Miracle Molecule

Carbon Dioxide Gas of Life

The astonishing story of a simple chemical that made life on Earth possible and continues its work today

Paul Driessen

Foreword by **Roy Spencer**

CFACT

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Carbon Dioxide: The Gas of Life

Tiny amounts of this miracle molecule make life on Earth possible.
Rising atmospheric CO_2 levels spur forest and crop growth,
help plants survive heat and drought, and feed the world.

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Roy Spencer

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Foreword

This book is very timely, and even long overdue.

We live in a time when what was once accepted science is now being rejected – often to be replaced by "facts" that simply are not factual. Prevailing fallacies about carbon dioxide are a good example.

As Paul Driessen observes in his introduction, many people today hear the words "carbon dioxide" and immediately react by thinking, "Oh, yes, that's the heat-trapping greenhouse gas that causes man-made global warming." But they're only partly correct and, as philosopher-poet Alexander Pope said three centuries ago, "a little learning is a dangerous thing."

It is true that carbon dioxide or CO_2 is one of the "greenhouse gases" that help Earth's atmosphere keep some of the sun's heat from escaping back into outer space, thereby maintaining our planet's temperature within ranges that support life.

In fact, if it weren't for carbon dioxide, nearly all life on Earth would end. That's because plants of every description – trees, grasses, algae, ocean phytoplankton and food crops – require CO2 for photosynthesis. It is photosynthesis that produces fiber for wildlife habitats and people's homes and clothing, food for animals and humans, and oxygen for people and animals to breathe. Without this "miracle molecule" we call carbon dioxide, Earth would be very different, inhabited by species that require methane or some other gas to sustain them.

Paul Driessen's brief book about this "gas of life" is certainly engaging. It revisits these important lessons and provides fascinating details about the many ways carbon dioxide enriches Earth's atmosphere, enhances our lives, and safeguards life itself. However, his book will likely be enraging for some readers, because it also challenges much of what people are being taught these days about carbon dioxide.

Having studied the atmosphere, climate change and climate politics for several decades, and having written about these topics in books, articles and scientific research papers, I know that CO_2 became a villain because of energy and environmental politics. This molecule might be the "gas of life." Atmospheric CO_2 might be over 99 percent natural in origin. But it is also a byproduct of burning fossil fuels – hydrocarbons like oil, gas and coal.

For reasons that I don't fully understand, some people and organizations decided that these fuels are bad or harmful, even though they still account for more than 80 percent of the energy that makes modern technologies, civilizations, health and living standards possible, in the United States and around the world.

Ironically, carbon dioxide is equally a byproduct of burning wood, grass and animal dung. These are the fuels that billions of people around the world must still rely on to heat their homes and cook their food. These people do not have access to fossil fuels, or to electricity generated by coal and natural gas, as well as by nuclear and hydroelectric power, and to a much lesser extent wind, solar and geothermal power. These energy-poor families live very precarious lives, immersed in poverty, misery, disease, childhood death and early demise even for those lucky enough to make it to their adult years.

Helping these people improve their lives is a moral imperative – yet one that is hampered greatly by current views about fossil fuels and carbon dioxide.

It is also interesting to note that atmospheric CO_2 levels are now about one and one-half times higher than they were when the modern industrial era began. In fact, carbon dioxide and other greenhouse gas emissions have increased about 11 percent just since 1995. However, despite that significant increase over the last two decades, there has been no statistically significant increase in planetary warming in 18 years. This is completely contrary to what computerized climate models and scientists concerned about a rapidly warming planet had predicted.

Many scientists, me included, now believe the warming influence of carbon dioxide has been greatly overstated. We believe it is likely to be much closer to 1 degree Celsius (1.8 degrees Fahrenheit) for a doubling of CO_2 to around 500 parts per million since the dawn of the industrial age.

It is highly unlikely that this level of warming would be harmful. Indeed, most plants and animals would respond very positively to moderately warmer planetary temperatures of this magnitude, especially on a planet with more carbon dioxide in the air.

