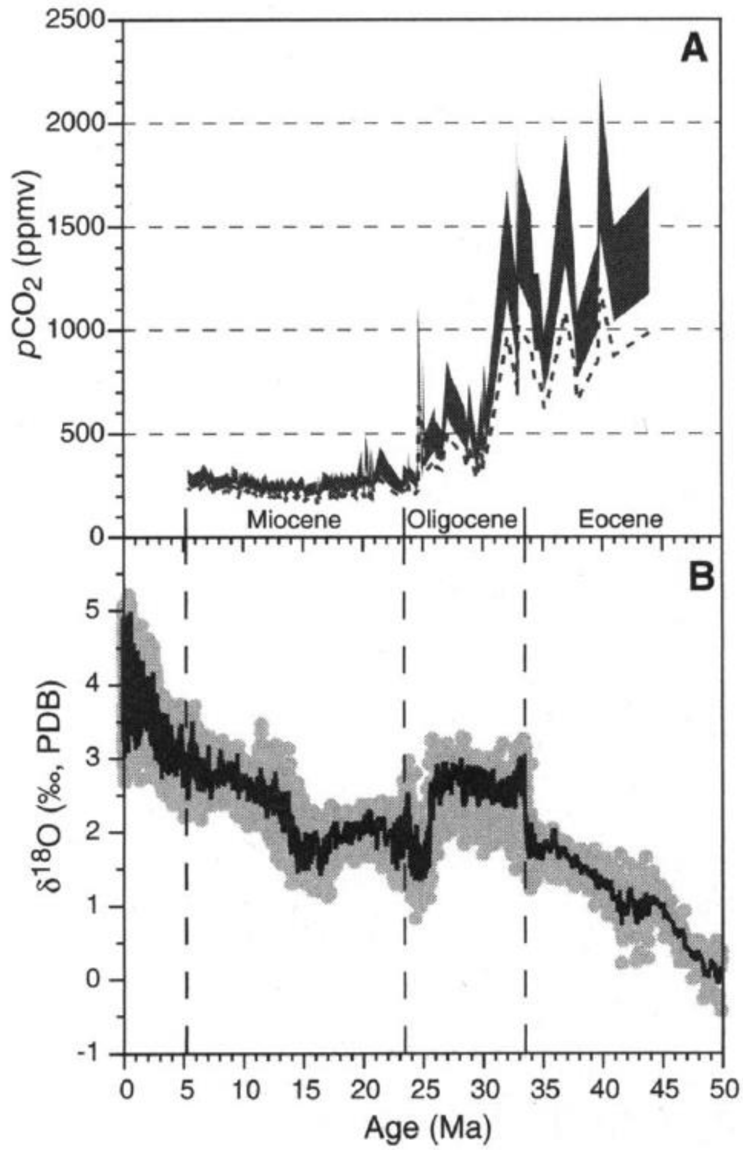
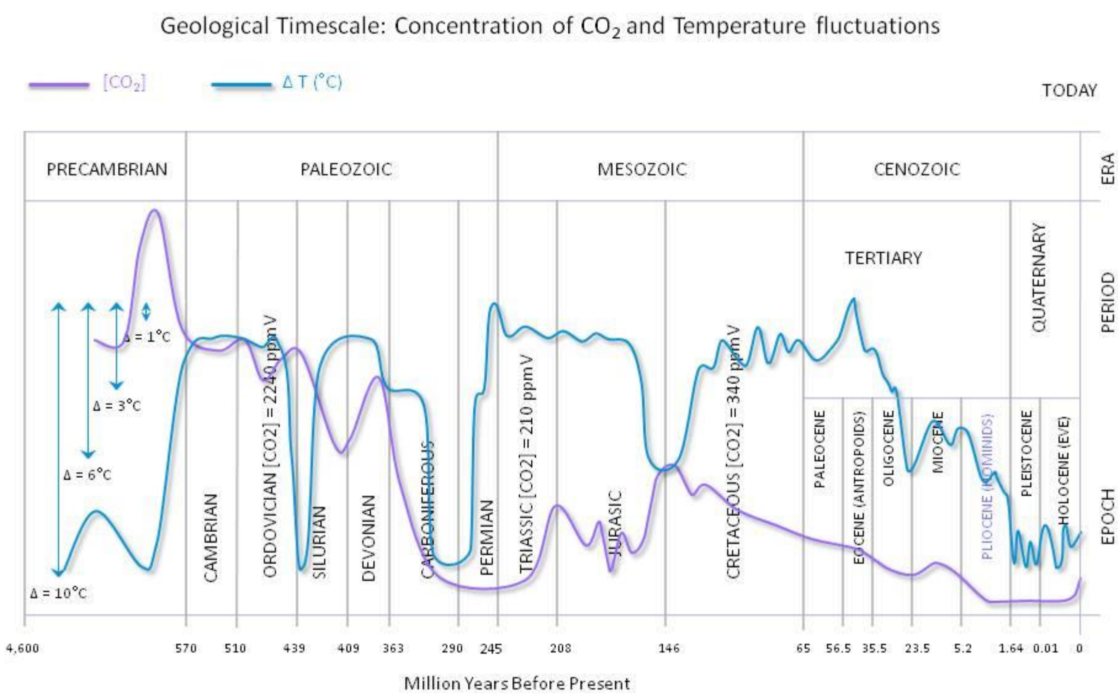


