Biotechnology in Agriculture and Forestry 67
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Series Editors

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Convergence of Food Security, Energy Security and Sustainable Agriculture

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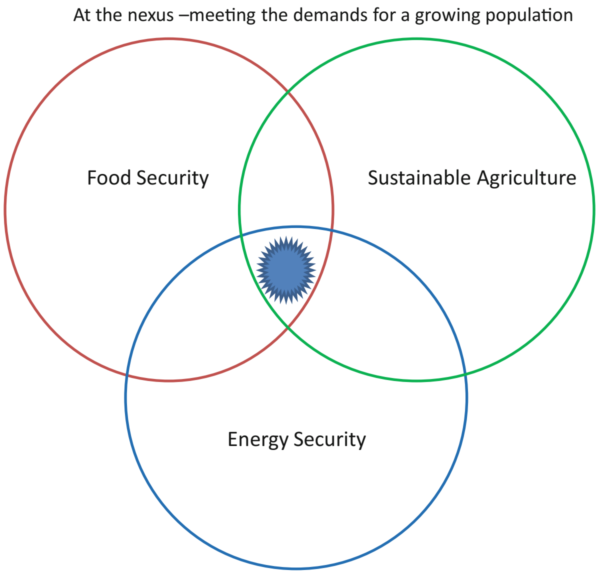
Foreword



Climate change, elevated carbon dioxide levels, exponential growth of humankind over the next half century, insufficient arable land to support the population, polluted fresh and marine waters, and decreased easily accessible and available energy sources are among the principal concerns of governments, scientists, and people across the globe as we continue into the twenty-first century. We are constantly bombarded and reminded with increasing urgency of the need to find solutions to these problems from a number of media sources, including nightly television newscasts. However, the “lay” opinions of various perceived problems often do not accurately reflect scientific knowledge and opinion. Furthermore, the popular press, as well as numerous scientific papers and reviews, have tended to key on only a few of these concerns at a time, but have failed to consider them in the context of their relatedness to each other. The diagram above is symbolic of the convergence of the ideas expressed in this book. Food/energy security and sustainable agriculture are inseparable issues in that each significantly affects the other. For example, changes in food prices are often attributed to the price of oil. A focus only on food security often results in unrealistic conclusions that are not energy secure or sustainable. In order to examine all three related issues within the context of each other, *Biotechnology in Agriculture and Forestry: Convergence of Food Security, Energy Security and Sustainable Agriculture* has integrated them into a focused discussion of sustainability and security. This book contains chapters written by renowned international authors, whose first-hand experiences have made them uniquely qualified to address and define the problems as well as to synthesize and propose potential solutions.

The book is launched by three poignant chapters concerned with sustainable food and energy policy in Part I. In these chapters, the authors remind us that among the critical needs in the near future will be food and energy security. The authors pursue sustainable solutions through innovation and research including rethinking and reconfiguring bioenergy production as well as regulatory issues.

Part II contains two chapters that are primarily devoted to sustainable land and water use. Soil conservation tactics including control of erosion, tillage, enhancement, and improvement are discussed in the context of sustainable agriculture. The second chapter also features the impact of technology and policy on land use.

Part III includes two chapters devoted to sustainable and secure food production. In this section, the first chapter explores why GMOs have received bad press from the popular media in the past and how corporations might better package their message to allay public mistrust. In the second chapter, the authors make a case for using soybeans as an excellent economical and sustainable source of omega fatty acids for human diets instead of depending on cold water fish species, which are less sustainable and perhaps even unsustainable in the future given overfishing.

Part IV has three chapters that discuss sustainable agriculture. In the first chapter, current and future "best practices" are examined in the context of sustainable agronomic systems. The authors of the second chapter in this section discuss soybean breeding throughout the twentieth century and related the gains made in yield to sustainability. The third chapter explores the tremendous impact that herbicide-tolerant crops have had on the food and fiber sources in the world as well as links the use of GMO crops and reduced tillage to soil quality improvement.

Part V looks at sustainable agricultural and food security at the international level. The first chapter in this part examines how the introduction of Bt resistant cotton varieties has significantly reduced use of herbicides, increased yield, and resulted in economic improvement in west Africa. The second chapter outlines the international educational and training programs of the Borlaug Institute. These programs have tremendous impact on sustainable agriculture in developing nations. The third chapter in this part describes a partnership between traditional breeding and biotechnology (Bt) to develop higher yielding, drought-tolerant white hybrid corn cultivars for farmers of sub-Saharan Africa.

Part VI examines the importance of agricultural chemicals and nutrient management in sustainable agricultural systems. The first chapter relates herbicide usage and weed control to soil management of erosion and water and fuel economy. The second chapter explores a program nutrient best management practices and improving nutrient use efficiency for crops.

