

Cambridge University Press

978-0-521-76399-8 - Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants

Ram B. Gupta and Ayhan Demirbas

Frontmatter

[More information](#)

GASOLINE, DIESEL, AND ETHANOL BIOFUELS FROM GRASSES AND PLANTS

The world is currently faced with two significant problems – fossil fuel depletion and environmental degradation – which are continuously being exacerbated due to increasing global energy consumption. As a substitute for petroleum, renewable fuels are receiving increasing attention due to a variety of environmental, economic, and societal benefits. First-generation biofuels – ethanol from sugar or corn and biodiesel from vegetable oils – are already on the market. The goal of this book is to introduce readers to the second-generation biofuels obtained from nonfood biomass, such as forest residue, agricultural residue, switchgrass, corn stover, waste wood, and municipal solid wastes. Various technologies are discussed, including cellulosic ethanol, biomass gasification, synthesis of diesel and gasoline, biocrude by hydrothermal liquefaction, bio-oil by fast pyrolysis, and the upgradation of biofuel. This book strives to serve as a comprehensive document presenting various technological pathways and environmental and economic issues related to biofuels.

Dr. Ram B. Gupta is the PWS Distinguished Chair Professor and Chair of the Chemical Engineering Graduate Program at Auburn University. He has published numerous research papers and holds several patents on biofuels, nanotechnology, hydrogen fuel, and supercritical fluid technology and is the recipient of several national awards. He is a Fellow of the Alabama Academy of Science. He served on the editorial advisory boards of *Industrial & Engineering Chemistry Research* and *Nanomedicine: Nanotechnology, Biology and Medicine* and is currently serving on the editorial boards of *Journal of Biomedical Nanotechnology*, *Research Letters in Nanotechnology*, *Open Nanomedicine Journal*, *International Journal of Chemical Engineering*, and *Research Letters in Chemical Engineering*. His recent books are *Nanoparticle Technology for Drug Delivery*, *Solubility in Supercritical Carbon Dioxide*, and *Hydrogen Fuel: Production, Transport, and Storage*.

Dr. Ayhan Demirbas is Professor and Vice Rector at Sirnak University. His research on renewable and sustainable energy has been published in 445 scientific papers. He served on the editorial advisory board of *Energy Conversion and Management* and is currently serving as the Editor-in-Chief of *Energy Education Science and Technology Part A: Energy Science and Research*, *Energy Education Science and Technology Part B: Social and Educational Studies*, *Future Energy Sources*, and *Social Political Economic and Cultural Research*. His recent books are *Biodiesel: A Realistic Fuel Alternative for Diesel Engines*, *Biofuels: Securing the Planet's Future Energy Needs*, *Biohydrogen: For Future Engine Fuel Demands*, *Biorefineries: For Biomass Upgrading Facilities*, *Methane Gas Hydrate*, and *Algae Energy*.

Cambridge University Press
978-0-521-76399-8 - Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants
Ram B. Gupta and Ayhan Demirbas
Frontmatter
[More information](#)

Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants

Ram B. Gupta
Auburn University

Ayhan Demirbas
Sirnak University



Cambridge University Press
978-0-521-76399-8 - Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants
Ram B. Gupta and Ayhan Demirbas
Frontmatter
[More information](#)

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo

Cambridge University Press
32 Avenue of the Americas, New York, NY 10013-2473, USA
www.cambridge.org
Information on this title: www.cambridge.org/9780521763998

© Ram B. Gupta and Ayhan Demirbas 2010

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without the written
permission of Cambridge University Press.

First published 2010

Printed in the United States of America

A catalog record for this publication is available from the British Library.

Library of Congress Cataloging in Publication data

Gupta, Ram B.
Gasoline, diesel, and ethanol biofuels from grasses and plants / Ram B. Gupta,
Ayhan Demirbas.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-521-76399-8 (hardback)
1. Plant biomass. 2. Forest biomass. 3. Biomass energy. I. Demirbas,
Ayhan. II. Title.
TP248.27.P55G87 2010
662'.88—dc22 2009042276

ISBN 978-0-521-76399-8 Hardback

Cambridge University Press has no responsibility for the persistence or
accuracy of URLs for external or third-party Internet Web sites referred to in
this publication and does not guarantee that any content on such Web sites is,
or will remain, accurate or appropriate.

