Contents

List of Figures xix
List of Tables xxv
Foreword xxvii
Preface xxix
Acknowledgments xxxi
Author xxxiii

1. Introduction to Renewable Energy 1
1.1 Introduction 1
1.2 Advantages and Disadvantages of the Use of Renewable Energy Resources 2
1.2.1 Advantages 2
1.2.2 Disadvantages 2
1.3 Renewable Energy Resources 3
1.3.1 Solar Energy 3
1.3.2 Wind Energy 6
1.3.3 Biomass Energy 7
1.3.4 Hydro Power 9
1.3.5 Geothermal Energy 11
1.3.6 Salinity Gradient 15
1.3.7 Fuel Cells 15
1.3.8 Tidal Energy 16
1.3.9 Wave Energy 18
1.3.10 Ocean Thermal Energy Conversion Systems 19
1.3.11 Human, Animal, and Piezoelectric Power 20
1.3.12 Cold Fusion and Gravitational Field Energy 21
1.4 Renewable Energy Conversion Efficiencies 22
1.5 Renewable Energy Resources—Why? 23
1.6 Summary and Conclusion 24
1.7 Problems 24
1.7.1 Carbon Dioxide Required to Make Carbohydrates 24
1.7.2 Kinetic Energy of a Mass of Wind 25
1.7.3 Carbon Dioxide Production during Ethanol Fermentation 25
1.7.4 Theoretical and Actual Power from Water Stream 25
1.7.5 Theoretical Thermal Conversion Efficiency of Rankine Cycle 25
1.7.6 Fuel Cell Efficiencies 25
1.7.7 Tidal Power Calculations 25
1.7.8 Solar Water Heater Conversion Efficiency 25
1.7.9 OTEC Energy Conversion 26
1.7.10 Solar PV Conversion Efficiency 26
References 26

2. Solar Energy **29**
2.1 Introduction 29
2.2 The Solar Constant and Extraterrestrial Solar Radiation 30
2.3 Actual Solar Energy Received on the Earth's Surface 31
2.4 Solar Energy Measuring Instruments 32
2.5 Solar Time 33
2.6 Geometric Nomenclatures for Solar Resource Calculations 35
2.7 Extraterrestrial Solar Radiation on a Horizontal Surface 40
2.8 Available Solar Radiation on a Particular Location 42
2.9 Solar Energy Conversion Devices 45
2.9.1 Solar Thermal Conversion Devices 45
2.9.1.1 Solar Refrigerators 45
2.9.1.2 Solar Dryers 47
2.9.1.3 Solar Water Heaters 49
2.9.2 Solar Photovoltaic (PV) Systems 50
2.9.3 Solar Thermal Electric Power Systems 52
2.9.4 Solar Thermal Power Systems with Distributed Collectors 53
2.9.5 Solar Thermal Power Systems with Distributed Collectors and Generators 53
2.9.6 High-Temperature Solar Heat Engines 54
2.10 Solar Collector System Sizing 55
2.11 Economics of Solar Conversion Devices 57
2.12 Summary and Conclusions 59
2.13 Problems 60
2.13.1 Extraterrestrial Solar Radiation 60
2.13.2 Solar Time 60
2.13.3 Solar Declination Angle 60
2.13.4 Angle of Incidence 60
2.13.5 Hour Angle, Time of Sunrise, and Number of Daylight Hours 60
2.13.6 Theoretical Daily Solar Radiation, H_o 60
2.13.7 Theoretical Hourly Solar Radiation 61
2.13.8 Clearness Index to Estimate Beam and Diffuse Radiation 61
2.13.9 Sizing Solar PV Panels 61
2.13.10 Economics of Solar Energy 61
References 61

3. Wind Energy **63**
3.1 Introduction 63
3.2 Basic Energy and Power Calculation from the Wind 65
3.3 The Worldwide Wind Energy Potential 69
3.4 The Actual Energy and Power from the Wind 69
3.5 Actual Power from the Wind 72
3.6 Windmill Classification 73
3.6.1 Classification according to Speed 73
3.6.1.1 High-Speed Windmills 73
3.6.1.2 Low-Speed Windmills 73
3.6.2 Classification according to Position of Blades 73
3.6.2.1 Upwind Windmills 73
3.6.2.2 Downwind Windmills 74

