新生物学丛书

# 生物燃料

（影印版）

## 可再生能源、农业生产和技术进步对全球的影响

BIOFUELS: GLOBAL IMPACT ON RENEWABLE ENERGY, PRODUCTION AGRICULTURE, AND TECHNOLOGICAL ADVANCEMENTS

〔美〕D. Tomes
〔澳〕P. Lakshmanan　编著
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科学出版社

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## 内 容 简 介

生物燃料领域是生物技术相关学科中被讨论得最多的研究领域。本书艺术地总结了生物燃料的经济现状、农业生产力和可持续发展，以及全球视角。本书很好的把生物燃料的知识分隔成了不同的章节和特定知识点，使之更易阅读和理解。此外，每章的参考文献都是进一步研究的宝贵资源。

本书的涉及范围广泛，一方面可以在实验室和教学中向学生介绍最新的技术进展，另一方面也可以让关注于生物燃料在国际范围内的经济分析的企业家们感到兴趣。



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# 《新生物学丛书》丛书序

当前，一场新的生物学革命正在展开。为此，美国国家科学院研究理事会于2009年发布了一份战略研究报告，提出一个“新生物学”（New Biology）时代即将来临。这个“新生物学”，一方面是生物学内部各种分支学科的重组与融合，另一方面是化学、物理、信息科学、材料科学等众多非生命学科与生物学的紧密交叉与整合。

在这样一个全球生命科学发展变革的时代，我国的生命科学研究也正在高速发展，并进入了一个充满机遇和挑战的黄金期。在这个时期，将会产生许多具有影响力、推动力的科研成果。因此，有必要通过系统性集成和出版相关主题的国内外优秀图书，为后人留下一笔宝贵的“新生物学”时代精神财富。

科学出版社联合国内一批有志于推进生命科学发展的专家与学者，联合打造了一个21世纪中国生命科学的传播平台——《新生物学丛书》。希望通过这套丛书的出版，记录生命科学的进步，传递对生物技术发展的梦想。

《新生物学丛书》下设三个子系列：科学风向标，着重收集科学发展战略和态势分析报告，为科学管理者和科研人员展示科学的最新动向；科学百家园，重点收录国内外专家与学者的科研专著，为专业工作者提供新思想和新方法；科学新视窗，主要发表高级科普著作，为不同领域的研究人员和科学爱好者普及生命科学的前沿知识。

如果说科学出版社是一个“支点”，这套丛书就像一根“杠杆”，那么读者就能够借助这根“杠杆”成为撬动“地球”的人。编委会相信，不同类型的读者都能够从这套丛书中得到新的知识信息，获得思考与启迪。

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2012年3月

# In Vitro Cellular and Developmental Biology - Plant

## "A Message from the Editor-in-Chief, Dwight T. Tomes"

'Biofuels: Global Impact on renewable energy, production agriculture, and technological advancements'

This comprehensive volume developed under the guidance of guest editors Prakash Lakshmanan and David Songstad features broad coverage of the topic of biofuels and its significance to the economy and to agriculture. These chapters were first published by In Vitro Cellular and Developmental Biology In Vitro Plant in 2009 and consists of 15 chapters from experts who are recognized both for their scientific accomplishments and global perspective in their assigned topics.

The subject of biofuels is multi faceted and must be considered in the context of economic, agricultural productivity and sustainability as well as global perspectives. The first section is devoted to a combination of a historical perspective (David Songstad) and the current research of the DOE Bioenergy Science Center (Russ Miller).

In the popular press, biofuels are portrayed as a competitor to food production and the reason for food price inflation. The primary factors for food price increases such as oil prices, emerging economies, weather and currency fluctuations are outlined in detail (Greg Phillips). Furthermore, the economics of biofuels (Andy Aden) lead to more realistic conclusions of the positive contribution of biofuels to agriculture and energy sustainability. The feed stocks for biofuels are varied depending on location and availability. These feedstocks can arise from multiple monocot species (Jose Gonzalez-Hermandez), dedicated energy crops (Russel Jessup), grasses (Katrin Jocob), or woody short-rotation crops (Hinchee). The international perspective from Brazil with their mature biofuels practices with sugarcane (Paulo Arruda) and from the emerging economies of India (Mambully Gopinathan) and China (Chun-Zhao Liu) adds to the understanding of biofuels from a global perspective.