Biotechnology in Agriculture and Forestry: Convergence of Food Security, Energy Security and Sustainable Agriculture will serve as an important source of information for regulators, scientists, and laymen alike. It will stimulate a much-needed discussion of food and energy security as they relate to sustainable agriculture and foster a rational basis for making decisions on crucial issues that affect our daily lives.

Knoxville, TN R. N. Trigiano
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Preface

One of the greatest concerns of the current generation is how are we going to provide food for the next generation in a manner that respects our finite natural resources. However, perhaps the critical question is how are we going to feed the next two generations especially with a global population expected to exceed nine billion people by 2050 (http://esa.un.org/UNPP and http://www.census.gov/main/www/popclock.html). With the expectation of feeding a growing population, additional pressure is placed on how we more efficiently utilize the natural resources required for food production. This includes land, water, fertilizer, and other resources and how to employ these in a sustainable manner. We are concerned about appropriate management of our agricultural resources at the beginning of the twenty-first century; therefore, it is imperative that we start to plan now for managing these resources in a sustainable way for the year 2050 and beyond.

From the time man made the transition from a nomadic to agrarian society, land has been altered for the purpose of growing cultivated crops. The earliest record of deforestation for the purpose of plant cultivation was approximately 9,000 years ago in the Ghab Valley of Northwest Syria (Yasuda et al. 2000). Since this time, man has primarily relied on incorporation of more land for agricultural production as the primary means for increasing food production at the expense of the native species that were originally present. Increased incorporation of arable land for food production continues today, particularly in developing countries. The FAO in a 2012 report by Alexandratos and Bruinsma described both increase and decrease of arable land for food production projections. More specifically, there will be a reduction in arable land in developed countries (North America and Europe primarily) and an increase in land for producing food in developing countries (primarily Asia, South America, and Africa). Within Latin America, it has been estimated that the rate of deforestation of humid tropical forests to be 5.8 ± 1.4 million hectares lost each year, with a further 2.3 ± 0.7 million hectares of forest visibly degraded (Achard et al. 2002). The net change across all world regions inclusive of developing and developed countries is for more land to be used for food production (Alexandratos and Bruinsma 2012). With land being a finite resource, continuing this pattern is not sustainable. Therefore, it is imperative that food production be increased on the land that is currently utilized for agricultural purposes.

In a recent FAO report, How to Feed the World in 2050, the three drivers affecting food security are population growth, increase in urbanization, and increase in income (FAO 2009). A good example of increased urbanization and increased income over the past decade has been in Asia, particularly China and India (Zhou et al. 2004; Bloom and Finlay 2009). It is expected that additional demand on the food system will come from those individuals living in countries with rapidly growing economies where the variety of foods consumed will likely increase (Edgerton 2009). This additional pressure on food production will increase in addition to the pressure placed by the demand due to an increase in the sheer number of people by 2050.

The World Health Organization in 1996 defined Food Security as when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life. The USDA, in a 2013 study by Coleman-Jensen et al., defined Food Security as households that have consistent, dependable access to enough food for active, healthy living. Furthermore, the authors quantified this and determined that 85.5% of U.S. households were Food Secure throughout all of 2012, indicating that 14.5% of U.S. households were Food Insecure at least some time during the year in 2012. The WHO and USDA definitions are certainly similar in scope, and there is some ambiguity in the details.

Hand-in-hand with Food Security is Energy Security. The International Energy Agency (IEA) defines Energy Security as uninterrupted availability of energy sources at an affordable price. The United States Congressional Budget Office defines Energy Security as the ability of households and businesses to accommodate disruptions of supply in energy markets. Clearly these definitions define energy security from two different perspectives and leads to ambiguity regarding the discussion involving energy security.

What is the definition of Sustainable Agriculture? Recently, in the United States, there has been considerable pressure to alter the definition of sustainable agriculture from how it is defined by the United States Department of Agriculture. It is important to have a definition that is endorsed by the Federal government as it will serve as the central element for program grants, such as the Sustainable Agriculture Research and Education (SARE) program through NIFA. The definition of sustainable agriculture utilized by SARE is as follows:

The term "sustainable agriculture" (U.S. Code Title 7, Section 3103) means an integrated system of plant and animal production practices having a site-specific application that will over the long term:

- Satisfy human food and fiber needs.
- Enhance environmental quality and the natural resource base upon which the agriculture economy depends.
- Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
- Sustain the economic viability of farm operations.
- Enhance the quality of life for farmers and society as a whole.

The 1990 U.S. Farm Bill emphasizes sustainable agriculture upon three key components: environmentally friendly, economically viable, and accepted by society.

