No.6 of New Energy Frontier

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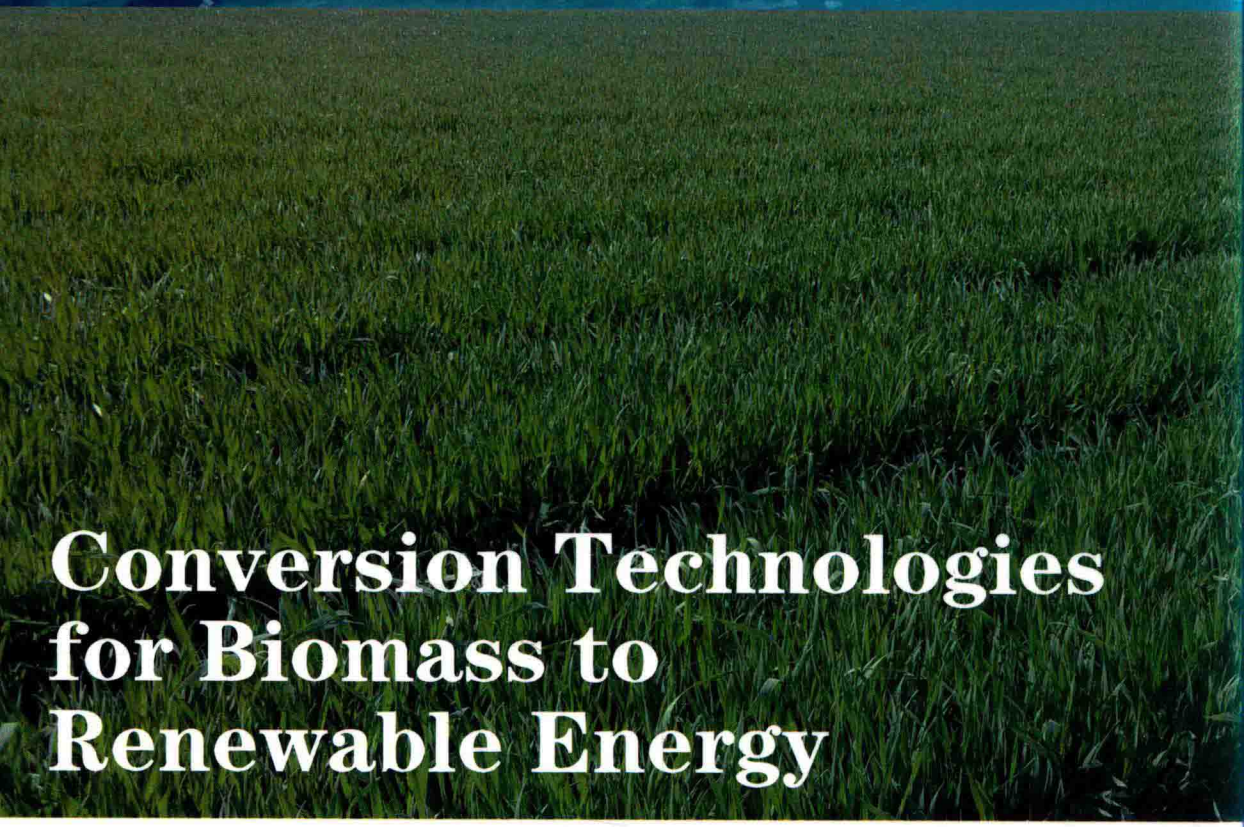

Conversion Technologies for Biomass to Renewable Energy

Shu Geng Jay J. Cheng
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Brief Introduction

This book describes diverse sources of bio-material such as agricultural and forestry residues, special cultivated energy plants, aquatic plants like algae and urban organic waste (Chapters 1) and the logistics of biomass production, harvesting, transportation and storage (chapter 2). It also presents detailed methods whereby these materials can be processed to generate various forms of clean bioenergy such as biogas (Chapter 3,7), biodiesel (Chapter 4), bioethanol (Chapter 5), and clean biochar and other bio-products (Chapter 8). In chapter 6, the modern advanced combustion system is introduced to improve burning efficiency. This simple approach could improve human and environmental health enormously, especially in rural areas of developing countries. The Application of Life Cycle Analysis on algae energy balance and the environmental impact of the bio-energy processes are discussed in Chapter 9. This book is intended to be practical and useful to those who are involved in bio-energy production.

