

Table of contents

About the book series	vii
Editorial board	ix
List of contributors	xxxi
Foreword by Bill Stout	xxxiii
Editors' Foreword	xxxv
About the editors	xxxvii
Acknowledgements	xxxix

Section 1: Introduction

1. Towards a sustainable energy technologies based agriculture	3
<i>Jochen Bundschuh, Guangnan Chen & Shahbaz Mushtaq</i>	
1.1 Introduction	3
1.1.1 Challenges	8
1.2 Sustainable energy options in agriculture	10
1.2.1 Energy efficiency and energy conservation	10
1.2.1.1 Enhancing irrigation and energy efficiency of the irrigated systems	11
1.2.1.2 Cooling and heating	12
1.2.2 Use of biomass and biomass waste for carbon-neutral production of biofuel, electricity and bio-coal fertilizers	12
1.2.3 Decentralized renewable energy systems (solar, wind, geothermal)	13
1.2.4 Economic benefit of green food	13
1.3 Conclusions	13

Section 2: Energy efficiency and management

2. Global energy resources, supply and demand, energy security and on-farm energy efficiency	19
<i>Ralph E.H. Sims</i>	
2.1 Introduction	19
2.1.1 Energy access	20
2.1.2 Environmental impacts	22
2.1.3 Food price and energy nexus	22
2.2 Global energy trends	24
2.2.1 Bridging the emissions gap	26
2.3 Other major related issues	28
2.3.1 Economic viability	28
2.3.2 Competing land uses	28
2.3.3 Dangerous climate change	28
2.3.4 Existing efforts are inadequate	29
2.4 Global energy supply for agriculture	30

2.5	Energy efficiency in agriculture	32
2.5.1	Tractors and machinery	34
2.5.2	Irrigation	34
2.5.3	Fertilizers	35
2.5.4	Dairy farms	36
2.5.5	Sheep and beef farms	38
2.5.6	Intensive livestock production and fishing	39
2.5.7	Greenhouse production	42
2.5.8	Fruit production	44
2.5.9	Cropping	46
2.6	Conclusions	48
3.	Energy in crop production systems	53
	<i>Jeff N. Tullberg</i>	
3.1	Introduction	53
3.2	Energy distribution in farming systems	53
3.3	Input energy efficiency	55
3.3.1	Farm machinery operations	55
3.3.2	Tractive power transmission	55
3.3.3	Efficiency of tractor-powered tillage	57
3.4	Land preparation by tillage	58
3.4.1	Tillage equipment	58
3.4.2	Tillage objectives and functions	59
3.5	Embodied energy	60
3.5.1	Machinery	60
3.5.2	Fertilizer	62
3.5.3	Agricultural chemicals	63
3.6	More energy-efficient cropping systems	64
3.6.1	General considerations	64
3.6.2	No-till and conservation agriculture	65
3.6.3	Controlled traffic farming	68
3.6.4	Precision and high-technology	70
3.6.4.1	Precision agriculture	70
3.6.4.2	Precision guidance	70
3.6.4.3	Robotics	71
3.6.5	Cropping system energy comparisons	72
3.7	Conclusion	73
4.	The fossil energy use and CO ₂ emissions budget for Canadian agriculture	77
	<i>James Arthur Dyer, Raymond Louis Desjardins & Brian Glenn McConkey</i>	
4.1	Introduction	77
4.1.1	Energy use issues	77
4.1.1.1	GHG emissions	77
4.1.1.2	Energy supply	77
4.1.1.3	Food security	78
4.1.1.4	Biofuel crops	78
4.1.1.5	CC adaptation	78
4.1.2	Defining the farm energy budget	78
4.1.2.1	Group 1	79
4.1.2.2	Group 2	79
4.1.2.3	Group 3	80
4.1.2.4	Excluded energy terms	80