By contrast, if Earth were to *cool* by this amount, the impacts on forest, grassland and crop growth, and on wildlife and humans, would likely be very detrimental, especially if they occurred in a world where atmospheric carbon dioxide levels decline from their current state.

In this book, Driessen pays little attention to these energy and political issues. He simply offers information and perspectives on carbon dioxide that differ from what are being taught in our schools, news media and political arenas. His little book is fast-paced, informative, and more enjoyable and easy to understand than any scientific publication you are likely to encounter.

So take an hour or two from your busy schedule, and enjoy this short course in biology.

Roy W. Spencer, PhD

Principal Research Scientist, University of Alabama, Huntsville, bestselling author of *Climate Confusion: How global warming hysteria leads to bad science, pandering politicians and misguided policies that hurt the poor*, and recipient of NASA’s Exceptional Scientific Achievement Medal

Author’s Introduction

This book is about carbon dioxide – CO_2 for short.

If you’re like most Americans, the term elicits a pretty negative reaction. Carbon dioxide is the heat-trapping greenhouse gas that causes man-made global warming, you’ve been told. And global warming causes melting polar ice caps, rising seas, violent storms, roaring floods, scorching droughts, hellish forest fires, and enough catastrophes to threaten modern civilization and even our very planet.

You’re probably also aware that the United Nations Intergovernmental Panel on Climate Change condemns man-made carbon dioxide emissions for all this and more. You may also have heard that the United States Supreme Court has given the U.S. Environmental Protection Agency the authority to regulate carbon dioxide as a “pollutant” that “endangers human health and welfare.”

I’ve written many articles and several reports and book chapters addressing these concerns. Suffice it to say the verdict is still out. Thousands of knowledgeable scientists, including many who once accepted these claims, now strongly doubt that humans or carbon dioxide have replaced the many powerful and complex natural forces that have caused minor to enormous climate changes throughout Earth and human history. They also question claims that any impacts from fossil fuels are likely to be bad, dangerous or even catastrophic. They point out that oil, natural gas and coal have produced higher living standards, better health and nutrition, and vastly superior sanitation and disease control than even kings and queens enjoyed a century ago.

This book leaves those fascinating issues for another day.

Having studied geology, chemistry and ecology in high school and some twenty college courses, I’ve always been fascinated by the intricacies of Earth and biological sciences and processes. I’ve also been amazed at the ways certain chemicals play incredibly vital roles in our bodies’ well-being and the health of our planet: too much, and disaster or death results; too little, and disaster or death results. Salt is one example. Carbon dioxide is another.

I’ve also been amazed at how little most Americans know about basic science – and at how easily they can thus be confused or misled on many important issues.

I don’t mean anything personal by that. As the famous cowboy humorist Will Rogers once said, everybody is ignorant, only on different subjects. Americans certainly aren’t stupid, and ignorance is curable. A little dose of good information usually cures even moderate to severe ignorance in a jiffy.

We also don’t need to take it too personally that a 2014 *Time* magazine headline said, “Americans are really, really bad at answering questions about science.” It seems *Discovery News* researchers had found that one in four Americans actually believes the sun revolves around the Earth. (Of course you know it's the other way around.) And a 2013 Pew Research Center and *Smithsonian* magazine survey found that only one American in five knows which gas makes up most of Earth's atmosphere. (You're right. It's nitrogen, not oxygen or carbon dioxide.)

However, in the good news corner, in 1990 only 49 percent of high school graduates had completed a chemistry course; by 2009 the number had risen to 70 percent. That bodes well.

Returning to the topic at hand, my studies and ongoing work also taught me that biological scientists have a very different view about carbon dioxide – one that may challenge many of your assumptions and compel you to reconsider carbon dioxide in its proper, positive light.

So, what is carbon dioxide, or CO_2? It's a molecule, composed of three atoms: one carbon (the C) and two oxygen (the O_2). The brief refresher course that follows will recap the basic science and convey numerous useful and fascinating nuggets about plants and the world we live in.

