# Composting and Climate Change;
# Opportunity in A Carbon Conscious World

**By David Sutherland Hill, © 2008**

There is little doubt in the educated world today that the climate of the Earth is changing. We might debate whether these changes are occurring due to anthropogenic (human) activities, or whether they are the natural result of biogenic activities and geological, astronomical, and physical phenomenon. But change is occurring, and there is substantial evidence that human activities are a major influence precipitating and accelerating this change.[1]

Current levels of $CO_2$ in the upper atmosphere and methane in the lower atmosphere are noticeably higher than at any time in the previous thousand years, and there is new evidence that current levels are higher than at any time in the previous six hundred and fifty thousand years[2]. More importantly, the current increase can be traced over a period of time beginning in approximately 1750, around the earliest start of the Industrial Revolution, and accelerating dramatically over the last 50 to 70 years in conjunction with increased population, technology, and energy demands.[3] (See Figure 1.) Previous to 1750, UA (upper atmospheric) $CO_2$ levels averaged consistently about 260 to 270 parts per million (ppm) by volume. Today UA $CO_2$ levels are approaching 400 ppm and levels are climbing at a much faster pace than at any time in the past 250 years.[4] The rate of acceleration has increased notably since 1960, and, since 1990, has increased significantly again. At the current pace, we will reach levels of 500 ppm of $CO_2$ in the upper atmosphere by 2050.[5]

To understand the importance of this increase, we must briefly examine how climate works. Figure 2 shows a simplified view of the carbon-cycle as it existed prior to 1750. Carbon, the basis of life on Earth, is available in finite quantities. We cannot create more. There is only what exists. So, much as other finite substances such as nitrogen, sulphur, and phosphorous, carbon is recycled through the bio-, geo-, and eco- systems of the planet. Plants pull carbon dioxide from the lower atmosphere, using the carbon to build sugars and starches and giving off oxygen as a bi-product. Animals (including humans) respire the oxygen and exhale carbon dioxide as a bi-product. Deceased organisms (plants and animals) release their carbon in chemical and bio-chemical decomposition, as carbon dioxide or methane ($CH_4$) depending on whether the reactions are aerobic or anaerobic, and as volatile organic compounds (VOC's) in both pathways. This occurs both on land and in the seas. In the oceans, organisms that are not eaten sink to the bottom after death, where they gradually decay releasing carbon compounds that rise to the surface and are volatilized on contact with the atmosphere. Significant amounts of methane are trapped beneath the ocean floor as decaying masses are covered by silt and sand. Inorganically, carbon is converted to carbonate with calcium to create shells, and limestone, and several other minerals. Organic matter which is trapped in areas where rapid biological decomposition does not occur, eventually – over eons – becomes fossil fuels. All life is fueled by incoming solar radiation. In fact, the incoming solar radiation is enough to make our planet's surface much warmer than it is. Venus, for example, has a surface temperature of 500 degrees Celsius.[6] It is our layers of atmosphere, and the composition of those layers, that allow enough solar energy to be reflected from the surface and escape back into space to maintain our surface temperature profile in a relatively comfortable range.

Energy is reflected from the surface as infrared radiation, and how effectively it is reflected is largely determined by the nature of the gases it must pass through. Gases are either transparent or opaque to various types of radiation. Transparent means that a given radiation can pass through the particular gas molecules with no inhibition or interference. Opaque means that a given radiation will be inhibited to some degree by a given gas molecule. For example, carbon dioxide is opaque to infrared radiation. Gases that are opaque to energies reflected from the Earth's surface are said to be "greenhouse gases (GHG's)[7]. While carbon dioxide is far from the worst of the greenhouse gases in this regard, it is opaque to several other GHG's. Consequently, increased levels of carbon dioxide in the upper atmosphere act as a blockade, and result in increased percentages of other GHG's such as methane and nitrous oxides in the lower atmosphere. These trapped gases act as an increasing barrier, slowing reflectivity and keeping more radiated heat energy in the lower atmosphere longer. Why is Venus so hot? Because it's atmosphere is almost entirely carbon dioxide. Consequently a much higher percentage of hot solar radiation remains in Venus' lower atmosphere continuously[8] because the $CO_2$ keeps it there. Climate is basically an expression of the relationship between the rate of incoming solar radiation, the rate of infrared reflection, the amount of infrared reflection that is retained in the lower atmosphere, and the amount of time that reflected radiation is retained.

