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Biofuel Crop Sustainability

Bharat P. Singh

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Edited by

Bharat P. Singh
Fort Valley State University
Fort Valley, GA, USA

WILEY Blackwell

Editorial offices: 2121 State Avenue, Ames, Iowa 50014-8300, USA
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
9600 Garsington Road, Oxford, OX4 2DQ, UK

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Contributors

Shaun D. Berry, Becker Underwood, Gillitts, South Africa

Nanthi Bolan, Centre for Environmental Risk Assessment and Remediation (CERAR), University of South Australia, Mawson Lakes, Australia

K.B. Cantrell, USDA-ARS Coastal Plains Soil, Water, and Plant Research Center, Florence, SC, USA

Dmitri Chatskikh, George Lemaître Centre for Earth and Climate Research, Earth and Life Institute, Catholic University of Louvain, Louvain-la-Neuve, Belgium

Christina Eynck, Linnaeus Plant Sciences Inc., Saskatoon Research Centre, Saskatoon, Canada

Kevin C. Falk, Agriculture and Agri-Food Canada, Saskatoon Research Centre, Saskatoon, Canada

Andrew Fieldsend, Research Institute of Agricultural Economics, Budapest, Hungary

John H. Fike, Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Wonae B. Fike, Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Thomas R. Fox, Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA, USA

Wolfgang Friedt, Department of Plant Breeding, Justus Liebig University Giessen, Giessen, Germany

Cole Gustafson (Late Chair), Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND, USA

A. Hastings, Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, UK

J. Hillier, Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, UK

Patrick G. Hunt, USDA-ARS Coastal Plains Soil, Water, and Plant Research Center, Florence, SC, USA

Abdullah A. Jaradat, USDA-ARS Research Lab and Department of Agronomy and Plant Genetics, University of Minnesota, Morris, MN, USA

Shailesh Joshi, South African Sugarcane Research Institute, Mount Edgecombe, South Africa

L. Chris Kiser, Department of Forest Resources, Abraham Baldwin Agricultural College, Tifton, GA, USA

Rocky Lemus, Department of Plant and Soil Sciences, Mississippi State University, MS, USA

Thein Maung, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND, USA

Bruce McCarl, Department of Agricultural Economics, Texas A&M University, College Station, TX, USA

Eric Obeng, Fort Valley State University, Fort Valley, GA, USA

Anna Ovchinnikova, Cargill Europe BVBA, Mechelen, Belgium

Sudhanshu S. Panda, GIS/Environmental Science Gainesville State College, Oakwood, GA, USA

David J. Parrish, Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

József Popp, Faculty of Applied Economics and Rural Development, University of Debrecen, Debrecen, Hungary

David Ripplinger, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND, USA

K.S. Ro, USDA-ARS Coastal Plains Soil, Water, and Plant Research Center, Florence, SC, USA

David Saxowsky, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND, USA

Balaji Seshadri, Centre for Environmental Risk Assessment and Remediation (CERAR), University of South Australia, Mawson Lakes, Australia

Dev Shrestha, Biological and Agricultural Engineering Department, University of Idaho, Moscow, ID, USA

Bharat P. Singh, Fort Valley State University, Fort Valley, GA, USA

Hari P. Singh, Fort Valley State University, Fort Valley, GA, USA

P. Smith, Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, UK

Jeff Smithers, School of Engineering, University of KwaZulu-Natal, Pietermaritzburg, South Africa

Kenneth C. Stone, USDA-ARS Coastal Plains Soil, Water, and Plant Research Center, Florence, SC, USA

Rianto van Antwerpen, South African Sugarcane Research Institute, Mount Edgecombe, Department of Soil, Crops and Climate Sciences, University of Free State, Bloemfontein, South Africa

Tania van Antwerpen, South African Sugarcane Research Institute, Mount Edgecombe, South Africa

Michael van der Laan, Department of Plant Production and Soil Science, University of Pretoria, Hatfield, Pretoria, South Africa

Johann Vollmann, Division of Plant Breeding, Department of Crop Sciences, University of Natural Resources and Life Sciences, Vienna, Tulln, Austria

J. Yeluripati, Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, UK

Preface

Agriculture by nature is an unsustainable system. Crops take more out of soil than it has the ability to replenish under normal conditions. Being aware of this fact, throughout history man has tried to supplement the difference by various means with different degrees of success. It was no accident that the location of the first agriculture-based civilization was Mesopotamia, meaning "land between two rivers." The flood water every year brought new rich alluvial soils down the river to enrich the farmland with nutrients. With increases in population, people migrated from the optimal to the best land and climate they could find, and in time were forced to settle for marginal soils and climates. However using ingenuity, mankind found ways to supplement what soil was not able to offer and used the climate to the fullest. Man's incessant desire for more, while at the same time having more mouths to feed started to take toll on the soil, the primary agricultural resource. Ancient scholars saw the development of this trend and warned against tendencies that made agricultural systems unsustainable. The evidence of such warnings is found in the literary archives of the Indus Valley, Chinese, and the Middle Eastern civilizations. In modern times, detriment to soil and climate became endemic with the large-scale use of chemicals and machineries in agriculture starting in the 1930s. Present scholars, like their ancient predecessors, raised the alarm and the "dust bowling" by mechanical agriculture created general awareness of the awaiting catastrophes from the overexploitation of agricultural resources.

The World Commission on Environment and Development of the United Nations General Assembly of 1987, also known as the Brundtland Commission provides the latest definition of sustainable agriculture. Under this definition, sustainability includes the long-term survival of agriculture as an economic enterprise benefitting not only the farmer, but the society as a whole, with due regard to the preservation of the quality of life in aesthetics, health, and culture by preserving the wholeness of the surrounding environment. It is similar to the concept followed during ancient agrarian times, components of which were lost during the Industrial Age. For example, Indian villages were a cluster of households; farming families were the nucleus and other families provided essential services to farmers, with the right of a portion of the harvest. Thus, essentially the part of the harvest a farmer could keep for his family in relation to other families in the village was fixed. Nonfarm families sold part of the harvest to exchange goods and services among themselves. This model of agrarian economy was sustainable because it created a system of exchange of goods and services that benefitted all members of the village. It also put the responsibility upon farmers to follow agricultural practices that guaranteed land to produce harvests year after year because the whole village depended on them. The farmer grew up sharing farm responsibilities from childhood and learning from his elders how to keep land productive and safe before assuming a decision-making role. People paid tribute to trees, rain, and animals and folklores were built around even the virtues of crows and vultures to ascribe their important contribution to human sustainability and to perpetuate this knowledge to future generations.

