

energy science

principles, technologies, and impacts

John Andrews and Nick Jelley

OXFORD
UNIVERSITY PRESS

Contents

| | |
|----------------------------|-----|
| Acknowledgement of sources | xiv |
|----------------------------|-----|

| | |
|--|----------|
| 1 Introduction | 1 |
| 1.1 A brief history of energy technology | 1 |
| 1.2 Global energy trends | 8 |
| 1.3 Global warming and the greenhouse effect | 10 |
| 1.4 Units and dimensional analysis | 13 |
| SUMMARY | 15 |
| FURTHER READING | 15 |
| WEB LINKS | 15 |
| EXERCISES | 16 |

| | |
|---|-----------|
| 2 Thermal energy | 18 |
| 2.1 Heat and temperature | 18 |
| 2.2 Heat transfer | 19 |
| 2.3 First law of thermodynamics and the efficiency of a thermal power plant | 24 |
| 2.4 Closed cycle for a steam power plant | 24 |
| 2.5 Useful thermodynamic quantities | 27 |
| 2.6 Thermal properties of water and steam | 29 |
| 2.7 Disadvantages of a Carnot cycle for a steam power plant | 32 |
| 2.8 Rankine cycle for steam power plants | 33 |
| 2.9 Gas turbines and the Brayton (or Joule) cycle | 36 |
| 2.10 Combined cycle gas turbine | 38 |
| 2.11 Fossil fuels and combustion | 39 |
| 2.12 Fluidized beds | 41 |
| 2.13 Carbon sequestration | 41 |
| 2.14 Geothermal energy | 42 |
| SUMMARY | 47 |
| FURTHER READING | 49 |
| WEB LINKS | 49 |

| | |
|---|-----------|
| LIST OF MAIN SYMBOLS | 49 |
| EXERCISES | 50 |
| <hr/> | |
| 3 Essential fluid mechanics for energy conversion | 53 |
| 3.1 Basic physical properties of fluids | 53 |
| 3.2 Streamlines and stream-tubes | 54 |
| 3.3 Mass continuity | 54 |
| 3.4 Energy conservation in an ideal fluid: Bernoulli's equation | 55 |
| 3.5 Dynamics of a viscous fluid | 58 |
| 3.6 Lift and circulation | 62 |
| 3.7 Euler's turbine equation | 65 |
| SUMMARY | 66 |
| FURTHER READING | 67 |
| LIST OF MAIN SYMBOLS | 68 |
| EXERCISES | 68 |
| <hr/> | |
| 4 Hydropower, tidal power, and wave power | 70 |
| 4.1 Hydropower | 71 |
| 4.2 Power output from a dam | 72 |
| 4.3 Measurement of volume flow rate using a weir | 73 |
| 4.4 Water turbines | 74 |
| 4.5 Impact, economics, and prospects of hydropower | 79 |
| 4.6 Tides | 80 |
| 4.7 Tidal power | 84 |
| 4.8 Power from a tidal barrage | 84 |
| 4.9 Tidal resonance | 85 |
| 4.10 Kinetic energy of tidal currents | 86 |
| 4.11 Ecological and environmental impact of tidal barrages | 87 |
| 4.12 Economics and prospects for tidal power | 87 |
| 4.13 Wave energy | 88 |
| 4.14 Wave power devices | 90 |
| 4.15 Environmental impact, economics, and prospects of wave power | 95 |
| SUMMARY | 95 |
| FURTHER READING | 96 |
| WEB LINKS | 97 |
| LIST OF MAIN SYMBOLS | 97 |
| EXERCISES | 97 |

| | |
|--|------------|
| 5 Wind power | 99 |
| 5.1 Source of wind energy | 99 |
| 5.2 Global wind patterns | 100 |
| 5.3 Modern wind turbines | 103 |
| 5.4 Kinetic energy of wind | 104 |
| 5.5 Principles of a horizontal-axis wind turbine | 105 |
| 5.6 Wind turbine blade design | 107 |
| 5.7 Dependence of the power coefficient C_p on the tip-speed ratio λ | 111 |
| 5.8 Design of a modern horizontal-axis wind turbine | 114 |
| 5.9 Turbine control and operation | 117 |
| 5.10 Wind characteristics | 118 |
| 5.11 Power output of a wind turbine | 121 |
| 5.12 Wind farms | 122 |
| 5.13 Environmental impact and public acceptance | 122 |
| 5.14 Economics of wind power | 125 |
| 5.15 Outlook | 126 |
| 5.16 Conclusion | 129 |
| SUMMARY | 129 |
| FURTHER READING | 130 |
| WEB LINKS | 130 |
| LIST OF MAIN SYMBOLS | 130 |
| EXERCISES | 130 |