A balance is achieved between energy in, energy out, and energy retained. Climate is the expression of that balance. On Venus, balance has been achieved at 500 degrees Celsius. On Earth, the balance for most of the last eon has been approximately 20 degrees Celsius.[9] The above explanation is, of course, greatly simplified. Other factors such as the Earth's rotation, its angle of orientation, and its position in its elliptical orbit relative to the Sun, are important factors in determining climate in any given period of time. Historically, climactic change occurred when geological events impacted carbon levels. For example, major volcanic eruptions would release huge amounts of carbon as ash and lava. This is carbon that previously was not part of the above referenced carbon cycle. This carbon was locked beneath the Earth's surface, or "sequestered". Prior climate changes were caused almost entirely by geologic or astronomical events, and by the physical factors such as tilt and orbital location mentioned above. The activities of man were not a factor. However, carbon dioxide levels have risen 42% to 45% since 1750. That means many billion tonnes of carbon have been added to the cycle. If humanity is the cause, we should be able to isolate and quantify the activities supplying the carbon.

Figure 3 is a representation of the carbon cycle with anthropogenic activities added. You see three major additions : the burning of fossil fuels, mechanized agriculture, and deforestation for development, alternate land usage, and timber needs. In the modern world, quantifying these levels can be done with relative ease and accuracy thanks to record keeping and computers. This is especially true of fossil fuel burning. We know very accurately, for example, that about 7.8 billion tonnes or 7.8 gigatonnes of carbon are emitted from fossil fuel burning each year.[10] With agriculture and deforestation there is less certainty and more debate on the numbers. Deforestation eliminates plants that were previously capturing atmospheric carbon dioxide. It allows much soil carbon to be lost due to erosion and soil disturbance during construction projects. Mechanized agriculture routinely strips soil organic carbon during tillage activities, replacing the organic fraction with inorganic fertilizers. Current studies range in deforestation carbon loss estimates from 2 gigatonnes to 5 gigatonnes annually[11]. Concurrently, agricultural carbon emission numbers are estimated at 5.1 to 6.1 gigatonnes of carbon dioxide equivalents (2005)[12]. However, while some scientists support the concept that agricultural carbon loss is largely offset by agricultural carbon input[13], there is very limited evidence to this effect and much disagreement. Even if a relative balance between agricultural losses and gains is being achieved currently, the amount of carbon lost prior to this achievement from agricultural and deforestation practices must be considered separately and has not been balanced. It is possible to calculate the scope of the overall soil carbon loss by measuring soil organic content over a given period of time. For example, average soil organic content in the agricultural sections of the US measured six percent to eight percent in 1920.[14] By the year 2000, the average was two percent to three percent organic matter, and much of the soil was measuring less than one percent organic matter. This loss is measured in only the top metre of soil, but calculated over the hundreds of thousands of hectares involved, the totals are substantial.

For example, in 2002, 434,160,000 acres of US land were in agricultural use[15], with 302,700,000 actually in cropland with the remainder in use as pasture and animal production areas. That is approximately 122,500,000 hectares in use as cropland. It is true that carbon loss occurs in the pasture land and livestock production areas as well, but for our purposes, the crop land – the tilled land – will be a sufficient example. By using the top metre over the above area (122.5 million hectares or 1.225 trillion square metres), a volume of 1,225,000,000 cubic metres can be calculated. Soil typically weighs 1.0 to 1.2 tonnes per cubic metre.[16] Using 1 tonne per cubic metre for convenience, we calculate that the first metre of depth in the above farmland contained 1.225 trillion tonnes of soil. When this soil contained eight percent organic matter, the total organic matter equaled 98 billion tonnes. At a level of three percent, the organic content equals only thirty-seven billion tonnes. That means that 51 billion tonnes of carbon rich compounds have been stripped from the soil and added to the carbon cycle since 1900 just from the croplands of the USA. Certainly some of this carbon has been returned through new plantings. Additionally, in the early part of the twentieth century more acreage was in grasslands, and total cropland usage was certainly less earlier in the century. These factors would decrease the above number. However, carbon losses from erosion and land usage changes as we built our cities and parking lots would have added additional tonnes of carbon to the loss. Suffice it to say that the number of tonnes of soil carbon lost in the US is substantial.