The debate over the definition of sustainable agriculture has been ongoing for several years (see Redick, Chap. 3) and extends far beyond the United States to virtually every country in the World. In the future, there will be a need for a global definition of Sustainable Agriculture that spans all the continents. Clearly a balance is necessary regarding the definition of Sustainable Agriculture and, more so, regarding the interaction of Food Security, Energy Security, and Sustainable Agriculture. This was the impetus behind the creation of this book and its title "Convergence of Food Security, Energy Security and Sustainable Agriculture." It is the convergence where we need to be as a global community to serve the caloric needs of humanity. It is the convergence where we need to be as a global community to grow the food that we need for life. It is the convergence where we need to be as a global community to insure that our children and grandchildren have food to eat in the next generation and beyond.

San Diego, CA David Songstad

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Contents

Part I
Food and Energy Security and Sustainable Agriculture Policy

Chapter 1
Creative and Innovative Research: Our Only Hope for Achieving Sustainable Food and Energy Security

Gale A. Buchanan and Raymond L. Orbach

1.1 Introduction

1.1.1 Energy Security

Few issues grabbed the attention of the American people as did $4 gasoline in the summer of 2008 (U.S. Energy Information Administration http://www.eia.gov). Since then, any decrease in the price of petroleum and petroleum-based products carries the potential for a return to the days of profligacy. Sales of fuel efficient vehicles spiked at the height of gasoline prices but slowed with softening of gasoline prices. However, there is evidence of increasing public concern with development of more hybrid and electric cars. In fact there are approximately 30 companies developing hybrid or electric vehicles at present. Success of each of these ventures remains to be seen. While there are those who are no longer concerned about the seriousness of energy challenges, it is clear that basing our country's energy future on fossil fuel alone, a finite resource, is not a viable course for the United States or any nation.

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1.1.2 Food Security

Food security is quite a different matter, but is just as serious. Today there are some one billion people who do not receive adequate caloric intake for good health (Gates Foundation, http://www.gatesfoundation.org/agriculturaldevelopment). Approximately 80 % of undernourished people live in seven countries: China, India, Bangladesh, Pakistan, Ethiopia, Indonesia and the Democratic Republic of Congo (UN-FAO 2010). Adequate nutrition is the first step toward societal advancement in education and infrastructure development in rural and urban communities (http://www.gatesfoundation.org). Associated with this are the people, perhaps as many as a billion, that do not receive adequate protein, fat, important minerals, and/or essential vitamins. For example, it is estimated that several hundred thousand individuals lose their sight or perish each year due to vitamin A deficiency (Potrykus 2010). The FAO reports that a child dies every 6 s from undernourishment (UN-FAO 2010).

Achieving sustainable food security and energy security are two of the most important challenges facing our planet. Both food and energy are critically necessary for survival of our civilization as we know it. While agriculture is only a part (most would argue a critical part) of the energy challenge, agriculture is totally responsible for the food challenge. This challenge involves not only increasing supply but also facilitating the movement of produce from farms to communities where the food is needed. In many regions of the world, linking the harvest of crops to the market is a challenge because of a variety of issues including transportation, infrastructure and lack of commodity price information in the marketplace (Gates Foundation, http://www.gatesfoundation.org/topics/Documents/agricultural-development-fact-sheet.pdf).

1.2 Challenges and Expectations

1.2.1 Energy Consumption

Global energy consumption is going to increase steadily for the next several years. The United States Energy Information Administration estimates that world marketed energy consumption will increase by 49 % from 2007 to 2035. Total energy demand in non-OECD countries will increase by 84 % compared with an increase of 14 % in OECD countries (http://www.eia.doe.gov/oiaf/ieo/highlights.html). The estimated energy consumption in 2035 will be 739 quadrillion British Thermal Units (BTU), which is double of that consumed in 1990 (http://www.eia.doe.gov/oiaf/ieo/world.html).

If we attempt to supply the total transportation fuel needs with fossil fuels, the rate of increase of greenhouse gases (GHG) emitted into the atmosphere will continue to accelerate (U.S. Energy Information Administration http://www.eia.

doe.gov/oiaf/ieo/emissions.html). We must find ways to meet the increasing demand for energy without adding irresponsibly to greenhouse gases. Wang et al. (2007) reported that GHG emissions for corn-based ethanol are reduced by as much as 52 % compared with that from gasoline. This, of course, may be reduced because of slightly less energy content of ethanol. Furthermore, considering the impact of research as a whole, Burney et al. (2010) estimated that each dollar invested in agricultural yields has resulted in 68 fewer kgC (249 kgCO_2e) emissions relative to 1961 technology ($14.74/tC or approximately $4/t$CO_2$e), avoiding 3.6 GtC (13.1 GtCO_2e) per year.