4.2	Methodology	80
4.2.1	Modeling farm energy consumption	80
4.2.2	Computations for field operations	81
4.2.3	Response to tillage systems	82
4.2.4	Converting energy use to fossil CO ₂ emissions	82
4.2.5	Interfacing farm energy use with other GHG emission models	84
4.3	Farm energy use calculations	85
4.3.1	Land use areas	86
4.3.1.1	Land use	87
4.3.1.2	Farm field operations	87
4.3.1.3	Farm energy use budget	88
4.3.1.4	Fossil energy use for livestock production	88
4.4	Results	90
4.5	Discussion and conclusions	91
5.	Energy efficiency technologies for sustainable agriculture and food processing	97
	<i>Lijun Wang</i>	
5.1	Introduction	97
5.2	Energy consumption in the agricultural production and food processing	97
5.2.1	Energy consumption in the agricultural production	97
5.2.2	Energy consumption in the food industry	99
5.2.2.1	Overview of energy consumption in the food industry	99
5.2.2.2	Energy use in different food manufacturing sectors	100
5.2.2.3	Energy use for production of different food products	101
5.2.3	Energy sources in the agricultural and food industry	101
5.2.3.1	Energy sources for agricultural production	101
5.2.3.2	Energy sources for food processing	101
5.2.4	Energy efficiency in agricultural production and food processing	104
5.3	Energy conservation and management in agricultural production and food processing	105
5.3.1	Energy conservation in agricultural production	105
5.3.2	Energy conservation in the utilities in food processing facilities	106
5.3.2.1	Energy savings in steam supply	106
5.3.2.2	Energy savings in compressed air supply	107
5.3.2.3	Energy savings in power supply	107
5.3.2.4	Energy savings in heat exchanger	107
5.3.2.5	Energy savings by recovering waste heat	108
5.3.3	Energy conservation in energy-intensive unit operations of food processes	108
5.3.3.1	Energy savings in thermal food processing	108
5.3.3.2	Energy savings in concentration, dehydration and drying	109
5.3.3.3	Energy savings in refrigeration and freezing	110
5.4	Utilizations of energy efficiency technologies in agricultural production and food processing	110
5.4.1	Application of novel thermodynamic cycles	111
5.4.1.1	Heat pump	111
5.4.1.2	Novel refrigeration cycles	112
5.4.1.3	Heat pipes	115
5.4.2	Application of non-thermal food processes	116
5.4.2.1	Food irradiation	117
5.4.2.2	Pulsed electric fields	117
5.4.2.3	High-pressure processing	117

5.4.2.4	Membrane processing	118
5.4.2.5	Supercritical fluid processing	118
5.4.3	Application of novel heating methods	118
5.4.3.1	Microwave and radio frequency heating	118
5.4.3.2	Ohmic heating	119
5.4.3.3	Infrared radiation heating	119
5.5	Summary	120
6.	Energy-smart food – technologies, practices and policies	123
	<i>Ralph E.H. Sims & Alessandro Flammini</i>	
6.1	Introduction	123
6.1.1	The key challenges	124
6.1.2	Scales of agricultural production	127
6.1.2.1	Subsistence	128
6.1.2.2	Small family farms	128
6.1.2.3	Small businesses	129
6.1.2.4	Large farms	129
6.2	Energy inputs and GHG emissions	130
6.2.1	Energy inputs for primary production	134
6.2.1.1	Tractors and machinery	134
6.2.1.2	Irrigation	135
6.2.1.3	Fertilizers	135
6.2.1.4	Livestock	136
6.2.1.5	Protected cropping in greenhouses	136
6.2.1.6	Fishing and aquaculture	136
6.2.1.7	Forestry	137
6.2.2	Energy inputs for secondary production	137
6.2.2.1	Drying, cooling and storage	137
6.2.2.2	Transport and distribution	137
6.2.3	Food processing	139
6.2.3.1	Preparation and cooking	139
6.3	The human dimension	140
6.3.1	Food losses and wastage	140
6.3.2	Changing diets	143
6.3.3	Modern energy services	144
6.4	Renewable energy supplies from agriculture	145
6.4.1	Renewable energy resources	146
6.4.2	Renewable energy systems	147
6.4.2.1	Biomass and bioenergy	149
6.4.2.2	Non-biomass renewable energy	151
6.4.3	The potential for energy-smart agriculture	151
6.4.3.1	A landscape approach to farming systems	151
6.4.3.2	Institutional arrangements and innovative business models	154
6.5	Policy options	155
6.5.1	Present related policies	156
6.5.2	Future policy requirements	157
6.5.2.1	Agriculture	157
6.5.2.2	Energy access	158
6.5.2.3	Climate change	159
6.5.2.4	Efficient energy use	159
6.5.2.5	Renewable energy deployment	159
6.5.2.6	Human behavior	161
6.6	Achieving energy-smart food	162

