Opportunities and Challenges of Biofuels as Renewable Energy: A Literature Review

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Abstract

As a renewable energy source, the use of biofuels can play an important role in tackling climate change and mitigating global warming. While biofuels present a promising, sustainable alternative to traditional fossil fuels, their production in the U.S. faces significant social, environmental, and economic challenges. This study examined existing research studies and publications and summarized the opportunities and challenges currently faced by biofuel production in the U.S. from three perspectives: social, environmental, and economic. Despite the many benefits of biofuels, major limitations include food shortages, high cost of production, and greenhouse gas emissions during the process. To address these disadvantages, an alternative approach is proposed, which involves growing algae-based biofuels from wastewater, genetically modified crops, integrated pest and weed management, as well as the potential use of food waste for biofuel production and biopesticides.

Introduction

Biofuels refer to liquid, solid, or gaseous fuel produced by the conversion of biomass such as bioethanol from sugar cane or corn, charcoal or wood chips, and biogas from anaerobic decomposition of wastes (Alam & Tanveer, 2020). Biofuels are made by combining the biomass of plants or other organic matter and conventional gasoline or diesel. Biomass is any organic matter — including plant matter, vegetable oil, and animal fat — that can be converted into fat. Since the amount of fossil fuels used is reduced in this process, the resulting mixture burns more cleanly (Carlisle & Runge, 2023). The two major types of biofuels are bioethanol and biodiesel, also known as first-generation biofuels. Bioethanol is an alcohol produced from the fermentation of sugars and starch from crops; Biodiesel consists of mainly fatty acids and is manufactured from vegetable oil and animal fat.

The demand for biofuels is unquestionably on the rise for reasons of energy efficiency and sustainability, as well as for reducing greenhouse gas emissions. As a renewable energy source, the use of biofuels can play an important role in tackling climate change and mitigating global warming, especially through avoiding dependence on excessive fossil fuels and acting as a cleaner alternative. While biofuels present a promising, sustainable alternative to traditional fossil fuels, their production in the U.S. faces significant social, environmental, and economic challenges. Therefore, it is necessary to find and implement alternative solutions such as algae-based biofuels and genetically modified crops to mitigate harm to ecosystem services and local communities.

This study intends to answer the following questions: What research has been done and what the research findings are regarding (1) the opportunities and challenges currently faced by biofuel production in the U.S. and (2) ways to ensure that biofuel production does not degrade the sustainability of the environment and local communities in the U.S.

Methods

This study conducted a literature review on biofuels as a renewable energy. It examined existing research publications and summarized findings regarding the opportunities and challenges currently faced by biofuel production as well as alternative solutions to address the challenges.

Opportunities and Challenges of Biofuels

Biofuels offer a multitude of advantages that make them a promising alternative to conventional fossil fuels. However, they also have some major limitations. This section summarizes the advantages and disadvantages of biofuels from three perspectives: environmental, social, and economic. Important considerations include economic and energy efficiency, resource availability, environmental effects, and socioeconomic inequality.

What Are the Advantages of Biofuels?

Through an environmental lens, biofuels use renewable energy sources derived from organic materials such as crops, agricultural residues, and waste, making them sustainable and reducing dependency on finite fossil fuel resources. Their production process often involves carbon fixation through photosynthesis, effectively offsetting carbon emissions and mitigating climate change. Compared to fossil fuels, greenhouse gas emissions are reduced by 12% with the production and combustion of ethanol and by 41% with biodiesel (Hill, 2006).

From a social perspective, Biofuels can improve air quality and public health because they exhibit lower emissions of pollutants compared to conventional fuels.

From the economic perspective, the implementation of biofuels can also be used to address the frequent oil supply crisis, with the potential to enhance energy security by diversifying fuel sources and reducing reliance on imported oil. Advancements in biofuel technology continue to increase efficiency and decrease production costs, making them increasingly competitive with traditional fuels. Biodiesel yields 93% more energy than the energy invested in its production which promotes environmental sustainability (Hill, 2006). They also contribute to rural development by providing economic opportunities for farmers and creating jobs in the biofuel industry (Hunsberger, 2014).

What Are the Disadvantages of Biofuels?

Currently, the production and usage of biofuels have many disadvantages. From the environmental perspective, pesticide use when growing biomass leads to aquatic/soil ecotoxicity and human toxicity, since pesticides have toxic compounds (Foong et al., 2022). A study on a cherry tomato plantation showed pesticide use contributed to 58% of human toxicity potential (Guo et al., 2021). Pesticides can harm human health. For example, Aldicarb, a popular insecticide, leads to hormonal disorders/skin diseases; and Alachlor, a popular herbicide, is associated with lung and liver tumors (Sánchez et al., 2020). Also, an increase in ethanol production leads to an increase in cropland cover as well as an increase in emissions (Hertel et al., 2010).