1.2.2 Future Food Production

Dr. Norman Borlaug, recipient of the 1970 Nobel Peace Prize, the U.S. Presidential Medal of Freedom, and the U.S. Congressional Gold Medal is known as the "Father of the Green Revolution" for his pioneering work developing high-yielding wheat varieties for areas with limited cultivated land and increasing population. In 2002, Dr. Borlaug gave a speech commemorating his receiving the 1970 Nobel Peace Prize where he stated, "It took some 10,000 years to expand food production to the current level of about five billion tons per year. By 2025, we will have to nearly double current production again. This cannot be done unless farmers across the world have access to current high-yielding crop-production methods as well as new biotechnological breakthroughs that can increase the yields, dependability, and nutritional quality of our basic food crops." In Dr. Borlaug's (see Borlaug et al., Chap. 12) last written words to the scientific community, in CAST Issue Paper 45 he recounts, "We made great strides in the first Green Revolution by bringing improved agricultural techniques, seeds and technology to poor underdeveloped and developing countries. But in the next 50 years we're going to have to produce more food than we have in the last 10,000 years, and that is a daunting task. I, therefore, have called for a second Green Revolution" (Council for Agricultural Science and Technology (CAST) 2010).

The demand for both food and energy will increase dramatically in the coming decades. Agricultural economists have projected the demand for agricultural production at 143 % of year 2000 output in 2025 and 179 % of 2000 output in 2050 (Tweeten and Thompson 2009). This is primarily driven by the fact that demographers predict that world populations will reach 9.2 billion by mid century (Bongaarts 2009), over a two billion increase above the approximately 7.2 billion people living on the planet in 2014 (http://www.census.gov/main/www/popclock.html). Specifically, nearly all of this future growth occurs in Africa, Asia (excluding Japan, Australia and New Zealand) and Latin America (Bongaarts 2009).

People around the world have rising expectations for enhanced quality of life that includes improved health, better nutrition, more meat and dairy products (Deaton 2008; Edgerton 2009). People also want many of the other things that make for a better life such as a comfortable home and personal transportation.

Dahl (2005) reported that in 2001 China identified auto manufacturing as one of the key "pillar" industries of the Chinese economy and announced a 5-year plan to implement a primarily domestic industry that could offer a Chinese family car at a price that would encourage widespread ownership. As a result of this, between 2000 and 2004, production of passenger cars in China jumped from 605,000 to 2.33 million. This is just one example of an emerging economy that will increase the demand for energy. As this demand for energy increases, the need for renewable fuel development will become paramount. This is especially true given total fossil fuel production will continue to grow, but only slowly for the next 15–30 years and then reach a peak plateau for another 10–15 years (Nehring 2009). Ultimately, world fossil fuel production per capita will begin an irreversible decline between 2020 and 2030 (Nehring 2009). If alternatives to fossil fuels are not identified, global energy insecurity will result during this century.

1.2.3 Food Security and Energy Security Are Inseparable

It is important for society to realize that food security and energy security are inseparable. In 2008, there was concern that corn-based ethanol and soy-based bio-diesel were the reasons for rising food prices. Since this time, several economic studies have been published that describe corn and soybean use in biofuels as one of several reasons of the rise in food prices. The other reasons include the devaluation of the US dollar, rising price of oil, increased demand for food in emerging economies (e.g., China and India) and weather conditions that affected crop production (Abbott et al. 2008; Henderson 2008; Armah et al. 2009). Ironically, food prices fell in 2009 as the price of oil also decreased; however, in 2009, there was 10.6 billion gallons of corn-based ethanol produced versus 9.0 billion gallons in 2008 (http://www.ethanolrfs.org). Domestic food security in the United States has been and is a reality today because of three main assets. These include (1) our agricultural research and education system that develops and transfers new and innovative technology and business practices, (2) management skills and abilities of farmers and ranchers and the agricultural industry to adopt new and innovative technologies and (3) the natural resource base of this country that includes productive soils, a favorable climate and nutrient and water resources. A portion of our domestic energy requirement can be as secure as food in this country because it requires similar assets.

Sugarcane is also a crop with food and fuel utilities. It is predicted that by 2020, Brazil will be planting approximately 14 million hectares of sugarcane, producing more than one billion tons of cane, 45 million tons of sugar, and 65 billion liters of ethanol (Matsuoka et al. 2009). Furthermore, and also in Brazil, the burning of bagasse (crushed cane stalks) is expected to produce enough electricity to meet or exceed that produced by hydroelectric (Jank 2008). It is interesting that combustion of bagasse for power is not a new idea; it was first described as a fuel source for power production approximately 80 years ago (Adams 1934).