7.	Energy, water and food: exploring links in irrigated cropping systems	171
	<i>Tamara Jackson & Munir A. Hanjra</i>	
7.1	Introduction	171
7.1.1	Energy in agriculture	172
7.2	The energy-water nexus in crop production	172
7.2.1	Energy for irrigation	173
7.2.1.1	Factors affecting irrigation energy use	174
7.2.2	Energy and fertilizer	175
7.2.3	Energy and agrochemicals	175
7.2.4	Energy for machinery and equipment	176
7.2.4.1	Factors affecting input energy use for crop production	176
7.3	Patterns of energy consumption in irrigated agriculture	177
7.3.1	Study sites	177
7.3.2	Data requirements	178
7.3.3	Analyzing water application and energy consumption	179
7.3.3.1	Crop water requirements	179
7.3.3.2	Energy accounting	179
7.3.4	Results and discussion	181
7.3.4.1	Water application and energy consumption: baseline conditions	181
7.3.4.2	Potential energy and water savings using pressurized irrigation systems	183
7.3.5	Summary	187
7.4	Options for sustainable energy and water management in irrigated cropping systems	187
7.4.1	Technical interventions	187
7.4.2	Policy strategies	188
7.5	Conclusions	189
8.	Energy use and sustainability of intensive livestock production	195
	<i>Jukka Ahokas, Mari Rajaniemi, Hannu Mikkola, Jüri Frorip, Eugen Kokin, Jaan Praks, Väino Poikalainen, Imbi Veermäe & Winfried Schäfer</i>	
8.1	Energy and livestock production	195
8.1.1	What is energy	196
8.1.2	Energy consumption and emissions	197
8.1.3	Direct and indirect energy	198
8.1.4	Efficiency	199
8.1.5	Energy analysis	199
8.1.5.1	Methodology of energy analysis	199
8.1.5.2	Energy ratio	201
8.1.5.3	Specific energy consumption	202
8.1.5.4	Types of energy analysis	204
8.2	Livestock production sustainability	205
8.2.1	Sustainability	205
8.2.2	CO ₂ – equivalents	207
8.2.3	Livestock GHG emissions	207
8.3	Energy consumption in livestock production	208
8.3.1	Feed material production	208
8.3.1.1	Crop production	209
8.3.1.2	Grass and hay production	210
8.3.1.3	Concentrate production	211
8.3.2	Ventilation	212
8.3.3	Illumination	213
8.3.4	Heating of animal houses	215

8.3.4.1	Heat conduction	215
8.3.4.2	Heat losses by ventilation	218
8.3.5	Energy use follow-up	218
8.4	Energy use and saving in livestock production	219
8.4.1	Energy consumption in livestock production	219
8.4.2	Energy consumption in milk production	221
8.4.2.1	Milk production system	221
8.4.2.2	Energy used in milk production	222
8.4.2.3	Feed production and feed material	223
8.4.2.4	Use of direct energy	223
8.4.2.5	Milking and milk cooling	223
8.4.2.6	Lighting	226
8.4.2.7	Ventilation	226
8.4.2.8	Water pumping and hot water	228
8.4.2.9	Bringing up young cattle	228
8.4.3	Energy consumption in pork production	229
8.4.3.1	Pork production	229
8.4.3.2	Pork production energy consumption	231
8.4.3.3	Feed production and feed material	232
8.4.4	Energy consumption in broiler production	232
8.4.4.1	Broiler production	232
8.4.4.2	Energy consumption in broiler production	233
8.4.4.3	Lighting	235
8.4.4.4	Ventilation	236
8.4.4.5	Heating	237
8.4.4.6	Feed and feeding	238
8.5	Conclusions	239
9.	Diesel engine as prime power for agriculture: emissions reduction for sustainable mechanization	245
	<i>Xinqun Gui</i>	
9.1	Diesel engine as prime power for agriculture	245
9.2	Global non-road emissions regulations	246
9.3	Building blocks of diesel engines	250
9.3.1	Combustion system	250
9.3.2	Electronic engine control system	252
9.3.3	Fuel injection system	254
9.3.4	Turbocharging	255
9.3.5	Exhaust gas recirculation	257
9.4	After treatment technologies	259
9.4.1	Particulate matter and NO _x	259
9.4.2	Exhaust filtration	259
9.4.3	Regeneration types	259
9.4.4	Active regeneration technologies	260
9.4.5	Diesel oxidation catalyst (DOC)	261
9.4.6	Diesel particulate filter (DPF)	262
9.4.7	Catalyst canning	263
9.4.8	Exhaust fuel dosing system	263
9.4.9	After treatment system integration and controls	264
9.4.9.1	DOC outlet temperature control	264
9.4.9.2	Soot loading prediction	265
9.4.9.3	Active regeneration control	266

9.4.10 Diesel engine NO _x aftertreatment technologies	268
9.4.10.1 Selective catalytic reduction (SCR)	268
9.5 Meeting diesel emissions through tiers	269
9.5.1 Tier 3 and earlier engines	269
9.5.2 Meeting US EPA Tier 4	270
9.6 Biofuel for modern diesel engines	273
9.7 Summary and perspectives	273

