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Carbon Dioxide: The Gas of Life

Tiny amounts of this miracle molecule make life on Earth possible

A *Special Report* for the Committee For A Constructive Tomorrow

By Paul Driessen

PROSPERING LIVES • PROMOTING PROGRESS • PROTECTING THE EARTH • PROVIDING EDUCATION

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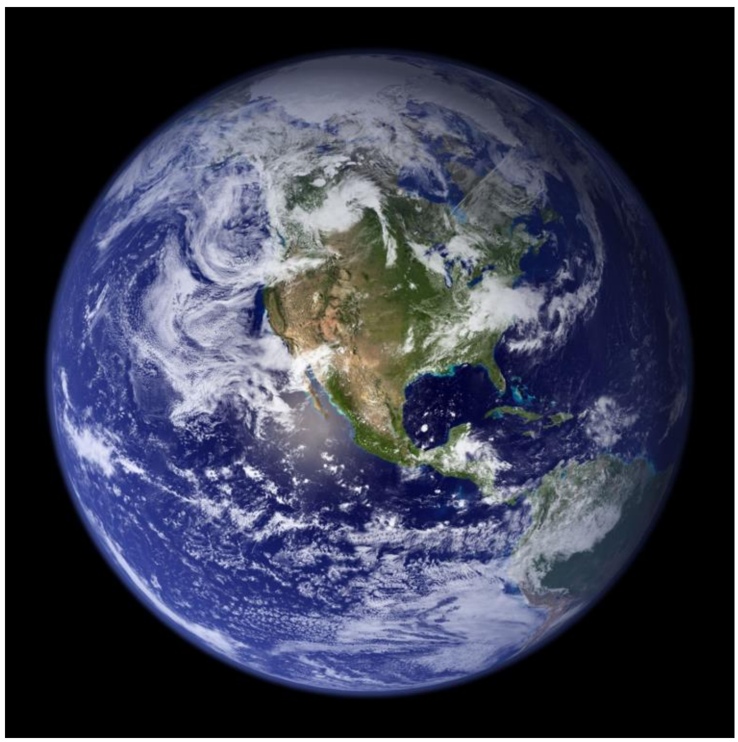
Not many years ago, an infection from a puncture wound, tooth extraction or spoiled food was often an agonizing death sentence. At the very least, it could mean an amputated limb – and before ether and other anesthetics, about all you could get to dull the pain was a slug of whiskey or a leather strap to bite down on. The discovery of penicillin and other antibiotics saved countless millions of lives.

The Salk vaccine eradicated polio in most of the developed world, and Edward Jenner's pioneering work launched medical advances that ultimately eliminated smallpox worldwide. Today, Artemisinin-based drugs are saving millions from horrible agony, brain damage and death from malaria.

It is truly miraculous that tiny doses of these medicines can purge the body of deadly infections, ease pain or protect people against diseases that once devastated entire families, communities and nations. In a similar way, minuscule amounts of vitamins, minerals and trace elements (like selenium) in our bodies enable our brains and metabolisms to function properly, or safeguard us against diseases and allergens, and against contaminants that volcanoes, deep sea vents, rock erosion and forest fires have been releasing into our air and water since the Earth was formed.

Similarly, at the planetary level, carbon dioxide (CO_2) is truly a miracle molecule for plants.



In units of volume, its concentration is often presented as parts per million: 400 ppmv, or simply 400 ppm. That's the almost infinitesimal amount of carbon dioxide our Earth now has in its atmosphere.

Even more amazing, *400 ppm* is an increase of about 120 ppm since 1800 – a time when many scientists say plants were comparatively starved for carbon dioxide. That's when our planet began to emerge from the Little Ice Age that had cooled the Earth and driven Viking settlers out of Greenland. As the oceans warmed, they began releasing some of carbon dioxide that is stored in their water, just as a warm bottle of beer or soda starts bubbling away its CO_2. At the same time, the Industrial Revolution and growing human populations began burning more wood and fossil fuels, adding still more CO_2 to the atmosphere.

Little by little, atmospheric carbon dioxide concentrations rose to where they are today.

Put another way, carbon dioxide now makes up just 400 molecules out of every million molecules of gases in Earth's atmosphere. The other main components are nitrogen at 78.08% (780,800 ppm); oxygen at 20.95% (209,500 ppm); argon at 0.93% (9,300 ppm); and water vapor at 0.25% (2,500 ppm, on average globally, although water vapor's concentration varies from a tiny 10 ppm in the coldest parts of the Arctic and Antarctic, to as much 5% or 5,000 ppm in hot, humid air masses).

In more everyday language, the 400 ppm of carbon dioxide now in our Earth's atmosphere is 0.04 percent – the equivalent of 40 cents out of one thousand dollars, or 1.4 inches on a football field. That's an incredibly small amount. (The atmosphere's oxygen concentration is equivalent to 21 yards of a football field.) And the 120 ppm increase between 1800 and 2013 is equivalent to 12 cents out of $1,000, or a half-inch on a football field.

However, like the proverbial size of the fight in a dog, this Lilliputian amount of CO_2 makes all life on earth possible – including our own. Carbon dioxide is truly the "gas of life," a miracle molecule.