Meeting the demand for food and fuel in sugarcane has been met by using improved technology. Development of new sugarcane varieties has reduced the risk of yield losses to disease, and this has contributed to the 50 % increase in average yield since 1975 leading to a dramatic increase in ethanol production from 2,500 l/ha in 1975 to about 7,000 l/ha currently (Goldemberg 2008). It is estimated that sugarcane breeding can contribute significantly to realize the predicted 9,000 l/ha alcohol production for the next decade (Matsuoka et al. 2009). Again, sugarcane as a food and fuel crop joins corn and soybeans as testimony that food security and energy security are inseparable.

1.3 Energy

1.3.1 Future Energy Needs and Greenhouse Gases

One critical question today is how the energy needs of the future world economies will be met without adding dangerously to atmospheric greenhouse gases. The energy and environmental challenge confronting us in this century is truly monumental. It is one of the most important challenges our civilization has faced.

1.3.2 Alternative Energy Sources

Achieving sustainable energy security requires both more efficient use of energy and the development of new energy sources. The fundamental truth is that fossil fuels are a finite resource that will one day become so expensive that we shall be forced to seek alternatives (Nehring 2009).

It is fortunate that we have come to this realization with time to improve efficiency and to develop alternatives. It is safe to say we are rapidly exiting the era of cheap energy and entering a stage of increased cost of petroleum based on information provided by the Energy Information Administration (Fig. 1.1). We are also entering an era where the predictability of fossil energy costs is somewhat uncertain due to increased global demand and diminished supplies as evident by the variability in price shown in Fig. 1.1.

We have several alternative energy options: wind, hydro, biomass, geothermal, nuclear, solar, ocean waves, and currents. While each of these options has unique features and attributes, they have one thing in common—the need for more research to enable them to reach their full potential to become a practical part of the energy solution (Council for Agricultural Science and Technology (CAST) 2010). These alternative energy options must ultimately be competitive with fossil fuel costs eventually without subsidies, and they must be sustainable without harm to the environment.

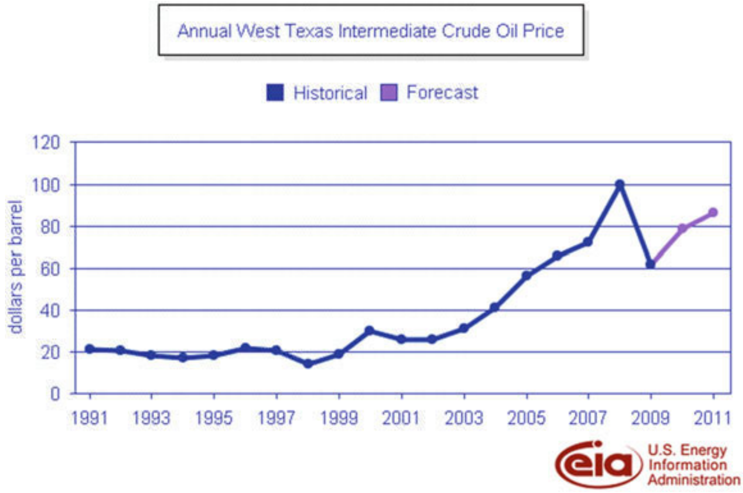

Fig. 1.1 Annual West Texas intermediate crude oil price

Each of these approaches has differing degrees of potential. Nuclear power lost luster after Three Mile Island especially the Chernobyl and Fukushima daichi disasters. The impact of the last nuclear reactor incident in Japan following the 2011 earthquake/tsunami is still being determined (Christodouleas et al. 2011). However, nuclear power's widespread use in some countries, notably France, puts this option squarely back on the table. A recent National Academy of Sciences report indicates that spent nuclear fuel can be mined for its energy through use of alternative (closed) nuclear fuel cycles that reprocess used fuel to produce new fuel. In principle, these alternative fuel cycles could extend fuel supplies and reduce the amount of long-lived nuclear waste (National Academy of Sciences 2010). Many see wind, geothermal, and hydro as great options (Lu et al. 2009), but with limited current capacity. Solar energy, utilizing photovoltaic cells and green plant photosynthesis, offers great potential (Lewis and Nocera 2006). The sun provides an inexhaustible source of energy at least for the next 3–5 billion years. Sufficient energy from the sun reaches the earth in 1 h to supply our every need for a full year (Lewis and Nocera 2006). The challenge is to capture the sun's energy in a usable form and to build systems that can supply energy on an uninterrupted basis to meet demands. Another advantage of the sun's energy is that it is available to all nations on the planet. Harnessing the sun's fusion energy process on the earth, though complex and difficult, is yet another avenue to explore. The construction of ITER is underway in France, with hopes for provision of electricity into the grid by 2050 (Harding et al., 2012).