Carbon, of course, is coal, charcoal, graphite, diamonds, the carbon part of hydrocarbons, the carbon portion of plant cellulose, and the carbon component of all carbon-based life forms, from microbes to monkeys, elephants, eels, dogs, cats – and human beings.

Oxygen is what we must breathe in to stay alive, and what most fires need to burn.

Carbon dioxide is what we breathe out when we exhale. As we're going to find out – or start to remember from the science courses we did take – it's also much more than that.

To begin with, carbon dioxide is a chemical. That may raise red flags for some readers, as surveys suggest that about a third of Americans hear "chemical" and think "bad." They perceive chemicals as what you find on an ice cream carton's ingredients list, after milk, cream and sugar: unpronounceable words like propylene glycol monoesters and mono- and diglycerides. They're chemical additives, artificial stuff that's not natural, so they can't be good for you, you've been told.

So, if carbon dioxide is a chemical, it can't be good for you either, some might think. However, everything in the universe is made of chemicals – including our own bodies, the carbon dioxide we exhale with every breath, and the paper on which books used to be printed.

The fact is, chemicals aren't just exotic substances made in laboratories or found on food labels. Anything that's "matter" is a chemical: any liquid, solid or gas; any pure substance or mixture of substances; anything that occupies space and can be weighed (that is, has mass); anything composed of one or more of the "elements" – the building blocks of nature like hydrogen, carbon, oxygen, zinc, iron, lead and uranium – over 100 in all, in the periodic table of elements.

Earth's atmosphere consists of 78.09 percent nitrogen, 20.95 percent oxygen, 0.93 percent argon, and a mere 0.040 percent carbon dioxide. In other words, the carbon dioxide in our atmosphere is equivalent to just 40 cents out of 1,000 dollars.

Water vapor is yet another vital component of Earth's atmosphere, of course. Its presence ranges from about 0.1 percent above Antarctica and deserts like the Sahara, to around 4 percent in steamy jungles or rain forests.

Ironically, water vapor is also a byproduct of burning *all* of these carbon-based fuels – not just oil, natural gas and coal, but also wood, grass and animal dung. Water vapor is also a much more significant greenhouse gas than carbon dioxide. However, it enters the atmosphere via evaporation from every body of water on Earth, and thus cannot be controlled. It also does not fit the political narrative about fossil fuels and is therefore generally left out of discussions about energy and climate change.

Moreover, the very idea that our courts could rule that water vapor is a "pollutant," or that governments would attempt to regulate water evaporating from the earth's water bodies, is so absurd that it clearly has no political value. (They've done both with carbon dioxide, as you probably know.) That also helps to explain the neglect of water vapor in most current climate change studies.

We will likewise save those fascinating issues for another day. This book examines only the biological aspects of carbon dioxide.

That atmospheric carbon dioxide comes from numerous sources. The vast majority are found in nature. Only a tiny fraction is from the combustion of hydrocarbon or fossil fuels.

But what a monumental difference that carbon dioxide makes. In fact, as Dr. Spencer observes in his Foreword, without that little bit of CO_2 virtually all life on Earth would cease to exist. Without that little bit of CO_2 we could be back to primordial times.

It's hard to imagine, but Earth's original atmosphere contained virtually no oxygen, a molecule so chemically active that primordial planet-forming conditions forced it to combine with other molecules to form mineral compounds. Even today oxygen remains the most abundant element in the Earth's mineral crust, always in combination with other elements like iron, with which it forms magnetite (Fe_3O_4), limonite (Fe_2O_3) and other colorful ferrous ores.

Oxygen began to accumulate as a gas in the atmosphere only around 2.5 billion years ago, during what scientists call the Great Oxygenation Event, about a billion years after the appearance of cyanobacteria and algae, the first oxygen-releasing organisms. They finally made the development of oxygen-consuming animal life possible. In fact, oxygen is still so active that it continuously reverts to primeval conditions, combining with hydrogen to create water and with numerous minerals. Atmospheric oxygen must therefore be continuously replenished by plant photosynthesis – which needs that trace gas, CO_2.