Eliminate CO_2, and plants would shrivel and die. So would lake and ocean algae or phytoplankton, grasses, kelp and other water plants. After that, animal and human life would disappear. Even reducing carbon dioxide levels too much – sending it back to pre-industrial levels, for example – would have terrible consequences for crops, other plants, animals and humans. Sending it back to wooly mammoth Ice Age levels would be catastrophic.

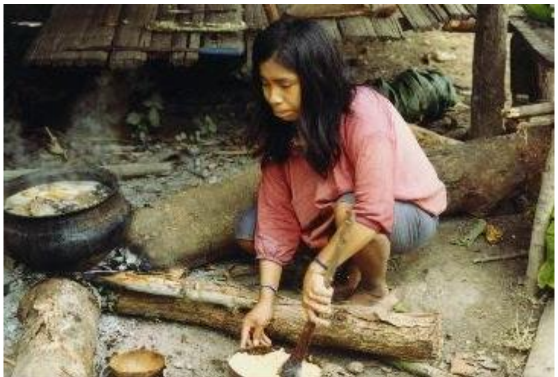
By contrast, the more carbon dioxide there is in the atmosphere, the more it is absorbed by plants of every description – helping them to grow faster, better, and even under adverse conditions like limited water, extremely hot air temperatures, or infestations of insects and other pests.

Moreover, as trees, grasses, algae and crops grow faster and become healthier and more robust, animals and humans enjoy better nutrition on a planet that becomes greener and greener.

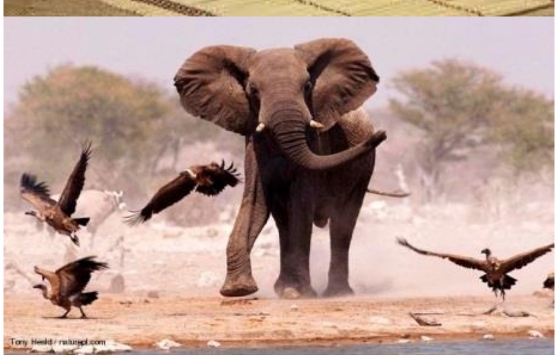
In fact, CO_2 is more than merely a plant fertilizer, as important as that is. CO_2 is also a *pollution fighter*. The gas of life – this miracle molecule – does not merely enable land, lake, river and ocean plants to grow and prosper. It doesn't just make life on Earth possible, and *enhance* our health, welfare and environmental quality.

Carbon dioxide actually *reduces the harmful effects of pollutants* like ozone and nitrous oxides in the air, or too much nitrogen fertilizer in the soil. It helps plants in those environments survive or even prosper, and provide greater value to wildlife and humans. On top of that, more CO_2 in the air enables plants to survive conditions of prolonged heat, drought and flooding that would otherwise kill them.

SOURCES OF CARBON DIOXIDE



Carbon dioxide comes from many sources, including the wood, grass and dung burned by poor families around the world (above); the fermentation processes of bread and beer (below & next page); natural sources such as animals, volcanoes and deep sea vents; and many others.



Where does this miraculous, nutritious carbon dioxide come from?

One source of course is fossil fuels: oil, natural gas, gasoline, diesel and coal. In fact, any organic matter releases carbon dioxide when it is burned: grasses, wood and dung in the heating and cooking fires used by millions of poor families all over the world – as well as forest and grass fires, and homes and buildings when they burn down. Biofuels like ethanol and E10 gasoline blends also release CO_2 when we use them in our cars and trucks, whether those fuels were derived from corn (maize), algae, switchgrass or palm oil.

(Carbon dioxide should not be confused with carbon monoxide or CO, another odorless byproduct of combustion that is highly toxic to humans and animals. Carbon monoxide – not carbon dioxide or CO_2 – is the reason buildings must be properly ventilated, to prevent fireplace or furnace emissions from killing inhabitants.)

As we learned in school, plants absorb carbon dioxide during photosynthesis, using sunlight or artificial light as an energy source to convert CO_2 and water into sugars, cellulose and other carbohydrates – and release oxygen as a "waste" product. (Thank goodness for some waste products!) But when plants die and decay, they *release* carbon dioxide back into the atmosphere. (So do deceased animals.)

In fact, constant measurements at a monitoring station at Mona Loa, Hawaii show that atmospheric CO_2 levels change with the seasons: increasing as plants absorb the miracle gas during the growing season, and declining as their new foliage dies and decays during fall and winter months.

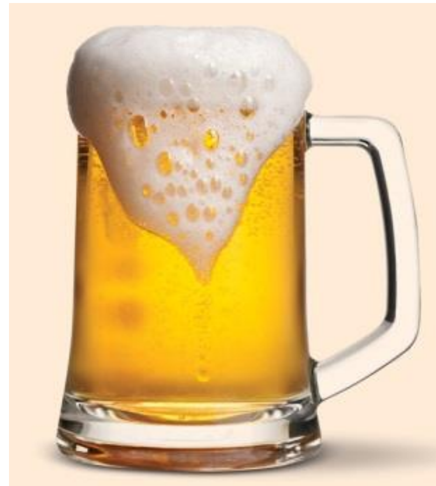
Beer, champagne and soft drinks – and bread, pizza, donuts and cakes – release carbon dioxide as part of their fermentation process. Natural mineral springs, like the one in France used by Perrier, also contribute to atmospheric CO_2 concentrations. Of course, fish, sharks and whales, dogs and cats, lions, tigers and bears, elephants, humans, insects and all other animals exhale carbon dioxide when they breathe.