3.6.3 Classification according to Orientation of Blade Axis 74
3.6.3.1 Vertical Axis Windmills 74
3.6.3.2 Horizontal Axis Windmills 74
3.7 Wind Speed Measuring Instruments 75
3.8 Wind Power and Energy Calculations from Actual Wind Speed Data 77
3.8.1 The Rayleigh Distribution 77
3.8.2 The Weibull Distribution 80
3.9 Wind Design Parameters 84
3.9.1 Cut-In, Cut-Out, and Rated Wind Speed 84
3.9.2 General Components of Horizontal Axis Windmills for Power Generation 84
3.9.3 Wind Speed Variations with Height 86
3.9.4 Wind Capacity Factor and Availability 87
3.10 Comparative Cost of Power of Wind Machines 88
3.11 Conclusion 89
3.12 Problems 90
3.12.1 Kinetic Energy from Wind 90
3.12.2 Power from the Wind 90
3.12.3 Power Differential as Wind Speed Is Doubled 90
3.12.4 Actual Power from Windmill 90
3.12.5 Rayleigh Distribution Estimate 90
3.12.6 Estimating Average Wind Speed from Rayleigh Distribution 91
3.12.7 Average Wind Velocity for a Given Site and Hours of Occurrence 91
3.12.8 Estimate Weibull Parameters k and c from Linear Regression Data 91
3.12.9 Wind Speed at Different Elevation 91
3.12.10 Payback Period for Wind Machine 91
References 91

4. Biomass Energy 93
4.1 Introduction 93
4.2 Sources of Biomass for Heat, Fuel, and Electrical Power Production 95
4.2.1 Municipal Solid Wastes 95
4.2.2 Municipal Sewage Sludge 96
4.2.3 Animal Manure 96
4.2.4 Ligno-Cellulosic Crop Residues 97
4.3 Biomass Resources That May Have Competing Requirements 97
4.3.1 Oil Crops 97
4.3.2 Sugar and Starchy Crops 98
4.3.3 Fuel Wood 98
4.3.4 Aquatic Biomass 98
4.4 Various Biomass Conversion Processes 99
4.4.1 Physico-Chemical Conversion Processes 99
4.4.1.1 Biodiesel Production 99
4.4.2 Biological Conversion Processes 102
4.4.2.1 Bio-Ethanol Production 102
4.4.2.2 Biogas Production 104

4.4.3 Thermal Conversion Processes 107
4.4.3.1 Pyrolysis 107
4.4.3.2 Gasification 108
4.4.3.3 Eutectic Point of Biomass 110
4.4.3.4 Combustion Processes 112
4.5 Economics of Heat, Fuel, and Electrical Power Production from Biomass 113
4.5.1 Biodiesel Economics 113
4.5.2 Ethanol Economics 114
4.6 Sustainability Issues with Biomass Energy Use 115
4.7 Conclusion 116
4.8 Problems 116
4.8.1 Area Required to Build a Power Plant 116
4.8.2 Electrical Power from MSW 117
4.8.3 Feedstock Requirement for a 3 MGY Biodiesel Plant 117
4.8.4 Sugar Needed to Produce Ethanol 117
4.8.5 Biogas Digester Sizing 117
4.8.6 Residence Time for Biomass Conversion in Fluidized Bed Reactors 117
4.8.7 Chemical Formula for Biomass 117
4.8.8 Air-to-Fuel Ratio (AFR) Calculations 118
4.8.9 Eutectic Point of Biomass 118
4.8.10 Area Needed for Wood Power 118
References 118

5. Hydro Power 121
5.1 Introduction 121
5.2 Power from Water 123
5.3 Inefficiencies in Hydro Power Plants 125
5.4 Basic Components of a Hydro Power Plant 127
5.5 Water Power–Generating Devices 129
5.5.1 Water Wheels and Tub Wheels 130
5.5.2 Turbines 130
5.5.3 Specific Speeds for Turbines 131
5.5.4 Turbine Selection 132
5.6 Hydraulic Ram 134
5.6.1 Construction and Principles of Operation 134
5.6.2 Hydraulic Ram Calculations 136
5.6.3 Design Procedures for Commercial Rife Rams 138
5.6.4 Specifying Pipe Sizes and Discharge Pipe Lengths 139
5.6.5 Starting Operation Procedure for Hydraulic Rams 140
5.6.6 Troubleshooting Hydraulic Rams 141
5.7 Types of Hydro Power Plant 141
5.7.1 On the Basis of Operation 141
5.7.2 Based on Plant Capacity 142
5.7.3 Based on Head 142
5.7.4 Based on Hydraulic Features 142
5.7.4.1 Conventional 142
5.7.4.2 Pumped Storage Systems 142
5.7.5 Based on Construction Features 147