Biofuel is as old as man's discovery of how to light fire. Use of solid biofuel for cooking and the burning of plant oils for light was common until the start of the twentieth century. Using liquid biofuels for light and later as automotive fuel was not uncommon during the early 1900s. Cheap coal, kerosene, and later petroleum, however, slowly eroded plants' monopoly as energy providers and ultimately pushed them into subservient roles. Uncertainty regarding uninterrupted petroleum availability from disturbed regions of the world, which coincidentally have the greatest petroleum reserves, along with the intentions shown by petroleum-owning nations to use fuel as a political tool and fix prices outside the market domain have necessitated the shift to alternate fuel sources. Added to it was the clear evidence of detrimental impact of petro-fuels on the environment and, specifically, their connection to global warming. Thus, in the search for alternatives, there were two broad requirements: energy sources that are reliable and available year after year and secondly is environment friendly. Solar, wind, geothermal, hydro, and biofuel were perceived to meet the criteria. Biofuel is unique in the energy mix; it is the only fuel available both in solid and liquid forms and with the potential to match the multi-byproduct generation ability of petro-fuel. It is also the most suitable form of transportation fuel for the vehicles currently on the road. As the feedstock for biofuel comes from agriculture, the sustainability of feedstock production systems automatically becomes a matter of importance in consideration of this energy source. Keeping in mind that agriculture currently is mainly a food and fiber enterprise, noninfringement by biofuels of this primary function is also of paramount importance.

This book covers all aspects of sustainability as defined under the Brundtland Commission's definition, with the adage of food-over-fuel-priority underpinning all chapters. I have been fortunate to assemble the ablest authors from different countries. My sincere appreciation and thanks to all of them for graciously accepting my invitation to join in this exercise of providing a comprehensible scientific treatise on the different aspects of sustainability as it relates to biofuel crop production. The food-versus-fuel debate is highly emotional and some scientists have taken sides. I have tried my best to select authors who can provide objective deliberation and to examine each chapter carefully for science-based description. I hope this book proves useful to all concerned with agriculture, sustainability, and biofuel.

In closing, I would like to extend my sincere thanks and gratitude to my associate, Eric Obeng, for his assistance at every step of this editorial exercise. Without his help, this burden would have been lot heavier. I would like to dedicate this book to my 4-year-old grandson, Ayan—he never ceases to amaze me with his voracious appetite for reading anything with pictures and constantly attempts to discover things that are around him and which are intentionally hidden from him. What his parents call mischief, to me is just an innovative mind—the sign of a genius.

Bharat P. Singh
Fort Valley State University
Fort Valley, GA, USA

Biofuel Crop Sustainability

Chapter 1

Biofuel Crop Sustainability Paradigm

B.P. Singh

Fort Valley State University, Fort Valley, GA, USA

Introduction

Relevance of Sustainability

The topic of biological sustainability has been covered comprehensively by Morse (2010). In this review, the author contends that sustainability is more of a human centric term concerned with the survival of *Homo sapiens*. The origin of life by most accounts dates back some 3.5 billion years, to within just a billion years of Earth's own coming into existence. Living organisms evolved in many different forms and shapes (commonly referred to as species) to have multiple options of survival available for the various changes Earth may undergo over time. Sure enough, climate change is built into nature, yearly rotation with the change of season, occasional changes resulting from ocean current temperature variations, and drastic changes from gradual buildup or abrupt geological behavior such as ice age, volcanic eruptions, etc. At the same time, change through evolution is built into the constitution of living organisms, this continuous process is commonly known as mutation. Endowed with this gift of adaptability, living organisms have learned to flourish when the environmental conditions are optimal, sustain themselves when conditions become limiting, and survive when conditions turn harsh. Indeed, numerous species have disappeared in the course of time, but on the other hand, new resilient species have emerged. Sepkoski (2002) has developed a compendium of fossil marine genera, which is helpful in understanding the historical course of generation and extinction of marine species. There have been several periods of mass species extinction, one most noteworthy being Permian–Triassic event (about 250 million years ago) that killed up to 96% of marine species (Raup and Sepkoski, 1982; Rohde and Muller, 2005). As a matter of fact, though it has been stipulated that the extinction rate of living species has hovered around 99%, planet Earth remains the flourishing habitat of life. Reassuringly, there also appears to be an increase in the number of marine genera in the past 500 million years (Morse, 2010). Thus, it can be safely concluded that life has evolved a large window of survivability from catastrophic climatic events by continually transforming itself to adjust to widely different surroundings.

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Human beings are only one among approximately 8.7 million eukaryotes inhabiting Earth. So, in nature's scheme of things, human extinction would be a mere footnote in its long history of evolution. However, for human beings, the subject of survival of *H. sapiens* is personal and of paramount importance. Creativity and innovation has been the hallmark of human existence. This human capability was first evidenced in the change from hunter/gatherer lifestyles with the constant search for food and water to being settled at a reliable water source and practicing agriculture for year-round reliable supply of food. The constant modernization since that period has brought us where mankind is today. Inventing preventions against diseases and developing shelters that provided safety from the vagaries of weather have drastically improved chances of human beings to live through the kinds of nature's episodes that resulted in the extinction of other species. These efforts have also cut the rate of mortality resulting in an exponential human population growth giving the species a better chance of being left with enough residual stock to repopulate in the event of a catastrophe. Human beings were cognizant of the fact that they were able to achieve all these feats due to their unique ability to exploit the earth to their benefit. All these successes, however, made mankind overconfident and led to the development of the notion that it was immune to nature's consequences and has the inalienable right to use Earth's resources at pleasure. However, the apparent gap between resource demand and resource availability became obvious to the wise centuries ago, and voices of concern have been raised intermittently for generations. More recently, it has become very clear that what many people and nations consider development, if not carried out more thoughtfully and better planned, will ultimately wipe out the very essential resources that man had taken for granted and the consequences could be calamitous. The book *Population Bomb* (Ehrlich, 1968), the United Nations Conference on the Human Environment (UNCHE) (UNEP, 1972), World Commission on Environment and Development (WCED) (United Nations General Assembly, 1987) (also known as the Brundtland Commission after its chairman), from which the definition for sustainable development was derived, and several subsequent worldwide forums are manifestations of concerns regarding resource availability and resource consumption. Sustainable development was defined by the WCED as "the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Thus, parity in the right of the present and future generations in sharing the earth's resources was brought to clear focus. The details of the report also emphasized the importance of sharing the resources so that the poor of the world are not left behind. Thus was born the current version of the term "sustainability," which imbibes the theme of the survival and the perpetuation of high quality of life for all mankind of the present and future generations inhabiting different regions of planet Earth. The domain of sustainability born out of the environmental concern, thus, was expanded to incorporate the ingredients of sharing and social justice. Part of the reason for this change was the realization that the environment had no boundaries and all mankind must partake in its preservation, but this was only feasible if material benefits provided by resource exploitation were shared.