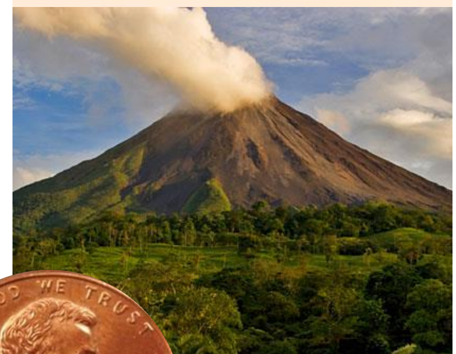
Volcanoes and deep sea vents also release prodigious amounts of carbon dioxide. Indeed, they were the original sources of the CO_2 that helped launch life on earth. The periodic shifts in ocean current patterns in the southern tropical Pacific, known as El Niño and La Niña, also affect carbon dioxide levels. El Niño warms the sea waters and causes them to *exhale* huge amounts of CO_2 into the atmosphere; La Niña events cool waters and cause them to *absorb* more CO_2, which spurs the growth of oceanic algae.

All these human activities combined pump about 70 million tons of carbon dioxide into the atmosphere every day. This sounds like a lot, but it's actually trivial.

Earth's total atmosphere weighs about 5.7 quadrillion tons; so the daily human contribution of CO_2 is equivalent to about one penny out of $1 million.

However, as you will see, all these sources, put together, are doing some pretty miraculous things for our planet.





The Penny Harvest Field at Rockefeller Center consisted of $1 million in pennies. The 600,000 pounds of pennies were spread out over a 165 x 30 foot field. The daily human contribution of CO_2 to the atmosphere is about equivalent to adding one more penny to this field.

ENHANCING OUR FOOD SUPPLIES

More than seven billion people inhabit the Earth today. Demographers expect that number to increase to nine billion or more by 2050, mostly in developing countries. Nearly two billion struggle to survive on less than two dollars per person per day.

Over a billion are malnourished, with insufficient protein and energy in their diets; even more suffer some form of micronutrient deprivation; and many are on the edge of starvation, mostly in Africa. Recurrent floods, droughts and insect infestations make growing more food in many of these places as difficult as it has been throughout most of human history.

Compounding these challenges, global grain demand could double over the next couple of decades, because per-capita real income is rising, more people want to eat better as they escape crushing poverty, and those improved diets include larger amounts of farm-raised, grain-fed meat, poultry and fish.

Almost two decades ago, environmental scientist Paul Waggoner wrote an essay, "How much land can ten billion people spare for nature?" His article underscored the already growing tension between the need for land to feed and sustain humans – and the need to keep land in its natural state to support plants, fish and wildlife. As human populations have increased, they have utilized virtually all the best farmlands and encroached significantly on marginal farmlands that should be preserved as wild plant and animal habitat.

How well mankind handles this challenge of increased crop production from the same or less acreage may mean the difference between global food sufficiency and rampant human starvation in the coming decades – and between the survival and extinction of many species of plants and animals.

In the past, people simply put more land under cultivation, raised more cattle, pigs and chickens on more land, and exploited more fishery stocks. Today, however, those options are increasingly limited, because most of these resources are already being utilized. That means more food will have to be produced from the same lands and waters, to feed humans while preserving wildlife habitats and biodiversity – because we have a moral obligation, as responsible stewards of our Earth and its resources, both to ensure better food supplies for people … and to avoid sending more plant and animal species into oblivion.

Further complicating the matter, developed countries are converting more acreage from farming to forest and other natural areas. That means *developing* countries will have to shoulder most of the responsibility for feeding their own larger populations, by growing greater quantities of more nutritious foods, while also preserving what is left of tropical and temperate forests, savannas and grasslands that support so many unique plants and animals, including the large African and Asian wildlife species.

Modern agricultural methods – mechanized equipment, hybrid seeds, synthetic fertilizers, insecticides, improved irrigation methods and other advances – dramatically improved crop yields per acre between 1933 and 2000. Biotech (genetically modified) corn, soybean, cotton, canola and other crops have enabled farmers to slash insecticide use, grow drought-resistant varieties, and switch to no-till methods that preserve soil structures and organisms, thereby reducing erosion and water use. Biotechnology also helps farmers increase yields even further: per acre, per unit of fertilizer applied, and per gallon of water used (via rain or irrigation). Hot houses for growing tomatoes and other specialty crops are also paying big dividends in many developed countries.

Many of these technologies have yet to reach farmers in poor countries, but the generally positive trends mean that impoverished families all across the globe are enjoying improved incomes, living standards and nutrition. These modernization trends are also helping wildlife and the environment, because anything that improves per-acre crop yields also reduces the amount of land that needs to be farmed, and increases the acreage that can be left as or returned to wildlife habitat.