Figure 11. A. The decline in atmospheric CO2 since early Eocene times to the Pliocene Epoch in ppm. B. Oxygen isotope record of changing oceanic temperature from early Eocene to the present. The oxygen isotope record shifts up from right to left as the temperature cools. After Pagani et al. p.602

Shifts in oxygen isotope ratios track temperature changes. These shifts can be determined by studying the composition of the shells of sea creatures, in this case benthic foraminifera. Foraminifera are a type of amoeboid protist that forms shells from calcium carbonate in the ocean water. The shells preserve the ratio of the stable isotopes of Oxygen-16 and Oxygen-18 that are present in the ocean at the time the shells form. The ratio of these isotopes preserved in the shell is dependent upon the temperature of the ocean water. When the forams die their shells become part of the sea bed and eventually part of the great masses of limestone rock found all over the world. In addition it is known that the various species of forams inhabit different temperature regimes in the ocean, so when examining sea bed cores the changes in foram species track changes in environments based upon the changing temperature of the ocean water. This property of foram species can be used to independently corroborate the temperature changes indicated by the changing O18/O16 ratio.

Since the ratio of O_{18}/O_{16} changes with temperature much information about palaeoclimate can be inferred by studying these changes through time. When the amount of O_{18} increases relative to the amount of O_{16} it implies a cooling of the ambient temperature. As long ago as 1953, S. Epstein, Harold C. Urey and colleagues were able to determine that an increase of 0.22% of O_{18} relative to O_{16} translated into an equivalent cooling of 1°C. (1.8°F). In the graph above from Pagani et al. one can see that the O_{18} has generally been increasing relative to O_{16}, though with some interruptions, through the last 50 million years, corresponding to a progressive cooling of the global climate. One can also see that there were enormous swings in carbon dioxide and the atmospheric decline seems to have proceeded in a stepwise manner. We can clearly see near the terminal point of the oxygen isotope graph there is a major signal in the isotopic ratios correlating with the inception of glacial-interglacial cycles about 2.6 million years ago and the transition from the Pliocene to the Pleistocene Epochs.

The following graph provides a coherent image of the status of atmospheric carbon dioxide throughout Earth history. One thing that becomes apparent upon studying the graph is that CO_2 concentrations and temperature do not track. Sources for the graph are as listed in the caption. [See also Nasif Nahle. **Cycles of Global Climate Change**." *Biology Cabinet Journal Online*, July 2009.]



1- *Analysis of the Temperature Oscillations in Geological Eras* by Dr. C. R. Scotese © *2002*. 2- Ruddiman, W. F. 2001. *Earth's Climate: past and future*. W. H. Freeman & Sons. New York, NY. 3- Mark Pagani *et all*. *Marked Decline in Atmospheric Carbon Dioxide Concentrations During the Paleocene*. Science; Vol. 309, No. 5734; pp. 600-603. 22 July 2005. *Conclusion and Interpretation* by Nasif Nahle ©2005, 2007.