Sustainable Agriculture—Definition and Description

Agriculture is at the forefront of any sustainable development deliberation. This is because mankind exploits the earth most for agriculture than for any other enterprise. Agriculture, on the one hand, has the potential to provide many essentials of human life in perpetuity if harnessed appropriately, but on the other hand, if proper precautions are not exercised, can lead to the destruction of the very resources on which mankind desperately depends for survival and lifestyle support.

Many definitions of sustainable agriculture are available in the literature. The following are samples:

Allen *et al*. (1991): A sustainable agriculture is one that equitably balances concerns of environmental soundness, economic viability, and social justice among all sectors of society.

Lehman *et al*. (1993): Sustainable agriculture consists of agricultural processes, that is, involving biological activities of growth or reproduction intended to produce crops, which do not undermine our further capacity to successfully practice agriculture.

Yunlong and Smit (1994): Sustainable agriculture refers to the use of resources to produce food and fiber in such a way that the natural resource base is not damaged and that the basic needs of producers and consumers can be met over the long term.

The U.S. Code Title 7, Chapter 64, Subchapter 3103 gives the legal definition of sustainable agriculture for use by the United States Department of Agriculture. It is described as 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 based 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 phrase "sustainable agriculture" is often used in the limited sense to describe agricultural practices that lower input requirement and preserve soil quality while maintaining economic yield. It is not unusual to associate it with organic farming. Singh *et al*. (2005) summarized the intent of sustainable agriculture into four farm-level goals: (1) to make better use of farm-based resources, (2) to minimize the needs of external inputs, (3) to prevent loss and degradation of farm soil and water resources, and (4) to maintain the quality of farm and rural life. The practice of sustainable agriculture requires the knowledge of interactions between soil and crop that result in optimum harvests at minimal economic and environmental cost. The methodologies include precision agriculture, integrated pest management, green manuring, crop residue management, soil carbon and nitrogen cycling, and other prudent farm resource managements. To be clear, sustainable agriculture does not call for going back to the farming practices that forced farmers to subsistence living and urban migration, but on the other hand, to guide them toward the right ways to adopt new agricultural innovations for maximum benefit today and times to come.

This concept of sustainability came into sharp focus during the 1980s. The need to reconsider the strategy of employing highly profitable machinery and chemical inputs at that time arose from the realization that the short-term profitability was being achieved at the expense of long-term continued fitness of the farm to produce crops and generate income on the long term. The turn-over plowing led to soil structural instability and erosion, and excessive chemical use led to pollution of the surrounding and broader environment. In addition, the constant increase in the demand for bigger machinery to plow deeper and more acres and more chemicals to control all kinds of pests rendered farming enterprise unstable, with inputs and their costs continuing to spiral upward, yields fluctuating year to year due to exacting climatic requirements, and increasing losses from pathogens and pests as they became resistant to chemicals. This created the need to develop a strategy whose aim, simply put, was to make sure that the gains made in the agricultural productivity are preserved in perpetuity. This can only happen if the soil and water resources are prudently used and rejuvenated and the soundness of farm ecology is maintained. Thus, while sustainable farmers continue to use tractors, they use new plows that disturb the soil to a minimum, thereby preventing erosion. The emphasis on the control of weeds, insects, and diseases on crop plants remains unchanged; however, new methods consist of a combination of chemicals, pest–predator control, crop rotation, and increased plant resistance, and other innovative means to prevent a toxic combination of soil, water, and crop. Farmers continue supplementing nutrients to increase the crop yield, but they use not only chemical fertilizers, but also rely on leguminous nitrogen fixation, increased availability of bound soil nutrients through enhanced microbial activity, etc. Sustainable agriculture, thus, is not a movement against industrialized agriculture, but one for an economically and environmentally viable option.

Relevance of Sustainability to Agriculture through Time

Awareness to sustainable agriculture has been shaped by the wisdom of generations starting from prehistoric times to the present, born out of experience and events of centuries. "He who plants even one tree, goes directly to Heaven and obtains *Moksha* (salvation)" (*Matsya Purana*, 59.159; period unknown, prehistoric) proclaims ancient Hindu scripture. The cutting of trees and destruction of flora were considered sinful acts. The Indian thinker Kautilya's *Arthashastra* (Aristotle's period; ~300–400 BC) prescribed various punishments for destroying trees and plants. Rapid agricultural expansion in different societies were accompanied by environmental problems. While Watson (1974, 1983) describes the "Arab Agricultural Revolution" as part of the Islamic Golden Age between the eighth and thirteenth centuries, Gari (2002) has accounted the concern expressed by several environmentalists of the period of the pollution of air, water, and soil that this revolution created as a result of wrong agricultural practices.

In the near-term historical context, the "Dust Bowl" period in American agriculture serves as a reminder to the detriment of unsustainable practices on agriculture itself, and to the environment at large. With the newly introduced farm tractors mounted with moldboard plows, farmers developed the notion that more and deeper plowing translated into better yields. They did not realize that they were endangering the most precious commodity on the farm—the soil itself. Drought is a part of nature's weather cycle and the American Great Plains went through it during the 1930s. The dry winds over the barren fields with loose soil created storm clouds stretching hundreds of miles. The dust clouds created severe health hazards and disrupted normal daily life stretching across all Great Plain States and reaching as far as the nation's capital. On Sunday, April 14, 1935, the dust cloud was so dense that the day has been remembered as Black Sunday and the whole region was referred to as "Dust Bowl" (Figure 1.1). It was estimated that 100 million acres of farm top soil were lost to the wind. This led to the passing of soil conservation legislation and the adoption of better soil management practices.