The IPCC estimates that 1,405 million hectares of cropland exist worldwide.[17]
Although most EU countries have acted more responsibly toward soil carbon than the US, the same problems and events have occurred, albeit to a lesser extent. Nevertheless, it becomes obvious that the number of tonnes of carbon lost on a worldwide basis to agriculture and alternate land usage is very large and very significant. In a widely accepted study published by R. Lal of Ohio State University, the total loss from agriculture and land use conversion since the beginning of the Industrial Revolution is estimated at 136 billion tonnes, plus or minus 5 tonnes.[18] (See Figure 4.)

These numbers make it obvious that fossil fuel burning is only part of the anthropogenic impact. But we must have food, and we must have fuel to produce and transport that food. Understanding and acknowledging the role of soil carbon losses in the greenhouse gas emissions problem, presents a fantastic opportunity.

In a recent study published in Waste Management and Research, Favoino and Hogg calculated that an increase of only 0.15% in organic carbon in the arable soils of Italy would offset all fossil fuel emissions from that country for one year.[19] Similar studies have shown 0.15% to 0.45% increases in organic carbon in arable soils would have a similar positive impact in most industrialized countries. Lal calculates a sequestration potential of up to 1.2 gigatonnes of carbon per year in croplands, range and grass lands, and degraded and desertified soils. [20] If this sequestration could be accomplished in conjunction with energy conservation practices, the impact would be significant. The IPCC concludes that 89% of the potential mitigation of agricultural emissions comes from increased soil carbon sequestration techniques.[21] Favoino and Hogg recommended building the stable organic fraction of soil by adding mature composts and manures.[22] Many other scientists are reaching the same set of conclusions. While we must continue to decrease the burning of carbon – including biofuels, and while we must continue to develop alternative energy sources and emission reduction strategies, offsetting current emissions by carbon sequestration may be the only viable way to slow the effects of climate change and provide an additional time frame for the development and implementation of new energy technologies, strategies, and practices. And the most obvious and attainable sink for that sequestration is the soil.

Carbon sequestration then becomes a major opportunity, but with several challenges. Where do we get enough carbon? How do we process it in the least emissions-intensive ways with the most organic carbon retained? How do we make an end product stable and mature enough, fast enough, to be part of the solution to emissions rather than part of the emissions problem?

The waste industry has access to significant amounts of carbon. The EU generates more than 1.3 billion tonnes of waste annually,[23] and the US another 1.4 billion.[24] In the EU, as much as 40 percent of that waste is estimated to be typical organics, with another 15 percent to 20 percent consisting of carbon rich paper products and paperboard.[25] Obviously, not all of that material is separated and contaminant free, but a significant portion is clean and available, and should be processed to stable, sequesterable forms. Safely sequestering just one fifth of the carbon-rich waste materials in the EU could constitute as much as 20 to 30 million tonnes of carbon, and 70 to 100 million tonnes of $CO_2$ equivalents.

Processing these materials in modern, energy efficient and cost efficient methods is the true challenge. There is much research into new methods of stabilizing carbon in various waste materials and storing it in the earth, simply to limit the quantity of carbon that can be added to the carbon cycle. These include various forms of pressurized treatment, pyrolysis, and chemical treatments. Over the next several years, it is probable that many of these technologies will be fully developed, proven, and implemented. But what about now? What can the waste industry do currently to offset its own emissions and perhaps the emissions of other generators as well? One of the obvious possibilities is stabilization of the carbon using the composting process. However, it is essential that this process be examined to determine the true value of its role in a carbon conscious world, and if that value can be improved.