To reemphasize my earlier point, and put the subject in perhaps overly simplistic terms: Humans and animals exhale carbon dioxide when they breathe. Plants inhale it from the atmosphere to power photosynthesis and, in the process, release oxygen. People and animals inhale that oxygen, to make their own lives possible. It is wondrous symbiotic arrangement – the circle of life, as Simba would say.

Carbon dioxide truly is the "miracle molecule," the "gas of life." The details of how it converts our planet into the amazing blue and green orb it is are addressed in the remainder of this short book. I hope you find it lively and informative.

Miracles in Tiny Doses

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 excruciating pain while they cut it off 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 combination therapy (ACT) 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 heavy metal contaminants that volcanoes, deep sea vents, and rock erosion 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. Seas filled with icebergs and the huge island became too cold for crops or forage for animals.

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.) The 120 ppm increase between 1800 and 2014 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 a miracle molecule, the "gas of life."

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, deprived of food, most animal and human life would quickly 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. That helps 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.

Rising carbon dioxide levels also help plants overcome stresses caused by rising soil salinity, which can result from repeated irrigation. On top of all 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

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 or E15 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. Carbon dioxide becomes toxic to humans only in concentrations above 5% or 50,000 ppm, or 125 times the current atmospheric level.)

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 Mauna Loa, Hawaii show that atmospheric CO_2 levels change with the seasons: declining as plants absorb the miracle gas during the growing season, and increasing as plants reduce or cease photosynthesis and their recent 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.

Enhancing 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, especially 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 wild plants, fish and wildlife. As human populations have increased, they have utilized virtually all the best farmlands and encroached significantly on marginal farmlands that could and 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 plant and animal species.

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. That necessity arises 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, switch to no-till methods that preserve soil structures and organisms, reducing erosion and water use, and increase yields even further: per acre, per unit of fertilizer applied and per gallon of water used (rain or irrigation).

Hot houses for growing tomatoes and other specialty crops year-round are also paying big dividends near urban centers in many developed countries, by utilizing higher temperatures and carbon dioxide levels, controlled irrigation, hydroponics and other methods.

Many of these technologies have not yet reached farmers in poor countries, but where they have once-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 decreases the amount of land that needs to be farmed, reduces dependence on wild fish and game for protein, 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 used in biofuel production.

According to the U.S. Department of Energy, corn-based ethanol requires up to 29,000 gallons of fresh water per million Btu of energy produced – and soybean biodiesel consumes as much as 75,000 gallons per million Btu. By contrast, hydraulic fracturing or fracking requires 6 to 12 gallons of fresh or brackish water per million Btu. The 2013 ethanol quota required corn grown on an area the size of Iowa: more than 35,000,000 acres.

Equally problematical is the idea of replacing coal with trees to generate electricity, as with the huge Drax power plant in York, England. Fuel for Drax comes from the southeastern United States, where trees are cut and converted into wood pellets that are transported on fossil-fuel-powered ships to Britain. Replicated at other power plants, this approach would result in major forest habitat losses.

These practices are 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 the importance of increasing per-acre crop yields.

One essential element in boosting crop production on existing farmland all over the world is reducing regulatory, financial and other impediments to helping poor farmers acquire modern agricultural technologies (including biotechnology, fertilizers, irrigation equipment, mechanized equipment and pesticides) that could double, triple or even quadruple their yields per acre, just as they have in the United States.

Equally helpful would be continued increases in atmospheric carbon dioxide levels. The impact on crops and other plants would likely be astounding. CO_2 is truly a secret weapon – a miracle molecule – in the war on global hunger and poverty, as well as habitat 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, while also 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. This CO_2 enrichment augments the supply of the most basic of all plant foods (carbon dioxide) and increases the efficiency of plants' water and nutrient use.