Section 3: Biofuels

10. Biofuels from microalgae	277
<i>Malcolm R. Brown & Susan I. Blackburn</i>	
10.1 Introduction	277
10.1.1 Introduction to biofuels	277
10.1.2 History of investigation of biofuels from microalgae	277
10.1.3 Potential advantages of microalgae as biofuel feedstock	278
10.1.4 Overview of the production of biofuel from microalgae	278
10.1.5 Current status of commercial microalgal biofuel production and future prospects	280
10.2 General properties of microalgae	281
10.2.1 Taxonomy and general characteristics	281
10.2.2 Sourcing and maintaining microalgae species or strains	281
10.2.3 Chemical profiles of microalgae	282
10.2.3.1 Proximate composition	282
10.2.3.2 Qualitative aspects of proximate composition – amino acids and sugars	283
10.2.3.3 Lipid class and fatty acids	283
10.2.3.4 Other chemical components within microalgae of commercial interest	284
10.3 Selection of strains as candidates for biofuel feedstock	286
10.3.1 Growth rates and environmental tolerances from small-scale cultures	286
10.3.2 Screening for total lipid, and fatty acid quality	286
10.3.3 Other strain selection criteria	288
10.4 Scaling up production of microalgae biomass	288
10.4.1 General considerations	288
10.4.1.1 Light and temperature	289
10.4.1.2 Inorganic nutrients	290
10.4.1.3 CO ₂	290
10.4.1.4 Land and water	291
10.4.2 Pond systems	291
10.4.3 Photobioreactors (PBRs)	294
10.4.4 Fermentation systems	296
10.4.5 Hybrid growth systems	296
10.4.6 Productivities of microalgae growth systems	296
10.4.7 Improving productivity through technical and biological approaches	298
10.4.7.1 Culture system design	298
10.4.7.2 Ecological approaches	298
10.4.7.3 Breeding and genetic engineering	299
10.5 Harvesting of microalgal biomass	299
10.5.1 Flocculation	300
10.5.2 Gravity sedimentation	300
10.5.3 Flotation	301
10.5.4 Centrifugation	301

10.5.5	Filtration	301
10.5.6	Other separation techniques	302
10.6	Conversion of biomass to biofuels	302
10.6.1	Drying of microalgae biomass	302
10.6.2	Extraction of oil	303
10.6.3	Processes and biofuel products from microalgae	303
10.6.3.1	Biodiesel production	303
10.6.3.2	Bio-oil production by hydrothermal liquefaction	304
10.6.3.3	Gasification for syngas	304
10.6.3.4	Pyrolysis for bio-oil, biochar and syngas	304
10.6.3.5	Direct combustion	305
10.6.3.6	Fermentation processes to produce ethanol	305
10.6.3.7	Hydrogen through fermentation or biophotolysis	306
10.6.3.8	Anaerobic digestion for methane production	307
10.7	Towards commercial production	307
10.7.1	Current industry state	307
10.7.2	Economics of biofuel production	308
10.7.3	The concept of an integrated biorefinery	310
10.7.4	Environmental sustainability and life cycle analysis (LCA)	311
10.7.5	Political and social factors	313
10.8	Conclusion	313
11.	Biodiesel emissions and performance	323
	<i>Syed Ameer Basha</i>	
11.1	Introduction	323
11.1.1	Need of biodiesel	323
11.1.2	Biofuel	325
11.1.3	Production of biodiesel	326
11.2	Biodiesel emissions	326
11.2.1	NO _x	328
11.2.2	CO _x	329
11.2.3	HC emissions of biodiesel	329
11.2.4	Particulate matter (PM) emissions	330
11.3	Biodiesel performance	330
11.3.1	Brake specific fuel consumption	330
11.3.2	Efficiency	331
11.4	Effect of a catalyst or additive	331
11.4.1	Effect of a catalyst on biodiesel emissions	331
11.4.2	Effect of catalysts and additives on biodiesel performance	332
11.4.2.1	Brake specific fuel consumption	332
11.4.2.2	Efficiency	332
11.5	Conclusions	332
12.	Biogas	335
	<i>Paul Harris & Hans Oechsner</i>	
12.1	Introduction	335
12.2	What is biogas?	335
12.3	Brief history	336
12.4	Anaerobic digestion	337
12.5	Uses of biogas	338
12.6	Uses for liquid/sludge	339
12.7	Modeling digester performance	339
12.8	Digester performance	339
12.9	Types of digesters	341

