

CONTENTS

Preface	ix		
1 The Universal Link: Energetics, Energy, and Power	1	2.5 Geoenergetics: Heat, Plate Tectonics, Volcanoes, Earthquakes	47
1.1 Evolution of Energetics: From Aristotle to Einstein	2	3 Photosynthesis: Bioenergetics of Primary Production	61
1.2 Approaches to Understanding: Concepts, Variables, Units	12	3.1 Photosynthetic Pathways	62
2 Planetary Energetics: Atmosphere, Hydrosphere, Lithosphere	23	3.2 Global Primary Productivity	69
2.1 Sun: The Star and Its Radiation	24	3.3 Productivities of Ecosystems and Plants	74
2.2 Energy Balance of the Earth: Radiation Fluxes	29	3.4 Phytomass Stores	78
2.3 Hydrosphere and Atmosphere: Thermal and Mass Fluxes	36	3.5 Autotrophic Scaling	84
2.4 Water and Air in Motion: Kinetic Fluxes	39	4 Heterotrophic Conversions: Consumer Bioenergetics	89
		4.1 Metabolic Capabilities	90
		4.2 Ectotherms and Endotherms	97
		4.3 Locomotion	102
		4.4 Biomasses and Productivities	110
		4.5 Heterotrophs in Ecosystems	113

5 Human Energetics: People as Simple Heterotrophs	119	9 Fossil-Fueled Civilization: Patterns and Trends	241
5.1 Energy Sources and Basal Metabolism	120	9.1 Fuels and Fossil-Fueled Electricity: Energy Production and Trade	242
5.2 Requirements and Uncertainties	125	9.2 Nonfossil Contributions: Biomass and Primary Electricity	247
5.3 Thermoregulation	131	9.3 Global Consumption Patterns: Growth and Inequality	257
5.4 Limits of Human Performance	134	9.4 Qualitative Changes: Transitions and Efficiencies	264
5.5 Gathering, Hunting, and Fishing	139	9.5 Energy Conservation: Gains and Rebounds	268
6 Traditional Food Production: Humans as Solar Farmers	147	10 Energy Costs: Valuations and Changes	273
6.1 Extensive Practices	149	10.1 Energy Cost of Energy: Net Gains	276
6.2 Permanent Cropping	152	10.2 Basic Materials: From Concrete to Fertilizers	281
6.3 Muscles, Implements, Machines	155	10.3 Structures and Products: From Buildings to Computers	288
6.4 Cropping Intensification	161	10.4 Crops and Animal Foods: Subsidized Diets	291
6.5 Traditional Agricultures	166	10.5 Modern Food System: Gains, Costs, Efficiencies	300
7 Preindustrial Complexification: Prime Movers and Fuels in Traditional Societies	173	11 Environmental Consequences: Metabolism of Fossil-Fueled Civilization	307
7.1 Animate Power: Human and Animal Muscles	174	11.1 Power Densities: Energy and Land	308
7.2 Water and Wind: Wheels and Mills	180	11.2 Energy Conversions and Heat Rejection	315
7.3 Phytomass Fuels and Metallurgy: Wood, Charcoal, Crop Residues	188	11.3 Energy and Water	320
7.4 Construction: Methods and Structures	192	11.4 Energy and the Atmosphere	324
7.5 Transportation: Roads and Ships	196	11.5 Interference in Grand Biospheric Cycles	327
8 Fossil Fuels: Heat, Light, and Prime Movers	203	12 Energetic Correlates: Complexities of High-Energy Civilization	335
8.1 Coals: The Earliest Modern Fuels	206	12.1 Energy and the Economy	335
8.2 Hydrocarbons: Crude Oils and Natural Gases	210	12.2 Energy and Value	341
8.3 From Extraction to Combustion: Modern Fossil Fuel Industries	217	12.3 Energy and the Quality of Life	346
8.4 Mechanical Prime Movers: Engines and Turbines	228		
8.5 Fossil-Fueled Electricity: Generation and Transmission	235		

12.4 Energy and War	351
12.5 Energy and the Future	356

13 Grand Patterns: Energetic and Other	
Essentials	365
13.1 Energy in the Biosphere	366
13.2 Energy and Civilization	372
13.3 The Challenges Ahead	380
 Appendix	 389
Selected Abbreviations, Acronyms, and Symbols	399
References	401
Name Index	461
Subject Index	463