That common knowledge is buttressed by the results of numerous scientific studies of atmospheric carbon dioxide enrichment: more than 3,500 sets of experimental conditions, involving some 550 plant species, to evaluate increases in biomass (dry weight) – and over 2,000 separate experimental conditions analyzing how 470 different plant species increased their rates of photosynthesis.

In several of these studies, scientists determined that 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 an amazing *50-80 percent*.

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

Non-food crops like cotton also fare much better when atmospheric carbon dioxide levels are higher. One study was conducted 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, combined with and three atmospheric CO_2 concentrations. (The temperature combinations were 77° F by day with 59° F at night, and 95° F by day with 77° F at night, corresponding to 25/15°C and 35/25°C, with 400, 600 and 800 parts per million of carbon dioxide at each temperature.)

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 uptake was 43 percent greater at 700 ppm than at 400 ppm for plants grown in a low-water setting and 79 percent greater for plants grown in a high-water environment – 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 for at least several days – which often 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. The real test involves food crops and other plants grown outdoors in normal fields, forests, meadows and prairies.

“Real-World” Studies

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. Those studies confirmed what researchers found in greenhouses.

- 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. The researchers concluded that reduced sensitivity to severe drought, arising from higher carbon dioxide levels in the atmosphere, 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 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, these gains occurred even though rising ozone levels (from cars and other sources) adversely affected growth.

For many animal species (including insects, reptiles, amphibians and mammals) habitats, ranges and populations have increased in recent decades, and much of this is due to rising atmospheric CO2 levels, many scientists believe. Other species have simply adapted to changed conditions. Forests and grasslands alike have increased their growth rates and biomass production, even where soil moisture and nutrients were less than optimal or insect predation was a problem.

Similar improvements were seen in food and other human crops.

Between 1961 and 2007, average U.S. corn yields increased by 240 percent, from 1.6 tons per acre per year to 3.8 tons per acre per year, while 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.

And the good news has continued. In August 2014, the U.S. Department of Agriculture forecast that the United States corn crop would exceed its 2013 record of 13.9 billion bushes, which itself was almost a billion bushels above the previous record. The USDA predicted that farmers would harvest more than 14 billion bushels in 2014. Experts attributed these incredible increases to steadily improving hybrid and GM seeds, fertilizers and pesticides, as well as to longer growing seasons, moderately warmer temperatures, more precipitation and higher atmospheric carbon dioxide levels.

Global corn production has also increased significantly in recent years, as have U.S. and worldwide yields for wheat, rice and soybeans.

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 seed, fertilizer, pesticide, irrigation and other agricultural 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 adverse impacts on wildlife and environmental quality will decline.

At the same time, the higher CO_2 levels have also improved the vitality of Earth's terrestrial habitats, resulting in a noticeable "greening" of the planet, including forests, grasslands and deserts.

Plant scientists believe this is likely to continue as carbon dioxide levels rise further, more than offsetting any hypothetical harm from global warming or changing weather patterns. Even if the world cools slightly, as some climatologists think is going to happen over the next few decades, more atmospheric CO_2 reduce the damage that would otherwise result from shorter growing seasons and reduction in arable farmland on a colder planet.

(The 2009, 2011 and 2014 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 CO2 Science Plant Growth Database lets people search for even more studies among the thousands of results that are listed there; see http://www.co2science.org/data/plant_growth/plantgrowth.php.)

Plant Responses to Higher CO_2 Levels

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.

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.

