The New York Review of Books

Volume 50, Number 8 · May 15, 2003

Review

What a World!

By Freeman J. Dyson

by Vaclav Smil

MIT Press, 346 pp., $32.95

It is refreshing to read a book full of facts about our planet and the life that has transformed it, written by an author who does not allow facts to be obscured or overshadowed by politics. Vaclav Smil is well aware of the political disputes that are now raging about the effects of human activities on climate and biodiversity, but he does not give them more attention than they deserve. He emphasizes the enormous gaps in our knowledge, the sparseness of our observations, and the superficiality of our theories. He calls attention to the many aspects of planetary evolution which are poorly understood, and which must be better understood before we can reach an accurate diagnosis of the present condition of our planet. When we are trying to take care of a planet, just as when we are taking care of a human patient, diseases must be diagnosed before they can be cured.

The book has two themes, a major and a minor one. The major theme is the description of the biosphere. The biosphere is the interacting web of plants and rocks, fungi and soils, animals and oceans, microbes and air, that constitute the habitat of life on our planet. To understand the biosphere, it is essential to see it from both sides, from below as a multitude of details and from above as a single integrated system. This book gives a comprehensive account of biological details and a summary of the global cycles of matter and energy that tie the system together. Every detail and every cycle is documented with references to the technical literature. There are forty pages of bibliography, containing more than a thousand references, ranging from John Ray's 1686 *History of Plants* to the 2001 report of the Intergovernmental Programme on Climatic Change. The bibliography will make this book a useful work of reference for students and teachers. The text is also intended to be read by ordinary citizens who are not students or teachers but have a serious interest in environmental problems.

The minor theme of the book is the life and work of Vladimir Vernadsky. Vernadsky did not invent the word "biosphere," but he was the first to make it a central concept unifying the study of the earth with the study of life. In Russia he is honored as one of the leading figures of twentieth-century science, while in the West his name is hardly known. Vaclav Smil, who is himself a bridge between East and West, a Russian living in Canada, uses this book as an opportunity to bring Vernadsky to life and to make the West aware of his ideas. Every chapter begins with a quotation from Vernadsky's book *The Biosphere*, which summarized his thinking and was written for a wide audience. The first chapter, with the title "Evolution of the Idea," begins with Vernadsky saying, "A new character is imparted to the planet by this powerful cosmic force. The radiations that pour upon the Earth cause the biosphere to take on properties unknown to lifeless planetary surfaces, and thus transform the face of the Earth." The last chapter, with the title "Civilization and the Biosphere," begins with the quotation "Man, alone, violates the established order."

The meaning of this last quotation becomes clearer when we place it in its context. Man violates the established order not only by burning coal and oil but by farming and weeding. This is what Vernadsky wrote:

> In cultivated areas it is only at the expense of great effort that civilized man can secure crops unmixed with weeds which spring up everywhere. Before man appeared on the Earth, the vegetation everywhere must have reached its maximum possible development, a state of equilibrium, attained through centuries of growth. Such a state can be seen in the virgin steppes which still exist in parts of Russia.... As far as the eye could see, there was nothing but the waist-high growth of feather-grass, a continuous clothing to the Earth, protecting it against the heat of the sun. Moss and lichen, profiting by the conservation of the moisture in the soil, remained green throughout the heat of summer under the shadow of the leaves.
>
> Man, alone, violates the established order and, by cultivation, upsets the equilibrium.... He sees this when he is obliged to oppose the pressure of life in defending against this invader fields which he wants to cultivate. He sees it, too, if he watches the surrounding world of nature with attentive eyes; the secret, silent, inexorable fight for existence waged all around him by green vegetation. Sensing this movement, he may experience the reality of the assault of the forest on the steppe-land, or the gradual suffocation of the forest by the rising tide of lichens from the tundra.

In these words we hear the authentic voice of Vernadsky, talking like the doctor Mikhail Astrov in Chekhov's play *Uncle Vanya*. His statement of the facts is scientifically accurate, but is expressed in the language of drama and poetry. Vernadsky and Chekhov were contemporaries. Both belonged to the circle of philosophizing intellectuals that Chekhov portrays so poignantly in his plays. Vernadsky was a Chekhov character who also happened to be a world-class scientist.

