The Realities of CO_2: Seeing through the Smog of Rhetoric and Politics

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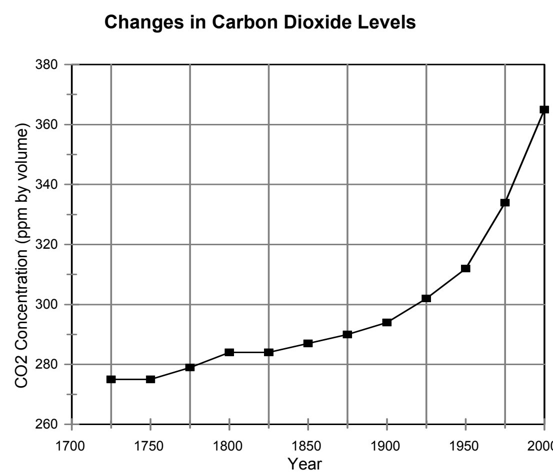
Global atmospheric changes and related climatic impacts are a topic of increasing concern. While no disciplined mind can rationalize that increases in the concentration of atmospheric carbon dioxide (CO_2) are not having an effect on the climate of the earth, just what the specific effects in any given location at any given point in time are as yet speculative, and probably incalculable. The fact, however, that the exact climatic relationships of the future are incalculable does not obviate the need to consider that there will be consequences for any policies or program approaches that are having measurable impacts on the physics, chemistry, and biology of the earth.

As is shown in the graph below (after Neftel, et al. 1994), there is no argument that atmospheric carbon dioxide levels have been rising steadily since the industrial revolution, and that the rate of change has risen exponentially since World War II. There is a general recognition that this is an untenable trend, but undisciplined thinking has led to spurious responses, policies, and programs to deal with the situation.

There are four common assertions that deserve to be examined. I believe that glib



acceptance of these assertions is leading to massive miscarriages of environmental policy and thinking. They are usually rendered somewhat as follows:

1. Tree planting can offset the use of fossil fuel and mitigate the impact on global warming by storing (sinking) carbon in the wood of the tree.

[1]This is an essay, not a refereed paper on the subject of carbon cycling. It comes from frustration I feel concerning the happy-talk about “carbon credits” and “carbon sequestration.” It is my hope that it will cause serious citizens to think beyond the rhetoric that is swamping the communications landscape and manifesting itself in both government and private information pieces. Our relationship with the earth and obligations to our posterity deserve better than that which is spilling from the pantheon of contemporary thinkers.

2. Burning in grasslands causes air pollution and contributes to global warming by giving off carbon dioxide.

3. The principal source of atmospheric carbon dioxide emissions is the internal combustion engine.

4. The burning of natural gas is the best alternative to the use of petroleum-based fuels.

1. "Planting trees can offset the burning of fossil fuel."

Fossil fuels include those that are derived from gaseous CO_2 that was "fixed" as hydrocarbon[2] some 250 million years ago in the Paleozoic period and, therefore, is surplus CO_2 in the atmosphere when burned (oxidized) in this era. Commonly used fossil fuels include coal, gasoline, diesel fuel, and natural gas.

Since it is possible to estimate the rates at which trees use (reduce) CO_2 in photosynthesis (figure 1), and since we know how much CO_2 is released when fossilized hydrocarbons are burned (oxidized) it is possible to approximate the number of trees it would take to offset the burning of fossil fuel.

If, for example, young trees are planted for the purpose of "sinking" CO_2, (removing CO_2 from the atmosphere), certain assumptions must be made. It reasonably can be assumed that young, vigorous, deciduous trees, will have an effective leaf surface of 10,560 ft^2 per tree. One then can estimate that each tree on the average, would "take up" (convert to hydrocarbon through reduction) about 25 pounds of CO_2 net each year in the North Temperate Zone.[3]

In order to calculate how many trees would be necessary to offset emissions, it is necessary to know that approximately 16 pounds of CO_2 are produced for each gallon of gasoline (fossil hydrocarbons) that is oxidized.[4]

Figure 1: *Photosynthesis*, a reduction reaction, is the process that "fixes" the carbon to store the food energy all living cells need. In photosynthesis, when 6 molecules of CO_2 + 6 molecules of water (H_20), with chlorophyll activated by light energy (about 675 kcal), are brought together in a special, enzyme-mediated chemical reaction, the result (in one common transformation), is a 6-carbon sugar. The reaction can be expressed essentially as follows.