24 Things More CO_2 Helps Plants Do Better

Increasing amounts of CO2 in earth's atmosphere and the air in greenhouses –

- Augments the supply of the most basic of all plant foods (carbon dioxide) for forest, grassland, food crop and other plant species
- Improves plant nitrogen fixation and photosynthesis
- Increases vegetative "biogenic volatile organic compounds," further spurring photosynthesis
- Stimulates plant cell division, protein synthesis, productivity and overall plant growth
- Reduces stomata size, so fewer water molecules escape and there is less stress on plants
- Increases carbon gained in plant tissue per unit of water lost by transpiration
- Increases the production of glomalin, a protein produced by fungi living in symbiotic association with most of Earth's vascular plants (terrestrial and wetland species, including ferns and seed-bearing pants) that use specialized tissues to carry water and minerals through the plant)
- Increases the number, surface area and biomass of lateral roots and fine-roots
- These more extensive root systems help plants extract more water and mineral nutrients from the soil more efficiently, and absorb them into the plant structure and biomass
- Enables plants to produce more and larger flowers, which improve plant productivity and survival
- Improves overall soil quality and stability, by increasing beneficial soil organisms
- Improves the ability of plants to utilize soil nutrients and fertilizer through their roots
- Protects plants against pollution, heat and drought
- Improves plant resistance to diseases, viruses, pathogens and insects
- Helps plants recover more quickly from stresses imposed by prolonged dry spells
- Expands plant ranges and ground cover, reducing soil erosion
- Helps desirable crop and other plant species resist invasion by weeds
- Augments wood density in trees, making trunks and branches stronger and more solid
- Helps Earth become greener and more hospitable to wildlife

- Expands crop yields per acre, reducing the need to turn more habitat land into farmland
- Helps enhance quantity and quality of fatty-acids (lipids), for improved nutrition
- Increases the quantity and potency of vitamin C, antioxidants and many other health-promoting substances found in plant tissues, thereby improving dietary benefits for humans and animals alike
- Improves the production, quantity and bio-availability of health-promoting substances in medicinal or "health-food" plants
- Enhances food security for millions of people

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 that plants use to convert carbon dioxide into glucose and other carbohydrates which 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. Indeed, 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 mineral nutrients from the soil, obtain sufficient phosphorus when that element is in short supply in soils, and absorb these nutrients more efficiently into the plant structure, thereby increasing biomass.

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 toxics will build up in soil, while also increasing the overall stability of soil particles and other components.

More airborne carbon dioxide increases carbon in soils, stimulating microbial decomposition which makes more soil nitrogen available and counteracts potential nitrogen limitation problems. It also enables plants to produce more and larger flowers, which improve plant productivity and survival.

Rising CO_2 reduces the negative effects of ozone pollution that would otherwise adversely affect the photosynthesis, growth and yield of trees and agricultural crops. It helps plants overcome stresses caused by rising soil salinity, due to long-term irrigation.

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.

But is it possible that rising CO2 could cause ocean acidification?

It is sometimes suggested that human carbon dioxide emissions are making oceans acidic. In reality, Earth's oceans are not acidic; they are mildly alkaline – and most marine scientists say it is impossible for their vast volumes of water to become acidic, especially from mankind's fossil fuel combustion.

Making oceans acidic would require that seawaters change from their current mildly alkaline pH of 8.1 into the acidic realm, meaning below the neutral level of 7.0 on the 14-point pH scale. This scale is logarithmic, meaning each 1.0 change is ten times higher or lower than the previous number. (Most rainwater is mildly acidic, at pH 5.6, which refers to the "potential of hydrogen" or availability of hydrogen molecules in chemical reactions.)

What scientists have observed in the world's oceans is a decline of about 0.1 pH units since the modern industrial age began. At this rate, marine scientists say, it would take some 700 years for seawater to become even minimally acidic, due to human emissions. (Moreover, that assumes human CO_2 emissions will continue at their current rate, which is highly unlikely, since energy technologies change greatly over time, and fossil fuel use will likely decline over the coming decades and centuries.)

The effects of any pH changes on marine life are hard to determine, though it's almost certain that any impacts will be far from cataclysmic. The natural variability of oceanic pH levels over a few years or decades is often much greater than changes forecast by the Intergovernmental Panel on Climate Change and attributed to rising CO_2 levels in the atmosphere. Moreover, most aquatic life is extremely resilient and has survived, adapted to and thrived in pH fluctuations and other seawater changes spanning decades, centuries and millennia.