Another thing becomes apparent from studying this graph. Throughout the Pleistocene Epoch on Earth, the period encompassing the past 2.6 million years of ongoing glacial ages, carbon dioxide concentrations have been at their lowest in all of Earth history since Precambrian times. Only since the end of the great ice age 11 to 12 thousand years ago did concentrations begin to rise from their depressed Pleistocene state and only within the past century have they risen to more normal amounts when looked upon within the larger context of Earth history.

The information presented here inexorably leads one to surmise that the amount of carbon dioxide in the Earth's atmosphere has been preternaturally low throughout the Pleistocene, and, that by releasing a small but significant amount into the global atmosphere we human beings are stimulating a revival of an impaired biosphere, an impairment resulting from a planetary disruption occurring some 2.6 million years ago that initiated the cycle of increasingly erratic climatic and environmental behavior which has continued to manifest as the repetitive lurching into and out of glacial ages.

Two years after the publication of Pagani et al. the journal *New Phytologist* published a paper by Lewis H. Ziska and James A. Bunch, both research plant physiologists with the U. S. Department of Agriculture. These authors provide a valuable perspective on the matter of changing atmospheric CO_2 concentrations:

> "Although terrestrial plants evolved at a time of high atmospheric CO_2 (4-5 times present values), concentrations appear to have declined to relatively low values during the last 25—30 million yr. However, records of atmospheric CO_2 concentration beginning in the late 1950s on Mauna Loa provide proof that the global atmospheric concentration of CO_2 was increasing. These recent increases, and the projected concentrations of atmospheric CO_2 . . . by the end of the century, therefore represent an upsurge of an essential resource, exceeding anything plants have experienced since the late Tertiary. [see: Ziska, Lewis H. & James A. Bunce (2007) **Predicting the impact of changing CO_2 on crop yields: some thoughts on food**: *New Phytologist*, vol. 175, pp. 607 – 618]

Note that, once again, we have scientists observing the effects of carbon dioxide enrichment and describing it as a benefit, "an upsurge in an essential resource." Here it is − the reality that AGW devotees and partisan factions deny − carbon dioxide is an "essential resource" not a pollutant!

In their final thoughts the author's state:

> "Given a current population of more than six billion with a projected increase of an additional billion every 12 yr, being able to reliably predict the impact of changing CO_2/climate on global crop productivity certainly should be 'food for thought' for scientists and policy makers."

"Food for thought" indeed. It is exceedingly difficult for scientists engaged in this research to come forward to elaborate on the benefits of rising carbon dioxide, as has been demonstrated by the treatment of researchers like Sherwood Idso, Willie Soon, Judith Curry, Richard Lindzen and many others who have been outspoken, as well as the fact that grant money is tied to global warming orthodoxy and the notion that carbon dioxide is a pollutant that must be regulated. One should take note of the fact that within the last year alone the Obama administration has transferred 1 billion dollars of American taxpayer's money to the Green Climate Fund. To see how this compares with money contributed by the oil and gas industry to global warming critics and dissenters see my comprehensive review "Who Are the Real Climate Change Deniers." I am sure that some of the work of the GCF is valuable. However, to think that the enormous amounts of money flowing into the coffers of various "green" groups and industries, now amounting to billions annually, does not play a role in determining suppositions about climate change is exceptionally naive. The homepage of the GCF states "Climate change is the defining challenge of our time. The human impact on our planet is unprecedented. . . Given the urgency and seriousness of the challenge, the Fund is mandated to make an ambitious contribution to the united global response to climate change."

Here I must make a comment to provide a context for the statement that the human impact on our planet is unprecedented. Of course it is unprecedented, unless, that is, there was a time when global human population stood at some 7 billion, comparable to today, which I am not in any way suggesting. Compared to the impact of previous generations of humans on the Earth of course the impact of 7 billion is going to be unprecedented. But when compared with the impacts of natural forces upon the Earth over time the imprint of humankind could prove to be rather ephemeral.