Existing composting methods have not changed noticeably in thirty years. They require excessive burning of fossil fuels, produce unacceptable levels of odours unless only the most benign materials are processed, and continually emit carbon as carbon dioxide and a host of volatile organic compounds (VOC's) such as ketones and aldehydes. Therefore composting must be examined in two ways. First, in terms of the emissions produced by fuel consumption in the machines and equipment utilized in the process, and second, in terms of the carbon lost from the materials themselves as $CO_2$ and VOC's.

Work is currently underway among several major consulting firms toward the creation of models for $CO_2$ equivalents produced in various types of composting. At least 2 of these models should be completed by early 2009. My own research conducted on 3 UK sites and 4 US sites indicates that a range of 300 to 530 tonnes of $CO_2$ equivalents are produced by fossil fuel burning for each 25,000 tonnes of materials composted.[26] This number, however, represents only a minor portion of the carbon emitted by and during the process itself. One study is currently underway testing initial carbon content of the incoming materials and final carbon content of the outgoing composts in 4 different types of processes involving the composting of green wastes alone and green wastes with minimal amounts of source separated fruits and vegetable wastes. Samples will be collected at different times of the year from each facility and in sufficient number to provide acceptable levels of data. I am a co-author of this study which we hope to conclude no later than September, 2009, and publish early in 2010. While this study is far from complete, early numbers indicate that standard windrow processes lose 55% to 75% of the carbon in their incoming materials , and vessel processes and aerated static pile processes lose 45% to 60% of the carbon in their incoming materials, prior to consideration of emissions from fuel burning.

While more data and analytical test results are essential in proving this postulation, mathematics can provide a reasonable model for consideration. In the following example, incoming numbers are estimates based on the opinions of the compost producers. Outgoing numbers are actual values, based on third party analytical test results provided by the producers.

Using a 25,000 tonne per year model, the four producers involved, estimated annual average starting carbon to nitrogen ratios of 25 to 1 with an average of 1% nitrogen. One percent of 25,000 tonnes is 250 tonnes of nitrogen. Using a C to N ratio of 25 to 1, carbon would then account for 6250 tonnes. 4 different sets of final analytical numbers were collected from each processor and checked for final C and N content. The average final N content was 0.9 % with a C to N ratio of 14 to 1. Weight loss from water and volatilization averaged 21% at the 4 facilities. Consequently, the final weight of total material recovered is calculated at 19,750 tonnes. Therefore, if N equals 0.9 %, total N equals 177.75 tonnes and total C equals 14 times that amount or 2,488.5 tonnes of carbon. If the operators are accurate in their assumptions, this will represent a loss of 3,761.5 tonnes of the starting carbon and a net loss of 1,273 tonnes of carbon for each 25,000 tonnes of incoming materials. This is a loss of just over 60% of the total carbon with a retention rate of just under 40%. Current windrow composting methodologies may very well prove to be generators of greenhouse emissions rather than providers of carbon credits.

In the past, the EEA, the USEPA, and the IPCC[27] have considered this loss to be biogenic. But that attitude is changing. A closer examination of biodegradation of equivalent materials in natural surroundings suggests a much lower loss of carbon due to the insulating qualities of native covers such as leaves or other matter over the detritus, and the slower speed and uninterrupted cycles of the process in nature.[28] Indeed, in the ongoing study mentioned previously, we will undertake to measure carbon loss in similar materials decomposing in varied "natural" environs as well as in compost.

Nevertheless, the purpose of this document is not to suggest the elimination of either windrow or in-vessel composting, but rather to suggest that a tremendous opportunity exists to improve these processes with regard to carbon husbandry. When the existing methodologies of these processes were devised, carbon sequestration was not a consideration or even one of the determining factors. Odour, sterilization, and speed of reasonable stabilization were the main considerations. Now, in a carbon conscious world, we must re-examine the efficacy of the very rules and principles on which these processes are founded and explore the possibilities for improvement.

