

Contents

Introduction	1
Chapter 1. Dealing with Entropy on a Daily Basis	3
1.1. Entropy in the household	3
1.2. An example of an entropy crisis at home	5
1.3. Where does all the disorder go?	5
1.4. Disorder and pollution	7
1.5. Entropy and the second law of thermodynamics	8
1.5.1. Water desalination	8
1.5.2. Heat transfer	9
1.5.3. Entropy and the states of matter	10
1.6. From the household to the biosphere	11
Chapter 2. A Short History of the Biosphere	13
2.1. The billion year time scale	13
2.1.1. The apparition of life	14
2.1.2. Photosynthesis	14
2.1.2.1. Photosynthesis and entropy reduction	15
2.1.2.2. Photosynthesis and the green color of plants	16
2.1.3. The ozone layer and the spread of life	17
2.2. The biosphere on the 100 million year time scale	17
2.2.1. Carbon dioxide atmospheric content and temperature: the greenhouse effect	18
2.2.1.1. The infrared radiation	19
2.2.1.2. Greenhouse gases	19
2.2.2. Climate evolution and carbon storage	20
2.3. Carbon storage: carbonates and fossil fuels	21
2.3.1. Carbon storage in carbonates on the billion year time scale	22

2.3.2. Carbon storage as fossil fuels on the 100 million year time scale	23
2.3.3. Formation of coal deposits: the carboniferous age	24
2.3.4. Oil and gas deposits	26
2.4. Ice ages	26
2.5. The last 10 million years	27

Chapter 3. How Much Energy do We Need? 31

3.1. Different forms of energy and power	32
3.2. Energy conversion	36
3.3. Energy use and entropy release	39
3.3.1. Heat rejection	39
3.3.2. Entropy release	41
3.4. Energy needs and costs	41
3.4.1. Food energy	41
3.4.2. Food versus other energy needs	43
3.4.3. A family's energy needs	44
3.4.4. A family's energy costs	45
3.4.4.1. Food energy costs	46
3.4.4.2. The different energy costs	46
3.4.5. Energy needs at the society level and the entropy problem	48
3.5. Can society survive with a lower entropy release?	50

Chapter 4. Entropy in Thermodynamics and Our Energy Needs 53

4.1. Entropy in thermodynamics	53
4.1.1. Heat and mechanical work as two forms of energy: the first law of thermodynamics	53
4.1.2. Thermodynamic cycles	55
4.1.3. Work performed in a thermodynamic cycle	58
4.1.4. The Carnot cycle	60
4.1.5. Entropy change: introducing the second law of thermodynamics	62

4.1.6. Energy, entropy and free energy	64
4.2. Entropy at the molecular level	65
4.3. Energy needs and man generated entropy	68

Chapter 5. Climate Change: What We Know and What We Don't **71**

5.1. Time scale and temperature scale	72
5.1.1. The earth's temperature over the last few hundred thousand years	72
5.1.2. How well understood is the periodicity of interglacial periods	77
5.1.3. The Milankovitch cycles	78
5.1.4. Problems with the Milankovitch cycles	79
5.1.5. Towards a longer interglacial period?	81
5.2. The CO ₂ cycles	82
5.3. Anthropogenic temperature changes	85
5.3.1. The CO ₂ anthropogenic footprint	87
5.3.2. The temperature rise in modern times	90
5.3.2.1. Evolution of the temperature since 1900: the start of anthropogenic effects	91
5.3.2.2. Expected temperature rise in the 21 st century	95
5.3.2.3. Consequences of further temperature rise: ice melting	96
5.4. Climate changes in space and time: back to entropy	98
5.5. The entropic meaning of sustainable development	99
5.6. Concluding remarks	101

Chapter 6. Fighting Entropy with Technology **103**

6.1. Motivation for fighting entropy increase: ensuring climate stability	103
6.2. By how much do we need to reduce anthropogenic entropy release	105
6.3. Entropy management strategies	106

6.3.1. Minimizing irreversibility processes by developing technology I: the motorcar	107
6.3.1.1. The all-electric motorcar	108
6.3.1.2. The battery problem	109
6.3.1.3. The hydrogen car	110
6.3.1.4. But where will the electricity for the all-electric car come from?	111
6.3.2. Minimizing entropy production by improving technology II: space heating and cooling	112
6.3.2.1. Two types of solutions: improved insulation or increased thermal mass	113
6.3.2.2. Keeping the temperature constant is a question of time scale	114
6.3.2.3. Towards zero entropy release buildings	115
6.3.3. Reducing entropy release in industry	117
6.4. Energy generation impact on global entropy release	117
6.4.1. Energy generation from renewable sources	118
6.4.1.1. Biomass	118
6.4.1.2. Solar heating	119
6.4.1.3. Thermal solar electricity	120
6.4.1.4. Photovoltaics	124
6.4.1.5. Wind turbines	126
6.4.2. Non renewables: fossil fuels versus nuclear	128
6.4.2.1. Improving the use of fossil fuels	128
6.4.2.2. Pros and cons of carbon storage	129
6.4.2.3. Nuclear power plants	130
6.4.3. Transport of electrical power	132
Chapter 7. Towards a World without Fossil Fuels	135
7.1. Increasing entropy and increasing energy needs	135
7.2. The retreat of oil	136
7.3. How much oil is left anyhow?	137
7.4. Replacing oil and gas by coal for residential heating?	140
7.5. Can we replace oil for transportation?	141

7.6. Can coal be displaced as the major primary fuel?	142
7.7. Displacing coal with renewables	142
7.7.1. Competition for land space	143
7.7.2. Production potential of solar power in desert areas	143
7.7.3. The potential for wind power production	146
7.7.4. Distributed renewable power	149
7.7.4.1. Solar water heaters	149
7.7.4.2. Distributed photovoltaics	149
7.7.5. About costs	151

Chapter 8. A Changing World **153**

8.1. A realistic objective	154
8.2. The supply side	155
8.2.1. Distributed power supply	155
8.2.2. Wind power	156
8.2.3. Large scale solar electricity	157
8.2.4. The importance of improved electricity networks for the implementation of renewables on a large scale	157
8.2.5. Switching back to coal	159
8.2.6. Nuclear energy as a replacement for coal fired plants	160
8.3. Reducing the power consumed in developed countries	161
8.3.1. The case for the electric car	162
8.3.2. Family energy budget and power spent at the society level	164
8.4. The dangers	165
8.4.1. Is there a climate run away?	165
8.4.2. Is carbon dioxide atmospheric content a sufficient indicator?	166
8.4.3. Food supply	167
8.4.4. Renewables and water	169

Index **171**