If we consider why the human population has never been as great as the present we are lead directly to the realization that for most of the time that modern *homo sapiens sapiens* has occupied this planet, the Earth has been in the grip of the brutal cold of an ice age. We know from recent history that times of global cooling have been detrimental to human population growth and times of global warming have been conducive to population expansion and social advancement. (I will have much more to say about this in another essay.) Given what we have discussed about the ineffectiveness of agriculture in a low carbon environment we can begin to understand the natural constraints imposed on human population growth. What this remark by the Green Climate Fund ignores, and that I have been opining on for years, is the reality of catastrophic NATURAL climate change that has occurred over and over and over again. Let us be clear: in the quote above from the GCF, when the website states that climate change is the defining challenge of our time, they are referring exclusively to anthropogenic climate change. There is no place in their discussion for purely natural change. And when they talk about a "united global response to climate change" they are referring to the complete control of energy from production, through distribution to consumption, with every step in the process of energy utilization heavily regulated, taxed and limited by governments, bureaucracies and self-serving political factions. Such a response system if ever implemented would be the ultimate tool of absolute social control and it will have little to no effect on climate change whatsoever. There is no way that, in this context, a "united global response" could mean anything other than a totalitarian system of social control, whose only affect will be to leave human civilization unprepared and unable to cope with natural climate change.

In any case, the perspective one ought to derive from all this is that the determination of what constitutes the natural, correct, appropriate, or optimum amount of carbon dioxide in the atmosphere depends upon whether you take the long view or the short view. As demonstrated, evidence suggests that at the time huge ice sheets began to claim large swaths of the Earth's surface carbon dioxide levels were considerably lower than earlier times of climatic optimum when the poles were ice free, and, looking back across the paleoclimate record since that time, sometimes it appears that carbon dioxide levels and global temperature were tracking and others times not.

But before proceeding further, I must add a detail in regards to what Pagani and colleagues referred to as "a striking climate shift across the Eocene/Oligocene boundary." This time interval between 33 and 34 million years ago was one of tremendous global change and upheaval. In addition to climatic changes there were sudden and rapid mass extinctions across the boundary, vast geomorphic and biotic changes and what is probably most significant is that there were at least two large scale cosmic impacts now documented, and probably other smaller impacts, onto the Earth during this time. It may, in fact, have been a period of intensified asteroid or comet bombardment that initially triggered the "striking climate shift" and pushed the evolution of the planetary environment in a new direction, leading into "the extraordinary climate history of the Paleogene" and a steady trend toward long term climate cooling, finally culminating in the onset of the great glacial-interglacial cycles that marked the onset of the Pleistocene Epoch 2.6 million years ago, the epoch which we have, supposedly, been out of only for the last 10 thousand years. I will take up the role of great impacts in the history of the Earth in another essay, for now note that there are two massive impact craters associated with the late Eocene/early Oligocene transition, one in Siberia and one under Chesapeake Bay, USA, proof that Earth suffered a major cosmic double punch at the termination of the Eocene. Additional evidence is now overwhelming that since those times Earth has suffered dozens to hundreds of major cosmic impacts, each of which would have had significant effects on the global environment and climate.

Is Climate Change Becoming More Severe?

Most climatologists are in agreement that the global climate has warmed somewhere around a degree Fahrenheit since the middle of the 19th century and the easing of the Little Ice Age. Actually the IPCC placed the warming at about .85 degree Celsius. However, and this is a fact: one degree of warming, or even 2 degrees, is well within the range of natural variability, as measured over decades, through centuries and up to millennia, and there is no way of determining that the warming of the last century is not entirely natural, or if not, to what extent it is natural vs anthropogenic. It is also accepted by computer modelers working for the IPCC (Intergovernmental Panel on Climate Change) that the relatively miniscule increase of carbon dioxide in the global atmosphere by the burning of fossil fuels alone is not enough to initiate catastrophic warming, so the modelers amplify the effect by introducing positive feedbacks primarily in the form of water vapor. But the reality of such amplification is by no means certain either. In another essay I will address the larger context of changing global temperatures through time, a perspective whose absence from the discussion precludes any meaningful comprehension of modern climate variability.