12.10	Gas storage	342
12.11	Safety	344
12.11.1	Fire/explosion	344
12.11.2	Disease	344
12.11.3	Asphyxiation	345
12.11.4	Summary	346
12.12	Advanced digestion	346
12.12.1	High rate digesters	347
12.12.2	Two stage digesters	347
12.12.3	Anaerobic filters	348
12.12.4	Upflow anaerobic sludge blanket (UASB) digesters	348
12.12.5	Suspended growth digesters	348
12.12.6	Salt water digesters	348
12.12.7	Solid digestion	348
12.13	Packaged units	349
12.14	Startup	349
12.15	Monitoring digester operation	350
12.15.1	Indication of CO ₂ percentage	350
12.15.2	Measuring gas pressure	351
12.16	Burners	351
12.17	Fault finding	352
12.18	Construction tips	353
12.19	Conclusions	353
13.	Thermal gasification of waste biomass from agriculture production for energy purposes	355
	<i>Janusz Piechocki, Dariusz Wiśniewski & Andrzej Białowiec</i>	
13.1	Introduction	355
13.2	Biomass waste	355
13.2.1	Properties of biomass	357
13.2.2	Biomass for energy production	357
13.3	Thermal gasification	361
13.3.1	Pyrolysis as the basic process of biomass gasification	362
13.3.2	Biomass torrefaction	363
13.3.3	Gasification – basic reactions	365
13.3.4	Biomass gasification methods	367
13.3.5	Byproducts of biomass gasification and elimination methods	376
13.3.6	Design parameters of gasification reactors	377
13.4	Summary	379
14.	An innovative perspective: Transition towards a bio-based economy	383
	<i>Nicole van Beeck, Albert Moerkerken, Kees Kwant & Bert Stuij</i>	
14.1	Introduction: Why we need a bio-based economy	383
14.1.1	Towards a sustainable future	383
14.1.2	Relationship between agriculture and energy	383
14.1.3	What are the challenges?	384
14.1.4	The smart approach: a bio-based economy	385
14.2	Agriculture: The foundation of a bio-based economy	386
14.2.1	Agriculture and food	386
14.2.2	Soil fertility	388
14.2.3	Land use	388
14.2.4	Wastes in the food chain	390
14.2.5	Agrification policy at the origin of non-food industrial applications of biomass	390

14.3	Biomass at the basis of sustainable energy supply	392
14.3.1	Current energy demand	392
14.3.2	Food for thought: energy demand versus food demand	393
14.3.3	The carbon balance: the theoretical potential for a bio-based economy	394
14.3.4	Sustainability of biomass	396
14.4	A cascading approach for sustainable deployment of biomass and the Trias Biologica	398
14.5	Case studies of cascading in The Netherlands	400
14.5.1	Facts and figures of The Netherlands	400
14.5.2	The Trias Biologica: the sugar case	401
14.5.2.1	De-carbonization	401
14.5.2.2	Substitution of fossil carbon with bio-based carbon	403
14.5.2.3	Cascading	404
14.5.2.4	De-carbonization	405
14.5.2.5	Substitution	405
14.5.2.6	Cascading	406
14.5.3	Bio-refinery: the grass cascading case	406
14.5.4	Making circular chains: the manure case	408
14.6	Discussion and conclusions on impact and prospects	410

Section 4: Access to energy

15.	Increasing energy access in rural areas of developing countries	419
	<i>Xavier Lemaire</i>	
15.1	Introduction	419
15.1.1	The current situation of energy access in developing countries and the opportunity offered by the RETs	419
15.1.1.1	Contrasting situation across continents	419
15.1.1.2	The rationale for decentralized generation with RETs	420
15.1.1.3	How to deliver energy services to remote places, and what services to deliver?	420
15.2	Policy and institutions for energy access	421
15.2.1	The role of energy regulators and rural electrification agencies	421
15.2.1.1	Light-handed regulation	422
15.2.1.2	Standards and codes of practices	422
15.2.1.3	Planning	423
15.2.1.4	Who should be regulating off-grid electricity services, and why?	424
15.2.2	Funding and the question of subsidies	424
15.2.2.1	Targeted subsidies	425
15.2.2.2	Subsidies for mini-grid technologies	426
15.2.2.3	Subsidies for decentralized stand-alone systems	426
15.2.3	The role of rural energy service companies (RESOs)	426
15.2.3.1	Different business models for increasing energy access in rural areas with small decentralized RET systems	427
15.2.3.2	Cash purchase and micro-credit models	427
15.2.3.3	Fee-for-service models	429
15.2.3.4	Fee-for-service versus micro-credit models	430
15.2.3.5	Increasing energy access by using by-product of agriculture	431
15.3	Conclusion	432

Subject index	437
Book series page	455