Essentially, biofuel production is an application of fermentation technology and a major determinant of the feasibility of different biofuel products. This section contains the most up to date treatment of plant modification of the lignin pathway

(Z.Y. Wang), the use of plant expressed enzymes for cellulosic ethanol (Manuel Sainz), integration of biorefineres and high-value co-products (W. Gibbons and S. Hughes), and biodiesel production (Bryan Moser).

This book is an excellent resource of diverse biofuels knowledge organized by major areas and specific topics in an easily accessible and readable format. The broad scope of this book has application in the lab and classroom for the latest technological advances and also for the entrepreneur for the economic analysis and international scope of biofuels. Furthermore, the references within each chapter are a valuable resource for further study.

# Contents

# Chapter 1
# Historical Perspective of Biofuels: Learning from the Past to Rediscover the Future

**David Songstad, Prakash Lakshmanan, John Chen, William Gibbons, Stephen Hughes, and R. Nelson**

**Abstract** This issue of *In Vitro* Plant is dedicated to various aspects of biofuel research and development. The editors have sought the experts in this field and solicited manuscripts for this special issue publication from various academic institutions, government (USDA, DOE), industry (Mendel, Alellyx, Canavilas, Syngenta, Monsanto), and various countries (USA, China, Brazil, India, and Australia). This has resulted in state-of-the-art articles describing ethanol and also biodiesel research. These publications highlight the status of biofuel research across the globe and also focus on private, public, and government interests. This is especially noteworthy in that President Barack Obama has stated that renewable energy is a pivotal aspect of his policy for the USA. The objective of this introduction is to provide the reader with the pertinent background information relative to the biofuel efforts within the private sector, academia, and government laboratories. In particular, the history of biofuel research and commercialization is provided as well as a summary of the various crop systems available for biofuel production.

**Keywords** Biofuel • Bioethanol • Biodiesel • History

## History of Bioethanol

Those not familiar with the legacy of bioethanol might believe that this is a late twentieth century development. Those that experienced the Arab oil embargos of the 1970s remember this period as the first vocal call for a domestic source of renewable energy to counter the rapid escalation in oil prices that has continued through the early twenty-first century. However, the reality is that ethanol was developed as an alternative fuel before the discovery of petroleum by Edwin Drake

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in 1859 (Kovarik 1998). Prior to this year, the energy crisis revolved around finding a replacement for the diminishing supply of whale oil, which was commonly used as a lamp oil. Other lamp oils derived from vegetables and animals were also used, but whale oil was preferred. By the late 1830s, ethanol blended with turpentine (refined from pine trees) was used to replace the more expensive whale oil.

During this time period, Samuel Morey invented the internal combustion engine (US Patent 4378 Issued April 1, 1826) which was fueled by a combination of ethanol and turpentine. Morey's patent was entitled "Gas or Vapor Engine" and was signed by President John Quincy Adams and Secretary of State Henry Clay (Hodgson 1961). Morey was able to use this engine to power a boat at speeds of 7 to 8 mph. Unfortunately, Morey was unable to find an investor to further develop the internal combustion engine. However, in 1860, the German inventor Nicholas Otto rediscovered the internal combustion engine and also used an elixir containing ethanol as fuel. He was denied a patent but was able to secure initial funding from Eugen Langen, who interestingly owned a sugar refining company and most likely had associations with ethanol markets in Europe (Kovarik 1998).