The environmental movement of the 1950s and 1960s in the United States brought to focus the need of constant vigilance to ward disaster from the well-intentioned introduction of new practices or inputs to the agricultural systems. *Silent Spring* (Carson, 1962) was a wake-up call to the increased use of pesticides, especially DDT (1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane) post–World War II in agriculture. These pesticides were effective against crop pests, but their lethality was not targeted and DDT in particular was identified as causing

Figure 1.1. Abandoned farmstead in the "Dust Bowl" region of Oklahoma, showing the effects of wind erosion, 1937. *Source*: USDA (1937).

the thinning of bird eggs and their failure to hatch; thus the book's title was chosen to bring to attention the ultimate consequence of DDT, namely the silencing of spring because of the absence of birds. These efforts hastened the research in the development of targeted chemicals for use in agriculture and the institution of a ban on DDT in the United States at the end of 1972.

A new reminder that constant vigilance is essential to maintain the delicate balance between the agriculture and nature comes from the current near-extinction status of vultures (the Great Indian Bustard) in India. Diclofenac (2-(2,6-dichloranilino) phenylacetic acid) is an anti-inflammatory drug that was commonly prescribed to cattle before its ban for veterinary use in 2006. The vultures feeding on the carcass of recently treated dead cattle were lethally poisoned because the prescribed doses based on cattle body weights were exceptionally high for their system. Vultures have a special significance in the life chain in India, where they serve sanitary function, feeding not only on dead animals, but also on the human corpses belonging to the nature-conservationist religious group of Zoroastrians, who leave them at silent towers to be consumed by vultures and crows, who they believe were created for that purpose. The interaction of agriculture and environment is dynamic, multifaceted, and complex, and at the same time fragile, calling for constant vigilance and innovations to modify practices to fit the unique situations.

Biofuel and Biofuel Crops

Biofuel is an abbreviation for biomass fuel. Therefore, in the broad sense of the term, fossil fuels are also biofuels. Autotrophs convert a fraction of the sun's energy into the chemical energy that is held within complex organic matters. This chemical energy has two ultimate fates: much of it is eventually released (mostly as heat) while the remainder is locked within carbon-rich deposits (coal, oil, and gas). Biofuels differ from all other renewable energy sources in their unique characteristic of possessing the ability to substitute not only energy but also all fossil-fuel-based products. There are two main differences between biofuels and fossil fuels: (1) biofuel is a fuel produced from currently harvested biomass while fossil fuel was formed from biomass produced long ago and (2) biomass conversion to biofuel is in a timeframe of just a number of days while conversion to fossil fuel required millions of years. Essentially then, it is the rate of conversion that separates two similar origin fuels, one into renewable and the other into nonrenewable category.

Biofuels are currently derived from both direct and indirect biomass (animal raised on biomass) sources. The current sources of biomass are rather limited confined to selected field and tree crops, animal fat, and biological residues and wastes. However, for a futuristic outlook, the list is expansive, the geographical area for procurement vast, and may even include biomass generated from here to practically unfeasible processes like artificial photosynthesis. Odum (1971) lists the array of primary productivity (g m^{-2} yr^{-1}) of different ecosystems worldwide: deserts—3, cultivated lands—650, grasslands—600, moist forest—1290, estuaries and coral reefs—2000, continental shelf waters—350, and deep ocean—125. Although many years have passed since the quoting of these numbers by Odum, these have changed little since. The difference in the primary productivity is striking, but the reasons behind them are well understood. Deserts lack water, and continental shelf and deep-water oceans lack nutrients to support phytoplankton (Morse, 2010). Those falling in the in-between range are arranged in the order of climatic and resource optima of their ecosystems.

Many opportunities exist for creative rearrangement of ecosystems to create new optimal growth environments. Many of the vast deserts lie next to oceans, the largest water reservoir. In one scenario, algal ponds can be developed in deserts where there is plenty of sunshine and unlimited supply of water from the sea to grow salt-tolerant algal strains; otherwise these ponds can be placed in the sea itself. It is also within the realm of possibility to change the genetic makeup of selected plant species so that they can produce optimal amounts of biomass utilizing high-salt waters. Seeding of the ocean with limiting nutrients has been suggested as a means to provide suitable medium for optimal phytoplankton growth. A number of attempts have been made for seeding of the oceans with iron (Boyd, 2007), but the effectiveness of such techniques as well as their broad effects on ocean ecosystem have been much debated (Buesseler *et al*., 2008). However, if such endeavors eventually bear fruit as a result of science and technology succeeding in creating localized phytoplankton-based ocean ecosystems, the harvests of biomass could be enormous. Some of this phytoplankton biomass may be source for biofuel feedstock. It would also lead to exponential increases in the ocean CO_2 sequestration as well as in yields of marine-based meats. The exchange of a meat-based diet with a seafood-based diet will not only be a healthy food option for consumers but will also release grasslands currently used for raising animals. Such land could then be put into producing grass-based biofuel feedstocks.