The assertion that we are seeing increased severity and frequency of storms, hurricanes, inclement weather, drought, and all the other things that are now being blamed upon or linked to "climate change," meaning anthropogenic greenhouse warming, is contradicted by proxy records, the historical record and our own direct experience of the last century. There is no evidence, for example, that the severity, intensity or frequency of hurricanes have increased commensurate with rising CO_2 concentrations. Likewise with droughts, storms in general, or any other extreme weather or climate events. Yet the claim is regularly made and then propagated by mainstream media, as if it was a given, that all of this is happening right now to an intensified degree and somehow the claims are never accompanied by any verifiable supporting data or evidence. (See here for a tabulation of some of the extreme environmental and climate phenomenon occurring during several centuries before significant increases in atmospheric CO_2) Sea level rise over the last century, about 6 to 8 inches, has proceeded at the same pace that it did the previous century, before humans were burning fossil fuels. Glaciers have been receding rather steadily since the end of the Little Ice Age in the early to mid-19th century, again, since before humans were burning fossil fuels or contributing meaningfully to the atmospheric carbon pool. In upcoming essays I shall examine some of these questions about increasing climate severity in greater depth in another essay.

Concluding Remarks and Thoughts for the Future

To bring this little treatise on the relationship between the planetary biosphere and carbon dioxide to a close I will refer back to the work of Rogers and Dahlman, authors of **Crop responses to CO_2 enrichment** from which I quoted earlier. Reiterating the words of these authors, the two factors absolutely essential for proper function of vital plant processes are photosynthetic activity and water use, both which are enhanced in a carbon dioxide enriched environment, and, most importantly, as far as the human perspective is concerned, they say, "The proper function of these two vital plant processes can spell the difference between feast and famine," a circumstance that ought to be pondered deeply by those with a vested interest in the future.

"The difference between feast and famine."

Adequate food and water are two of the most critical issues facing a large portion of the human race. With Earth's population approaching 10 billion within two generations an increase of 30% in the global food supply could spell the difference between successfully avoiding mass starvation and extreme famine. It should be borne in mind that famine often precedes the outbreak of widespread epidemics due to malnourishment compromising human immune systems. Widespread hunger could be the factor that kindles the global pandemic that so concerns some medical professionals. To some eco-fanatics a major depopulation might be construed as a good thing. On the other hand it need not happen and there is no doubt whatsoever that the human species can learn to live in harmony with the Earth.

Feast or famine?

Is it possible that the outcome of these two strikingly different scenarios for the future might be significantly affected by the addition of a bit more carbon dioxide to the global atmosphere?

Is it possible that the reclamation of now arid and desolate regions of the planet might become a reality by the addition of a bit more carbon dioxide to the global atmosphere?

Is it possible that the range of Earth's vegetation canopy has been at its geographical limit under ambient concentrations of carbon dioxide and that its range is now expanding with increased availability of CO_2?

Is it possible that the cycle of glacial ages gripping the Earth for the past 2 ½ million years has caused the accelerated siphoning and sequestration of the global atmospheric carbon dioxide budget through intensified weathering, locking away vast amounts of it into the ocean floor and ultimately Earth's crust and, thereby, contributing to a self-perpetuating, negative feedback, amplification of global cooling?

Is it possible that through releasing a tiny fraction of the huge amount of stored carbon dioxide the intensity of glacial-interglacial transitions might be ameliorated to some extent?

Is it possible that some agency, at this point unidentified, effected a major environmental downturn at the dawn of the Quaternary some 2.6 million years ago, an event from which the Earth has never fully recovered, and that now, by releasing a tiny fraction of sequestered carbon dioxide, we humans, are providing terrestrial nature with the very remedy she requires to return to her full glory?

These are all legitimate questions to ask, questions we must not be deterred from asking because they go against the agendas of certain political factions, factions who, if their policies come to pass, would drive human civilization back to the Dark Ages.

What is needed is an honest accounting of the true social cost of carbon. One that recognizes that there is a direct benefit as well as a cost. What is also needed is research uncontaminated by political agendas. And, the inclusion of the study of NATURAL climate change – another 800 pound gorilla in the room, what Hermann Flohn, one of the founding fathers of modern climatology, called the Sword of Damocles suspended above the Earth.

I am not here arguing that all is rosy with continued rise in atmospheric carbon dioxide. There will be negatives and limitations, as with any change or any course of action. The use of fossil fuels needs to be superseded at some point for sure. But it has become clear that the case for imminent carbon dioxide fueled catastrophe is being overstated, and this for political and economic reasons. There are some very interesting possibilities on the horizon as far as alternatives to fossil fuel are concerned, but the irony is that to get there from here and to make the conversion is going to require a major expenditure of energy, energy available now and in the near future in the form of fossil fuels. That is why it is critically important that our extraction and consumption of energy from the vault of Nature be directed to the highest and best use in the meantime.