Less water needed for agriculture means more water is freed up for wildlife and growing urban needs. Biodiversity and sustainable agriculture benefit greatly.

On the other hand, the increasing focus on biofuels means millions of acres of farmland are being diverted from food crops, millions of acres of rainforest and other wildlife habitat are being plowed under, and billions of gallons of water are being used, to produce corn, jatropha, palm oil and other crops for use in biofuel production.

This is continuing despite the success of new seismic, deep drilling, hydraulic fracturing and other technologies in discovering and producing huge new reserves of oil and natural gas. Those discoveries demonstrate that we are *not* running out of fossil fuels and could deemphasize biofuels, thereby making still more land and water available for food production and wildlife conservation.

The fact that the United States and other countries still want to increase biofuel production, while so many people are malnourished and starving, underscores why it is so important to increase per-acre crop yields.

One way to boost crop production on existing farmland all over the world is to reduce regulatory, financial and other impediments to helping poor farmers acquire modern agricultural technologies that could double, triple or even quadruple their yields per acre, just as they have in the United States.

Another way is for atmospheric carbon dioxide levels to continue rising, as hopefully they will continue to do. The impact on crops and other plants will likely be astounding. CO_2 is truly a secret weapon – a miracle molecule – in the war on global hunger and poverty (and species loss).

Carbon dioxide enrichment of Earth's atmosphere will increase yields per acre worldwide and ensure that more people have access to greater quantities of more nutritious food, improving human lives, while reducing impacts on wildlife and the environment.

Growers have long known that increasing the CO_2 levels in greenhouses dramatically improves plant growth, especially when inside temperatures are also elevated. Doing this augments the supply of the most basic of all plant foods (carbon dioxide) and increases the plants' water and nutrient use efficiency.

A 300 ppm increase in the air's CO_2 concentration improves the productivity of herbaceous plants by *30-50 percent*, and of woody plants by *50-80 percent*, scientists have determined.

Indian researchers found that lentils, peas, beans and other legumes grown in air with 700 ppm carbon dioxide improved their total biomass by 91 percent, their edible parts yield by 150 percent and their fodder yield by 67 percent, compared to similar crops grown at 370 ppm carbon dioxide. It does this by stimulating nitrogen fixation in the legumes, helping them to form stronger symbiotic relationships with nitrogen-fixing soil bacteria, further increasing photosynthetic rates.

Chinese scientists calculated that rice grown at 600 ppm CO_2 increased its grain yield by 28 percent with low applications of nitrogen fertilizer, and 32 percent with more nitrogen fertilizer.

U.S. Department of Agriculture researchers discovered that sugarcane grown in sunlit greenhouses at 720 ppm CO_2 and 11 degrees Fahrenheit (6 degrees Celsius) higher than outside ambient air produced stem juice an amazing *124 percent* higher in volume than sugarcane grown at ambient temperature and 360 ppm carbon dioxide. They concluded that sugarcane grown under conditions of higher temperatures and carbon dioxide levels will use less water, utilize water more efficiently, handle dry spells better, and produce more sucrose.

Similar results have been observed with almost all crops tested. Higher carbon dioxide levels boost crop growth rates and yields dramatically, especially when temperatures are a few degrees higher than the ambient outdoor temperatures we typically experience today.

Non-food crops like cotton also fare much better when atmospheric carbon dioxide levels are higher. One study was done in the University of Georgia's Envirotron, a cluster of specialized greenhouses that can adjust temperatures, carbon dioxide levels and other environmental parameters, to analyze plant growth, interactions between plants and various environmental stresses, and agricultural economics under different ecological conditions. Researchers placed cotton plants in chambers maintained at six combinations of two daytime and nighttime air temperature regimes (77° F day / 59° F night and 95° F day / 77° F night; 25/15°C and 35/25°C) and three atmospheric CO_2 concentrations (400, 600 and 800 parts per million).

At harvest, the cotton's final boll weight was 1.6 times heavier at 600 ppm, compared to 400 ppm, and 6.3 times heavier at 800 ppm than at 400, under the lower temperature conditions. The difference was even more pronounced at the higher daytime/nighttime temperatures: the final boll weight was 23 times heavier at 600 ppm and 34 times heavier at 800 ppm, compared to ambient (400 ppm) CO_2 levels.

Another Envirotron study examined loblolly pines, one of the most important trees in the southeastern United States. Above-normal temperature had no effect on nutrient assimilation rates, probably because the trees thrive under conditions all the way from 68 to 95° F (20 to 35°C). The effect of CO_2 was substantial, however. Nutrient accessibility at 700 ppm was 79 percent higher than at 400 ppm in the low-water treatment and 43 percent higher in the high-water treatment – indicating that loblolly pines would do well even during a drought, if carbon dioxide levels are high enough.

The flip side of droughts, of course, is too much water. That generally means complete submergence in water – which typically kills plants. However, researchers have found that tree and rice species they studied were able to survive, and even continue growing, under conditions of prolonged submergence, such as following a flood – if the air had high carbon dioxide levels.