Contents

<i>Preface</i>	<i>page xiii</i>
1. Introduction	1
1.1 Energy	1
1.2 Petroleum	3
1.2.1 History of Petroleum Exploration	4
1.2.2 Petroleum Refining and Shipping	5
1.2.3 Classification of Oils	7
1.2.4 Petroleum Reserves and Crude Oil Production	9
1.2.5 Crude Oil Pricing	11
1.3 Natural Gas	12
1.3.1 Methane from Gas Hydrates	15
1.4 Coal	15
1.5 Biofuels	16
1.5.1 Ethanol	17
1.5.2 Methanol	18
1.5.3 Butanol	19
1.5.4 Biogas	20
1.5.5 Hydrogen	20
1.5.6 Biodiesel	22
1.5.7 Bio-Oil	22
1.5.8 Diesel from Fisher–Tropsch Technology	22
1.5.9 Biocrude	23
1.5.10 Biochar	24
1.6 Summary	24
2. Air Pollution and Global Warming from the Use of Fossil Fuels	25
2.1 Introduction	25
2.2 Air Pollution	25
2.2.1 Nitrogen Oxides	27
2.2.2 Sulfur Dioxide	27

vi	Contents
2.2.3	Fine Particles 27
2.2.4	Mercury 28
2.2.5	Lead 29
2.3	Carbon Dioxide Emissions 30
2.4	Greenhouse Effect 33
2.5	Global Warming 36
2.5.1	Argument against Global Warming 38
2.6	Kyoto Protocol 38
2.7	Carbon Credits 39
2.8	Carbon Sequestration 39
2.9	Summary 40
3.	Renewable Energy Sources 41
3.1	Introduction 41
3.2	Biomass 42
3.3	Hydropower 46
3.4	Geothermal 47
3.5	Wind 49
3.6	Solar 50
3.7	Ocean Energy 52
3.8	Biogas 53
3.9	Summary 54
4.	Biomass Availability in the World 56
4.1	Introduction 56
4.2	Biomass Definition 56
4.3	Biomass Sources 58
4.3.1	Solid Wastes 58
4.3.2	Agriculture Residue 59
4.3.2.1	Cereal Straw 59
4.3.2.2	Corn Stover 60
4.3.2.3	Rice Husk 60
4.3.2.4	Bagasse 60
4.3.3	Energy Crops 61
4.3.4	Pulp and Paper Industry Waste 64
4.3.5	Wood and Forest Waste 65
4.3.6	Algae 66
4.4	World Potential to Product Biomass 67
4.5	Biomass Characterization 67
4.5.1	Moisture Content 69
4.5.2	Ash Content 69
4.5.3	Heating Value 70
4.5.4	Organic Chemical Composition 70
4.5.5	Density 71
4.6	Summary 72