Finally, laboratory studies of seawater pH levels are generally unable to reproduce or mimic real-world oceanic conditions. They thus yield results that differ markedly from what is actually observed in nature. Concerns about ocean acidification therefore seem to be misplaced.

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 plants, food, and Earth health.

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 fete 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!

Sources

Jesse Ausubel, Iddo Wernick and Paul Waggoner, "Peak Farmland and the Prospects for Sparing Nature," *Population and Development Review*, vol. 38 (supplement), Population Council and Rockefeller University (2012), http://phe.rockefeller.edu/docs/PDR.SUPP%20Final%20Paper.pdf.

Robert M. Carter, *Climate: The counter consensus*, London: Stacey International (2010), pages 83-85.

Congress of Racial Equality, *Voices from Africa: Biotechnology and the subsistence farmer* (2005): a 20-minute video documentary about how biotechnology has increased crop yields, improved nutrition and incomes, and greatly reduced pesticide use for farming families in Kenya and South Africa.

Brian Fagan, *The Little Ice Age: How climate made history, 1300-1850*, New York: Basic Books (2000), especially Chapter 2, "The Great Famine," and Chapter 6, "The Specter of Hunger."

Indur Goklany, *Humanity Unbound: How fossil fuels saved humanity from nature and nature from humanity*, Washington, DC: Cato Institute (2012).

Craig D. Idso, *The Many Benefits of Atmospheric CO_2 Enrichment,* Science and Public Policy Institute and Center for the Study of Carbon Dioxide and Global Change (2010), presenting 55 ways in which increasing atmospheric CO_2 levels benefit Earth's biosphere: its plant, animal and human inhabitants. Summary at: http://www.co2science.org/education/book/2011/55BenefitsofCO2Pamphlet.pdf

Craig D. Idso, Sherwood B. Idso, Robert M. Carter, S. Fred Singer, *et al., Climate Change Reconsidered II: Biological Impacts,* Non-governmental International Panel on Climate Change, Chicago: Heartland Institute (2014), pages 13-161, 473-493, 822-833; http://heartland.org/media-library/pdfs/CCR-IIb/Full-Report.pdf.

Craig D. Idso, Robert M. Carter, S. Fred Singer, *et al., Climate Change Reconsidered: 2011 interim report of the Non-governmental International Panel on Climate Change*, Chicago: Heartland Institute (2011), pages 197-315, 333-335, 341-342; http://www.nipccreport.org/reports/2011/2011report.html.

Craig D. Idso, S. Fred Singer, *et al., Climate Change Reconsidered: The report of the Nongovernmental International Panel on Climate Change* (NIPCC), Chicago, IL: Heartland Institute (2009), pages 361-578; http://www.nipccreport.org/reports/2009/2009report.html.

(All three NIPCC volumes summarize the results of hundreds of studies by hundreds of researchers all over the world, on carbon dioxide, floods, droughts, and numerous other aspects of the science of global and regional climate change, CO_2 enrichment, global agriculture and other subjects.)

Roy Innis, *Energy Keeper, Energy Killers: The new civil rights battle*, Bellevue, WA: Merril Press (2008), pages 1-4, 33-55. (The role of affordable energy in advancing and protecting civil rights.)

Harrison H. Schmitt and William Happer, "In Defense of Carbon Dioxide: The demonized chemical compound is a boon to plant life and has little correlation with global temperature," *Wall Street Journal*, May 8, 2013.

Roy W. Spencer, *The Great Global Warming Blunder: How mother nature fooled the world's top climate scientists*, New York: Encounter Books (2010), pages 43-47, 124-138.

James M. Taylor, "Crop production sets records in 2014," *Environment & Climate News*, November 2014, page 3.

www.CO2science.org – the award-winning website of the Center for the Study of Carbon Dioxide and Global Change. Established to disseminate reports and commentary on new developments in analyzing and quantifying the climatic and biological consequences of rising carbon dioxide levels in the Earth's atmosphere, the Center publishes a weekly online magazine, *CO2 Science*, containing editorials on topics of current interest, as well as mini-reviews of recently published peer-reviewed scientific journal articles, books and other educational materials.