Other studies found that desirable crop and other plant species actually fare better against intrusive weeds when CO_2 levels are higher. It seems weeds are less able to take over gardens when primary species are growing robustly under those enhanced conditions.

Of course, not all crops can be grown in greenhouses, at doubled CO_2 levels and optimally higher temperatures – and poor farmers in developing countries cannot afford greenhouses.

"Real-world" studies confirm what researchers found in greenhouses

However, studies of natural forest and crop growth during recent periods of rising atmospheric carbon dioxide levels, between 1950 and 2010, found similar improvements under "real-world" conditions.

- Young trees in Wisconsin and Minnesota grew faster in recent years than they did several decades ago. As atmospheric carbon dioxide concentrations rose from 316 ppm in 1958 (when scientists began tracking CO_2 levels) to 376 ppm in 2003, the growth of trees 11-20 years old increased by 60 percent, and tree ring width expanded by almost 53 percent. (That was just a 60 ppm increase in carbon dioxide – 6 cents out of $1000. Imagine what a 100 or 200 ppm rise could do!)
- An analysis of Scots pines in Catalonia, Spain showed that the trees' diameter and cross-sectional area expanded by 84 percent between 1900 and 2000. Researchers concluded that this was due to the fertilization effect of rising carbon dioxide levels, combined with an average 0.34° F (0.19° C) per decade rise in temperature across the study region during the last half of the century.
- University of Minnesota scientists found that plant growth rates became less sensitive to drought as carbon dioxide concentrations increased. They compared the growth of trees and other plants during the first half of the twentieth century (which included the terrible Dust Bowl years), when CO_2 levels rose only 10 ppm – to the period 1950-2000, when CO_2 increased by 57 ppm – and concluded that reduced sensitivity to severe drought improved plant survival rates by almost 50 percent.
- In Switzerland, researchers examined several high altitude alpine plant species that were thought to be especially sensitive to warmer temperatures. They discovered that, because of rising carbon dioxide levels, "alpine plant life is proliferating, biodiversity is on the rise, and the mountain world appears more productive and inviting than ever." One scientist stated that "no alpine plant species has become extinct" and, in the coming years, alpine areas might actually "support a previously unseen mosaic of richly flowering and luxuriant plant communities of early Holocene character."

Other researchers used actual historical (real-world) data for land use, atmospheric CO_2 concentration, nitrogen deposition, fertilization, ozone levels, rainfall and climate – combined with their knowledge of plant physiology and growth – to develop a computer model that simulates

21 THINGS MORE CO_2 HELPS PLANTS DO BETTER

Increasing amounts of CO_2 in earth's atmosphere and the air in greenhouses:

1. Augments the supply of the most basic of all plant foods (carbon dioxide)
2. Improves plant nitrogen fixation and photosynthesis
3. Increases vegetative "biogenic volatile organic compounds," further spurring photosynthesis
4. Stimulates plant cell division, protein synthesis, productivity and overall plant growth
5. Reduces stomata size, so fewer water molecules escape and there is less stress on plants
6. Increases carbon gained in plant tissue per unit of water lost by transpiration
7. Increases the number, surface area and biomass of lateral roots and fine-roots
8. Helps plants absorb more water and soil nutrients more efficiently
9. Improves overall soil quality and stability, by increasing beneficial soil organisms
10. Improves the ability of plants to utilize soil nutrients and fertilizer through their roots
11. Protects against pollution, heat and drought
12. Improves plant resistance to diseases, viruses, pathogens and insects
13. Helps plants recover more quickly from stresses imposed by prolonged dry spells
14. Expands plant ranges and ground cover, reducing soil erosion
15. Helps desirable crop and other plant species resist invasion by weeds
16. Augments wood density in trees, making trunks and branches stronger and more solid
17. Helps Earth become greener and more hospitable to wildlife
18. Expands crop yields per acre, reducing the need to turn more habitat land into farmland
19. Helps enhance quantity and quality of fatty-acids (lipids), for improved nutrition
20. Increases quantity and bio-availability of vitamin C and antioxidants in plant tissue
21. Enhances food security for millions of people

plant growth responses for grasslands, forests, wetlands and agriculture in the southern United States from 1895 to 2007.

They found that "net primary productivity" improved by an average of 27 percent during this 112-year period, with most of the increased growth occurring after 1950, when carbon dioxide levels rose the most, from roughly 310 ppm in 1950 to 395 ppm in 2007. Moreover, gains occurred even though rising ozone levels (from cars and other sources) adversely affected growth.

Between 1961 and 2007, average US corn yields increased by 240 percent, from 1.6 tons per acre per year to 3.8 tons per acre per year. Moreover, some researchers have predicted that advances in agronomics, breeding and biotechnology will lead to an average corn yield in the US of just over 8.1 tons per acre per year in 2030. Similar increases worldwide would be a boon for people and wildlife alike.

Perhaps most amazing – and most important for our planet and people – are the latest findings by Dr. Waggoner and his colleagues, Jesse Ausubel and Iddo Wernick. They calculated that – thanks to steadily improving yields by farmers all around the world between 1960 and 2012 – humanity has been able to avoid having to plow additional wildlife habitat land equal to *twice the area of South America*!