Contents	vii
5. Conventional Ethanol Production from Corn and Sugarcane	73
5.1 Introduction	73
5.1.1 Ethanol	73
5.1.2 Ethanol Fuel	73
5.2 Ethanol in Ancient Times	74
5.3 Current Ethanol Production	75
5.4 Fermentation	76
5.5 Ethanol from Sugarcane	79
5.6 Ethanol from Corn	79
5.6.1 The Corn Wet-Milling Process	80
5.6.2 The Corn Dry-Milling Process	80
5.6.3 Byproducts	81
5.7 Separation and Purification	82
5.8 Summary	83
6. Ethanol from Biomass by Fermentation	84
6.1 Challenges with Corn-Based Ethanol	84
6.2 Cellulose in Biomass	84
6.3 Sugars from Cellulose	88
6.4 Factors Affecting Lignocellulose Digestibility	88
6.4.1 Lignin Content	88
6.4.2 Hemicelluloses Content	89
6.4.3 Acetyl and Other Inhibitor Content	89
6.4.4 Cellulose Crystallinity and Degree of Polymerization	90
6.4.5 Surface Area of Pore Volume	90
6.5 Biomass Pretreatment	90
6.5.1 Physical Pretreatments	91
6.5.2 Chemical Pretreatments	91
6.5.2.1 Dilute Acids	92
6.5.2.2 Peracetic Acid (C ₂ H ₄ O ₃)	93
6.5.2.3 Concentrated Sulfuric Acid	93
6.5.2.4 Concentrated Phosphoric Acid	94
6.5.2.5 Ionic Liquids	94
6.5.2.6 Alkali	95
6.5.2.7 Ammonia	95
6.5.2.8 Organic Solvents	95
6.5.3 Hydrothermal Pretreatment	96
6.5.4 Physicochemical Pretreatments	96
6.5.4.1 Steam Hydrolysis and Explosion	96
6.5.4.2 Ammonia Fiber Explosion (AFEX)	97
6.5.4.3 Supercritical Carbon Dioxide	97
6.6 Cellulose Hydrolysis to Produce Sugars	98
6.7 Fermentation of Sugars to Ethanol	99
6.7.1 Xylose Fermentation	100

viii	Contents
6.8 Ethanol Separation and Purification	101
6.9 Summary	101
7. Biodiesel from Vegetable Oils	102
7.1 What Is Biodiesel?	102
7.2 History	102
7.3 Vegetable Oil Resources	103
7.3.1 Nonedible Oil Resources	106
7.4 Transesterification	107
7.4.1 Catalytic Methods	107
7.4.2 Noncatalytic Supercritical Alcohol Method	108
7.4.3 Recovery of Glycerol	109
7.4.4 Reaction Mechanism	110
7.5 Current Technologies	111
7.5.1 Raw Materials and Feedstock Preparation	112
7.5.1.1 Choice of Alcohol	113
7.5.2 Batch Process	114
7.5.3 Continuous Process	115
7.5.4 Single-Phase Cosolvent Process	115
7.5.5 Supercritical Methanol Process	116
7.6 Fuel Properties of Biodiesels	117
7.6.1 Viscosity, Density, and Flash Point	117
7.6.2 Cetane Number, Cloud, and Pour Point	119
7.6.3 Combustion Efficiency	120
7.6.4 Comparison of Methyl with Ethyl Esters	120
7.6.5 Emissions	120
7.6.6 Biodegradability	121
7.6.7 Engine Performance	121
7.7 Disadvantages of Biodiesel	122
7.8 Summary	122
8. Diesel from Biomass Gasification Followed by Fischer–Tropsch Synthesis	123
8.1 Diesel Fuel	123
8.1.1 Diesel from Petroleum	123
8.1.2 Diesel from Coal	125
8.1.3 Diesel from Biomass	126
8.2 Gasification of Biomass to Produce Syngas	126
8.2.1 Types of Gasifiers	128
8.2.2 Gasification Chemistry	130
8.3 Conditioning of Syngas	131
8.4 FT Synthesis to Produce Diesel	132
8.4.1 Reactor Configurations	133
8.4.2 Catalysts	135