Fossil Fuel versus Biofuel

The market accepts higher prices for gasoline and diesel compared to electricity because of their unique adaptation as fuels for transportation energy. Drivers like the comfort of being able to travel for hundreds of miles after filling the tank, the presence of widespread infrastructure for refill, and the convenience of spending just a few minutes to complete the refilling process. For biofuels to compete with entrenched transportation fossil fuels, they not only need competitive pricing, but also the ability to fit into the same infrastructure built for gasoline and diesel and give out the energy output per unit volume similar to the fossil fuel so that drivers do not miss the comfort of long drives before refills. Rapid advances in research and technology have been made in recent years and proponents believe that it is just a matter of time before biofuels will be able to compete with fossil fuels on all counts. Perception is another factor favoring fossil fuel with which biofuels have to contend. Consumers do not shift from a reliable commodity that is time tested and to which they have become accustomed to another commodity new to the market, without being convinced of added benefits. In the case of biofuels, the advantage is touted in the forms of reduction of greenhouse gases (GHGs), freedom from the unreliable foreign sources of supply and distortion of price by oil cartel countries, improvement in the balance of payment and trade deficit, creation of hundreds of thousands of new jobs in rural communities, and decentralization of transportation industry. However, there is a vocal opposition that is not convinced of the environmental benefit of biofuel. This group is concerned that biofuel is detrimental to the poor because it competes for food grain, raising prices and vying for land used for producing grain, leading to food shortage. While a certain group of farmers have benefitted from the legislation-regulated biofuel boom, the farming community at large has yet to be brought on board to the enterprise by providing assured outlet at profitable prices for feedstock produced on the farm. Thus, biofuel as transportation fuel at this time can be best compared to a toddler growing into a healthy adult—whether it will grow into a mature vehicular energy source depends upon numerous conditionality, and unpredictable. However, considering the growing consciousness of the negatives attached to fossil fuel and biofuels' potential for providing the comparable substitute commodity, the current push for biofuels appear appropriate and support for research and development warranted, so that the full extent of their capability to substitute fossil fuels can be ascertained and a reasonable timeframe for achieving this potential can be set.

Biofuel Sustainability Concept

The International Energy Agency (IEA, 2011) has separated sustainability into three main categories—social, environmental, and economic—and listed indicators to aid in their evaluation (Figure 1.2).

Among social components, employment has been one of the main forces behind biofuel push at different times. Land issues will become an important factor as the biofuel industry expands and demand for volume of feedstock grows, needing large acreage. Integration of limited-resource farmers into biofuel feedstock production will be critical, especially in developing

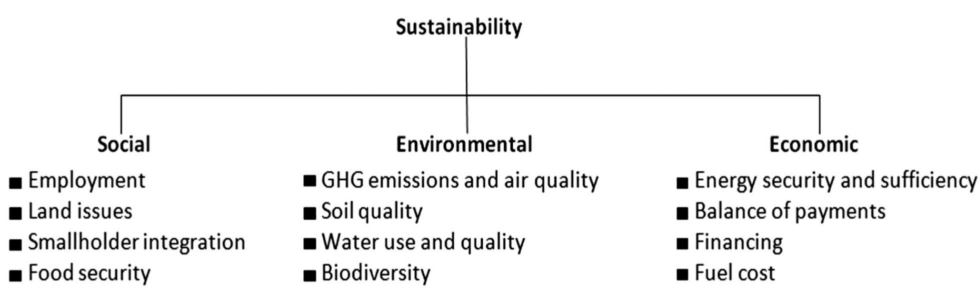

Figure 1.2. Biofuel sustainability framework. *Source*: IEA (2011).

countries dominated by small landholders. The food versus fuel debate intensified as demand of maize for ethanol drew outcry worldwide. However, the concern has been noted and there is a shift underway toward nonfood perennial crops for feedstock use but the transition will take time. In addition, to ensure that the acreage under food crops does not shrink under competition from biofuel crops, marginal lands have been targeted for future biofuel crop production, leaving aside fertile soils for food crops.

The role of plants in GHG remediation has been known for a very long time. Concerns regarding global warming caused by the burning of fossil fuels has led to the intensification of the search for nonpolluting energy sources. In this context, the historical knowledge that ethanol and plant oils can be used in place of petrol and diesel to run automobiles was the obvious reason for biofuels to come into focus. The octane-boosting property has already made biofuels a commonly found additive in gasoline. However, not all environmentalists are convinced of the GHG remediation abilities of biofuels and life-cycle analyses of different biofuel feedstock crops are in progress to determine crop-specific remediation value. Low-input systems, especially of fertilizers that are emitters of substantial GHG (carbon dioxide) during synthesis and field application (nitrous oxide) are being designed and emphasis is on crops that are perennial in nature. Perennial crops should be more efficient in nutrient recycling and threat of erosion from yearly cultivation for planting would be avoided. Perennials catch nutrient runoff to surrounding surface water and their deep root systems act as control against nutrient leaching. Alarm has been raised in recent years at the rapid rate of destruction of tropical forests, mostly in Southeast Asia. These forests harbor great diversity of flora and fauna among them, with some species designated endangered. However, the blame for forest destruction rests first on logging for timber, followed by new plantations for oil palm to meet world market demand for cooking oil. Burgeoning populations in developing countries, where most of these forests are situated, adds to the pressure from a number of new people looking for farming land. No doubt initial zeal for biofuel crop production under incentives led to some deforestation, but fortunately, many regulations and certifications have been recently put in place to safeguard against the encroachment upon virgin land that created threat to biodiversity.

Economic sustainability for biofuel industry is going to be challenging. The United States, Brazil, and European Union together with several developing countries have set definitive goals for biofuel. However to this date, price supports, incentives, import restrictions, mandates, or a combination of these have been needed to keep the biofuel industry going. Biofuels have just not been able to compete with fossil fuel on their own. Even when they manage to find a foothold in the high petroleum price environment, they will be at the mercy of the Organization of the Petroleum Exporting Countries (OPEC), which possesses the ability to flood the market at will and drive out competition, as their cost of production is extremely low. Energy security and sufficiency concerns have been raised by importing nations repeatedly at the time of high prices, but as soon as prices become affordable, these concerns evaporate. Balance of payment in trade due to the petroleum import burden is a perpetual problem for a large number of countries, but deficit financing has become the norm with their governments, notwithstanding long-term consequences of such a policy. Financing of infrastructure for biofuel is problematic, because financial institutions do not want to take risks without a definite rate of return model to guarantee the payback. Thus, industries have been greatly dependent on governmental guarantee or assurance of price support through of mandates, etc. It is hoped that with time biofuel competitiveness with petroleum fuel will improve as a result of greater efficiency in feedstock production, higher yield, engineering advancement in post-harvest processing, and development of biofuels with drop-in ability.