Those incredible increases in average yield per acre of food and other crops are due in large part to advances in agricultural and irrigation technology, in part to more farmers around the world having access to these modern technologies – and in part to increases in atmospheric carbon dioxide levels.

These and numerous other research studies confirm that rising carbon dioxide enrichment of Earth's atmosphere will increase yields per acre worldwide and ensure that more people have access to greater quantities of more nutritious food, while impacts on wildlife and environmental quality decline.

(The 2009 and 2011 volumes of the Nongovernmental International Panel on Climate Change report, *Climate Change Reconsidered*, and Dr. Craig Idso's CO2science.org website summarize hundreds of similar studies of crops, forests, grasslands, alpine areas and deserts enriched by carbon dioxide. The CO_2 Science Plant Growth Database lets people search for even more studies among the thousands of results that are listed there.[1])

What happens in plants when carbon dioxide levels increase?

Green plants use carbon dioxide to create food for themselves – to grow, survive and propagate. In the process, directly or indirectly, they create food for all life, including humans: either we eat the plants, or we eat meat, eggs or dairy products from an animal that has eaten plants. Literally thousands of studies demonstrate that higher atmospheric carbon dioxide levels enhance the growth of all plants and food crops – directly, by helping them create more of their edible parts, or indirectly by helping them resist drought and pollution.

More CO_2 in the air means enhanced rates of photosynthesis and biomass production for virtually every kind of plant and every part of the plant: wheat and rice, corn and alfalfa, peas and beans, cotton, trees of every description, sugarcane, and almost anything else you can think of … stems, branches, roots, seeds, flowers and edible parts … on every continent … and in every ecosystem, from temperate forests to tropical rainforests, mountain areas, deserts, lakes, rivers and oceans.

Plants use carbon dioxide as their most fundamental and essential building block. More CO_2 generally means more and larger flowers; higher seed mass and germination success; and improved plant resistance to droughts, diseases, viruses, pathogenic infections like downy mildew disease, air pollutants like ozone, and salt or nitrogen accumulation in soils. It improves the ability of plants to utilize land, water, soil nutrients and fertilizer.

[1] See http://www.co2science.org/data/plant_growth/plantgrowth.php

Elevated CO_2 also helps to enhance the quantity and quality of fatty-acid chains called lipids, which are vital for the well-being of nearly all living organisms. It also increases the quantity and bio-availability of vitamin C and antioxidants in plant tissue, making crops more nutritious.

Higher CO_2 levels improve plants' water use efficiency – ensuring faster and greater carbon uptake by plant tissues, with less water lost through transpiration. In other words, *carbon gained* in plant tissues (in the form of sugars and other carbohydrates, seeds, proteins and other products) *per unit of water lost* by transpiration through stomata increases significantly. In fact, water use efficiency can actually *double*, when the air's carbon dioxide level doubles.

Higher atmospheric CO_2 levels thus reduce the amount of water plants lose through their leaves, so that they can survive periods of reduced water supplies. Elevated CO_2 allows plants to compensate for arid conditions and helps them recover more quickly from the severe water stress imposed by dry spells.

More carbon dioxide protects plant roots and foliage from pathogens, diseases and insects that feed on them, thereby stabilizing soils and reducing erosion. It also helps plants expand their ranges and thus the amount of ground they cover, even in deserts.

Elevated CO_2 levels also increase the wood density in trees – increasing the solidity and strength of tree branches and trunks, and making the trees better able to survive storms … and their lumber more desirable for building and furniture making.

The benefits of rising carbon dioxide in Earth's atmosphere are profound, increasingly obvious, and the most basic reason our planet is becoming greener, better able to support more hungry people, and more hospitable to wildlife species that otherwise could be pushed closer to the brink of extinction.

Finally, rising CO_2 levels let us increase our production of vital food crops, enhancing food security for millions of people, without taking more land and water away from nature and wildlife.

How do they do it? The physiology of CO_2 enrichment

How exactly do plants respond to rising carbon dioxide levels, and achieve these gains?

As every student learns, plants use energy from the sun to convert carbon dioxide from the air and water and minerals from the soil into carbohydrates and other molecules that form roots, stems, leaves, seeds and "fruits." They do this with the help of catalytic action from an unfamiliar but vital enzyme called RuBisCO, the most abundant protein in leaves and probably on Earth (not to be confused with Nabisco).

This enzyme plays a key role in carbon fixation, the process plants use to convert carbon dioxide into glucose and other carbohydrates that build plant structures, from roots and stems, to leaves, flowers, seeds and fruits. (RuBisCO is the acronym for Ribulose-1,5-Biphosphate Carboxylase Oxygenase.)

More airborne carbon dioxide lets plants reduce the size of their stomata, little holes in the leaves that plants use to inhale carbon dioxide building blocks. When CO_2 is scarce, the openings increase in size, to find and capture sufficient supplies of this "gas of life." But increasing stomata size means more water molecules escape, and the water loss places increasing stress on the plants, eventually threatening their growth and even survival.