5.8 Environmental and Economic Issues 149
5.9 Conclusions 150
5.10 Problems 150
5.10.1 Theoretical Power from Water 150
5.10.2 Actual Efficiencies of Micro Hydro Units 151
5.10.3 Hydro Power Plant Calculations 151
5.10.4 Pump Specific Speed 151
5.10.5 Volumetric Efficiency of Hydraulic Rams 151
5.10.6 Energy Efficiency of Hydraulic Rams 151
5.10.7 Specifying Drive Pipe Size and Lengths 151
5.10.8 Specifying Drive Pipe Size Using Rife Ram 151
5.10.9 Pumped Storage Power Production 152
5.10.10 Pumped Storage Power Production Water Use 152
References 152

6. Geothermal Energy 153
6.1 Introduction 153
6.2 Temperature Profile in Earth's Core 154
6.3 Geothermal Resource Systems 158
6.3.1 Liquid-Dominated Systems 158
6.3.2 Vapor-Dominated Systems 159
6.3.3 Hot Dry Rock Systems 159
6.3.4 Geo-Pressure Systems 159
6.4 Geothermal Resource Potential in Texas 160
6.5 Geothermal Power Cycles 161
6.5.1 Analysis of the Thermodynamic Cycle (Exell, 1983) 162
6.5.2 Energy Flows or First Law Analysis 163
6.6 Geothermal Heat Pumps 168
6.6.1 Geothermal Heat Pump (Opposite of Refrigeration) 171
6.7 Geothermal Power Cycles 174
6.7.1 Non-Condensing Cycle 174
6.7.2 Straight Condensing Cycle 175
6.7.3 Indirect Condensing Cycle 177
6.7.4 Single Flash System 177
6.7.5 Double Flash System 177
6.7.6 Binary Fluid Cycle 178
6.8 Geothermal Power Applications 180
6.9 Levelized Cost of Selected Renewable Technologies 182
6.10 Environmental Effects of Geothermal Power Systems 183
6.11 Conclusion 184
6.12 Problems 185
6.12.1 Well Selection 185
6.12.2 The Ideal Rankine Cycle 185
6.12.3 Efficiency of Ideal Geothermal Cycle 185
6.12.4 Changes in Efficiency and Power Output 186
6.12.5 COP of Ideal Refrigeration Cycle 186
6.12.6 Ideal Vapor Refrigeration System 186
6.12.7 Power Consumed in Heat Pump 186
6.12.8 Cost Comparison 187

6.12.9 Number of Households Served by Geothermal Facility 187
6.12.10 ROI of Geothermal Heating and Cooling 187
References 187

7. Salinity Gradient 189
7.1 Introduction 189
7.2 The Solar Pond 190
7.2.1 Advantages 193
7.2.2 Disadvantages 194
7.3 Energy of Sea Water for Desalination 194
7.4 Pressure-Retarded Osmosis (PRO) 195
7.4.1 PRO Standalone Power Plants (Statkraft, Netherlands, 2006) 197
7.4.2 Statkraft Prototype (Norway, Co.) 197
7.5 Reverse Electro-Dialysis (RED) 198
7.6 Specific Applications or Locations 201
7.7 Limitations and Factors Affecting Performance and Feasibility 202
7.8 Performance and Costs 203
7.9 Potential Energy and Barriers to Large-Scale Development 204
7.10 Environmental and Ecological Barriers 205
7.11 Conclusions 206
7.12 Problems 206
7.12.1 Sensible Heat from Solar Pond 206
7.12.2 Theoretical Carnot Cycle Efficiency 207
7.12.3 Osmotic Pressure Calculations 207
7.12.4 Work Done against Pressure 207
7.12.5 Energy Required to Boil Seawater 207
7.12.6 Size of PRO Unit to Generate Given Power 207
7.12.7 Amount of Membrane to Use to Generate Power for a Household 207
7.12.8 RED Salinity Gradient System 207
7.12.9 Cost of RED Power Plants 208
7.12.10 Simple Payback Period for Salinity Gradient Power Plant 208
References 208