$$6CO_2 + 6\,H_2O + \text{light}\ \ 6\ \ C_6H_{12}O_6 + 86O_2$$

Living cells obtain the food energy essentially through an opposite process, *respiration,* where the simple sugar, in the presence of oxygen, oxidizes and yields energy plus carbon dioxide and water.

$$C_6H_{12}O_6 + 6O_2\ \ 6\ \ 6CO_2 + 6\,H_2O + 8\ \text{energy}$$

[2] A hydrocarbon is a molecule in which carbon atoms are bonded together with other carbon atoms, usually in a single bond, into a carbon-carbon chain in which the other available bonds are prevailingly with hydrogen atoms. The "natural gasses" are relatively short, 1-4-carbon chains: methane, ethane, propane, and butane. Gasoline contains mostly 5-8-carbon chains: pentane, hexane, heptane, and octane. Diesel fuel, jet fuels, kerosene, and the like are multi-carbon alkanes of mostly 15 or more. Coal is mostly bulk organic carbon.

[3] It should be noted, that many if not most of the living cells of a tree are non-chlorophyllous, and that all of the cells of the tree must respire during the growing season, a process that uses oxygen (O_2) returns CO_2 back to the atmosphere. The remaining carbon is "stored," mostly as cellulose within roots and trunk, which is the non-living wood; it is this net creation of wood that we are saying incorporates the 25 lbs of CO_2 per year.

[4] This might seem like a great weight of atmospheric gas, but this is how it works: a gallon of gasoline weighs about 6 lbs and is about 80 percent carbon by weight. Hydrocarbons are made prevailingly of carbon-carbon atom chains with regularly attached hydrogen atoms. When the hydrocarbon is oxidized (burned), the hydrogen atoms are replaced by oxygen

So, how many growing trees does it take to offset the burning of fossil fuels? To make the calculations relatively simple, assume locally that there are about 3 million drivers in the Chicago region, each of whom travel 10,000 miles per year in cars that run at an average fuel consumption rate of about 25 miles per gallon. This is probably a conservative assumption, particularly since many motor vehicles languish idly at toll plazas and since the number of tractor trailer trucks seems to burgeon each year.. Twenty-five miles per gallon would yield about 0.63 lbs of CO_2[5] per mile, which is equivalent to about 40 miles per tree.

In the aggregate then, in one year, Chicago drivers will generate about 18.9 billion pounds (9.5 million tons) of atmospheric CO_2 gas. If the average tree takes up 25 pounds of CO_2 per year, then 756 million trees would need to be planted in the Chicago area alone to compensate for CO_2 produced from automobiles. In order to allow room for crown growth, one would have to allow 40 trees to the acre,[6] which means that one would need 18.9 million acres of land per year—50% of the size of the state of Illinois. Each of the drivers would have to plant 260 trees without using any fossil fuel in the process.

Also consider that when trees die and decompose, most of the fixed carbon is liberated as CO_2. Thus the trees must either live and grow forever or be buried deep in into the ground where the carbon can be stored; each tree that dies must be replaced without the use of fossil fuel and Illinois would have to comprise more acres of available space for tree planting each year.

Some programs seek to "offset carbon emissions" by setting aside stands of existing forest with the noble motive but spurious idea of protecting the "stored" carbon of this era. There are absolutely crucial reasons for protecting our remnant wooded lands but their appointment as offsets for continued carbon emissions cannot be one of them.

Trees, as all living things, are priceless and important elements of the landscape, but to suggest that planting them results in any practical compensation for the profligate oxidation of fossil fuel does not take into account the fact that, in the Temperate Zone at least, their wood is an integral component of the contemporary carbon cycle.

2. "Grassland fires cause air pollution."

Year by year, healthy perennial grasslands "fix" more carbon below the ground than is decomposed. Most of that which is fixed above the ground in leaf and stem tissue is returned to the atmosphere during the grassland burn as water vapor, light, and CO_2—CO_2 that was fixed in our current era (post-glacial or Holocene), not the Paleozoic as is the case with fossil fuels. Given the fact that more carbon is fixed than burns or is decomposed after a growing season, there is a net removal of CO_2

atoms so that each carbon atom is separated from all the others and heat is released. Oxygen atoms are quite heavy in relation to hydrogen atoms, so the resulting product is water vapor and 16 lbs of CO_2. This rapid oxidation, or burning, is essentially the same chemical transformation as respiration (see figure 1.)

