CO_2 Rising

The World's Greatest Environmental Challenge

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Preface

The most colossal environmental perturbation in human history is in the air. It is in every breath you take, in every wind, every cloud, each hurricane, and all skies everywhere, day and night. Ever-increasing concentrations of the heat-trapping greenhouse gas carbon dioxide (CO_2) are already disrupting the planetary energy balance, as is perhaps most visible in the melting of mountain glaciers and Arctic sea ice. The alterations to life caused by this increase are relatively mild so far, but they will increase in intensity in coming decades.

Consequences will sweep all portions of the globe. During this century and beyond, they will shape the climate, the diversity and distribution of living things, agriculture, water supplies, and the directions our technologies take. The rise in CO_2 will either help unite the emerging global society to counteract a shared alarm or divide it into competing camps.

When fossil fuels such as coal, oil, and natural gas are combusted, they release CO_2 as a waste by-product. That CO_2 is not an ordinary pollutant; it is an inherent result of the conversion of energy. It is ejected skyward, thereby letting loose carbon atoms that had been outside the biosphere system for millions of years during natural sequestration deep underground. Wafted worldwide, the waste carbon

then infiltrates all parts of the surface biosphere system—the circulating webs of air, water, and soil, all of which include myriads of living creatures. In short, the newly created CO_2 enters what is known as the global carbon cycle. With loops within loops within loops, as in a Jackson Pollack painting, the global carbon cycle is one of the world's natural wonders. And unlike the Grand Canyon and other natural wonders, one need not travel to visit it. It's all around. We are embedded in the global carbon cycle, indeed privileged to live within it. And we are obliged to understand the profound changes that are unfolding.

The goal of this book is to set forth, in plain language and telling images, the essential facts about the dynamics of fossil-fuel-derived CO_2, what happens when it becomes part of the global carbon cycle, and how its creation is tied to humanity's material well-being. Great debates loom before us. What will be the concentration of CO_2 in the future? How will the new climate affect agriculture, ecosystems, and sea level? What energy systems will power civilization? Will collective decisions about energy policy be based on some degree of guesswork—informed though it might be—about the future dynamics of Earth's air, water, and life? Will we be able to continue global economic development yet protect ourselves against dangerous climate change? What are our odds of navigating safely into the future?

Definite answers to several of these difficult questions are either beyond the scope of this book or unknown. But I hope to provide a look at CO_2 and the carbon cycle that is both detailed and wide in scope, for the perturbation to the global carbon cycle lies at the core of the questions above. My aim is to not make the material too highly specialized. But neither will I hold back information that is essential to understanding the complexities of the challenge we face. I will tell you how the CO_2 increase was discovered at a laboratory on a Hawaiian mountain, how we now know from ice cores that the amount of CO_2 is already more than 33 percent greater than it has ever been in at least half a mil-

lion years, and how the increase can be due to human activities even though it is a fact that soil bacteria generate an annual flow of CO_2 to the atmosphere that is nearly 8 times that generated by all our combustion of fossil fuels. You will see, for example, how there can be no net contribution to the CO_2 increase from the breathing of billions of humans.

Our bodies are made of carbon. So are trees. Carbon in the ocean is required by the floating hordes of tiny green plankton. Carbon is the structural core of carbohydrates, fats, proteins, DNA, and other biological molecules. The climate effects that we now read about and see almost daily in the media become much more salient when grounded in the material reality of how carbon shapes life and how the global carbon cycle links all organisms to one another and to the atmosphere.

Examining how wealth, energy use, and CO_2 emissions are linked, I will show how the emissions are tied to present and future trends in the global economy. From trends in the linkages, it is possible to work out why CO_2 will continue to increase, and at what rates, given what is known about the carbon cycle, and with a reasonable eye to the uncertainties. Reining in the increase will require further development of sources of energy that do not emit CO_2, such as carbon sequestration, solar, wind, nuclear, and a half dozen other potential answers to the need to deploy new sources of energy. There are big-picture issues that go beyond any debate, say, about a few wind turbines off the shore of Cape Cod.

Debates about the global environment, about climate warming, about fossil fuels, and about new energy systems have to face the issue of global equity on a per capita basis with respect to the CO_2 emissions, which spread globally no matter where they are emitted. For example, in the year 2050 will the United States' per capita CO_2 emissions still be more than 4 times the world average? Will the world even have an example of a complex, economically developed society with extremely

low CO_2 emissions? The economic machine will probably roll on pretty much as it has been, at least for the global total, as developing countries produce more emissions. But what will the United States and other large per capita emitters do? The post-2050 odds on the gamble with Earth's climate will be more favorable if the countries with high per capita emissions start showing the way to a materially prosperous future with low emissions *right now*.

I begin the book by introducing the CO_2 molecule and its "greenhouse property" of blocking the very form of energy by which Earth cools itself. I also introduce the carbon cycle and — as a literary device — a carbon atom I call Dave.

Named after C. David Keeling, a distinguished carbon-cycle scientist, the carbon atom Dave serves (I hope) as a way of revealing the fascinating paths that actual carbon atoms take during their global circuits. I want to show you the carbon cycle from a carbon atom's point of view. Each chapter includes a vignette from the life of Dave the carbon atom. These vignettes relate to the substantive technical content that follows. In the first several chapters, for example, Dave's presence in an alcohol molecule in a glass of beer illustrates how a loop in the global carbon cycle works, his passage through a gas analyzer in the early 1960s leads to the topic of the discovery of the worldwide rise of CO_2, and his transit from the atmosphere into the ocean shows that circuits extend from plants to soils to air to water and back.

I was not able to introduce everything I wanted to by following a single atom of carbon. Dave, for example, entered the biosphere naturally — from the dissolution of a mineral in a limestone cliff during the last Ice Age. Some of the pathways in this book had to come from carbon atoms brought into the biosphere by the combustion of fossil fuels. Thus, I introduce several other atoms: Coalleen, Oiliver, Methaniel, and Icille. By tracing the stories of these atoms, we will

look at the magnitudes of fluxes of different kinds of carbon in the biosphere, and the stability (or lack thereof) of the global carbon cycle in the past.

With the twin purposes of enhancing the enjoyment of our being alive as carbon-dependent organic beings and preparing the way for the later chapters, I planned the chapters in the first half of the book as relatively short primers on carbon fluxes that circulate among the great carbon-containing "bowls" of the biosphere. In the later chapters, I unfold the issues (already hinted at above) that are so challenging with respect to the future. These chapters too include episodes from the lives of my named carbon atoms—for instance, Oiliver and Methaniel are released from a burning stick used to cook a school lunch in Rwanda, and Dave passes through a wind turbine. But the material in the later chapters is denser, and the tone more pressing.

The book ends with Dave and the other named atoms making their separate exits from the biosphere many millennia from now. The fact of such long time scales is just one of the remarkable findings from the ongoing scientific investigation of the global carbon cycle, an endeavor in which I have been privileged to participate for more than two decades. Indeed, I hope that some of the process of science comes through in my discussions.

As you will see, I like graphs and charts. I am not trying to scare away readers who are not technically inclined; I am trying to facilitate a deep and personal understanding. I would be thrilled if you would look at my graphs and charts carefully, bring to them your own interpretations, and internalize them as pictures of how the great carbon cycle operates. It is my firm belief that we—as a global community—will have to understand the grand dynamics of the biosphere if we are to meet the challenges of the coming decades.