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Editor

Dr. Shu Geng recieved his Ph. D. degree from Kansas State University, and served as a Professor in the College of Agricultural and Environmental Sciences and was an Associate Dean of college of the University of California at Davis. He founded the School of Environment and Energy of Peking University at Shenzhen, China and served as its founding dean from 2009 to 2014. Currently, he serves as an endowed Chair Professor at Northwest Agriculture and Forestry University in Yangling, China. He is a consultant and adviser of more than 20 international companies, governmental agencies and research institutes. He organized and chaired many international conferences on environmental and agricultural sustainability. His research areas include environmental ecology, bioenergy, simulation models, and risk assessment of global environmental changes and water resource management. He has published 142 referred scientific papers and 5 books. Dr. Geng is the founder of AUCE. org (Association of US-China Exchange) and Dwa. org (International Safe Drinking Water Alliance). Dr. Geng is an elected Fellow of American Association for Advancement of Science (1995) and American Society of Agronomy (1997).

Authors

Jay J. Cheng is a Professor of Bioprocessing and Environmental Engineering in the Biological and Agricultural Engineering Department at North Carolina State University. He graduated from Jiangxi Institute of Technology (now Nanchang University) in China with BS in Chemical Engineering in 1982, St. Cyril & Methodius University in Macedonia with MS in Biological Engineering in 1987, and University of Cincinnati in USA with PhD in Environmental Engineering in 1996. He was a Fulbright Scholar at University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria in the academic year of 2005/2006. He was also a Visiting Professor at Peking University-Shenzhen Graduate School, Shenzhen, China in 2013 and 2014. Dr. Cheng's research has been focused on wastewater treatment and renewable energy production processes. His research effort has resulted in publications of a book, over 75 articles in refereed scientific journals, and more than 80 papers in national and international technical conferences. He has served as an Associate Editor for Journal of Environmental Engineering and Journal of Biology as well as in more than 15 national and international professional committees. Dr. Cheng has been recognized with several major awards including the First Place in Ph. D. Category of the Water Environment Federation Student Paper Competition in 1995, and the First Place Poster Presentation

Award at the Water Environment Federation 73rd Annual Meeting in 2000.

Guangqing Liu is the Dean of School of International Education, Professor in the College of Chemical Engineering and the Director of Biomass Energy and Environmental Engineering Research Center of Beijing University of Chemical Technology. He also serves as the Executive Secretary-general of China Alliance for Clean Stoves (CACS). Dr. Liu got his PhD Degree from China Agricultural University, and did research in University of California, Davis, as a visiting scholar. He published 50 academic papers, five book chapters and owns five China Patents. He has received more than 20 research grants from China Ministry of Science and Technology (MOST), China Notational Science Founding, and World Bank. He has been invited as a speaker in more than 20 international conferences in the USA, Canada, Japan, India, Indonesia, Thailand, Peru, Philippines, and Uganda. His research field including: Converting biomass wastes for biogas using fermentation; Biomass Pyrolysis Engineering for syngas and bio-char; Converting syngas to methane using bacteria fermentation; Clean biomass stoves design and emission testing; and Clean Energy Carbon trading.

Maurycy Daroch obtained his PhD at University of Liverpool in the United Kingdom in 2011 where he was awarded prestigious Marie Curie Fellowship in 2006. After completing PhD he worked in the private sector in the area of biomass resources development. Since September 2011 he is associated with Peking University-Shenzhen Graduate School, where in October 2013 was appointed as an assistant professor. In January 2014 received "Peacock Plan" award by the Shenzhen Municipal Government for his contributions to the school and city. Dr Daroch lectures on subjects of bioenergy and molecular biology at the Peking University School of Environment and Energy and is a strong supporter of problem-based learning. His area of research is focused at the interface of bioenergy and modern molecular biology (metabolic engineering and synthetic biology).