[5] There are also a lot of other toxic compounds generated from the oxidation of a gallon of gasoline in an internal combustion engine, such as oxides of nitrogen, carbon monoxide, and various incompletely oxidized hydrocarbons—some of them quite toxic, but the essential point here is not affected.

[6] A acre is 43,560 square feet, or a square about 209 feet on a side. In one commonly used "standard forest planting," the spacing recommendation ranges from 908 to 1210 trees per acre! The same specification specifically recommends using a "machine" to do the planting—which no doubt uses fossil fuel.

from the atmosphere every year.[7] The "smoke" is composed largely of CO_2 and water vapor. Generally, the more opaque the smoke, the greater the proportion of water vapor. The removal of atmospheric CO_2 is optimized in those grasslands that burn after each growing season, because the surface-area development of green leaves (photosynthetic surface) is maximized for the following year.

Trees in the Tall-grass Prairie biome are not generally the forms of life in which carbon is tied up in net amounts. Rather, the most abundant source of stored carbon in the prairie biome is soil organic carbon (SOC) that accumulates in the upper soil layers over the course of time. The organic-rich soils of Burnham and Powder Horn prairies near the south side of Chicago, for example, date back about 2800 years.[8] Their organic content was calculated to have accumulated at a rate ranging from 266-1225 pounds per acre per year.[9]

This accumulation rate is dependent on several factors, not the least of which is the wetness of the soil and the presence of deep, well developed fine root systems, such as is typified by grassland vegetation. Generally, the wetter the soil, the greater the rate of soil organic carbon accumulation, since decomposition generally occurs at a lower rate in a shortage of atmospheric oxygen. This organic carbon consists mostly of the residual, undecomposed material of the dead root systems of fibrous-rooted species such as grasses and sedges, which grow about a third of their living root system every year.[10]

The photosynthetic (reduction)/respiration (oxidation) chemistry is essentially the same as described for the trees, but there is little or no lignified (woody) tissue resident in the grassland system. It is from this post-glacial soil building process that the deep black soils of the Midwest developed. Indeed, these soils are the original reason why our agricultural productivity has been so fecund,[11] however temporarily.[12]

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[7] The limiting factors in the amount of carbon fixed per year include the growing season length, the amount of leaf surface per unit area, humidity, the average daily temperature, and the amount of available atmospheric CO_2 at ground level, which can drop to 0 on a July day at noon. Generally, a regularly burned grassland can fix as much as 3.5 to 4 tons of dry organic carbon above the ground per acre per year—and maybe half that in its fibrous root system.

[8] This coincides with the formation of the low sandy lakeplains that developed after the last glacial lake stage, Lake Algoma, which drained away about 3000 years ago.

[9] The organic-rich soils of these lake plain prairies illuminate the post-glacial history of carbon cycling near Chicago. Cores were analyzed for the carbon content to help reconstruct the vegetational history and carbon budget of wet prairies. A ^{14}C age of 2,805 ± 125 years B.P. from the basal muck of the Burnham Prairie at a depth of 14 cm dates the onset of wet prairie conditions and storage of carbon in the soil. Ash content of the muck ranged from 46.6–86.5%. The carbon content was calculated as 0.06–0.24 g/g of dry sediment, or about 50–230 kg of carbon/ha/year. Charcoal occurrence throughout the muck attests to the fact that the plant communities had been burned regularly, thereby cycling the phytomass to CO_2 and charcoal. Intense recycling of carbon by decomposer fauna is indicated by the dominance of fecal pellets and fungal hyphae in the organic residues and the absence of remnant pollen in the muck soils.

[10] Generally, grassland root systems in the prairie biome turn over about a third of their root system every year, a third growing and a third dying.

[11] In recent decades, of course, we have "improved" corn genetics and developed an ability to, at great cost, bring nutrients and water to worn out land in sufficient amounts to convince ourselves that increasing productivity from 40 bushels of corn per acre to 200 is progress—the presumption being that there will always be a "scientific" miracle available to mitigate the illusory but unsustainable endeavor of commodity food production.

