

# Contents

<b>CHAPTER 1</b>	<b>INTRODUCING RENEWABLE ENERGY</b>	
<b>1.1</b>	<b>Introduction</b>	<b>2</b>
	Force, energy and power	3
	Energy conservation: The First Law of Thermodynamics	4
	Forms of energy	4
	Conversion and efficiency	6
<b>1.2</b>	<b>Present-day energy use</b>	<b>6</b>
	World energy supplies	6
	Energy use in the UK	8
<b>1.3</b>	<b>Fossil fuels and climate change</b>	<b>10</b>
<b>1.4</b>	<b>Renewable energy sources</b>	<b>11</b>
	Solar energy: Direct uses	11
	Solar energy: Indirect uses	12
	Non-solar renewables	13
<b>1.5</b>	<b>Renewable energy in a sustainable future</b>	<b>14</b>
	<b>References and further information</b>	<b>15</b>
<b>CHAPTER 2</b>	<b>SOLAR THERMAL ENERGY</b>	
<b>2.1</b>	<b>Introduction</b>	<b>18</b>
<b>2.2</b>	<b>The rooftop solar water heater</b>	<b>19</b>
	The pumped solar water heater	19
	The thermosyphon solar water heater	20
<b>2.3</b>	<b>The nature and availability of solar radiation</b>	<b>21</b>
	The wavelengths of solar radiation	21
	Direct and diffuse radiation	22
	Availability of solar radiation	22
	Tilt and orientation	24
<b>2.4</b>	<b>The magic of glass</b>	<b>26</b>
	Transparency	26
	Heat loss mechanisms	27
<b>2.5</b>	<b>Low-temperature solar energy applications</b>	<b>30</b>
	Domestic water heating	31
	Domestic space heating	32
	Varieties of solar heating system	34
<b>2.6</b>	<b>Active solar heating</b>	<b>36</b>
	History	36
	Solar collectors	36
	Robustness, mounting and orientation	37
	Active solar space heating	38
	Interseasonal storage and solar district heating	39
<b>2.7</b>	<b>Passive solar heating</b>	<b>40</b>
	History	40
	Direct gain buildings as solar collectors	41
	Passive solar heating versus superinsulation	41
	Window energy balance	41
	General passive solar heating techniques	45
	Conservatories, greenhouses and atria	47
	Trombe walls	48
	Avoiding overshadowing	48
<b>2.8</b>	<b>Daylighting</b>	<b>49</b>
<b>2.9</b>	<b>Solar thermal engines and electricity generation</b>	<b>51</b>
	The first solar engine age	52
	The new solar age	54
	Power towers	54
	Parabolic trough concentrator systems	55
	Parabolic dish concentrator systems	56
	Solar ponds	56
	Ocean thermal energy conversion (OTEC)	57
	Solar chimneys	57
<b>2.10</b>	<b>Economics, potential and environmental impact</b>	<b>58</b>
	Domestic active solar water heating	58
	Swimming pool water heating	60
	Active solar space heating and district heating	60
	Passive solar heating and daylighting	60

Solar thermal engines and electricity generation	61	<b>3.12 PV integration, resources and future prospects</b>	<b>96</b>
<b>Conclusions</b>	<b>62</b>	Integration	96
<b>References</b>	<b>63</b>	PV resources	98
<b>CHAPTER 3 SOLAR PHOTOVOLTAICS</b>		The growing world photovoltaics market	98
<b>3.1 Introduction</b>	<b>66</b>	Future prospects: national and international PV research, development and demonstration programmes	99
<b>3.2 introducing photovoltaics</b>	<b>66</b>	Realizing the global potential	100