When the air's carbon dioxide levels rise – to 400, 600 or 800 ppm – the stomata shrink in size but still absorb ample CO_2 molecules. In fact, they can absorb so much more CO_2 that the plants grow faster and better, as discussed earlier. Because the stomata become smaller, the plants lose less water from transpiration and can survive extended dry spells much better.

In fact, plants growing in air that is rich in carbon dioxide keep growing even under arid conditions that would impair photosynthesis and stop plant growth under less optimal CO_2 conditions.

Depending on outside humidity and temperature, 100 or more water molecules can diffuse *out* of a leaf for every molecule of carbon dioxide that diffuses *in*. Because not every CO_2 molecule is converted into plant tissue, plants must absorb many hundreds of grams of water to produce one gram of plant biomass. That's a big reason why abundant atmospheric carbon dioxide is so important.

CO_2 greatly increases the biomass, numbers and total surface area of lateral roots and fine-roots, enabling plants to absorb more water and soil nutrients, and obtain sufficient phosphorus when that element is in short supply in soils. More CO_2 also enables common root-dwelling soil fungi to increase their production of a beneficial protein called glomalin, which decreases the risk that toxins will build up in soil, while increasing the overall stability of soil particles and other components.

Larger amounts of atmospheric carbon dioxide also enhance plants' nitrogen fixation rates, increase the level of vegetative "biogenic volatile organic compounds" (especially from trees) that further spur photosynthesis, and intensify the production of "monoterpenes," which aid plants that are experiencing serious heat stress or battling pathogens and insects that feed on plants.

These processes significantly stimulate plant cell division, protein synthesis, and the growth and biomass of plant stems, branches, leaves, flowers and other tissue that we see above ground. They green our planet, expand wildlife habitats, increase food production, and improve life for every living thing.

DOWN IN THE WEEDS

If you really want to get into the weeds – not the ones in your garden, but the weeds of scientific jargon and gritty details – this short excursion is for the inner botanist in you. There are three basic categories of plants: C3, C4 (or, more accurately, C_3 and C_4) and CAM. They describe the three ways plants convert carbon dioxide into carbohydrates. (No, C4 is not an explosive.)

C3 plants convert or "fix" carbon dioxide directly from the air into molecules that are then converted into carbohydrates (direct carbon fixation). About 85 percent of all plant species, and 95 percent of total plant biomass on Earth, are C3 varieties. Examples include wheat, rice, barley, soybeans, cotton, many forage crops, peanuts, beans and other legumes, sugar beets, spinach, most trees and most lawn grasses. In these plants, RuBisCO is the catalyst that speeds the attachment of a CO_2 molecule to a five-carbon sugar molecule, to make two three-carbon molecules (hence C_3) that then enter the Calvin-Benson cycle of photosynthesis, to be processed into glucose and other carbohydrates.

These plants evolved during the Mesozoic and Paleozoic eras, when Earth's atmosphere had far more carbon dioxide than today, suggesting that C3 species are actually undernourished in CO_2 in the context of their original evolutionary design. They thrive where atmospheric carbon dioxide levels are at least 200 ppm, temperature and light intensity are moderate, and soils have plentiful water.

However, during hot dry spells, the stomata in C3 plants close down to reduce water loss. This prevents adequate carbon dioxide from entering the leaves, reduces CO_2 concentration in the plant's leaves and chloroplasts, and lowers the CO_2:O_2 (carbon dioxide:oxygen) ratio. That causes RuBisCO to react with oxygen, instead of carbon dioxide – which leads to photorespiration (a complex series of substitute enzyme reactions that keep the plant growing but at greatly reduced efficiency), a net loss of carbon and nitrogen from the plant, and limited growth or even wilting and death.

This again underscores why abundant carbon dioxide is essential for healthier plants, more nutritious food, and a more prosperous Earth.

C4 plants get their carbon dioxide from four-carbon malates (salts and esters of malic acid, a carboxyl acid that is made by all living organisms and contributes to the pleasantly sour taste of fruits), rather than directly from the air. This CO_2 extraction process takes place in the chloroplasts of specialized "bundle sheath cells" not found in C3 plants, through additional chemical processes that require more energy, ultimately in the form of the more intense solar energy found in tropical climates. Those specialized cells then utilize the stored carbon dioxide to produce carbohydrates through the normal C3 processes. C4 species are thought to have evolved in more recent times than C3 plants.

The two-stage photosynthesis process found in C4 plants gives them the advantages of far more carbon dioxide for the Calvin cycle, optimal use of RuBisCO, and an absence of oxygen that causes photorespiration. The extra energy that C4 plant cells require to perform this two-step process explains why C3 plants outperform their C4 cousins when there is plentiful water and carbon dioxide. (This extra energy comes in the form of ATP, adenosine triphosphate, the high-energy molecule that stores energy that plants and animals need for almost everything they do.)

Less than 0.5 percent of all known plant species are C4 varieties. However, they include important food crops like corn, sugarcane, tomatoes, sorghum and millet, as well as plants like Bermuda grass, crabgrass and tropical grasses.