Vernadsky was a geochemist, born in 1863 in Kiev, the son of a professor of political economy. In 1889 he worked as a student with Pierre Curie in Paris, and in 1902 he became a full professor at Moscow University. After the first Russian revolution of 1905, which forced the Tsar to give some share in the affairs of government to a representative assembly called the Duma, Vernadsky was an important political figure. He was one of the founders of the Constitutional Democratic Party, generally known by its acronym Kadet. The Kadet party tried to provide the loyal opposition that Russia desperately needed in order to achieve far-reaching political reform without bloodshed. Unfortunately, the majority of intellectuals supported social revolutionary parties and did not believe in gradual reform.

Through the years from 1908 to 1918, Vernadsky remained a member of the central committee of the Kadet party, struggling to establish democratic government in Russia against bitter opposition from the Tsar's bureaucrats on the right and the social revolutionaries on the left. After the Bolshevik revolution, most of the Kadet leaders were executed. Vernadsky was spared because he was a famous scientist and had some friends in Lenin's inner circle, but his political life was over. He spent some years as an exile in Paris, giving lectures at the Sorbonne on geochemistry and writing his book *The Biosphere*. In 1926, at the age of sixty-two, he returned peacefully to Russia and published the book in Leningrad. He refused to join the Communist Party, but continued to live until his death in 1945 as one of the respected elder statesmen of Soviet science.

In Russia the disciplines of geochemistry and biology remained unified, with Vernadsky's vision of the biosphere as a central theme. After Vernadsky's death, his books and papers continued to be read and studied. Russian biologists aimed to understand life by integrating it into ecological communities and planetary processes. Meanwhile, in the West, biology developed in a strongly reductionist direction, the aim being to understand life by reducing it to genes and molecules. Reductionist biology was enormously successful and came to dominate the thinking of Western biologists.

There is in fact no incompatibility between reductionist and integrative biology. Genes and molecules and ecologies and biospheres are all essential parts of the world we live in. To understand our world fully, both kinds of biology are needed. If science had been uncontaminated by politics, the reductionist and integrative approaches to biology in the West and the East would have blended together during Vernadsky's lifetime and merged into a balanced view of the biosphere. But in the 1930s, biology in the Soviet Union was almost destroyed by Lysenko's murderous campaign against Mendelian genetics. In Russia reductionist biology was forbidden, and in the West the Russian tradition of integrative biology was discredited because Lysenko appeared to approve of it. In the West Vernadsky's ideas were ignored and his books were unread. A complete translation of *The Biosphere* into English was only published in 1998.[1] After seventy years of dominance of reductionist biology, Vernadsky's language now seems quaint and old-fashioned.

One of the great might-have-beens of history is the world that would have emerged if the statesmen of Europe had had the wisdom to deal peacefully with the Serbian crisis of 1914. If World War I had never happened, the rapid economic growth that Russia experienced from 1905 to 1914 would probably have continued. The Bolsheviks would probably have remained a small group of outlaws without any wide following, and would not have had an opportunity to seize power. The Tsar's government might have evolved into a constitutional monarchy, and the Kadet party might have emerged as the leader of a liberal parliamentary regime. In that imaginary world, Vernadsky might have been prime minister of Russia, guiding his country along the path of economic and scientific development, ending with full integration into the world community. After reading some of his writings, I have little doubt that he would have chosen to stay in politics if he had had the chance. He would not then have had time to resume his work as a scientist and write *The Biosphere*. Instead of being the founder of a new discipline of science, he might have been the savior of his country.

* * *

From Vernadsky and his dreams, I turn now to the major theme of Smil's book, which is the difficulty of understanding the behavior of the biosphere on a global scale. Even the nonliving processes governing weather and climate are difficult to understand. The living processes governing the fertility of forests and oceans are even more difficult. As an example to illustrate the difficulties, I look at the effects on the biosphere of carbon dioxide in the atmosphere. This is one of the subjects in Smil's book, but it is the reviewer, not the author, who is responsible for giving it emphasis here. As a result of the burning of coal and oil, the driving of cars, and other human activities, the carbon dioxide in the atmosphere is increasing at a rate of about half a percent per year.