A brief history of PV	66	<b>References</b>	<b>101</b>
<b>3.3 PV in silicon: basic principles</b>	<b>68</b>	<b>Further information</b>	<b>103</b>
Semiconductors and 'doping'	68	<b>CHAPTER 4 BIOENERGY</b>	
The p-n junction	71	<b>4.1 Introduction</b>	<b>106</b>
The PV effect	71	<b>4.2 Bioenergy past and present</b>	<b>108</b>
Monocrystalline silicon cells	75	From wood to coal	108
<b>3.4 Crystalline PV: reducing costs and raising efficiency</b>	<b>76</b>	Present biomass contributions	108
Polycrystalline silicon	76	<b>4.3 Biomass as a fuel</b>	<b>109</b>
Silicon ribbons and sheets	77	What are fuels?	109
Gallium arsenide	77	Biomass as a solar energy store	111
<b>3.5 Thin film PV</b>	<b>78</b>	Conversion efficiencies	112
Amorphous silicon	78	<b>4.4 Bioenergy sources I:</b>	
Other thin film PV Technologies	79	<b>Energy crops</b>	<b>113</b>
<b>3.6 Other innovative PV technologies</b>	<b>80</b>	Woody crops	114
Multi-junction PV cells	80	Agricultural crops	116
Concentrating PV systems	80	<b>4.5 Bioenergy sources II:</b>	
Silicon spheres	81	<b>Wastes</b>	<b>116</b>
Photoelectrochemical cells	81	Wood residues	116
'Third generation' PV Cells	82	Temperate crop wastes	117
<b>3.7 Electrical characteristics of silicon PV cells and modules</b>	<b>83</b>	Tropical crop wastes	119
<b>3.8 PV systems for remote power</b>	<b>84</b>	Animal wastes	119
<b>3.9 Grid-connected PV systems</b>	<b>85</b>	Municipal solid waste	120
PV systems for homes	85	Landfill gas	120
PV Systems for non-domestic buildings	89	Commercial and industrial wastes	122
Large, grid-connected PV power plants	90	<b>4.6 Combustion of solid biomass</b>	<b>123</b>
Satellite solar power	91	Combustion of wood and crop residues	123
<b>3.10 Costs of energy from PV</b>	<b>92</b>	Charcoal	124
Reducing the costs of power from PV	94	Combustion of municipal solid wastes	125
<b>3.11 Environmental impact and safety</b>	<b>95</b>	<b>4.7 Production of gaseous fuels from biomass</b>	<b>127</b>
Environmental impact and safety of PV systems	95	Anaerobic digestion	127
Environmental impact and safety of PV production	95	Anaerobic digesters for MSW	130
Energy balance of PV systems	96	Gasification	131

Pyrolysis to produce bio-oil	133	<b>5.10 Ranges of application</b>	<b>172</b>
Synthesizing liquid fuels	134	Specific speed	172
Fermentation to produce ethanol	134	<b>5.11 Small-scale hydroelectricity</b>	<b>173</b>
Vegetable oils to biodiesel	136	World-wide developments	173
<b>4.9 Environmental benefits and impacts</b>	<b>137</b>	SSH in the UK	175
Atmospheric emissions	137	<b>5.12 Environmental considerations</b>	<b>177</b>
Land use	139	Hydrological effects	177
Energy balance	140	Dams and reservoirs	179
<b>4.10 Economics</b>	<b>141</b>	Social effects	181
Energy Prices	141	Small-scale systems	182
Costing bioenergy	141	Comparisons	182
Electricity from wastes	142	<b>5.13 Integration</b>	<b>183</b>
Electricity from Energy crops	143	Power stations as elements in a system	183
<b>4.11 Future prospects</b>	<b>144</b>	Pumped storage	184