CO2 Science Plant Growth Database: lets people search for studies among thousands listed at http://www.co2science.org/data/plant_growth/plantgrowth.php

Online sources about carbon dioxide in Earth's atmosphere and in the photosynthetic process:

http://en.wikipedia.org/wiki/Carbon_dioxide_in_Earth%27s_atmosphere; http://hyperphysics.phy-astr.gsu.edu/hbase/biology/phoc.html; https://en.wikipedia.org/wiki/C3_carbon_fixation

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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.

Craig D. Idso is the founder and former President of the Center for the Study of Carbon Dioxide and Global Change. He has published peer-reviewed scientific articles on growing seasons, the seasonal cycle of atmospheric CO_2, world food supplies, urban CO_2 concentrations, and many other topics. Since 1998, he has been the editor and a chief contributor to the online magazine *CO_2 Science*. Dr Idso is the author of several books, the most recent of which, *The Many Benefits of Atmospheric CO_2 Enrichment*, details 55 ways in which the modern rise in atmospheric carbon dioxide is benefiting earth's biosphere. He has produced three video documentaries on carbon dioxide, climate change, and avoiding plant and animal extinctions, and serves as co-editor of the Nongovernmental International Panel on Climate Change (NIPCC). He is a member of the American Association for the Advancement of Science, Ecological Society of America, Honor Society of Phi Kappa Phi and other professional organizations.

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His articles have appeared in the *Wall Street Journal, Washington Times, Investor's Business Daily, New York Post, Houston Chronicle*, *Risk Management,* and other newspapers and magazines, and on news and opinion websites in the United States, Canada, Germany, Italy, Peru, Venezuela, South Africa, Uganda, Bangladesh and other countries.

Driessen's book, *Eco-Imperialism: Green Power - Black Death*, documents the harm that restrictive 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).

His 2014 eBook with Ron Arnold, *Cracking Big Green: To save the world from the save-the-Earth money machine*, presents sixteen shocking stories that expose the dark side of the multi-billion-dollar-per-year environmental movement and how it actually harms ecological values and people.

He was editor for *Energy Keepers - Energy Killers: The new civil rights battle*, by Congress of Racial Equality national chairman Roy Innis; *Rules for Corporate Warriors: How to fight and survive attack group shakedowns*, by Nick Nichols; and *Creatures, Corals and Colors in North American Seas*, by Ann Scarborough-Bull. His analyses have also appeared in *Conserving the Environment* (Doug Dupler, editor), *Resurgent Diseases* (Karen Miller, editor) and *Should Drilling Be Allowed in the Arctic National Wildlife Refuge?* (Tamara Thompson, editor), all part of the Gale-Cengage Learning "Opposing Viewpoints" and "At Issue" book series used in high schools and colleges; *Redefining Sovereignty: Will liberal democracies continue to determine their own laws and public policies, or yield these rights to transnational entities in search of universal order and justice?* (Orin Judd, editor); and other publications.

About the Publisher

The Committee For A Constructive Tomorrow (CFACT), founded in 1985, is a Washington D.C.-based non-profit public policy organization that works to promote market-based and safe technological solutions to domestic and international issues of environment and development.

CFACT's mission is "to enhance the fruitfulness of the earth and all of its inhabitants," It operates with an influential board of academic and scientific advisors; has an impressive "Collegians" educational program on U.S. college campuses; has been an active non-governmental organization (NGO) participant at United Nations conferences and summits; maintains a CFACT Europe branch, an international "Adopt-a-Village" program, and a Global Social Responsibility program; and has extensive media outreach through its award-winning Climate Depot news and information service and "Just the Facts" daily national radio commentary. CFACT is recognized as a tax-exempt, 501(c)(3) organization.

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