Everyone agrees that the increasing abundance of carbon dioxide has two important consequences. First, carbon dioxide is a greenhouse gas, transparent to sunlight but partially opaque to the heat radiation that transports energy from the earth's surface into space. Second, carbon dioxide is an essential nutrient for plants on land and in the ocean. The increase in carbon dioxide causes changes, both in the transport of energy through the atmosphere and in the growth and reproduction of plants. Opinions differ on two crucial questions. Are the physical or the biological effects of carbon dioxide more important? Are the effects, either separately or together, beneficial or harmful? In his last two chapters, Smil summarizes the evidence bearing on these questions, but does not presume to answer them.

The physical effects of carbon dioxide are seen in changes of rainfall, cloudiness, wind strength, and temperature, which are customarily lumped together in the misleading phrase "global warming." This phrase is misleading because the warming caused by the greenhouse effect of increased carbon dioxide is not evenly distributed. In humid air, the effect of carbon dioxide on the transport of heat by radiation is less important, because it is outweighed by the much larger greenhouse effect of water vapor. The effect of carbon dioxide is more important where the air is dry, and air is usually dry only where it is cold. The warming mainly occurs where air is cold and dry, mainly in the arctic rather than in the tropics, mainly in winter rather than in summer, and mainly at night rather than in daytime. The warming is real, but it is mostly making cold places warmer rather than making hot places hotter. To represent this local warming by a global average is misleading, because the global average is only a fraction of a degree while the local warming at high latitudes is much larger. Also, local changes in rainfall, whether they are increases or decreases, are usually more important than changes in temperature. It is better to use the phrase "climate change" rather than "global warming" to describe the physical effects of carbon dioxide.

The biological effects of carbon dioxide on plants can be seen in changes of rate of growth, ratio of roots to shoots, and water requirement, which are different for different species and may result in shifts of the ecological balance from one kind of plant community to another. Effects on plant communities will also cause effects on dependent communities of microbes and animals. Biological effects are difficult to measure but are likely to be large. Experiments in greenhouses with an atmosphere enriched in carbon dioxide show that the yields of many crop plants increase roughly with the square root of the carbon dioxide abundance. If this were true for the major crop plants grown in the open air, it would mean that the 30 percent increase in carbon dioxide produced by fossil fuel–burning over the last sixty years would have resulted in a 15 percent increase of the world's food supply. A similar increase might have occurred in the world production of biomass of all kinds. The word "biomass" means living creatures, plants and animals and microbes, plus the organic remains that are left over when the creatures defecate or die. Smil's Chapter 7 contains a comprehensive survey of the various kinds of biomass that drive the seasonal rhythms of the biosphere.

We do not know whether the increased yields observed in greenhouses with increased carbon dioxide are also occurring in open-air agriculture. Agricultural yields are limited by many factors other than carbon dioxide abundance. One factor that we know to be often limiting for plant growth is water abundance. If the supply of water is limiting, as it often is in times of drought, then increased carbon dioxide can still be helpful. The little pores in the leaves of plants have to be kept open for the plant to acquire carbon dioxide from the air, but the plant loses a hundred molecules of water through the pores for every one molecule of carbon dioxide that it gains. This means that increased carbon dioxide in the air allows the plant to partially close the pores and reduce the loss of water. In dry conditions, increased carbon dioxide becomes a water-saver and gives the plant a better chance to keep on growing.

The fundamental reason why carbon dioxide abundance in the atmosphere is critically important to biology is that there is so little of it. A field of corn growing in full sunlight in the middle of the day uses up all the carbon dioxide within a meter of the ground in about five minutes. If the air were not constantly stirred by convection currents and winds, the corn would not be able to grow. The total content of carbon dioxide in the atmosphere, if converted into biomass, would cover the surface of the continents to a depth of less than an inch. About a tenth of all the carbon dioxide in the atmosphere is actually converted into biomass every summer and given back to the atmosphere every fall. That is why the effects of fossil fuel–burning cannot be separated from the effects of plant growth and decay.

There are five reservoirs of carbon that are biologically accessible on a short time-scale, not counting the carbonate rocks and the deep ocean which are only accessible on a time-scale of thousands of years. The five accessible reservoirs are the atmosphere, the land plants, the topsoil in which land plants grow, the surface layer of the ocean in which ocean plants grow, and our proved reserves of fossil fuels. The atmosphere is the smallest reservoir and the fossil fuels are the largest, but all five reservoirs are of comparable size. They all interact strongly with one another. To understand any of them, it is necessary to understand all of them. That is why planetary ecology is not an exact science like chemistry.