<b>References</b>	<b>145</b>	<b>5.14 Economics</b>	<b>186</b>
CHAPTER 5 HYDROELECTRICITY		Capital costs	186
<b>5.1 Introduction</b>	<b>148</b>	Investing in hydroelectricity	188
<b>5.2 The Galloway hydros</b>	<b>148</b>	<b>5.15 Future prospects</b>	<b>190</b>
Origins	148	Small-scale hydro (SSH)	191
The scheme	149	References	192
Power	150	CHAPTER 6 TIDAL POWER	
The turbines	150	<b>6.1 Introduction</b>	<b>196</b>
The salmon	151	The nature of the resource	197
Economics	152	Basic physics	198
<b>5.3 Hydro: The resource</b>	<b>153</b>	Power generation	203
The world resource	153	<b>6.2 Technical factors</b>	<b>204</b>
World capacity and output	154	<b>6.3 Environmental factors</b>	<b>210</b>
<b>5.4 Stored energy and available power</b>	<b>155</b>	<b>6.4 Integration</b>	<b>215</b>
Stored potential energy	155	<b>6.5 Economic factors</b>	<b>218</b>
Power, head and flow rate	156	<b>6.6 Tidal energy potential</b>	<b>223</b>
<b>5.5 A brief history of water-power</b>	<b>157</b>	United Kingdom	223
The prime mover	157	World	225
Nineteenth-century hydro technology	160	<b>6.7 Tidal barrages: conclusions</b>	<b>228</b>
<b>5.6 Types of hydroelectric plant</b>	<b>161</b>	<b>6.8 Tidal streams</b>	<b>230</b>
Low, medium and high heads	162	Practical projects in the UK	231
Estimating the power	164	Tidal current projects and concepts around the world	234
<b>5.7 The Francis turbine</b>	<b>164</b>	<b>6.9 Tidal current turbines: the next stage</b>	<b>237</b>
Action of the turbine	164	<b>6.10 Tidal current assessment</b>	<b>239</b>
Maximizing the efficiency	167	References	241
Limits to the Francis turbine	167	CHAPTER 7 WIND ENERGY	
<b>5.8 'Propellers'</b>	<b>168</b>	<b>7.1 Introduction</b>	<b>244</b>
<b>5.9 Impulse turbines</b>	<b>169</b>	<b>7.2 The wind</b>	<b>245</b>
Pelton wheels	169	Energy and power in the wind	248
Turgo and cross-flow turbines	171		

<b>7.3</b>	<b>Wind turbines</b>	<b>249</b>	<b>Further Reading</b>	<b>295</b>
	A brief history of wind energy	249	Internet Sources	296
	Wind turbine types	252		
	Horizontal axis wind turbines	253		
	Vertical axis wind turbines	255		
<b>7.4</b>	<b>Aerodynamics of wind turbines</b>	<b>256</b>	<b>CHAPTER 8</b>	<b>WAVE ENERGY</b>
	Aerodynamic forces	256	<b>8.1</b>	<b>Introduction</b>
	Aerofoils	258		Recent history
	Relative wind velocity	259	<b>8.2</b>	<b>Introductory case studies</b>
	Harnessing aerodynamic forces	261	<b>8.3</b>	<b>Physical principles of wave energy</b>
	Horizontal axis wind turbines	261		303
	Vertical axis wind turbines	264		Typical sea state
<b>7.5</b>	<b>Power and energy from wind turbines</b>	<b>265</b>		303
	How much power does a wind turbine produce?	265		Variations in the wave power at any location
	How much energy will wind turbines produce?	266		307
	Estimating wind speed characteristics of a site	268		Wave direction
<b>7.6</b>	<b>Environmental impact</b>	<b>270</b>		308
	Environmental benefits of electricity generation by wind energy	270		What happens beneath the surface?