[12] The NRCS has estimated, for example, that across the state of Iowa, the topsoil averaged 18 inches in

Insofar as the long-term health and well-being of our economy and the world's ecological integrity is concerned, there is no sustainable antidote to the continued widespread burning of fossil fuel. For each acre of native grassland, however, particularly where fire is a regular occurrence, there is the possibility of storing up to 2,500 or more pounds of organic carbon each year—equivalent to about 150 gallons of oxidized gasoline.[13]

Currently the default alternative to deep-rooted perennial grassland in many unpaved landscapes is the turf-grass lawn. The usual management or maintenance in such landscapes is to mow 2-4 times per month, which burns about 1 gallon of gasoline per acre per mowing event in engines that, in most states, are not even equipped with a catalytic converter.[14] In a 36-week growing season that includes 18 to 36 mowings per year, 288 to 576 pounds of CO_2 per acre are emitted into the atmosphere. For every acre of the same landscape converted to native grassland, there could be that much less CO_2 burned; indeed, carbon would be sequestered.

In addition to water vapor, energy, and CO_2, the exhaust emissions of a lawn mower contain many toxic oxidation products, including polycyclic aromatic hydrocarbons and many of the same emissions that are prohibited from the exhausts of today's automobiles. By contrast, the emissions from grasslands, particularly those that burn annually, are negligible. The emissions from raked up piles of leaves, however, present a witch's brew of foul toxicants owing to variations in combustion temperature, oxygen availability, and moisture content. It is far cleaner to let the leaves lie in a thin layer and run a fire through them during the late fall.

3. "The burning of fossil fuel is primarily responsible for atmospheric increases in carbon dioxide."

While the profligate use of the internal combustion engine generates progressively greater concentrations of atmospheric inorganic carbon, it is not by any means the only source. Another is the practice of row-crop agriculture in soil that, with tillage or cultivation, annually oxidizes more soil organic carbon than is fixed every year. This is because in row-crop tillage the soil is turned over and the natural oxidation or "burning" of SOC by soil microorganisms is stimulated (Reicosky et al. 1999).

Reicosky (1998), for example, found that one pass of a moldboard plow caused 5 times as much CO_2 to be lost from the soil in a 19-day period than if plots were left untilled—representing the loss of more organic matter than was fixed all the previous year. In twenty studies in which the moldboard plow was used, the SOC was reduced by an average of 256 pounds per acre per year.

By contrast, in 10 other long-term studies where no-till practices were used, and much of the dry above-ground vegetable matter was allowed to lie, organic matter increased, with an

1840, right after most of the Indians had been "removed." By 1990, 10 inches had been lost to wind and water erosion, and of the remaining 8 inches, half of the tilth was gone. More ground has been lost since then. Good tilth is largely correlated with organic matter content, which once ranged as high as 25% or more in arable soils. Many farm fields today have less than 5%—if they have any topsoil remaining at all.

[13] The amount and rate of storage is quite variable, dependent upon many factors such as annual average temperature, soil wetness, soil type, slope aspect, etc.

[14] Chronic mowing keeps the leaf surface area unhealthy and at a minimum photosynthetic area for grass survival, severely retarding root system development.

average increase in soil organic carbon of 953 pounds per acre per year.[15]

On the average, oxidation of one pound of SOC forms 3.7 pounds of CO_2. Soil organic carbon is essentially a fossilized form of carbon that is stored in the topsoil. The carbon fixed in stems, leaves, and grain is carbon from the current year and is eventually returned to the atmospheric cycle. If the average row-crop field has a net loss of 250 lbs SOC/acre/yr, then the surplus CO_2 given off to the atmosphere is 925 lbs/acre. From the earlier discussion we can calculate that a car driven 10,000 miles annually at 25 mpg, produces approximately 6,300 pounds of CO_2. This equates to the weight of carbon produced in one year of row cropping 6.8 acres.

4. "Natural gas is the best available alternative as an energy sources."

It is often stated that natural gas, a fossil source of fixed carbon, is the long term solution to our energy problems. The assertion is usually stated in combination with the prediction that alternative sources of energy ". . . will never be sufficient to meet our growing needs."