As an example of the way different reservoirs of carbon dioxide may interact with each other, consider the atmosphere and the topsoil. Greenhouse experiments show that many plants growing in an atmosphere enriched with carbon dioxide react by increasing their root-to-shoot ratio. This means that the plants put more of their growth into roots and less into stems and leaves. A change in this direction is to be expected, because the plants have to maintain a balance between the leaves collecting carbon from the air and the roots collecting mineral nutrients from the soil. The enriched atmosphere tilts the balance so that the plants need less leaf area and more root area. Now consider what happens to the roots and shoots when the growing season is over, when the leaves fall and the plants die. The new-grown biomass decays and is eaten by fungi or microbes. Some of it returns to the atmosphere and some of it is converted into topsoil.

On the average, more of the above-ground growth will return to the atmosphere and more of the below-ground growth will become topsoil. So the plants with increased root-to-shoot ratio will cause an increased net transfer of carbon from the atmosphere into the topsoil. If the increase in atmospheric carbon dioxide due to fossil fuel–burning has caused an increase in the average root-to-shoot ratio of plants over large areas, then the possible effect on the topsoil reservoir will not be small. At present we have no way to measure or even to guess the size of this effect. The aggregate biomass of the topsoil of the United States is not a measurable quantity. But the fact that the topsoil is unmeasurable does not mean that it is unimportant.

Roughly speaking, half of the contiguous United States, not including Alaska and Hawaii, consists of mountains and deserts and parking lots and highways and buildings, and the other half is covered with plants and topsoil. Just to see how important an unmeasurable increase of topsoil may be, let us imagine that the increased root-to-shoot ratio of plants might cause an average net increase of topsoil biomass of one tenth of an inch per year over half the area of the contiguous United States. A simple calculation shows that the amount of carbon transferred from the atmosphere to the topsoil would be five billion tons per year. This amount is considerably more than the measured four-billion-ton annual increase of carbon in carbon dioxide in the atmosphere. So the increase of carbon dioxide in the atmosphere over the entire earth could be canceled out by an increase of topsoil biomass of a tenth of an inch per year over half of the contiguous United States.

A tenth-of-an-inch-per-year increase of topsoil would be exceedingly difficult to measure. At present we do not even know whether the topsoil of the United States is increasing or decreasing. Over the rest of the world, because of large-scale deforestation and erosion, the topsoil reservoir is probably decreasing. We do not know whether intelligent land management could ensure a growth of the topsoil reservoir by four billion tons of carbon per year, the amount needed to stop the increase of carbon dioxide in the atmosphere. All that we can say for certain is that this is a theoretical possibility and ought to be seriously explored.

Another problem mentioned by Smil that has to be taken seriously is a slow rise of sea level, which could become catastrophic if it continues to accelerate. We have accurate measurements of sea level going back two hundred years. We observe a steady rise from 1800 to the present, with an acceleration during the last fifty years. It is widely believed that the recent acceleration is due to human activities, since it coincides in time with the rapid increase of carbon dioxide in the atmosphere. But the rise from 1800 to 1900 was probably not due to human activities. The scale of industrial activities in the nineteenth century was not large enough to have had measurable global effects. A large part of the observed rise in sea level must have other causes. One possible cause is a slow readjustment of the shape of the earth to the disappearance of the northern ice sheets at the end of the ice age twelve thousand years ago. Another possible cause is the large-scale melting of glaciers, which also began long before human influences on climate became significant. Once again, we have an environmental danger whose magnitude cannot be predicted until we know much more about its causes.

The most alarming possible cause of sea-level rise is the rapid disintegration of the West Antarctic ice sheet, which is the part of Antarctica where the bottom of the ice is far below sea level. Warming seas around the edge of Antarctica might erode the ice cap from below and cause it to collapse into the ocean. If the whole of West Antarctica disintegrated rapidly, sea level would rise by five meters, with disastrous effects on billions of people. However, recent measurements of the icecap show that it is not losing volume fast enough to make a significant contribution to the presently observed sea-level rise. It appears that the warming seas around Antarctica are causing an increase in snowfall over the icecap, and the increased snowfall on top roughly cancels out the decrease of ice volume caused by erosion at the edges. This is another situation in which we do not know how much of the environmental change is due to human activities and how much to long-term natural processes over which we have no control.