Biofuel Sustainability—USA as Case Study

Sustained Rural Economy Impetus for Biofuel

Plant-based fuel was envisioned to be an important source of energy to drive automobiles when they were invented. Henry Ford's first automobile prototype in 1896 ran on ethanol. Ford Motor Company in 1908 released Model T which could run on gasoline, ethanol, or a mixture of the two. Rudolf Diesel ran his diesel engine on seed oil. The agrarian segment thus came to assume that while their participation in the old transportation industry ceased when horse drawn carriages were replaced with automobiles, they would participate in the new transportation industry by supplying fuel to run automobiles. In the United States, the alcohol tax levied on ethanol during the civil war period was lifted in 1906 with the help of President Theodore Roosevelt to make it affordable for use as fuel. In the beginning, gas stations were rare in rural America and many farmers made their own low-cost ethanol to run vehicles. World War I (1914–1918) saw a surge in the production of industrial alcohol reaching 50–60 million gallons yr^{-1}. The infamy of ethanol as a vice crippled its use for any other purpose when the eighteenth amendment to the US Constitution prohibited the manufacture, sale, or transport of alcohol beginning in 1920. The use of alcohol for fuel was still legal but had to be mixed with gasoline to prevent its use for drinking. Since the use of ethanol was more prevalent in rural areas and distillation was carried out on individual farms, it was very difficult to establish lawful purpose; thus, prohibition essentially ended the first era of ethanol-driven cars in the United States. Cheap and plentiful petroleum dominated the fuel for transportation vehicles through the twentieth century. However, rural Americans had not given up on their re-entry into transportation fuel market and farm state legislators continued in their attempts to pass legislation to help bring back biofuel. Their quest became urgent as the need to find alternative income sources in rural communities became essential to arrest the tide of emptying rural communities and constant addition to ghost townships starting in 1960s. Farmers lost farms at alarming rate due to depressed commodity prices. Globalization had lowered their ability to pass on added expenses while at the same time prices of external inputs like fuel, fertilizer, and labor., kept escalating.

Opportunity for the re-entry of biofuel into transportation arena arrived with the 1973 Arab Oil embargo. The petroleum crisis created by the embargo drew the world's attention to finding alternatives to petroleum. Brazil took the lead in deploying ethanol for running vehicles and remains the only country that produces cars that run on ethanol and filling stations with ethanol since the late 1970s.

Jimmy Carter was the President of the United States at the time of oil embargo. He came from a rural state and a rural community, with the first-hand knowledge of the suffering on the farms and surrounding communities. He was receptive to the proposition of easing the demand for import by boosting the oil inventory by adding ethanol. With the help of farm-state Senators, Congress passed legislation providing subsidy to ethanol produced for this purpose. Blenders mixed 10% ethanol with the gasoline and received a 50 cent tax break for every gallon of ethanol. Farmers also benefitted from government subsidy. The ethanol industry was shielded against competition from countries like Brazil through high tariffs. However, as energy crisis of 1970s eased, incentive to invest in alternative energy sources ebbed but ethanol remained the only holdover from the 1970s energy crunch, saved by the legislation to oxygenate gasoline to reduce pollution.

The Clean Air Act Amendments (CAA) of 1990 was the first environmental policy benefitting renewable fuels. It established the Oxygenated Fuels Program and the Reformulated

Gasoline Program in order to control levels of carbon monoxide and ozone in the air. Fuels under both programs were required to contain 2% oxygen. Since ethanol is 35% oxygen, blending ethanol to gasoline became popular to meet the mandated oxygen requirement under CAA. The Energy Policy act of 2005 eliminated the 2% oxygen requirement for reformulated gasoline and replaced it with a credit trading system. The new provision gave suppliers flexibility to add less renewable fuel to gasoline than required by the CAA by purchasing credits from suppliers who supplemented gasoline with more biofuel than required.

The new push for ethanol came under the administration of President George W. Bush (from Texas, a rural state). Congress passed the Energy Policy Act in 2005, which set a minimum requirement for ethanol use for automotive fuel, followed by another piece of legislation in 2007 that raised the threshold ethanol volume requirement sharply. The 2007 legislation mandated the use of 1.3 million barrels a day of ethanol by 2015 and 2.4 million barrels a day by 2022. To put this in perspective, the United States consumed 8.9 million barrels/day of gasoline for transportation in 2009.

United States Environmental Protection Agency (EPA) promulgated low sulfur diesel fuel standards for highway vehicles beginning July 2006 and nonroad vehicles beginning June 2010. Lowering sulfur in diesel also lowers its lubricity, the restoration of which is essential for full fuel efficiency. Biodiesel is an excellent lubricant and adding only 1–2% to the ultra-low-sulfur biodiesel is needed to restore the full lubricity. Lubricity additive could turn out to be a substantial market for biodiesel.

In summary, the credit for existence of current US biofuel industry belongs to legislations that provided incentives, mandates, and compliance requirements to promote biofuel production and use. The Energy Tax Act of 1978, the Energy Policy Act of 2005, and the Energy Independence and Security Act of 2007 (EISA) are landmark legislations affecting biofuels. Two US Presidents, Jimmy Carter and George W. Bush piloted landmark biofuel bills and signed them into law. Biofuels legislation passed by the US Congress is no different from any other legislation introduced and passed, in that those too had the impetus of lobbying, which in this case was from farming groups and driven by the desire of legislators from the farming states to their constituents' welfare. However, frequent oil crises and a desire for secure domestic supply of this essential commodity, together with the perception of environmental benefit from adding biofuel to gasoline or shifting to biofuel in a major way, have been motivation behind broader support for these energy bills.

Legislative Support and Guided Movement toward Sustainability

In early attempts to jump-start the biofuel industry, obviously, the known and proven methods of its production were adopted. We had the knowledge in producing grain crops and possessed experience of converting grain to alcohol. Similarly, oil from seed crops had been in use for centuries for burning to produce light. The food crops had been improved genetically through history for higher yield and better resistance to pests, and their method of cultivation have been continually advanced to optimize growth. Thus, when occasion arose for an expeditious increase in biofuel production, food crops were the only feedstock resource that was amply available and had a well-established supply chain. Maize was the crop of choice in the United States, because it has proven to yield highest among grain crops and already been used extensively for industrial purposes. Moreover, maize desperately needed another outlet to bring it out of the price doldrums. On the other hand, Brazil opted for sugarcane, because it has long been mainstay of its economy.