| | |
|--|------------|
| 6 Solar energy | 134 |
| 6.1 The solar spectrum | 135 |
| 6.2 Semiconductors | 136 |
| 6.3 p-n junction | 138 |
| 6.4 Solar photocells | 141 |
| 6.5 Efficiency of solar cells | 143 |
| 6.6 Commercial solar cells | 148 |
| 6.7 Developing technologies | 155 |
| 6.8 Solar panels | 160 |
| 6.9 Economics of photovoltaics (PV) | 161 |
| 6.10 Environmental impact of photovoltaics | 163 |
| 6.11 Outlook for photovoltaics | 164 |
| 6.12 Solar thermal power plants | 164 |
| SUMMARY | 170 |

| | |
|--|------------|
| FURTHER READING | 171 |
| WEB LINKS | 171 |
| LIST OF MAIN SYMBOLS | 171 |
| EXERCISES | 172 |
| <hr/> | |
| 7 Biomass | 175 |
| 7.1 Photosynthesis and crop yields | 175 |
| 7.2 Biomass potential and use | 179 |
| 7.3 Biomass energy production | 180 |
| 7.4 Environmental impact of biomass | 194 |
| 7.5 Economics and potential of biomass | 195 |
| 7.6 Outlook | 197 |
| SUMMARY | 197 |
| FURTHER READING | 198 |
| WEB LINKS | 198 |
| LIST OF MAIN SYMBOLS | 198 |
| EXERCISES | 198 |
| <hr/> | |
| 8 Energy from fission | 200 |
| 8.1 Binding energy and stability of nuclei | 201 |
| 8.2 Fission | 205 |
| 8.3 Thermal reactors | 212 |
| 8.4 Thermal reactor designs | 219 |
| 8.5 Fast reactors | 228 |
| 8.6 Present-day nuclear reactors | 230 |
| 8.7 Safety of nuclear power | 233 |
| 8.8 Economics of nuclear power | 234 |
| 8.9 Environmental impact of nuclear power | 235 |
| 8.10 Public opinion on nuclear power | 236 |
| 8.11 Outlook for nuclear power | 237 |
| SUMMARY | 239 |
| FURTHER READING | 240 |
| WEB LINKS | 240 |
| LIST OF MAIN SYMBOLS | 240 |
| EXERCISES | 240 |

| | |
|---|------------|
| 9 Energy from fusion | 244 |
| 9.1 Magnetic confinement | 245 |
| 9.2 D–T fusion reactor | 246 |
| 9.3 Performance of tokamaks | 251 |
| 9.4 Plasmas | 251 |
| 9.5 Charged particle motion in E and B fields | 253 |
| 9.6 Tokamaks | 257 |
| 9.7 Plasma confinement | 258 |
| 9.8 Divertor tokamaks | 264 |
| 9.9 Outlook for controlled fusion | 266 |
| SUMMARY | 271 |
| FURTHER READING | 272 |
| WEB LINKS | 272 |
| LIST OF MAIN SYMBOLS | 272 |
| EXERCISES | 272 |

| | |
|--|------------|
| 10 Generation and transmission of electricity, energy storage, and fuel cells | 274 |
| 10.1 Generation of electricity | 274 |
| 10.2 High voltage power transmission | 278 |
| 10.3 Transformers | 280 |
| 10.4 High voltage direct current transmission | 281 |
| 10.5 Electricity grids | 282 |
| 10.6 Energy storage | 282 |
| 10.7 Pumped storage | 283 |
| 10.8 Compressed air energy storage | 284 |
| 10.9 Flywheels | 285 |
| 10.10 Superconducting magnetic energy storage | 286 |
| 10.11 Batteries | 286 |
| 10.12 Fuel cells | 287 |
| 10.13 Storage and production of hydrogen | 288 |
| 10.14 Outlook for fuel cells | 292 |
| SUMMARY | 292 |
| WEB LINKS | 293 |
| LIST OF MAIN SYMBOLS | 293 |
| EXERCISES | 294 |

| | |
|--|------------|
| 11 Energy and society | 295 |
| 11.1 Environmental impact of energy production | 295 |
| 11.2 Economics of energy production | 299 |
| 11.3 Cost–benefit analysis and risk assessment | 304 |
| 11.4 Designing safe systems | 306 |
| 11.5 Carbon abatement policies | 308 |
| 11.6 Stabilization wedges for limiting CO ₂ emissions | 309 |
| 11.7 Conclusions | 312 |
| SUMMARY | 313 |
| FURTHER READING | 313 |
| WEB LINKS | 314 |
| EXERCISES | 314 |
| | |
| Numerical answers to exercises | 316 |
| Index | 319 |