The next era where biofuels became prominent was early in the twentieth century and was linked with the discovery of the automobile. Henry Ford envisioned automobiles that relied on ethanol as their fuel source (Kovarik 1998). Keen interest in ethanol as a fuel for automobiles was described in a 1906 New York Times article entitled "Auto Club Aroused Over Alcohol Bill" (Anonymous 1906). This article described concerns over the influence of ethanol on the gasoline industry in the quote "Gasoline is growing scarcer, and therefore dearer, all the time." This might be the first indication of competition between the petroleum and ethanol industries. Furthermore, Alexander Graham Bell was quoted in a 1917 National Geographic interview (Anonymous 1917) stating "Alcohol can be manufactured from corn stalks, and in fact from almost any vegetable matter capable of fermentation. Our growing crops and even weeds can be used. The waste products of our farms are available for this purpose and even the garbage of our cities. We need never fear the exhaustion of our present fuel supplies so long as we can produce an annual crop of alcohol to any extent desired." Dimitri and Effland (2007) commented that the $2.08 tax per gallon of ethanol, which was initially imposed in 1861 as a means to fund the Civil War, continued well past the war's conclusion and was finally removed in 1906 (this would equivalent to about $35/gallon ethanol tax in 2007 http://www.icminc.com/timeline). This obviously made ethanol more expensive than gasoline and favored use of gasoline for internal combustion engines. However, when this tax was removed, it was difficult for the ethanol infrastructure to compete with gasoline, the now accepted fuel for automobiles. However, it became apparent that "previously established industrial partnerships" emerged in the 1920s blocking use of ethanol as the solution to engine knock, in favor of tetraethyl lead (Dimitri and Effland 2007).

During the 1920s and 1930s, a new movement called Chemurgy emerged and was promoted by Henry Ford (Finlay 2004). Chemurgy can be thought of an early version of the agricultural "new uses" initiative, and it put pressure on the USDA to focus crop utilization on bio-based materials. Ethanol was prominent on the Chemurgy


**Fig. 1.1** Photo from April, 11, 1933 of a bioethanol fueling station in Lincoln, Nebraska. (Copyright permission to use photo in this publication by the Nebraska History Museum)

agenda, as evident for the need to produce synthetic rubber at the onset of World War II. In 1942 Congress appointed a "rubber czar" to over see the production of synthetic rubber only from agricultural resources and in 1943, nearly 77% of the synthetic rubber produced in the USA was derived from ethanol (Finlay 2004).

The World War years of 1917–1919 and 1941–1945 also witnessed an increase in ethanol demand in the USA due to the rationing of raw materials and natural resources, including gasoline. Ethanol was produced as an alternative to gasoline for domestic use. During the World War I years, ethanol production increased to 60 million gallons and this further increased during the World War II years to 600 million gallons (http://www.icminc.com/timeline). Proof of interest in bioethanol during this timeframe is evident in the photo provided in Fig. 1.1 (Credit—Nebraska History Museum) which shows a gasoline filling station of Earl Coryell in Lincoln, Nebraska, promoting 10% ethanol. This photo, taken in April, 1933, is an example of several gasoline filling stations throughout the midwestern region of the USA that were testing ethanol as a gasoline additive.

The 1974 Arab oil embargo also resurrected interest in ethanol production throughout the world. As before, much of the early interest in the USA was in the Midwestern states. In 1978, the College of Agriculture and Biological Sciences at South Dakota State University provided start-up funds and a campus building for Dr. Paul Middaugh (Fig. 1.2) of the Microbiology Department to begin work on