Contents	ix
8.4.2.1 Iron-Based Catalysts	135
8.4.2.2 Cobalt-Based Catalysts	136
8.4.2.3 Catalyst Supports	137
8.4.3 FT Synthesis in Supercritical Fluids	137
8.5 Fuel Properties of FT Diesel	138
8.6 Summary	139
9. Bio-Oil from Biomass Pyrolysis	140
9.1 What Is Bio-Oil?	140
9.2 Pyrolysis	140
9.2.1 Slow Pyrolysis	141
9.2.2 Fast Pyrolysis	142
9.3 Process Considerations	143
9.3.1 Feedstock Preparation	144
9.3.2 Heat Transfer Requirements	144
9.3.3 Effect of Metal Ions and Salts	145
9.3.4 Catalysis	145
9.3.5 Kinetics	145
9.3.6 Bio-Oil Yields	146
9.4 Pyrolysis Reactors	146
9.4.1 Bubbling Fluidized Bed	146
9.4.2 Circulating Fluidized Bed	147
9.4.3 Vacuum Pyrolysis	148
9.4.4 Ablative Fast Pyrolysis	148
9.4.5 Rotating Cone Pyrolyzer	149
9.4.6 Auger Reactor	150
9.4.7 Future Developments	150
9.5 Fuel Properties of Bio-Oil	151
9.5.1 Chemical Composition	152
9.5.2 Viscosity	152
9.5.3 Density	154
9.5.4 Acidity	154
9.5.5 Water Content	154
9.5.6 Oxygen	154
9.5.7 Char and Particle Content	154
9.5.8 Storage Stability	155
9.6 Upgrading of Bio-Oil	155
9.6.1 Solvent Fractionation	155
9.6.2 Deoxygenation	156
9.7 Summary	157
10. Biocrude from Biomass Hydrothermal Liquefaction	158
10.1 What Is Biocrude?	158
10.2 Hydrothermal Medium	158

x	Contents
10.2.1 Dielectric Constant	160
10.2.2 Ion Product	160
10.2.3 Solubility of Organics	161
10.2.4 Diffusivity and Viscosity	161
10.3 Liquefaction Process	161
10.3.1 Batch Process	162
10.3.2 Continuous Process	163
10.3.3 Pumping Biomass with Biocrude	164
10.4 Liquefaction Mechanism	165
10.4.1 Hydrothermal Treatment with Catalysts	167
10.4.2 Hydrothermal Treatment with Reducing Gases	169
10.5 Properties of Biocrude	169
10.6 Refinement and Upgrading of Biocrude	170
10.6.1 Hydrodeoxygenation	170
10.7 Critical Issues	171
10.7.1 Heat Integration	171
10.7.2 Biomass Feeding and Solids Handling	171
10.7.3 Recovery of Inorganics and Catalysts	173
10.7.4 Reactor Wall Effects	174
10.8 Summary	174
11. Solar and Wind Energy for Biofuel Production	175
11.1 Process Energy Needs for Biofuel Production	175
11.2 Wind Energy	176
11.3 Solar Energy	178
11.3.1 Solar Collectors	178
11.4 Direct Use of Solar Radiation	180
11.4.1 Gasification	180
11.4.2 Pyrolysis	180
11.4.3 Challenges with Use of Direct Solar Radiation	181
11.5 Storage of Solar Thermal Energy	181
11.6 Summary	182
12. Environmental Impacts of Biofuels	183
12.1 Biomass and the Natural Carbon Cycle	183
12.2 Environmental Impacts of Biomass Production	183
12.2.1 Land Use	184
12.2.2 Irrigation Water Consumption	185
12.2.3 Fertilizer and Pesticide Use	185
12.2.4 Ecosystem Diversity	186
12.3 Environmental Impacts of Biomass-to-Biofuel Conversion	186
12.4 Environmental Impacts of Biofuel Use	187
12.5 Life-Cycle Impacts	188
12.6 Summary	190

Cambridge University Press
978-0-521-76399-8 - Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants
Ram B. Gupta and Ayhan Demirbas
Frontmatter
[More information](#)

Contents	xi
13. Economic Impact of Biofuels	191
13.1 Biofuel Economy	191
13.2 Economic Impact of Corn Ethanol	192
13.3 Economic Impact of Sugarcane Ethanol	193
13.4 Economic Impact of Biodiesel	194
13.5 Future Economic Impact of Biomass-Based Biofuels	194
13.6 Economic Impact on Developing and Rural Economies	198
13.7 Summary	198
14. Biofuel Policy	200
14.1 Introduction	200
14.2 Brazilian Biofuel Policy	201
14.3 European Biofuel Policy	202
14.4 Chinese Biofuel Policy	203
14.5 Indian Biofuel Policy	204
14.6 The United States Biofuel Policy	205
14.7 Global Biofuel Projections	206
14.8 Summary	207
References	209
Index	225