Another environmental danger that is even more poorly understood is the possible coming of a new ice age. A new ice age would mean the burial of half of North America and half of Europe under massive ice sheets. We know that there is a natural cycle that has been operating for the last eight hundred thousand years. The length of the cycle is a hundred thousand years. In each hundred-thousand-year period, there is an ice age that lasts about ninety thousand years and a warm interglacial period that lasts about ten thousand years. We are at present in a warm period that began twelve thousand years ago, so the onset of the next ice age is overdue. If human activities were not disturbing the climate, a new ice age might begin at any time within the next couple of thousand years, or might already have begun. We do not know how to answer the most important question: Does our burning of fossil fuels make the onset of the next ice age more likely or less likely?

There are good arguments on both sides of this question. On the one side, we know that the level of carbon dioxide in the atmosphere was much lower during past ice ages than during warm periods, so it is reasonable to expect that an artificially high level of carbon dioxide might stop an ice age from beginning. On the other side, the oceanographer Wallace Broecker[2] has argued that the present warm climate in Europe depends on a circulation of ocean water, with the Gulf Stream flowing north on the ocean surface and bringing warmth to Europe, while a countercurrent of cold water flows south in the deep ocean. So a new ice age could begin whenever the cold, deep countercurrent is interrupted. The countercurrent could be interrupted when the cold surface water in the Arctic becomes less salty and fails to sink, and the water could become less salty when the warming climate increases the Arctic rainfall. Thus Broecker argues that a warm climate in the Arctic may paradoxically cause an ice age to begin. Since we are confronted with two plausible arguments leading to opposite conclusions, the only rational response is to admit our ignorance. Until the causes of ice ages are understood in detail, we cannot know whether the increase of carbon dioxide in the atmosphere is increasing or decreasing the danger.

The biosphere is the most complicated of all the things we humans have to deal with. The science of planetary ecology is still young and undeveloped. It is not surprising that honest and well-informed experts can disagree about facts. But beyond the disagreements about facts, there is another deeper disagreement about values. The disagreement about values may be described in an oversimplified way as a disagreement between naturalists and humanists. Naturalists believe that nature knows best. For them the highest value is respect for the natural order of things. Any gross human disruption of the natural environment is evil. Excessive burning of fossil fuels, and the consequent increase of atmospheric carbon dioxide, are unqualified evils.

Humanists believe that humans are an essential part of nature. Through human minds the biosphere has acquired the capacity to steer its own evolution, and we are now in charge. Humans have the right to reorganize nature so that humans and biosphere can survive and prosper together. For humanists, the highest value is intelligent coexistence between humans and nature. The greatest evils are war and poverty, underdevelopment and unemployment, disease and hunger, the miseries that deprive people of opportunities and limit their freedoms. As Bertolt Brecht wrote in *The Threepenny Opera*, "Feeding comes first, morality second." If people do not have enough to eat, we cannot expect them to put much effort into protecting the biosphere. In the long run, preservation of the biosphere will only be possible if people everywhere have a decent standard of living. The humanist ethic does not regard an increase of carbon dioxide in the atmosphere as evil, if the increase is associated with worldwide economic prosperity, and if the poorer half of humanity gets its fair share of the benefits.

Vernadsky, as Smil portrays him, was a humanist. He foresaw the gradual transformation of the biosphere into a noosphere. The word "noosphere," a sphere of mind, means a planetary ecology designed and maintained by human intelligence. He recognized that, as the noosphere comes into existence, "the aerial envelope of the land as well as all its natural waters are changed both physically and chemically." He understood that the maintenance of a noosphere places heavy responsibilities on human shoulders. But he had faith in the ability of humans to rise to the challenge. The main conclusion of Vernadsky's thinking, and the main conclusion of Smil's book, is that life is complicated and any theory that attempts to describe its behavior in simple terms is likely to be wrong.

Notes

[1] V.I. Vernadsky, *The Biosphere*, translated by D.B. Langmuir (Copernicus, 1998).

[2] W.S. Broecker, "Thermohaline Circulation, the Achilles Heel of Our Climate System: Will Man-Made CO^2 Upset the Current Balance?" *Science*, Vol. 278 (1997), pp. 1582–1588, cited by Smil.