CAM plants derive their name from the "Crassulacean acid metabolism" process of carbon fixation that evolved in some plants as a way to adapt to arid conditions. In these plants, stomata in the leaves remain shut during the day to reduce water loss through evapotranspiration – but then open at night to absorb carbon dioxide, which they store in vacuoles (special compartments in plant and animal cells) as malate (like C4 plants) and use in photosynthesis during the day.

These plants are most common in deserts and other environments where water is at a premium – and include cacti, jade and other succulents, pineapple, Spanish moss, orchids, some ferns and the Agave used to make tequila. They represent about 10 percent of all plant species. Interestingly, because C4 plants store CO_2 as malates or malic acid at night, their tissue is more tart during those hours and becomes progressively sweeter during the day, as the acid yields its carbon dioxide for photosynthesis.

Still other plants are intermediates between C3 and C4 varieties, displaying certain characteristics of each type. (Mushrooms are not plants, but part of a separate kingdom of living organisms called fungi.)

CONCLUSION

Carbon dioxide is truly the gas of life, a miracle molecule that makes all life on Planet Earth possible. As numerous studies have demonstrated, plants thrive best when CO_2 levels are high – in the atmosphere or in greenhouses and hothouses. More carbon dioxide means enhanced rates of photosynthesis and biomass production for virtually every kind of plant, and every part of every plant.

Carbon dioxide is a powerful weapon in the global war on poverty, malnutrition, hunger and species extinction. One of the worst things that could happen to our planet and the people, animals and plants inhabiting it would be for carbon dioxide levels to plunge back to levels last seen before the Industrial Revolution: from 400 ppm today to 280 or 290 ppm in 1870.

Decreasing CO_2 levels would be especially problematical if Earth cools, in response to the sun entering another "quiet phase," as happened during the Little Ice Age, particularly the Maunder Minimum, a prolonged period of minimal sunspots, from 1645 to 1715, when civilizations all over the world reported bitterly cold winters, short summers and growing seasons, crop failures, malnutrition and starvation.

If Earth cools again, growing seasons would shorten and arable cropland would decrease in the northern temperate zones. We would then need every possible molecule of carbon dioxide – just to keep agricultural production high enough to stave off mass starvation … and save wildlife habitats from being plowed under to replace cropland lost in higher latitude areas like Canada, northern Europe and Russia.

However, even under current conditions, crops and other plants, animals and people will benefit from more carbon dioxide. The "gas of life" is a miracle plant fertilizer that helps land, lake, river and ocean plants grow and prosper, greening the planet, nourishing wildlife habitats, and feeding Earth's growing populations of people who crave larger bounties of more nutritious food.

The gas of life also reduces the harmful effects of ozone and other pollutants, and of prolonged heat, drought and flooding that would shrivel or even kill plants under less optimal CO_2 conditions.

Carbon dioxide performs as many miracles for our planet as antibiotics and immunizations have for mankind. That is an amazing feat for a colorless, odorless, tasteless gas that represents just 0.04 percent of our atmosphere: the equivalent of just 40 cents out of $1,000 or 1.4 inches on a football field!

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PEER-REVIEWED BY

Dennis T. Avery grew up on a Michigan dairy farm and has returned to his roots on a small farm in Virginia's Shenandoah Valley. He is a proponent of nitrogen fertilizer, no-till farming with herbicides, and hybrid and genetically modified seeds – to feed more people while saving room for wildlife. Avery wrote the 1969 report for the President's National Advisory Commission on Food and Fiber, and received the 1983National Intelligence Medal of Achievement as the U.S. State Department's agricultural analyst. He is the author of *Saving the Planet With Pesticides and Plastic: The Environmental Triumph of High-Yield Farming.* His New York Times best-seller, *Unstoppable Warming Every 1,500 Years* (co-authored with S. Fred Singer) sold 200,000 copies. His forthcoming book, *Climate & Collapse*, details the terrible impacts of history's multiple "little ice ages" on humanity and food production.

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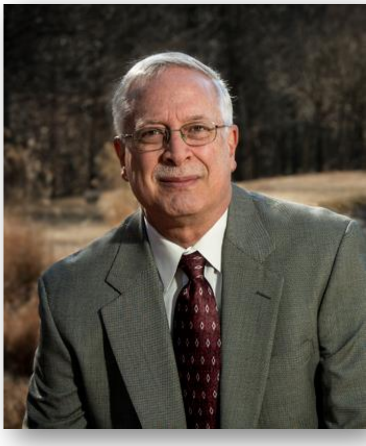

Paul Driessen is senior policy analyst for the Committee For A Constructive Tomorrow (CFACT) and Heartland Institute, public policy institutes that promote environmental stewardship, the enhancement of human health and welfare, and personal liberties and civil rights. He received an undergraduate degree in geology, biology and ecology, and a J.D. degree emphasizing environmental and natural resource law. Driessen writes and speaks frequently on the environment, energy and economic development, malaria eradication, climate change, human rights, corporate social responsibility and sustainable development.

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Driessen's book, *Eco-Imperialism: Green Power - Black Death*, documents the harm that developed country environmental policies often have on poor people, especially in developing countries, by restricting their access to life-enhancing modern technologies. It has been published in Argentina (Spanish), India (English), Germany (German) and Italy (Italian).

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ABOUT CFACT

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