1.4 Food

1.4.1 Development of an Agrarian Society

At one time in our civilization, food was a finite resource just as fossil energy is today. The development of agriculture not only enabled food to become a sustainable resource, the transition from a nomadic to agrarian society has resulted in a positive human experience where we now live longer and have generally happier lives (Veenhoven 2010). As this occurred, more and more people were freed to make the kind of contributions needed to build a civilization as we know today.

1.4.2 Domestication of Plant and Animals

Over the past 8,000 to 10,000 years man has become adept at agriculture (Diamond 2002). He has learned, mostly by trial and error, what species of plants and animals can be domesticated, how different geography and climates can be employed to grow such plants and animals, how to harvest the most desirable part of such plants and animals, and how to process and preserve the desirable aspects of these plants and animals. But man didn't stop there. One can speculate that for most of the first 8,000–10,000 years, his only tools were selection of the most desirable plants and animals. Perhaps the best example of early domestication of a crop is the domestication of modern maize from teosinte (Beadle 1939). However, it was the rediscovery of Mendel's publication that led to the serious effort towards incorporating research in agricultural experimentation and improvement. In this country, with the coming of the land grant universities, research was greatly strengthened, particularly in agriculture and the mechanic arts.

1.5 Energy Research

We remain convinced that achieving sustainable energy security can be accomplished through focused, dedicated, and adequately funded research and education programs. The successful pursuit of achieving a greater degree of energy security can be achieved through development of information, knowledge and technology. We must understand the long-term opportunities and risks before we deploy a proposed technology or process. Bypassing the research step will waste money and will lead to disillusionment and delay of success. There are many unknowns, and it is impossible to predict when a particular problem will be solved. However, the greater the commitment to research, the sooner there will be a solution.

1.5.1 USDA and DOE Committed to Energy Security

The Department of Energy (DOE) and the Department of Agriculture (USDA) are committed to performing the research that enables each of these agencies to reach their full promise. It is encouraging to see other Federal agencies, the Nation's universities and American industry becoming committed to these grand challenges. Nevertheless, government investment in research must be done in a stepwise manner that prevents overinvestment and promotes prudent investment in experimentation designed to promote energy security.

Achieving sustainable energy security for this country is one of the most daunting challenges we have ever faced. So far, the Nation's commitment to scientific research to deal with these challenges often ends in contentious debate rather than reaching consensus directed toward specific outcomes that can be measured and evaluated. However, there does appear to be an awakening to the need for greater investment in research. The past administration has made a sound, yet modest start. Hopefully, the current administration will pick up the challenge and keep the emphasis on strengthening research efforts.

1.5.2 Research Required to Reach Full Energy Potential

Each of the approaches to addressing the energy challenge including wind, geothermal, nuclear, solar electricity, solar biofuels, ocean and river currents, ocean waves and perhaps others require considerable research in order to achieve full potential of the approach. For example, the solar biofuels approach requires a far better understanding of sustainable production and harvesting of biomass. While we have had literally thousands of years to identify the most desirable plant species for food, there is great need to identify and settle on the most desirable species for energy. There is the long process of genetic improvement of these species for best energy production. It's a bit ironic that the most successful solar-biofuel approach to date is using centuries old plant species (sugarcane and corn) and centuries old conversion technology (yeast fermentation) to make ethanol. Other research challenges involve developing better approaches to conversion technology. This requires new and innovative technology for fuel production from cellulose, hemicellulose and lignocellulose. Arguments could be made for each of the other approaches to meeting the energy challenge. It is abundantly clear that there is significant research that must be done if we are to achieve sustainable energy security.

1.6 Food Research

1.6.1 Civil Stability Through Agriculture

Civilization as we know was made possible by agriculture. Indeed, as agriculture evolved, more of the population could pursue an education and contribute directly to the development of the activities that are now integral parts of our civilization. As the concept of research developed, the pace and advance of our civilization quickened. Associated with this development was an increase in population of the planet. This "transformation" has occurred in such a slow and deliberate fashion that most people do not realize or even appreciate how agriculture made our civilization possible. The demands and expectations facing agriculture and our current global civilization are daunting and can only be met by a constant infusion of new information, knowledge, and technology that can be gained only by research.

1.6.2 Second Green Revolution

There are several potential areas for research that could provide the new information and knowledge that could bring about a second green revolution. Briefly, this includes enhancing the quality of soils (see Hatfield, Chap. 4), enabling C_3 plants to utilize the C_4 photosynthetic pathway, nitrogen fixation in nonlegumes, incorporating the process of apomixes into crop plants, enhancing water and nutrition efficiency of crop species, improving energy efficiency of plants, improving pest resistance in plants and developing commodities with enhanced health benefits. Another important approach would be to develop new processing and conversion technology to provide for more efficient conversion of cellulose, hemicelluloses, and lignocelluloses to fuel (Council for Agricultural Science and Technology (CAST) 2010).