8. Fuel Cells 211
8.1 Introduction 211
8.2 The Various Types of Fuel Cells 215
8.2.1 Proton Exchange Membrane Fuel Cells 215
8.2.2 High-Temperature Proton Exchange Membrane Fuel Cell 216
8.2.3 Direct Methanol Fuel Cell 216
8.2.4 Alkaline Electrolyte Fuel Cell 217
8.2.5 Phosphoric Acid Fuel Cell 218
8.2.6 Solid Oxide Fuel Cell, High Temperature 219
8.2.7 Solid Acid Fuel Cell 220
8.2.8 Molten Carbonate Fuel Cell, High Temperature 220
8.2.9 Regenerative Fuel Cell 221
8.2.10 Solid Polymer Fuel Cell 222
8.2.11 Zinc-Air Fuel Cell 222

8.2.12 Microbial Fuel Cell 223
8.2.13 Other Fuel Cells: Biological, Formic Acid, Redox Flow and Metal/Air Fuel Cells 224
8.3 Data for the Different Major Types of Fuel Cells 224
8.4 Various Fuels Used for Fuel Cells and Issues 225
8.5 Advantages and Disadvantages of Fuel Cells 226
8.6 Balance of Plant 227
8.7 Existing and Emerging Markets for Fuel Cells 228
8.7.1 NASA Helios Unmanned Aviation Vehicle 229
8.7.2 Naval Research Lab Spider Lion 229
8.7.3 The PEMFC Commercial Fuel Cell Module by Ballard (NEXA TM 1.2kW) 231
8.7.4 Heliocentris Fuel Cell System 232
8.8 The Future of the Fuel Cell 233
8.9 Conclusions 233
8.10 Problems 234
8.10.1 Conversion Efficiency of a Direct Methane Fuel Cell 234
8.10.2 Maximum Conversion Efficiency for a Direct Methane Fuel Cell 234
8.10.3 Heat Energy Losses in a Direct Methane Fuel Cell 234
8.10.4 Hydrogen Needed (in kg) to Produce a Liter of Water 235
8.10.5 Potassium Carbonate Produced in an Alkaline Fuel Cell 235
8.10.6 Ideal Water and Carbon Dioxide Produced for a Direct Methane Fuel Cell 235
8.10.7 Zinc Needed for Every Tonne Zinc Oxide Produced in a Zinc-Air Fuel Cell 235
8.10.8 Practical Conversion Efficiency for a Direct Methanol Fuel Cell 235
8.10.9 Efficiency of a Spider Lion Fuel Cell 235
8.10.10 Efficiency of a Commercial Fuel Cell 236
References 236

9. Tidal Energy 239
9.1 Introduction 239
9.2 Worldwide Potential of Tidal Energy 242
9.3 How Tidal Energy Works 245
9.4 Tidal Power Generation Schemes 247
9.4.1 Single-Basin Ebb Cycle Power Generation 248
9.4.2 Single-Basin Tide Cycle Power Generation 250
9.4.3 Single-Basin Two-Way Power Generation 252
9.4.4 Double-Basin Systems 253
9.5 Other Tidal Power Generating Methods 256
9.6 Cost of Tidal Energy Systems 258
9.7 Environmental Concerns 259
9.7.1 Beneficial 259
9.7.2 Non-Beneficial 259
9.8 Conclusions 260
9.9 Problems 260
9.9.1 Variation of Tide Level with Time Using Sine Curve 260
9.9.2 Reservoir Volume Calculation 261

9.9.3 Time to Release Water from Reservoir 261
9.9.4 Power from Tidal Reservoir 261
9.9.5 Energy from Tidal Reservoir 261
9.9.6 Matching Household Energy Requirements 261
9.9.7 Water Level Decline with Time for a Given Basin 261
9.9.8 Power Generated from Small Basin 262
9.9.9 Power and Energy from Double-Basin System 262
9.9.10 Cost to Recover Initial Investment 262
References 262

