

Contents

Preface	xv
Acknowledgements	xvii
Author biography	xviii

Part I Introduction to bioenergy

1 Renewable energy and biomass	1-1
1.1 Introduction	1-1
1.2 The energy use sectors	1-2
1.3 Energy flow—from primary to end-use energy	1-3
1.4 Global primary energy and total final energy consumption	1-5
1.5 Share of renewable energy in the global final energy consumption	1-6
1.6 Share of renewable energy in global electrical power generation	1-7
1.7 Global share of biomass energy	1-7
Exercises	1-9
References	1-9
2 Introduction to solid biomass—properties and use	2-1
2.1 Introduction	2-1
2.2 Energy in biomass	2-2
2.2.1 Obtaining energy from biomass	2-2
2.2.2 Where does the energy in biomass reside?	2-4
2.2.3 Biomass as an energy source	2-8
2.3 Forms of solid biomass feedstock	2-9
2.3.1 Dedicated energy crops	2-10
2.3.2 Forestry and industrial residues	2-10
2.3.3 Municipal solid waste	2-11
2.3.4 Animal waste	2-11
2.3.5 Sewage	2-11
2.4 Energy uses of solid biomass	2-12
2.4.1 Case study: biomass energy use in the USA	2-12
2.5 The important properties of woody biomass	2-13
2.5.1 Moisture content	2-14
2.5.2 Energy content	2-15

2.6	Energy–moisture relations	2-16
2.7	Density–moisture relations	2-16
2.7.1	The density of wood	2-16
2.7.2	Density–moisture curves	2-17
2.8	Pre-treatment and densification of biomass	2-17
2.8.1	The need for densification	2-18
2.8.2	Pre-treatment of biomass	2-18
2.8.3	Densification techniques	2-19
	Exercises, questions and projects	2-20
	References	2-22
3	Thermal and thermochemical conversion of solid biomass	3-1
3.1	Introduction	3-1
3.2	Pathways for biomass conversion	3-2
3.2.1	Overview of biomass conversion processes	3-2
3.2.2	Thermochemical processes	3-3
3.3	Combustion	3-4
3.3.1	Nature of combustion	3-4
3.3.2	Combustion of solid biomass	3-6
3.3.3	The products of combustion	3-7
3.4	Pyrolysis	3-8
3.4.1	Introduction to pyrolysis	3-8
3.4.2	The pyrolysis process	3-8
3.4.3	Types of pyrolysis	3-9
3.4.4	Products of pyrolysis	3-11
3.4.5	Pyrolysis reactors	3-13
3.5	Gasification	3-14
3.5.1	What is gasification?	3-14
3.5.2	Overview of the gasification process	3-15
3.5.3	The chemistry of gasification	3-16
3.5.4	Uses of syngas	3-18
3.5.5	Gasifiers	3-19
3.6	Summary of thermochemical processes and products	3-19
	Exercises, questions and quizzes	3-20
	References	3-21

4 Chemical, biochemical and electrochemical conversion of biomass	4-1
4.1 Introduction	4-1
4.2 Chemical conversion of biomass	4-2
4.2.1 Transesterification and biodiesel	4-2
4.2.2 Hydro-treated vegetable oils as fuels for transportation	4-4
4.2.3 Synthetic fuels from syngas—the FTS process	4-5
4.3 Biochemical conversion of biomass through respiration	4-6
4.3.1 Cellular metabolism	4-6
4.3.2 Respiration and ATP	4-9
4.3.3 Anaerobic respiration and fermentation	4-12
4.4 Anaerobic digestion and methane fermentation	4-15
4.4.1 Introduction	4-15
4.4.2 Methane fermentation pathways	4-16
4.5 Electrochemical conversion of biofuels	4-16
4.5.1 Introduction—thermal vs electrochemical conversion of chemical energy	4-16
4.5.2 The importance of fuel cells	4-18
4.5.3 Blue hydrogen and hydrogen fuel cells	4-19
Exercises and questions	4-19
References	4-21

