



# Energy in Nature and Society

General Energetics  
of Complex Systems

VACLAV SMIL

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General Energetics of Complex Systems

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## PREFACE

*Energy is the only life and is  
from the Body;  
and Reason is the bound or outward  
circumference of Energy.  
Energy is Eternal Delight.*

William Blake, *The Marriage of Heaven and Hell* (1793)

Energy's definition in Blake's poem comes from the Devil, as he corrects what he feels to be one of the principal errors of sacred codes, namely, "That Energy, call'd Evil, is alone from the Body; & that Reason, call'd Good, is alone from the Soul." This book is preoccupied with more pragmatic and less contentious propositions, but it too owes its existence to fascination with energy's elusive qualities.

I wrote this opening paragraph in 1987 as I was beginning to work on what was intended to be both a comprehensive and an analytically unified survey of energy. The first goal was met by offering a more sweeping treatment of energy sources, flows, conversions, uses, and their

consequences in the Earth's biosphere and throughout the history of civilizations than was available at that time in any single volume. The second goal was pursued by using fundamental unifying metrics, most notably power density ( $\text{W}/\text{m}^2$ ) and energy intensity ( $\text{J}/\text{g}$ ) values. By far the most difficult task was to make sure that the forest of grand energy principles would not be obscured by the necessary focus on specific trees: inevitably, the book had to have thousands of numbers, and their torrent could be overwhelming.

*General Energetics: Energy in the Biosphere and Civilization* was published in 1991. Although it did not make waves compared to several of my "bestsellers," it found appreciative readers. My greatest satisfaction came from the judgment by Philip Morrison, for decades my model of clear and captivating scientific writing, who in *Scientific American* called the book "a work of tightly controlled audacity. . . . The pleasure and stimulation of the book come from its critical display of . . . unruly realities: its importance from the fact that serious argument on

any of these matters must take into account this army of decisive magnitudes Professor Smil has marshaled.”

For me *General Energetics* was an unprecedented project with multiple challenges and rewards. It took much longer to complete than any other book I have written, and the necessary research, endless calculations, and intermediate drafts turned up a great deal of fascinating information that had to be left out of that single volume. Consequently, *General Energetics* led directly to *Energy in World History* (1994) and a few years later to *Energies* (1998), and the work on several of its specific aspects also helped to inform parts of *Cycles of Life* (1997), *Feeding the World* (2000), *The Earth's Biosphere* (2002), and *Energy at the Crossroads* (2003).

As soon as the original book was published, I hoped that one day I could prepare a revised edition, but the continuing flood of new energy studies made it clear that a mere revision was not the way to go. My intent then became to retain the book's original divisions (combining chapters 5 and 6 was the only major change) but with deletions, rewrites, elaborations, expansions, introductions of new subjects, better illustrations, and more extensive references.

The fundamental goal has not changed: to produce a comprehensive, systematic, revealing (and hence interdisciplinary and quantitative) treatment of all major aspects of energy in nature and society. I believe the case for a book like this is even more compelling now than it was two decades ago. During the intervening years, energy has become even more prominent as the subject of scientific inquiry and public policy debates, and the consequences of its use raise even greater concern and anxiety, but approaches to its understanding and rational management continue to suffer from inadequate integration and insufficient understanding of complex wholes. My

objective thus remains the same as for *General Energetics*, so I end this preface by amending only slightly the closing paragraphs that I wrote in 1987.

I see a clear need for a book that not only embraces all essential energy sources, storages, flows, and conversions in a unified and systematic manner but that does so by combining an encyclopedic sweep and richness of detail with an evolutionary overview and analytical crispness, and that does not shy away from grand synthesizing generalizations or from acknowledging the inability to offer such statements. This is no modest goal, but I believe that Li Bo's ancient acute observation—"When the hunter sets traps only for rabbits, tigers and dragons are left uncaught"—justifies the attempt.

At the same time, this is also a very personal book. My fascination with energetics has been going on for more than 40 years, and new topics keep coming into closer focus. My interest in planetary energy flows and in bio-energetics started with university studies of climatology, geomorphology, zoology, and ecology, and these fields were soon augmented by work on energy economics, coal mining, and power plant engineering. Principal themes of my published energy research have been, chronologically, thermal electricity generation, acid deposition, coal mining, and internationalization of energy supply in the 1960s; atmospheric CO<sub>2</sub> modeling, evolution and forecasting of energy techniques, energy-economy correlations, and energy in China and other poor populous countries in the 1970s; biomass energies, grand biospheric cycles, energy analysis in agriculture, energy in agriculture and in human nutrition, energy in world history, and global dimensions of energetics in the 1980s and 1990s; and during the first years of a new millennium, energy's role in the creation and transformation of modern civilization.

A strong commonality tying these interests has been my fascination with unruly and fuzzy realities in preference to abstract models and dubious generalizations. Complexities and peculiarities of the real world and counterintuitive outcomes of many of its processes have seemed to me always more appealing than theoretical models. This preference requires a from-the-ground-up approach where gradual understanding of details and cumulative acquisition of the widest possible scope of information precedes any attempts at generalization. Inevitably, this book is marked by these interests and biases, but I have done my best to offer a balanced and comprehensive treatment free of excessive indulgence in favorite topics.

The aims are broad interdisciplinary coverage, richness of detail, clear analyses, syntheses rooted in the presented information, and commonsense generalizations. The means is a systematic and evolutionary account, but one whose boundaries and flavors are also clearly influenced by my scientific background, preferences, and lifelong fascinations and inclinations. The book takes just one of many possible routes to better understanding of energy in nature and in human societies, and its inherent sweep and complexity mean that it cannot be devoid of lapses and errors. But even if it were to fall far short of its ambitious mark, there is, as always, consolation in the wisdom of an ancient sage. Lao Zi, noting that it is void space that makes bowls and houses useful, wrote,

*So advantage is had  
From whatever is there;  
But usefulness rises  
From whatever is not.*