1.7 Ensuring Success

It is quite apparent that our planet must achieve sustainable food and energy security if our civilization is to survive and certainly to thrive. Furthermore, the need to realize that food and energy security are inseparable is key to our ability to achieve sustainability for each. Examples of this exist in corn-based ethanol (see Hughes et al., Chap. 2) where dried distillers grains (DDGS) are produced and used as animal feed where it can provide 35 % to 40 % of the nutritional value to feedlot cattle (Council for Agricultural Science and Technology (CAST) 2006). Ultimately, the inseparable nature of food and energy security goes back to the sun and the fact that it provides the energy required to produce plants for food and biofuels.

Research is a deliberate methodical process where every success answers questions but always opens vista with more questions to be addressed. This is, of course, how progress is made. There are no shortcuts to success. Most research advance comes in several incremental successes and with an occasional "breakthrough." Production of ethanol from cellulosic materials is receiving much research focus and funding, especially through the Department of Energy (Miller and Keller 2009). The path forward has been described in a review paper by Ragauskas et al. (2006) as one with options that must keep the carbon balance in perspective as well as recycling carbon waste from the refining process. In addition to fermentation as a means of producing biofuels, themochemical conversion of cellulosic biomass to biofuels is also an option (Phillips et al. 2007; Tao and Aden 2009). While cellulosic ethanol is being developed, Carlson et al. (2010) has proposed harvesting ethanol from corn-based ethanol and then combining the DDG by-product with biomass residue (corn stover, grass hay, wheat straw, etc.) to provide a cattle feed of elevated nutritional value.

Our survival requires that we have sustainable food and energy. This requires that we first conduct the research necessary to provide information, knowledge, and technology to address the challenge necessary for an adequate supply of both food and energy. It is foolish to try and implement a technology before fully understanding the research and its applications. Assuring success requires understanding the strengths and weaknesses of any new technology, which is the "development" portion of R & D.

We urge the U.S. Administration and all levels of Government and private industry to build on earlier efforts and commit resources to ensure a robust effort led by the Federal government and joined by the Nation's universities, nongovernmental organizations, and industry to perform the research that will enable this nation to achieve sustainable energy and food security.

We have no alternative.

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Chapter 2
Moving Toward Energy Security and Sustainability in 2050 by Reconfiguring Biofuel Production

Stephen R. Hughes, Bryan R. Moser, and William R. Gibbons

2.1 Introduction

For secure and sustainable bioenergy and biofuel production to become a reality by the middle of the twenty-first century, building on the current infrastructure and existing technology is essential. However, at the same time, we must make substantial improvements and/or changes in the feedstocks used, the process technologies applied, and the fuels produced, to achieve true sustainability (see Buchanan and Orbach, Chap. 1). A critical question is: What role will advanced biofuels play in the energy portfolio of the world 20–50 years from now? There is increasing evidence that commercial biofuel production can be reconciled with feeding humanity and preserving the environment, provided that we invest the time and effort needed to make the improvements necessary to achieve this goal (Lynd and de Brito Cruz 2010).

The biofuel production concept described in this chapter has the potential to meet the challenges of sustainability, sufficient supplies, and economic feasibility by combining proven technologies with promising innovations that are currently under development. We envision a decentralized, community-based system with integrated crossover bioprocessing units to convert biomass into third generation drop-in biofuels (long-chain alkenes, alkanes, and alcohols) and bio-derived chemicals. These systems could be developed on green-field sites or built onto first or second generation biofuel (biodiesel, ethanol) facilities.

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Such systems will require advancements in feedstocks used to produce biofuels and chemicals (Perlack and Stokes 2011). Plants (trees, row crops, grasses) bred for rapid growth, high yield, and desirable composition will be needed to support multiuse production of food, feed, fuels, and chemicals. Perennial plants able to grow with minimal inputs (fertilizer, pesticides, irrigation water) on lower quality (fallow) land would be most desirable in terms of sustainability. However crop residues or cover crops could provide dual use of land, as well as increased sustainability (Perlack and Stokes 2011; see Sripada et al., Chap. 8). Single-celled phototrophs (e.g., algae or cyanobacteria) that can fix CO_2 into oil are also emerging as potential feedstocks. Compared to the current biofuel production system, cyanobacteria, as autotrophic prokaryotes, do not require arable land and can grow to high densities by efficiently using solar energy, CO(2), water, and inorganic nutrients. Moreover, genetic techniques for cyanobacteria have been developed, and recently several chemicals including ethanol, isobutanol, and isoprene have been produced directly by engineered cyanobacteria (Zhou and Li 2010).