Here we come to what I think is the first and most glaringly obvious first step in getting our human act together on planet Earth: The abolition of war, which, in its preparation and execution consumes extreme amounts of energy, more in aggregate than any other human activity, and, in its aftermath, continues consuming large amounts of energy in the reconstruction and repair of destroyed infrastructure that already consumed energy in its creation and to which must be added the wasting of human capital and destroyed lives. The abolition of war would be the ultimate environmental and social conservation measure that we humans could realize, short of protecting the Earth from the next cosmic encounter. Beyond that, conservation and prudent use of all resources are manifestly very good things. How ironic that the environmental movement, generally composed of partisans of the Neoliberal left, supports a Democratic Party that has continued to encourage and promote the endless interventions and wars that squander our resources and trample on our liberties.

Secondly, an unleashing of the creative, entrepreneurial, inventive spirit that was once the primary animating force of the great enterprise called America will be the essential and indispensable prerequisite for achieving the conversion to a post-carbon future. This will come about as a natural consequence of the restoration of freedom, in spirit and in fact, freedom which is now being progressively and continuously abridged, degraded and stifled by the disproportionate growth of political, governmental and corporate bodies that consume ever greater amounts of our planet's natural capital in the commission of unproductive, counterproductive and destructive activities.

And we need debate. Lots of debate. Not "the science is settled, the debate is over" cop out of misanthropic neo-luddite eco-fanatics or the self-serving promoters of greenhouse warming doom. These misguided individuals would, in the implementation of their agenda, render the Earth vulnerable to the next cosmic encounter that will disrupt the balance of nature far beyond the meagre influence of human beings. And if you think that this idea is far-fetched, or belongs in the realm of science fiction, well, all I can say is that you haven't been paying attention. The scars of uncountable cosmic catastrophes are all around us, but few of us have eyes to see; the agents of these cosmic catastrophes are profusely abundant in our celestial neighborhood and are now showing themselves with disconcerting frequency. Evidence of the real threat to the environment of this planet is preserved beneath our feet and displayed over our heads, it is undeniable and it is there for all to see. But billions of dollars are being spent every year to create the illusion that human activities are destroying the Earth and too many people are falling for the computerized smoke and mirrors and statistical sleight of hand that has transformed a precious, life-sustaining trace gas into a ghastly demon of planetary destruction that can only be subdued by totalitarian control of society and a massive wealth transfer into the hands of government and vested interests.

So, in light of all of the foregoing, I am compelled to ask this question: Could it possibly be that the reality of the matter is the complete opposite of what we have been told now for almost 3 decades by the promoters of greenhouse doom – the self-serving political and economic partisans, and the fanatical environmentalists who obsess over a slight increase in a vital trace gas and believe that planetary salvation requires terminating industrial civilization?

On the other hand the conclusion has become unavoidable that by releasing a few hundred gigatons of the more than 100 million gigatons of carbon dioxide locked away in the rocks of this planet, we are literally stimulating a greening of the Earth and stimulating enough gentle warming to help nudge the planet out of the Little Ice Age, results completely unanticipated at the commencement of the fossil fuel age.

Meanwhile, to borrow Hermann Flohn's metaphor, there IS a Sword of Damocles that threatens the Earth, but our fixation on this life-giving trace gas as the agent of doom diverts our attention from the cosmic beast who lurks in the great deep, the beast that our ancestors knew all too well, and whose progeny hovers just outside the range of our perception in the realm of Uoroboros.

ΑΠΟΚΑΛΥΨΙΣ *Revelation 13 : 18*

Ωδϵ ἡ σοφία ϵ́στίν ὁ ἕχων νοῦν ψηφισάτω τὸν αρθμὸν τοῦ θηρίου· ἀριθμὸς γὰρ ἀνθρώπου ἐστίν. καὶ ὁ ἀριθμὸς αὐτοῦ ἑξαλόσιοι ἑξήκοντα ἕξ.

21st Century Translation: Here is Wisdom: Let him who hath understanding reckon the number of the Beast, for it is the number of carbon based life.

For convenience a list of all sources and references quoted or cited in this essay is appended.

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