The recent bioenergy-related legislations in the United States and elsewhere show continued legislative support for biofuel, but they now come with stipulations to prevent its excessive intrusion into food crops and require measurable proof of benefits to the environment. The US Energy Policy Act of 2005, for the first time, set a renewable fuel standard (RFS) for automotive fuels. Under its provisions, fuel suppliers must blend 4 billion gallons of renewable fuel into gasoline in 2006, increasing annually to reach 7.5 billion gallons in 2012. The EPA was required to set minimum ratio for renewable content after that period not to be less than the ratio in 2012. The Act also contained a provision to encourage the production of cellulosic ethanol, which stated that every gallon of ethanol produced from biomass equaled to 2.5 gal toward satisfying the RFS. The Energy Independence and Security Act of 2007 further expanded the RFS previously set by the Energy Policy Act. The new RFS started at 9 billion gallons in 2008 rising to 36 billion gallons in 2022. Beginning 2016, all the new increases in RFS target will have to be met with advanced biofuels derived from sources other than maize starch, with explicit allocations for cellulosic biofuels and biomass-based diesel. Under this mandate of the total 36 billion gallons, 21 billion gallons will have to be obtained from cellulosic ethanol and advanced biofuels. Although the two legislations did not provide direct loans or grants for the construction of biofuel plants, provisions for market guarantee ensured growth of the biofuel industry. The laws clearly were intended to serve as a bridge to transit maize-based ethanol into the next-generation technologies.

The Energy Independence and Security Act of 2007 directed EPA to develop time-based mandate for different categories of biofuel under the law (RFS2). It applied to all refiners, blenders, and importers of transportation fuel. Both domestically produced and imported biofuel were covered under the regulation. It also provided legal definition for renewable fuels and renewable biomass. Biofuels were separated into four categories on the demonstrated minimum GHG reduction standards in comparison to the petroleum fuel they replaced and verified by life-cycle assessment. The EISA emission computation is very stringent and it must include direct emissions during the entire fuel cycle from feedstock production, distribution, and final use by consumer as well as emissions from land-use change.

EPA used models to assign feedstocks and processes of production into different GHG emission threshold categories (Table 1.1).

The definition of renewable biomass includes planted crops and crop residue, planted trees and tree residue, animal wastes, algae, and yard and food wastes. To ensure that no virgin land is brought under cultivation for biofuel, planted crops and crop residue are permitted only from agricultural land that was cleared or cultivated prior to December 19, 2007, and actively managed or fallow, and nonforested. The cropland, pastureland, and USDA Conservation Reserve Program (CRP) land qualify under the definition but not rangeland, federal land, or other rural land. Similarly, only tree plantations existing on nonfederal or tribal land prior to December 19, 2007 qualified for biofuel certification. Biomass from slash and pre-commercial thinnings

Table 1.1. Classification of biofuels into different categories based on GHG emission.

Feedstock and process	GHG emission category (%)
Ethanol from maize starch at new natural gas fired facility	20
Butanol from maize starch	20
Ethanol from sugarcane	50
Diesel from soy oil, waste oils, fats, and greases	50
Diesel from algal oil	50
Cellulose ethanol	60

are only permitted from nonecologically sensitive nonfederal and nontribal forestland. The law also puts requirement of record keeping to the parties covered under the mandate. As Raghu *et al*. (2011) put it, "the emerging biofuel economy is likely to result in the single largest reconfiguration of the agricultural landscape since the advent of industrial agriculture," EISA wants to make sure that during such reconfiguration due diligence is exercised to preserve the environment and conserve forests and other natural ecosystems that provide critical services to different sections of population.

According to EPA (2011), the steps taken under EISA to produce 36 billion gallons of biofuel by 2022 will replace 13.6 billion gallons of fossil fuel, approximately 7% of the expected transport fuel consumption at that time. Biofuel replacement will save US$41.5 billion in oil import and result in reduced gasoline and diesel cost by 2.4 and 12.1 cents gal^{-1}, respectively. In addition, it is expected to reduce GHG emission by 138 MT, equivalent to taking about 27 million cars off the road. The farm income is projected to increase by US$13 billion in 2022. However, the negative effect of biofuel will show up in annual increased food cost by US$10 per person.

From the above, it appears clear that the governmental regulations support the rural economy through the biofuel industry, but also wants to make sure that biofuels are produced in sufficient volume to make a noticeable reduction in fossil fuel use, deliver GHG emission reduction, do not encroach upon natural ecosystem and are not in conflict with societal need for food. Another aspect related to biofuel is also apparent by now—that the push for biofuel thus far has needed governmental subsidy or mandate to support all levels of supply chain. From all indications, biofuel is not yet ready for open market competition.

Certain projections and recommendations have been made to heighten the commercial competitiveness of biofuel. The fossil fuel price is projected to increase in the future, putting biofuel in a better position to compete. It is to be remembered that one of the important reasons behind the economic pricing of fossil fuel is that fracturing allowed multiple product application of the feedstock and generation of valuable by-products. With the continuing improvement in biofuel technology, the possibility of valuable by-products to support lower biofuel price may be feasible. The search continues for microorganisms and enzymes that break down biomass into sugars as platform chemicals for a host of processes, biofuel being one of them. Laser *et al*. (2009) have provided a model-based analysis of the cost of production of biorefineries when they will be fully developed similar to today's petroleum refineries. They considered the two emerging processing approaches—biological and thermochemical—for the production of fuels, power, and/or animal protein. According to their calculation, the cost of production amounted to US$0.36–US$0.57 l^{-1} (US$1.37–US$2.16 gal^{-1}) petrol equivalent for a plant with the capacity of 4535 dry tonne feedstock/day, considering 12% internal rate of return, 35% debt fraction, and 7% loan rate. However, when the biological production of ethanol was combined with thermochemical production of fuels and/or power at the same scale and financial structure, cost came down to US$0.25–US$0.33 l^{-1} (US$0.96–US$1.24 gal^{-1}) petrol equivalent.