10. Wave Energy 265
10.1 Introduction 265
10.2 Power from Wave 266
10.3 World's Wave Power Resource 268
10.4 Various Generic Wave Energy Converter Concepts 269
10.4.1 Point Absorber Buoy 269
10.4.2 Surface Attenuator 274
10.4.2.1 Wave Contouring Rafts (Cockerell Rafts) 276
10.4.3 Oscillating Wave Surge Converter 276
10.4.4 Oscillating Water Column 276
10.4.5 Overtopping Device 277
10.4.6 Submerged Pressure Differential 278
10.5 Other Common Types of Currently Deployed Wave Energy Converters 279
10.5.1 Hose Pump 279
10.5.2 Salter's Duck 280
10.5.3 Masuda Buoy 281
10.6 Typical Hydraulic Circuit for Wave Generators 281
10.7 Approximating Wave Height Using Significant Wave Height, H_s 284
10.8 Beneficial and Non-Beneficial Environmental Impacts of Wave Power 286
10.8.1 Advantages 286
10.8.2 Disadvantages 286
10.9 Year-Round Distribution of Wave Energy 286
10.10 Economic Aspects and Potential Locations 287
10.11 Countries with Wave Energy Studies (IRENA, 2014) 288
10.11.1 United Kingdom 289
10.11.2 Australia 289
10.11.3 Denmark 289
10.11.4 United States 290
10.11.5 Belgium 290
10.11.6 Sweden 290
10.11.7 Ireland 290
10.11.8 Israel 291
10.12 Conclusion 291
10.13 Problems 292
10.13.1 Determine the Constant for Wave Power Equation 292
10.13.2 Basic Power from Wave 292

10.13.3 Wave Power in Storms 292
10.13.4 Total Power from Wave 292
10.13.5 Hydraulic Power Developed from Buoys 292
10.13.6 Hydraulic Power 293
10.13.7 Hydraulic Jack Power (Metric) 293
10.13.8 Hydraulic Jack Power (English System) 293
10.13.9 Piston Power for Surface Attenuator 293
10.13.10 Significant Wave Height (H_s) 294
10.13.11 Capital Cost of Wave Converters 294
References 294

11. Ocean Thermal Energy Conversion (OTEC) Systems 297
11.1 Introduction 297
11.2 The Basic OTEC System 299
11.3 OTEC Components and Temperature Profiles 299
11.4 Other Applications of OTEC 302
11.5 Uses of OTEC Systems 305
11.6 Basic Thermodynamic Cycle: Rankine Cycle 306
11.7 OTEC Power Generation Systems 309
11.7.1 Closed Cycle 309
11.7.1.1 Efficiency Calculations 312
11.7.2 Open Cycle 315
11.7.3 Hybrid Systems 316
11.8 Projects Under Way for OTEC Systems (IRENA, 2014) 317
11.8.1 Natural Energy Laboratory of Hawaii Authority (NELHA) 317
11.8.2 OTEC Projects in Japan 318
11.8.3 OTEC Facility in India 318
11.8.4 Other OTEC Projects Around the World 318
11.9 Technical Limitations and Cost (IRENA, 2014) 319
11.10 Conclusion 321
11.11 Problems 322
11.11.1 Heat Capacity of the Ocean 322
11.11.2 Ideal Carnot Cycle Efficiency 322
11.11.3 Volume of Water Needed for a 100 kW of Power 322
11.11.4 Calculating Water Pumping Power 322
11.11.5 Base Load Power Calculations 322
11.11.6 OTEC Closed Cycle Calculations 323
11.11.7 Actual OTEC Cycle Examples 323
11.11.8 Heat of Evaporation Calculations 323
11.11.9 Estimating the Number of Households Served by OTEC 324
11.11.10 Estimating the Initial Capital Cost of OTEC 324
References 324

12. Human and Animal Power, and Piezoelectrics 327
12.1 Introduction 327
12.2 Animal Power 330
12.2.1 Draft Animal Performance Compared with Mechanical Tractors 331