Ting Feng received a Bachelor's degree at the Sun Yat-Sen University with an honor of summa cum laude in 2009; Two Master's degrees at Peking University and National University of Singapore in 2013 respectively. A recipient of the Student Visiting Scholarship of Laurence Berkeley National Laboratory 2012 and the Environment Service Award at Peking University, School of Environment and Energy in 2013. Research areas include: bio-energy, lifecycle assessment and chemical extraction. Co-authored in two papers and a book chapter: The Influence of Solar Radiation and Water Demand on Microalgae Production (2014); Detection of avian influenza virus for improved food safety surveillance (2015); Life Cycle Assessment of Micro-algae (2015).

General preface to the textbook series

So far, there have been three major technological revolutions in the world. The first is the IT revolution, which started from the 1950s and experienced "IC-PC- Internet -Web" stages. It is still unfolding now. The second is the biotechnology revolution, which started from the discovery of DNA in the 1970s, and later promoted the great development of genetics, and currently arrived to the stage of personalized medicine. The third is the energy revolution, which started from the energy efficiency movement in the 1980s, and now entered the "energy efficiency and clean energy" stage. It is going to have extremely great potential in the future.

Under this background of energy revolution, the nation's first School of Environment and Energy was founded at Peking University in 2009. The educational goals of this school are to train the talent student into leaders for environmental protection, energy development and utilization, urbanization, and socio-economic development. Program of "Energy efficiency and clean energy engineering" is an important discipline in this school. It is also an important support for the country's future energy issue. This program includes four parts: renewable energy engineering, energy conservation engineering, energy policies, and energy information engineering. Textbooks are the foundation for discipline construction. For this reason, we organized the most famous experts and scholars in the related fields and wrote this textbook series. The series includes 13 textbooks, covering the field of policy, legal, and technology. The names of these books are as follows:

Foundation Textbooks

"Water and energy: evapotranspiration, thermal environment and energy balance"

"Water pollution and energy using chemistry"

"Urban water system and carbon emission"

"Environment and energy microbiology"

"Environmental research methodology and modeling"

Technology Textbooks

"Biomass energy conversion technology"

"Beyond green building: transformation in design and human behavior"

"Municipal solid waste management and recycle technologies"

"Energy technology development and environmental impact assessment"

"Energy-saving technology and sustainable design"

Policy and Management Textbooks

"Environmental and Energy Law"

"Carbon trading"

"Energy audits and energy efficiency policies"

As we all know, discipline construction is not a short-term behavior and it requires long-term efforts. Excellent textbooks are an essential foundation for the construction of a new discipline. We sincerely hope that the publication of this textbook series can promote the development of energy efficiency and renewable energy in China and in the world.

Editor-in-Chief: Guo Yu Qiu(Professor, Peking University)

Perface

According to the International Energy Agency, bioenergy accounts for roughly 10% of world primary energy supply in 2013. Its current use in less developed regions by direct combustion of wood material, however, can cause severe health and environmental impacts. Fortunately, many countries are rich in biomaterial, so the potential contribution of clean bioenergy for world energy supply is unlimited.

To directly address these critical global issues, Peking University established a graduate School of Environment and Energy in Shenzhen in 2009. Since then this school has grown steadily in terms of both faculty and students. As part of the curriculum development, the School's faculty wrote a series of books that integrate the concepts of environmental protection and renewable energy development for teaching and research. This book, Conversion Technologies for Biomass to Renewable Energy, is part of the series.

This book describes diverse sources of bio-material such as agricultural and forestry residues, special cultivated energy plants, aquatic plants like algae and urban organic waste (Chapters 1, 2). It also presents cutting-edge techniques whereby these materials can be processed or recycled to generate various forms of clean bioenergy such as biogas (Chapter 3,7), biodiesel (Chapter 4), bioethanol (Chapter 5), and clean bio-char and other bio-products (Chapter 8).

For example, in chapter 6, the modern advanced combustion system is introduced to improve burning efficiency. This simple approach could enormously improve human and environmental health, especially in rural areas of developing countries. The Application of Life Cycle Analysis on algae energy balance is discussed in Chapter 9. This systems approach is necessary to fully understand the efficacy and economy of the potential for algae to be used as a main energy supply source.

Many of the techniques we described in the book have already been widely used in the US, European, Latin American, China and elsewhere. As carbon neutral, biofuel is an ideal replacement for fossil fuel in battling the destructive problems of C- culmination and global climate change. The concepts and techniques presented in this book make it a valuable teaching resource for graduate courses in bioenergy or a key reference about bioenergy conversion methods generally.