Biofuel Sustainability Outlook

Economic Value

Singh (2010) has discussed the importance of industrial outlets for farm produce in order to maintain long-term viable farm economy. Rural communities throughout the world heavily reliant on income generated from farming have been suffering from poor economies. Setting aside recent increases in grain price, the farm commodity prices have been stagnant for a long time. For example, the price of soybean has hardly changed between 1981 and 2005 from US\$208 tonne^{-1} in 1981 to US\$223 tonne^{-1} in 2005. As a consequence of price stagnation, the total cost of producing a hectare of soybean for American farmers in 2005 was US\$663 against the gross value of US\$654 of the harvest (SoyStats, 2007). Creating multiple outlets for currently produced crops or finding alternate crops with market demand will generate new income for farmers. Diversification of enterprises will also give farmers the ability to switch between markets that bring the best prices for the produce and select enterprises requiring fewer inputs in years of adverse climatic conditions. Some of the cellulosic biofuel crops can be grown on marginal land that is generating little or no income at present, thus opening new avenue for increasing farm output.

The effect of market squeeze has been devastating for developing countries. While agriculture provides less than 2% of income and employment in developed countries, it happens to be the source of 35% of the gross domestic product of the less developed economies (Watkins and von Braun, 2003). Poor countries are not able to protect the livelihood of their farmers in globalized markets because they are bound by international laws or prevented through treaties. A good example of this is NAFTA (North American Free Trade Agreement), a trilateral treaty between the United States, Canada, and Mexico. It lowered maize price in Mexico to the level that subsistence farmers were forced out of the only livelihood they had known for generations and many were compelled to migrate to urban centers and into the United States in search of livelihood. Greater industrial demand for biofuel crops will increase their production in the poor countries, benefitting subsistence farmers and improving their standard of living.

The biofuel industry as a whole should be good for rural employment. This transportation fuel source is the only one among energy providers that permit rural population to participate in the generation end of the enterprise and not only as consumers. Biomass needed for biofuel is produced by agriculture and forestry located in rural areas and because of their bulkiness, it is economical for biofuel refineries to locate in proximity of feedstock source in rural communities rather than close to cities. Thus, rural job growth because of biofuel industry should spread across the spectrum from growing, harvesting, storage, and transportation of feedstock to employment in the biorefinery. Shumaker *et al*. (2006) found that construction of a 375 million liter maize-based ethanol plant in Georgia, the United States created a one-time economic output impact of US\$130 million to the state economy. Economic activity related to construction generated US\$51.7 million in labor income for 1203 jobs. Production of ethanol created annual economic output impacts of US\$335.8 million. Plant operations accounted for 50.2% of the total output impact, while 49.8% was attributed to maize produced in Georgia. Ethanol production generated US\$37.6 million in labor income from 1030 jobs to the Georgia economy. It also contributed US\$3.8 million and US\$3.1 million in taxes to the state and local governments, respectively. The following statistics compiled by Worldwatch Institute (2007) shows the value of biofuels to job creation: (i) biofuel industries require about 100 times more workers per joule of energy produced than petroleum industries; (ii) in Germany, the biodiesel industry generates roughly 50 times more jobs per tonne of raw oil than similar amount of diesel; (iii) job creation cost in Brazil is 25 times less for the ethanol industry than in the petroleum industry; (iv) in sub-Saharan Africa, a region-wide blend of biofuels to the tune of 10% for gasoline and 5% for diesel would provide job to between 700 000 and 1.1 million people; and (v) Jatropha farms in India could yield 313 person-days per hectare in the first year of the plantation and 50 person-days per hectare over the next 30–40 years.

Crop residues are projected to be an important component of cellulosic feedstock mix. At present, they are mostly treated as crop waste. Thus, this new use of farm produce heretofore of no economic value will add to the income earned by farmers from raising crops. However, it may not have much scope for creating new employment as existing farm personnel can accommodate this task by rearranging the scheduling of different operations on the farm. On the other hand, farmers may find it difficult to manage both harvesting of grains and residues within the weather window, and may prefer to give this task to a dedicated outfit in residue collection and delivery, thereby providing business opportunities to a new group of entrepreneurs.

Several tropical countries may turn out to be good source for feedstock and refined biofuel because of their climatic advantage in growing a number of high-biomass-accumulating crops. As most countries in this region fall under developing category based on their economic conditions, feedstock and refined biofuel could become important commodities for export enabling them to earn valuable foreign currency for essential imports. This would also help them in strengthening infrastructure needed for economic development and providing job opportunities to their rural population. Furthermore, it would cut down the costly fossil fuel imports as they substitute it in part by biofuel. Several biofuel refinery processes such as ethanol from sweet sorghum and pre-refinery feedstock preparation will provide opportunities to small entrepreneurs and refinery constructions will bring new investments. In the final analysis, biofuel export–import trade will stimulate economic activity in both developing and developed countries.

The biofuel feedstock market is mandate- and incentive–driven, and is expected to show stable growth because of the commitment by different governments. OECD/FAO (2011) predicts continued increase in the ethanol and biodiesel demand and reach 155 billion liters and 42 billion liters, respectively, by 2020. Also, biofuel prices to major biofuel feedstock prices should remain stable and biofuel prices on average 80% higher from the previous decade in the case of ethanol and 45% in the case of biodiesel.

Energy

According to the US Energy Information Administration statistics (EIA, 2007) demand for liquid fuels will increase to 118 million barrels/day by 2030. Most of this oil will come from the Middle East-controlled OPEC cartel. This monopolistic situation permits price manipulation outside of the free market, thereby creating risk to energy security of the importing countries. The sustained high price trend of recent years has been especially hard to the poor countries and has severely depleted their already scarce foreign exchange reserves. The situation clearly calls for alternative energy options and remedial strategies. Biofuels appear to be the best present alternative before other transportation sources such as hydrogen and electricity come on board.

There has been constant increase in global biofuel production, growing from 16 billion liters in 2000 to more than 100 billion liters (volumetric) in 2010 (IEA, 2011). Biofuels currently account for approximately 3% of total road transport fuel (on an energy basis). It is projected to increase to 9% by 2030 and to 27% of world transport fuel energy by 2050 (Figure 1.3). Most of the growth in biofuel use will occur in the United States, Europe, China, and Brazil (IEA, 2010).

Environment

Environmental Protection Energy (2011) estimates that emission from a gallon of gasoline and diesel amounts to 8887 g CO_2 gal^{-1} (gasoline factor is based on a recent regulation establishing GHG standards for model year 2012–2016 vehicles (75 FR 25324, May 7, 2010)