Part II The physics and technology of bioenergy use

5 The thermodynamics of heat engines	5-1
5.1 Introduction	5-1
5.2 Heat engine—basic concepts	5-2
5.3 Basic concepts of thermodynamics	5-4
5.3.1 System	5-5
5.3.2 State variables	5-5
5.3.3 State diagrams	5-6
5.3.4 Processes and paths	5-6
5.3.5 First law of thermodynamics	5-6
5.3.6 Cyclic processes	5-7
5.4 Principle of operation of the heat engine	5-8
5.4.1 New form of the first law	5-8
5.4.2 The second law of thermodynamics	5-9
5.4.3 Thermal efficiency	5-10

5.4.4 Carnot efficiency	5-10
5.5 Heat engine power cycles	5-11
5.5.1 Closed and open cycles	5-12
5.6 Types of heat engines	5-12
5.6.1 External and internal combustion engines	5-12
5.6.2 Turbines and piston engines	5-12
5.7 The Rankine cycle and the steam turbine	5-13
5.7.1 The realistic steam turbine with super-heating	5-14
5.7.2 Improving design with reheating	5-15
5.8 The Brayton cycle and the gas turbine	5-16
Exercises, questions and quizzes	5-18
References	5-20
6 Bioenergy-based power generation technology	6-1
6.1 Introduction	6-1
6.2 Principles of operation of thermal power plants	6-2
6.2.1 Generic design of thermal power plants	6-2
6.3 Types of thermal power plants	6-3
6.3.1 Characteristics of thermal power plants	6-3
6.3.2 Condensing and CHP power plants	6-3
6.3.3 A typical condensing coal-fired power plant	6-6
6.4 Combined cycle power plants	6-7
6.4.1 Multi-stage power plants	6-7
6.4.2 Integrated gasification combined cycle power plant (IGCCPP)	6-7
6.5 Bioenergy-fired thermal power plants in industrial application	6-8
6.5.1 Bagasse-fired power plants in the sugar industry	6-8
6.5.2 Solid biomass-fired power plants	6-9
6.5.3 Pyrolysis power plants	6-9
6.5.4 Biogas-fired power plants	6-11
Exercises and questions	6-14
References	6-16
7 Electrochemical conversion and storage of energy	7-1
7.1 Introduction	7-1
7.1.1 What are electrolyzers, fuel cells and batteries?	7-2
7.1.2 Introducing the electrochemical cell	7-3
7.1.3 How are electrolyzers, fuel cells and batteries related?	7-4

7.2	Types of fuel cells	7-5
7.2.1	Introduction	7-5
7.2.2	Fuel cell types	7-6
7.2.3	Summary of essential properties of fuel cells	7-8
7.3	Types of batteries	7-9
7.3.1	Primary batteries	7-9
7.3.2	Secondary (rechargeable) batteries	7-13
7.4	Battery research and development	7-16
	Exercises and questions	7-17
	References	7-18

Part III Liquid and gaseous biofuels for transportation and power generation

8	Introduction to liquid biofuels	8-1
8.1	Introduction	8-1
8.2	Types of biofuels	8-2
8.2.1	What are biofuels?	8-2
8.2.2	What are the generations of biofuels?	8-3
8.2.3	Issues with first generation biofuels	8-3
8.2.4	Biofuel blends	8-4
8.3	Global production of biofuels	8-4
8.4	Engine fuel properties and standards	8-5
8.4.1	Fuel properties	8-5
8.4.2	Gasoline and diesel engine fuels	8-8
8.4.3	Fuel standards and legislations	8-8
8.4.4	Biofuel standards	8-10
8.4.5	Fuel standards and legislations—the Australian case study	8-10
	Exercises, questions and activities	8-11
	References	8-12

9	Bioethanol and biobutanol	9-1
9.1	Introduction	9-1
9.2	Bioethanol	9-2
9.2.1	Fuel properties of ethanol	9-2
9.2.2	Industrial production of bioethanol	9-3
9.2.3	Metabolic pathways for bioethanol	9-3