Advanced conversion systems are also needed to transform biomass feedstocks into biofuels and chemicals. Efforts to improve the biochemical platform are focused on pretreatment strategies and engineering microbes and their enzymes to deconstruct carbohydrate polymers and produce long-chain hydrocarbons or alcohols. Thermochemical efforts are being directed toward integrated thermo-catalytic processes that can readily switch among a multitude of feedstocks. Conversion systems of the future must optimize the value of products produced, minimize energy and water use, be scalable to distributed processing networks (to minimize feedstock logistics challenges), and produce minimal waste products.

While the United States has produced corn-based fuel ethanol for over 30 years, a comprehensive energy security plan was lacking prior to the Energy Policy Act (EPAct) of 2005. To meet the requirements of the EPAct, EPA adopted a limited program that applied to the year 2006. This was followed by a more comprehensive program in May 2007 referred to as the Renewable Fuels Standard 1 (RFS1). Under RFS1, the required renewable fuel mandate for 2006 was set at 4.0 billion gallons, and this was to ramp up to 7.5 billion gallons by 2012. The Energy Independence and Security Act of 2007 (EISA) made significant changes in the structure and magnitude of the renewable fuel program. The revised statutory requirements of EISA specify the volumes of cellulosic biofuel, biomass-based diesel, advanced biofuels, and total renewable fuel that must be used in transportation fuel yearly from 2010 to 2022. The EISA fuel program, designated RFS2, mandates the use of 15.2 billion gallons/year of renewable fuel by 2012 and 36 billion gallons/year by 2022 (Federal Register 2010).

In 2010, US corn ethanol plants produced over 12 billion gallons of ethanol from 4.568 billion bushels of corn (Wilson 2011). The majority of the increased biofuel production called for in RFS2 is mandated to come from cellulosic feedstocks and is targeted at 16 billion gallons by 2022. Second generation biofuels include cellulosic ethanol and cellulosic diesel. Along with a projected 15 billion gallons/year of corn ethanol and 5 billion gallons/year of other renewable biofuels, such as biomass-based diesel, renewable hydrocarbons, and higher alcohols, the goal is to replace 20 % of current crude oil use in the United States by 2022 (Regalbuto 2009).

Replacing traditional gasoline, diesel, and jet fuels with renewable fuels will have a wide range of environmental, societal, and economic impacts. The significance and timing of these impacts will be affected by how rapidly biofuels replace petroleum-derived fuels, which in turn is affected by market forces (crude oil price and availability, feedstock prices), technology development, political conditions, and regulatory factors. The impacts of biofuel production on environmental, societal, and economic factors will be affected by the: (1) type of fuel produced and its use, (2) types and locations of the feedstocks, (3) locations, methods, and scale of conversion systems, (4) yields of products and coproducts from a given feedstock, and (5) challenges associated with use of these feedstocks (Federal Register 2010).

2.2 Present-Day Biofuel Production

2.2.1 Ethanol

The United States is currently the largest ethanol producer in the world (Renewable Fuels Association 2014c). The US ethanol industry expanded rapidly from the late 1990s to the present (Table 2.1), spurred by the phaseout of the gasoline additive methyl tertiary butyl ether (MTBE) and by state and federal mandates and tax incentives. The majority of present-day domestic ethanol biofuel production comes from approximately 190 operating facilities, processing mostly corn and similar grains, such as milo and barley. Most of these facilities are located in the Midwest near the site of feedstock production (Fig. 2.1); however, some are colocated with dairies or beef cattle feeding operations outside the Corn Belt. Seven small facilities convert simple sugars from food or beverage waste into ethanol, and in 2010, 3 million gallons were produced from two facilities using woody biomass as the feedstock (Renewable Fuels Association 2014a).

Over 90 % of corn ethanol plants use dry-grind technology, while the remaining facilities use wet-milling processes. Dry-grind facilities grind the entire corn kernel and generally produce one primary coproduct, dried distillers' grains with solubles (DDGS), which is a valuable livestock feed. Some distillers' grains are sold in a wet or modified wet condition for local use; however, storage and transportation are limiting factors. Two companies operate dry-mill ethanol plants that fractionate the corn upstream of ethanol production. They produce additional coproducts such as food- or fuel-grade corn oil and corn bran. Wet mill facilities separate the corn kernel into its components, germ, fiber, protein, and starch, prior to processing, and from these produce other coproducts, including gluten feed, gluten meal, and food-grade corn oil, in addition to DDGS (Federal Register 2010).

Ethanol production requires the use of water, electricity, and steam; the steam needed to heat the production process is usually generated on-site by burning natural gas. At least 27 plants use combined heat and power technology, producing their own electricity and using waste heat from power production for the process