Newer and more efficient technologies will inevitably be developed in the fu-

ture to replace current approaches in utilizing biomaterial for renewable energy generation. Even the technology changes over time, but the concepts presented in this book-the replacement of fossil fuel by renewable, clean bio-energy-will always be needed.

Shu Geng
Professor of Northwest Agriculture and Forestry University at Yangling,
Founding Dean of the School of Environment and Energy
Peking University at Shenzhen
Professor Emeritus, University of California at Davis

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| Chapter 1 | Biomass resources (Guangqing Liu and Jay J. Cheng)

1.1 Organic waste materials

1.1.1 Animal manure

Nutrient-rich animal manure not only contains organic matter and essential nutrient elements for plants such as N, P, K and other trace elements, but also a variety of bio-enzymes from animals' digestive tracts, vegetable feed and intestinal microorganisms. Thus, it plays an irreplaceable role in improving soil organic matter content, fertility and structure.

Although animal manure is a productive organic fertilizer, it must be digested through a microbial process such as composting for plants to utilize it effectively. If raw manure is introduced directly into soil without composting, it will not only fail to increase production, but also reduce fertilizer efficacy and lead to pollution of soil, water, the atmosphere and agricultural products, posing a serious threat to the environment. Without composting first, manure will decompose in the rhizosphere soil, consuming oxygen, producing heat that can burn crop roots, and giving off harmful emissions, such as ammonia and hydrogen sulfide, among other byproducts. Additionally, fresh manure may contain a variety of pathogenic microorganisms and parasites. Therefore, composting and innocuous treatment must be applied to offset these effects. The compositions of various animal wastes are shown in Table 1-1.

Table 1-1 Animal manure compositions (%)

Composition	Dung				Urine		
	Cattle	Sheep	Pig	Chicken	Cattle	Sheep	Pig
Moisture	80.0	68.0	82.0	80.0	92.5	87.5	94.0
Organics	18.0	29.0	16.0	—	3.00	8.0	2.5
Total nitrogen	0.30	0.60	0.60	1.24	1.00	1.5	0.50

Continued

Composition	Dung				Urine		
	Cattle	Sheep	Pig	Chicken	Cattle	Sheep	Pig
Soluble nitrogen	0.05	0.05	0.08	—	—	—	—
P	0.20	0.30	0.50	1.10	0.10	0.10	0.05
K	0.10	0.20	0.40	0.42	1.50	1.80	1.00

Animal manure chemical composition and concentrations reported in the *Poultry and Livestock Farms Biogas Project Development Guide*, published by the Ministry of Agriculture is listed in Table 1-2.

Table 1-2 Animal manure chemical composition and concentration

Issue	Pig		Cattle		Chicken dung
	Dung	Urine	Dung	Urine	
BOD_5/(mg/L)	63 000	5 000	24 500	4 000	65 000
TSS/(mg/L)	216 700		120 000	5 000	—
TS/(mg/L)	4 660	7 780	9 430	8 340	16 300
P_2O_5/(mg/L)	1.68	0.16	0.44	0.004	0.54
K_2O/(mg/L)	0.14	0.33	0.15	1.89	0.85

Due to the differences in livestock species and varying farm properties, feeding and management processes, as well as climate and season, livestock and poultry manure excretion will be quite different. For example, the volume of cattle manure per animal is significantly higher than that of other livestock and poultry; poultry manure is mixed discharge, so its total nitrogen content is higher than that of livestock manure; additionally, poultry manure moisture content improves markedly as summer water intake increases. Poultry and livestock manure excretion rates provided by different references are shown in Table 1-3 and Table 1-4.

Table 1-3 Poultry and livestock manure excretion

Issue		Cattle	Pig	Sheep	Chicken	Duck
Dung	(kg/d)	20.0	2.0	2.6	0.12	0.13
	(kg/a)	7300.0	398.0	950.0	25.2	27.3
Urine	(kg/d)	10.0	3.3	—	—	—
	(kg/a)	3650	656.7	—	—	—
Raising cycle/d		365	199	365	210	210