9.2.4	Issues with bioethanol fuel	9-6
9.2.5	Future biofuels through metabolic engineering	9-6
9.3	Biobutanol	9-8
9.3.1	Fuel properties of butanol	9-8
9.3.2	Industrial production of biobutanol	9-9
9.3.3	Butanol fermentation through the ABE process	9-9
9.3.4	Improving yield through metabolic engineering	9-10
	Exercises and questions	9-10
	References	9-11
10	Biodiesel, biogas and biomethane	10-1
10.1	Introduction	10-1
10.2	Biodiesel	10-2
10.2.1	Introduction	10-2
10.2.2	Biodiesel as a fuel	10-2
10.2.3	Fuel properties of biodiesel	10-3
10.2.4	Industrial production of biodiesel	10-4
10.2.5	Issues with biodiesel	10-7
10.3	Biogas and biomethane	10-7
10.3.1	Biogas	10-7
10.3.2	Biomethane or renewable natural gas (RNG)	10-9
10.3.3	Future supply outlook for biogas and biomethane	10-11
	Exercises and questions	10-12
	References	10-12
11	Emerging fuels for transport and power	11-1
11.1	Introduction	11-1
11.2	HVO—a better biofuel for diesel engines	11-2
11.2.1	Production of HVO	11-2
11.3	Syngas—a gas for many applications	11-3
11.3.1	Uses of syngas	11-3
11.4	The FTS process—synthetic fuels for conventional engines	11-4
11.5	Pyrolysis oil—new fuel for sea transport and power generation	11-5
11.6	Hydrogen—green fuel for EVs and storage	11-7
11.6.1	Hydrogen production	11-7
11.6.2	Hydrogen as a green fuel	11-9
11.6.3	Use of hydrogen—the hydrogen economy	11-10

Exercises and questions	11-11
References	11-13

Part IV Energy, climate change and an integrated global policy framework for development

12 Drivers and threats to global renewable energy production	12-1
12.1 Introduction	12-1
12.2 Who are the stakeholders in global energy?	12-2
12.3 Energy and global conflicts	12-5
12.4 The role of fossil fuel subsidies	12-6
12.5 New drivers for global RE production	12-9
12.5.1 Climate change	12-9
12.5.2 Energy access for all	12-9
Exercises and questions	12-10
References	12-11
13 Climate change and future energy technology	13-1
13.1 Introduction	13-1
13.2 The net zero by 2050 ultimatum from the UNFCCC	13-2
13.2.1 The Paris Agreement and its goals	13-2
13.2.2 The IPCC Special Report on 1.5 °C	13-3
13.2.3 High Level Dialogue on Energy (HLDE)	13-3
13.2.4 The Emissions Gap Report 2021	13-4
13.3 The science behind climate change	13-7
13.3.1 Global warming	13-7
13.3.2 Estimating emissions	13-11
13.4 COP26 and the global energy transition	13-12
13.4.1 Goals of COP26	13-13
13.4.2 New tools and opportunities for achieving net zero	13-14
13.5 The energy transition—an Australian case study	13-22
13.5.1 Australia's net zero plan	13-22
13.5.2 The role of Australian universities—ANU's grand challenge	13-23
13.5.3 Summary remarks	13-25
13.6 COP27	13-26
Exercises and questions	13-28
References	13-30

14 Energy, pandemics and an integrated global development plan	14-1
14.1 Introduction	14-1
14.2 Global poverty, the MDGs and the SDGs	14-2
14.2.1 Poverty and the MDGs	14-2
14.2.2 Energy access and the SDGs	14-5
14.3 Energy and economic well-being	14-6
14.3.1 Access to clean and modern energy	14-7
14.3.2 Link between poverty and traditional biomass energy	14-7
14.3.3 Clean energy vs traditional biomass energy	14-7
14.4 Addressing global crises and disasters	14-8
14.4.1 What are the global crises and disasters facing humans today?	14-8
14.4.2 What are the strategies used to address global crises and disasters?	14-9
14.4.3 Is there a better way of addressing global crises?	14-10
14.5 An integrated approach to the global challenges	14-11
14.5.1 How can we find better ways of solving our crises?	14-11
14.5.2 A suggested methodology	14-11
Exercises and questions	14-12
References	14-13