**Fig. 1.2** Dr. Paul Middaugh, Professor of Microbiology at South Dakota State University, 1964–1980. Developed first dry mill ethanol production plant from which much of the ethanol industry has been established; photo taken in 1974 (SDSU Photo Archives)

farm-scale ethanol production plant. The East River Rural Electric Cooperative provided $30,000 in funding as well. In 1979, Dr. Middaugh had established the first operating dry mill ethanol plant in the USA and operated it on a demonstration basis for about 18 mo. In 1980, Dr. Middaugh received a competitive research grant of $90,000 from USDA to determine yields, costs, and energy balances in this facility, while a $20,000 DOE grant was obtained to develop educational/training materials for ethanol plant operation. A team of researchers from the Departments of Plant Science, Microbiology, Agricultural Engineering, Mechanical Engineering, Animal Science, Dairy Science, and Economics will spend the next 4 yr establishing the technical and economic baseline for farm-scale ethanol production and developing many of the innovations still in practice today (Middaugh 1979). Dr. Middaugh's legacy continues through his students, two of which are coeditors of this Special Issue publication, Dr. William Gibbons and Dr. David Songstad.

Two of the first students on Dr. Middaugh's team were Paul Whalen and Dennis Vander Griend. Paul Whalen, a microbiology graduate student, established the processing parameters for the dry mill plant. Dennis, an undergraduate mechanical engineer, and his brother, Dave, were recruited by Dr. Middaugh to design, construct, and operate the distillation columns. The Vander Griend brothers continued their focus on ethanol, and Dave founded ICM in 1995 as a company that designs and constructs ethanol plants. Dave continues as the President and CEO of ICM in Colwich, KS (suburb of Wichita), while Dennis is the lead process engineer.

Other leading companies in the ethanol industry also have their roots in the Midwest. Jeff Broin, owner of POET, traces the beginnings of his company to the family farm in Minnesota where in 1986, they built an ethanol plant capable of producing 100,000 gal/yr of ethanol. In this same year, he purchased an existing ethanol plant in Scotland, SD and continues to use this plant to test engineering and design improvements that have been applied to the construction of 26 ethanol plants in seven states. The combined ethanol production of POET facilities now exceeds one billion gallons annually (Gabrukiewicz 2009).

VeraSun Energy was founded in 2001 by Don Endres of Brookings, SD. Through construction of new plants and acquiring existing plants through a merger with US Bioenergy, VeraSun became the largest ethanol producer in the USA, operating 16 ethanol plants across eight states with an average potential ethanol production capacity of 1.64 billion gallons per year (http://www.verasun.com/About/) VeraSun became a publically traded company on the New York Stock Exchange on June 14, 2006. However, VeraSun declared Chapter 11 bankruptcy in October, 2008 and announced in February, 2009, that some of the company's ethanol plant assets will be sold and all assets were auctioned on March 16, 2009. However, it is important to realize that ethanol production from these plants continues, only under new corporate management.

Recently, bioethanol has been criticized in the feed, food, fuel debate. In this special publication, Armah et al. described the economics associated with bioethanol and biodiesel and identified rising input costs (e.g., crude oil, labor, and transportation costs) as the main drivers associated with the rising price of food. This report, based on factual data, is contrary to the sensational stories often reported in the popular media. Furthermore, a recent report by Darlington (2009) reported that increasing US corn ethanol production to 15 billion gallons by 2015 will not result in significant conversion of non-agricultural lands into corn production in the USA or abroad. Rather, this will be possible due to the increased rate of growth of yield of corn as the result of advances in breeding and novel traits delivered through biotechnology.

## History of Biodiesel

The term "biodiesel" was first coined in 1988 (Wang 1988), but the history of using vegetable oil in place of diesel as a fuel dates back to 1900. The roots of what eventually became known as "biodiesel" extend back to the discovery of the diesel engine by Rudolf Diesel. The first demonstration of the diesel engine was at the 1900 World's Fair in Paris. Knothe (2001), in a book chapter entitled "Historical perspectives on vegetable oil-based diesel fuels," describes that the diesel engine built by the French Otto Company was tested at this event using peanut oil. It is not totally clear if Rudolf Diesel had the idea to use peanut oil because apparently, Diesel gives credit to this to the French government. Knothe (2001) also relates that the French government was interested in vegetable oil fuels for diesel engines because of its availability in their colonies in Africa, thereby eliminating the need to import liquid fuels or coal.