	Environmental impacts of wind turbines	270		308
	Electromagnetic interference	273		Moving into shallow water
	Wind turbines and military aviation	274		309
	Visual impact	274		Refraction
	Public attitudes to wind power	275	<b>8.4</b>	<b>Wave energy resources</b>
	Wind turbines and birds	276	<b>8.5</b>	<b>Wave energy technology</b>
	Additional environmental factors	277		310
	Planning and wind energy	277		312
<b>7.7</b>	<b>Economics</b>	<b>278</b>		Fixed devices
	Calculating the costs of wind energy	278		314
<b>7.8</b>	<b>Commercial development and wind energy potential</b>	<b>280</b>		Floating devices
	Wind energy developments world-wide	280		317
	Small-scale wind turbines	283		Tethered devices
	Local community and co-operatively-owned wind turbines	283		322
	Wind energy and buildings	284		Wave energy research and development activity around the world
	Wind energy potential	285	<b>8.6</b>	<b>Economics</b>
<b>7.9</b>	<b>Offshore wind energy</b>	<b>286</b>	<b>8.7</b>	<b>Environmental impact</b>
	Offshore wind energy in the UK	288	<b>8.8</b>	<b>Integration</b>
	<b>References</b>	<b>292</b>		334
				Wave energy for isolated communities
				334
				Wave energy for large electricity grids
				336
			<b>8.9</b>	<b>Future prospects</b>
				337
				<b>References</b>
				337
			<b>CHAPTER 9</b>	<b>GEOTHERMAL ENERGY</b>
			<b>9.1</b>	<b>Geothermal energy – an overview</b>
				342
				The mining of geothermal heat
				342
				The source of heat
				344
				Historical perspective
			<b>9.2</b>	<b>The physics of geothermal resources</b>
				350
				Primary ingredients
				350
				Volcano-related heat sources and fluids
				353
				The heat source in sedimentary basins
				355
				Geothermal waters
				357
				Why are there hot dry rocks?
				358

<b>9.3 Technologies for geothermal resource exploitation</b>	<b>359</b>	<b>10.5 Are renewable-energy supplies available when we want them?</b>	<b>394</b>
Resources in high-enthalpy steam fields	359	Renewables as heat suppliers	395
Dry steam power plant	360	Integrating renewable electricity	396
Single flash steam power plant	361		
Binary cycle power plant	362		
Double flash power plant	362		
Future developments	363		
Resources for direct use geothermal energy	363		
Ground source heat pumps	364		
Hot dry rock technology	368		
<b>9.4 Environmental implications</b>	<b>373</b>	<b>10.6 Some system solutions</b>	<b>404</b>
<b>9.5 Economics and world potential</b>	<b>375</b>	Grid strengthening	404
<b>9.6 Geothermal potential in the United Kingdom</b>	<b>378</b>	Demand management	405
Sedimentary basin aquifers	378	PV, micro-CHP and emergency generators	405
Hot dry rocks	379	Hydrogen – the fuel of the future?	406
<b>References</b>	<b>381</b>		
<b>Further reading</b>	<b>381</b>		
The world wide web	381		
Conference proceedings	382		
Background material	382		
<b>CHAPTER 10 INTEGRATION</b>		<b>10.7 Balancing economic options</b>	<b>410</b>
<b>10.1 Introduction</b>	<b>384</b>	Renewables and conservation	410
<b>10.2 The existing UK energy system</b>	<b>385</b>	Balancing economic and environmental considerations	411
Energy flows	385	Renewable energy and planning permission	413
Distribution	386		
<b>10.3 How much renewable energy is available?</b>	<b>388</b>	<b>10.8 Promoting renewables</b>	<b>414</b>
<b>10.4 Are renewable-energy supplies available where we want them?</b>	<b>391</b>	Supporting research and development	414
The present electricity grid	392	Targets	415
Wave, wind and tidal power	393	Legislation and building regulations	415
		Financial incentives	415
		Future EU policies	419
		<b>10.9 Energy scenarios: Danish examples</b>	<b>420</b>
		International Energy Agency projections	422
		<b>10.10 Global scenarios</b>	<b>422</b>
		Conclusions	429
		<b>References</b>	<b>430</b>
		Further information	432
		<b>Appendix</b>	<b>433</b>
		A1 Investing in renewable energy	433
		A2 Units	437
		<b>ACKNOWLEDGEMENTS</b>	<b>439</b>
		<b>INDEX</b>	<b>443</b>