Cambridge University Press

978-0-521-76399-8 - Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants

Ram B. Gupta and Ayhan Demirbas

Frontmatter

[More information](#)

Preface

The world is currently faced with two significant problems: fossil fuel depletion and environmental degradation. The problems are continuously being exacerbated due to increasing global population and per capita energy consumption. To overcome the problems, renewable energy has been receiving increasing attention due to a variety of environmental, economic, and societal benefits. First-generation biofuels (ethanol from sugar or corn, and biodiesel from vegetable oils) are already in the market, and second-generation biofuels from nonfood biomass are under development. The goal of this book is to introduce readers to the biofuels obtained from nonfood biomass, and for reference to provide the technologies involved in first-generation biofuels derived from food sources.

Chapter 1 discusses various nonrenewable (petroleum, natural gas, coal) and renewable forms of energy, and describes air pollution and greenhouse gas emission caused by the use of fossil fuels. Recent concern about carbon dioxide emissions, carbon sequestration, and carbon credits are discussed in Chapter 2. Chapter 3 provides an in-depth description of various renewable energy sources, including biomass; hydropower; geothermal, wind, solar, and ocean energy; and biogas. For the production of biofuels, the global availability of biomass is discussed in Chapter 4 along with the characterization and variations of biomass.

Conventional ethanol production from corn or sugarcane by fermentation technology is discussed in Chapter 5. Current techniques and various unit operations involved are presented, including saccharification, fermentation, distillation, and dehydration. The second-generation ethanol from cellulose is described in Chapter 6. It provides an in-depth coverage of various pretreatment techniques that are critical to the cost-effective production of cellulosic ethanol. In addition, xylose fermentation to improve the ethanol yield is discussed.

Chapter 7 discusses the production of biodiesel from vegetable oil by transesterification. The fuel properties of biodiesel are compared with those of petroleum diesel. Chapter 8 concerns the production of diesel from biomass. Processing of biomass gasification followed by Fischer–Tropsch synthesis of diesel and other liquid fuels is discussed. Chapter 9 outlines the production of bio-oil from biomass by the pyrolysis process. Various reactor designs for fast pyrolysis are described along

Cambridge University Press

978-0-521-76399-8 - Gasoline, Diesel, and Ethanol Biofuels from Grasses and Plants

Ram B. Gupta and Ayhan Demirbas

Frontmatter

[More information](#)

with the fuel properties of bio-oil, including its upgradation. Chapter 10 deals with the production of biocrude by hydrothermal liquefaction of biomass, in which various aspects of production and upgradation are presented to obtain fuel comparable to petroleum liquids.

Chapter 11 discusses the use of wind and solar energies to enhance biofuel production from biomass. The process heating and electricity needs can be satisfied so that a higher amount of biomass carbon is converted to liquid fuels. Chapters 12 and 13 discuss the environmental and economic impacts of biofuels, respectively. Chapter 14 summarizes current biofuel policies of major countries that are promoting biofuel production and use.

This book strives to serve as a comprehensive document to present various technological pathways and environmental and economic issues related to biofuels. As petroleum reserves are depleted, the world is faced with finding alternatives. Currently, the transport sector depends almost entirely on petroleum liquids (diesel, gasoline, jet fuel, kerosene), and to fill the gap, biofuel can provide a replacement. However, alternatives to petroleum must be technically feasible, economically competitive, environmentally acceptable, and easily available.

The authors are thankful for assistance from various people in preparation of this manuscript, including Mr. Sandeep Kumar, Mrs. Sweta Kumari, Dr. Lingzhao Kong, Mrs. Hema Ramsurn, and Prof. Sushil Adhikari. In addition, support from our families – Deepti, Pranjal, and Rohan Gupta; Elmas, Temucin, Kursat, Muhammet, Ayse Hilal, and Burak Demirbas – was key to the completion of this book.

Ram B. Gupta, Auburn, USA

Ayhan Demirbas, Trabzon, Turkey