Knowledge that vegetable oils could be used to fuel the diesel engine gave a sense of energy self-sufficiency to those countries producing oil crops, especially for those countries in Africa in the 1940s (Knothe 2001). This was especially the case during the World War II yr, where even in Brazil, export of cottonseed oil was prohibited so it could be used as a substitute for diesel (Anonymous 1943). In China, tung oil and other vegetable oils were used to produce a version of gasoline and kerosene (Cheng 1945; Chang and Wan 1947). Furthermore, prompted by fuel shortages during World War II, India conducted research on conversion of a variety of vegetable oils to diesel (Chowhury et al. 1942). This interest in biodiesel was also evident in the USA where research was performed to evaluate cottonseed oil as a diesel fuel (Huguenard 1951).

Related to this are the efforts of automobile entrepreneur Henry Ford and the development of the "soybean car" in 1941. Mr. Ford was a true visionary and was motivated by combining the strength of the automobile industry with agriculture. According to the Benson Ford Research Center, there was a single experimental soybean car built, and this was suspended due to World War II (http://www.thehenryford.org/research/soybeancar.aspx#). This car weighed 2,000 lbs, which was 1,000 lbs less than the all steel cars in production in 1941. This lightweight car would certainly be more fuel efficient than its heavier counterpart. The genius of Mr. Ford is clearly evident in a car made in part with soybean and propelled by ethanol derived from corn. However, production of the soybean car did not resume after the end of World War II, and this does illustrate the lesson on how difficult it can be to sustain innovation (Young 2003). Photos of the soybean car are available at the website listed above.

Since the 1950s, interest in converting vegetable oils into biodiesel has been driven more by geographical and economic factors than by fuel shortages. For instance, the USA is a top producer of soybean oil, whereas Europe produces large amounts of canola oil, and this essentially determines which oil is used for biodiesel within these geographies. Also, for those remote geographic locations to which fossil fuel refining and distribution are problematic, vegetable oil-based biodiesel is a sustainable and practical means to meet the fuel energy demands. Furthermore, sources for biodiesel have been expanded to include spent vegetable oil from the food service industry as well as animal fats from slaughterhouses (Knothe 2001). However, additional research is required to identify new oil crops to meet the increasing demand for biodiesel. A variety of tools including plant breeding, molecular breeding, and biotechnology are needed to increase oil production from conventional crops such as soybean and to develop new oil crops for specific regions.

## Conclusion

This introduction to the history of biofuels was intended to give the reader a deeper appreciation for the achievements of those previously that set the stage for the role of renewable biofuels in the twenty-first century. It is the intent that this overview will help establish a legacy of those that saw the vision of bioethanol and biodiesel yr ago, and it is on their shoulders that we now stand.

This introduction is dedicated to memory of Dr. Paul Middaugh (1920–2003).

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# Chapter 2
# The DOE BioEnergy Science Center-A U.S. Department of Energy Bioenergys Research Center

**Russ Miller and Martin Keller**

**Abstract** The BioEnergy Science Center, a nationally and internationally peer-reviewed center of leading scientific institutions and scientists, is organized and in operation as a U.S. Department of Energy Bioenergy Research Center. This Oak Ridge National Laboratory-led Center has members from top-tier universities, leading national labs, and private companies organized as a single project team, with each member chosen for its significant contributions in the Center's research focus areas. The recalcitrance of cellulosic biomass is viewed as (1) the most significant obstacle to the establishment of a cellulosic biofuels industry, (2) essential to producing cost-competitive fuels, and (3) widely applicable, since nearly all biofuels and biofeedstocks would benefit from such advances. The mission of the BioEnergy Science Center is to make revolutionary advances in understanding and overcoming the recalcitrance of biomass to conversion into sugars, making it feasible to displace petroleum with ethanol and other fuels.

**Keywords** Cellulosic biomass • Biofuels • Recalcitrance • Ethanol • Consolidated bioprocessing • Poplar • Switchgrass



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