12.2.2 Draft Horsepower Capability of Various Animals 331
12.2.3 Unique Perspectives of Animal Power 333
12.3 Human Power 334
12.3.1 Advantages of Humans for Energy Use 335
12.3.2 Disadvantages of Humans for Energy Use 336
12.3.3 Human Factors in Energy and Power: The Ergonomic Factors 336
12.4 Piezoelectrics 338
12.4.1 Applications of Piezoelectricity 340
12.4.2 High-Voltage Power Sources 340
12.4.3 Use of Piezoelectric Devices as Sensors 343
12.4.4 Piezoelectric Devices as Tiny Actuators 343
12.4.5 Piezoelectric Motors 344
12.4.6 Potential Future Applications of Piezoelectricity 344
12.5 Conclusions 345
12.6 Problems 345
12.6.1 Power from Animals 345
12.6.2 Power from Humans 345
12.6.3 Various Units of Power 346
12.6.4 Power from Groups of Animals 346
12.6.5 Energy Output of a Cow in the Form of Milk 346
12.6.6 Power of Humans over Longer Periods of Time 346
12.6.7 Power from Arms and Legs of Humans 346
12.6.8 Basic Piezoelectric Power from Numerous Repeated Cycles 346
12.6.9 Piezoelectric Power from Single Tap 346
12.6.10 Charging a Cell Phone with Piezoelectric Power 347
References 347

13. Cold Fusion and Gravitational Energy 349
13.1 Introduction 349
13.2 The Cold Fusion Theory 350
13.3 Calorimetry 353
13.4 Cold Fusion by Other Names 355
13.5 Key Figures in Fusion Energy Research 356
13.5.1 Randell L. Mills, Brilliant Light Power, New Jersey 356
13.5.2 Michael McKubre, Energy Research Center, SRI International 357
13.5.3 David J. Nagel, George Washington University 357
13.5.4 Rossi's E-Cat 357
13.5.5 International Thermonuclear Experimental Reactor 358
13.6 The Gravitational Power Potential 359
13.7 Tachyon Field Energy 361
13.8 Len's Law and Faraday's Law 363
13.9 Other Scientists Investigating Gravitational Field Energy and Other Renewables 364
13.9.1 Dr. T. Henry Moray, American Physicist 365
13.9.2 Professor Shinichi Seike, Director, Gravity Research Laboratory, Japan 365

13.9.3 Bruce De Palma's N-Machine 366
13.9.4 Paramahamsa Tewari of India and His Space Power Generator 367
13.10 Non–Energy-Related Applications of Gravitational Field Energy 371
13.11 Conclusions 371
13.12 Problems 372
13.12.1 Energy Balance in Electrolysis Setup 372
13.12.2 Heat Capacity of Calorimeters 372
13.12.3 Heat Released from Combustion of Chemicals 373
13.12.4 Energy Balance in N-Machine or N-Generator 373
13.12.5 Determining Magnetic Fluxes, Voltages, and Current in Conducting Coils 373
13.12.6 Estimating Gravitational Forces at Various Elevations 373
13.12.7 Calculating Acceleration due to Gravity at Various Elevations 374
13.12.8 Calculating Voltages, Current, and Magnetic Fluxes in Coils 374
13.12.9 Calculating Input and Output Power in an Electric Motor 374
13.12.10 Improving the PF of Resistive Motors 374
References 374

14. Environmental and Social Cost of Renewables 377
14.1 Introduction 377
14.2 Technical Advancement of Renewable Energy Technologies 378
14.3 Balance of Systems 382
14.4 Overall Economics and Levelized Cost of Renewable Energy 384
14.5 Life Cycle Analyses of Renewables 387
14.6 Pollutant Emissions of Some Renewable Energy Technologies 390
14.7 Sustainability Issues of Renewables 394
14.8 The Social Costs of Renewables 396
14.9 Conclusion 398
14.10 Problems 399
14.10.1 Area Required for Solar PV Systems 399
14.10.2 Algal Oil Production and Yield Calculations 399
14.10.3 Size and Cost of PV Systems for Large Commercial Applications 399
14.10.4 Balance of System Cost as Percentage of PV Cost 399
14.10.5 SO_2 Daily Emissions Rate for Coal Power Plants 399
14.10.6 SO_2 Daily Emissions Rate for Biomass Power Plants 399
14.10.7 Ozone and SO_2 Concentration Units from NAAQS Standards 400
14.10.8 Net Energy Ratio (NER) for Biofuels 400
14.10.9 Net Energy Balance (NEB) for Biofuels 400
14.10.10 Return on Investment for the Production Cost of Solar PV Systems 400
References 401

Appendix A: Table of Conversion Units 405

Index 407