To say that there will never be any replacement for any existing technology is utterly without vision. Consider similar apocryphal allegations such as "we will never have an economically viable replacement for candles." Or, "Any vehicle that goes more than 60 miles per hour will suck the wind out of a human being." Or, "Why would we want something that can merely fly from one end of the cow pasture to another." Then, later, "We will never be able to fly an airplane through the sound barrier."

[15] These accumulation figures do not take into account the gallons of fossil fuel burned to plant, fertilize, herbicide, pesticide, and harvest the fields.

Little in life is more wrong than the prediction that some particular product of the moment is the end of the line in technology and development. Certainly, natural gas oxidation is much cleaner than the combustion of petroleum-based products and most people agree that, with today's technologies, nuclear energy has shown itself to be an untenable solution. Still, the oxidation of natural gas adds surplus CO_2 to the atmosphere—which, of course, will continue our run toward an unsustainable, unpredictable, environmentally risky and probably economically debilitating future.

Summary

Î Planting trees or setting forests aside cannot offset the oxidation of fossil fuels because fossil carbon represents stored carbon from another era. Such organic carbon is converted to CO_2 in surplus amounts. Trees and vegetation of this era already are cycling carbon into the atmosphere at a rate and concentration to which contemporary life forms are adapted. Relatively sudden changes in atmospheric chemistry, such as we are seeing today, impose global system constraints at a rate to which most life forms have difficulty adjusting during their life spans and physiologic development; most cannot adjust at all. These rapid macrohabitat system changes are not in synchrony with other systems such as day length, genetics, physiology, and chemistry.

Ï Burning grasslands dominated by warm-season native grasses is a relatively clean burn in that the principal oxidant is CO_2 that was fixed in just the last year or so and is, therefore, part of the contemporary cycle. Many such grasslands that grow in loamy soils actually accumulate carbon, by sinking it in the deep black soils that develop under mid-grass to tall-grass prairies.

Those who seek to burn raked up piles of leaves in the Fall should be made aware that they risk diminishing the health and well-being of themselves and their neighbors. The annual, one-time event of grassland combustion, however, is not only a clean burn but one that contributes positively to air quality by facilitating the grassland's removal of net amounts of CO_2 from the atmosphere.

Đ The internal combustion engine and coal-fired utilities get the overwhelming attention when policy makers focus on atmospheric CO_2 increases and certainly they comprise a large proportion of the problem. But we cannot blithely ignore the contribution of mechanized row-crop agriculture in which tons of carbon, once fossilized in the deep black soils of the nation's arable land, are "burning" off every year, which means that row-crop agriculture is a major contributor to air pollution.

I do not know what the proportion of the world's "green house gasses" are emitted by row crop agriculture, but I suspect that it is progressively less than in times past, at least in North America. We have been extremely efficient in destroying the tilth of our soils over the last century. Many of North America's original soils had 20-30% organic matter at the beginning of European settlement, and in most areas near all of this has "burned" down to 5% or less—even as more and more quantities of petroleum products are being oxidized.

Ñ The burning of natural gas, while relatively clean, still converts carbon-hydrogen molecules fixed in another era to CO_2 molecules in excess of those in the contemporary atmosphere. It is a short-term alternative to be considered but its use must not relieve policy makers of the concern over atmospheric CO_2 level increases.

No amount of "happy talk" and half-baked science can get around basic physical laws. While the arithmetic values and examples drawn above are necessarily simplified, it is clear that casual attention to the consequences of our behavior does not diminish the realities of the global carbon cycle. The politics, demagoguery, and ignorance that cloud most important subjects in the North American dialectic may be beneficial to a few in the short term, but attempting to flimflam nature is another issue. Adjusting models, rates, and theories does not relieve the need to be attentive to reality.

To whatever degree we are embarked upon unsustainable approaches to energy, or any other aspect of economy, we should, in an organized but determined way, seek to understand and develop sounder approaches, so that our economy and well being will prosper for all in the long-term. The alternative to disciplined thinking and attention to the realities is that the earth itself will terminate any unsustainable behaviors in its own way, which is likely to be "insensitive," if not Draconian, to all parties involved. Even the purveyors of spurious solutions have children and grandchildren for whom it is hoped they care more than for their product of the moment.

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