While the length of this paper does not allow investigation into all forms of composting, we will take a brief look at windrow composting. In a study of emission rates from a windrow composting facility in 2005, Columbia Analytical Research and Testing concluded that 75% to 85% of all emissions occurred during the first 15 days of the process.[29] A 2007 study by the California Integrated Waste Management Board[30] showed that 80% of green waste VOC emissions occurred during the first 14 days and 70% of food waste VOC emissions occurred in the first 14 days. They also showed emission increases averaging 200% on days when the material was turned. Nevertheless, the proscribed methodology both in California, in most of the rest of the US, in the UK, and most of the EU is 3 turns in the first 15 days. In my research of the subject I was able to locate 4 credible studies and one compilation where windrow turning at various levels was compared to reduced turning or no turning[31]. In separate and independent studies, Michel, Hazelburn, and Richards proved definitively that turning is not a source of aeration unless it is repeated every three hours, a frequency that is self defeating as it does not allow sufficient gestation time for bacteria and fungi between turns. In these same three studies plus a study by Hepperly and a compilation by Jenkins, no advantage other than speed of processing was gained by turning. Hepperly showed that speed can be equaled with much diminished turning by proper pile construction and certain mineral additions, and my own research[32] has definitely proved, that speed can be accomplished by direct seeding of specific carbohydrates and enzymes, and use of the repelling qualities of cationic cellular units to enhance porosity. I was able to find dozens of papers mentioning that turning was essential and that more frequent turning was necessary early in the process. But not one of these papers used a control and compared the results of more turning versus less turning, or provided any evidence to support their assumptions.

It is a common perception that frequent turns are essential for pathogen and weed seed destruction. While I was unable to find a definitive study proving that 3 turns was better for pathogen kill than 1 turn or 2 turns or no turns, I was able to find several with results indicating that the excess heat from turning actually decreased pathogen elimination in the material by limiting diversity and eliminating many species that would normally successfully compete with pathogens for resources.[33] Additionally, Hepperly and Ziegler-Ulsh, in their comparative study, definitively showed better pathogen kill on one turn per month than on one turn per week.[34] Finally, every one of my own research sites is achieving PAS 100 pathogen kill standards with no turns in the first four weeks.

This brief research should be sufficient to prove that there is much work to be done concerning improving windrow composting methodologies, and that substantive research comparing current methods with other possibilities is essential. I mentioned my work with cationic cellular units and carbohydrate and enzyme availability. I have also begun research on development of a fabric that is transparent to oxygen on the outside but opaque to carbon dioxide, methane, and some VOC's on the inside. Such a fabric, if successful, could be used as a cover or as roofing material in a vessel or building. Other scientists are exploring other avenues, and, as our understanding of microbial activity and growth increases, and our research equipment and techniques improves, it is likely we will have many new methods of controlling and maximizing decomposition and carbon retention.

Although this paper has focused on windrow composting methodologies, it is equally important that forced aeration and vessel systems be evaluated for carbon retention as well. Improvements in these technologies are equally essential. They can be as simple as always pulling air down rather than pushing air upward. One aerated static pile facility in the United States is currently powering its aeration pumps with energy generated by recovered heat from the piles. This is accomplished by pulling oxygen down through the mass and collecting the condensed hot water and hot air for energy production.[35] This process automatically limits external carbon emissions by pulling them inward rather than forcing them outward. It is a short step from that current process as implemented, to recovery of the carbon in the hot air and water for reintroduction to the composting mass.

Because it has access to such vast amounts of carbon, it is in the interests of the waste industry to play a pivotal role in the development and implementation of these new technologies. In addition to the positive impact effective sequestration will have on the environment and climate, the financial rewards may be considerable as the carbon offset market grows and develops. As responsible citizens, and as responsible business people, we have an obligation to devise and develop waste processing technologies with the greatest rate of carbon recovery, and waste processing technologies with the least carbon footprint. Reasonable answers and new methodologies will become available with continued research. The waste and composting industries should be driving that research, and championing carbon conscious improvements. Change will not come without costs, but with these costs will come tremendous opportunities, and tremendous rewards.

# Notes

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