From the social perspective, the increased demand for biofuels leads to a decrease in food crop production due to biofuel crops taking up significant area. The reduction of food crop production due to biofuel cultivation will significantly affect malnourished communities, which will cause greater disproportionality among communities of different socioeconomic statuses as they struggle to meet their basic food needs (Hertel et al., 2010).

From the economic perspective, an increase in biofuel production leads to a decrease in exports of certain crops (those not used for biofuel production) from the US, which results in more cropland conversion in other parts of the world. A 50.15 GL per year increase in ethanol production decreases coarse grain exports from the US by 17% (Hertel et al., 2010). Since more cropland is converted to maize for biofuel production, the yields of other grains in the US drop by 15%, and the yields of oilseeds drop by 12% (Hertel et al., 2010). This creates an increase in price for other crops.

As shown in Figure 1, more crops being used to make biofuels also leads to higher US livestock feed prices and a decrease in consumption of livestock products (Hertel et al., 2010). Higher coarse grain prices cause a 42 percent decrease in maize grain use for feed and an increase in feedstock prices (Hertel et al., 2010). Figures 2 and 3 reflected that trend.

Figure 1. Impact of biofuels on feedstock and livestock price

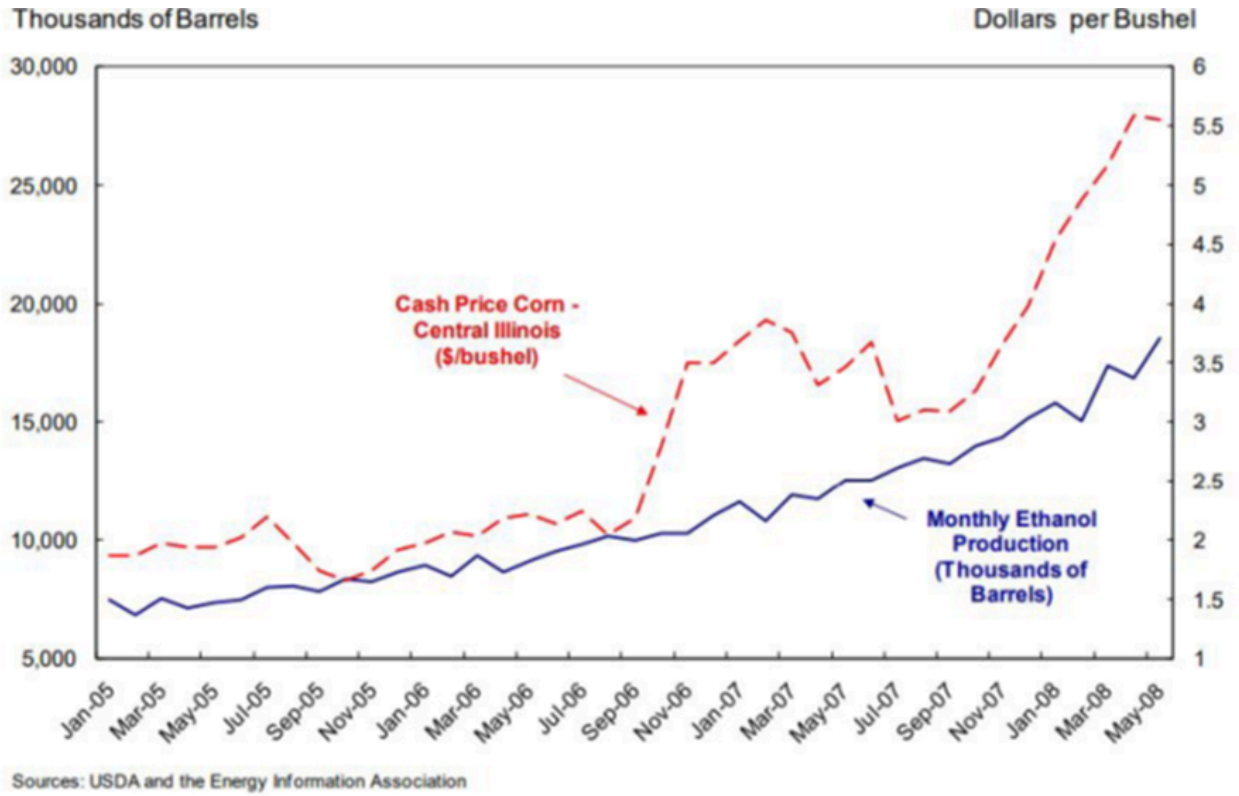

Figure 2. Corn price and US ethanol production, Jan. 2005 – Mar. 2008 (Baier et al., 2009)

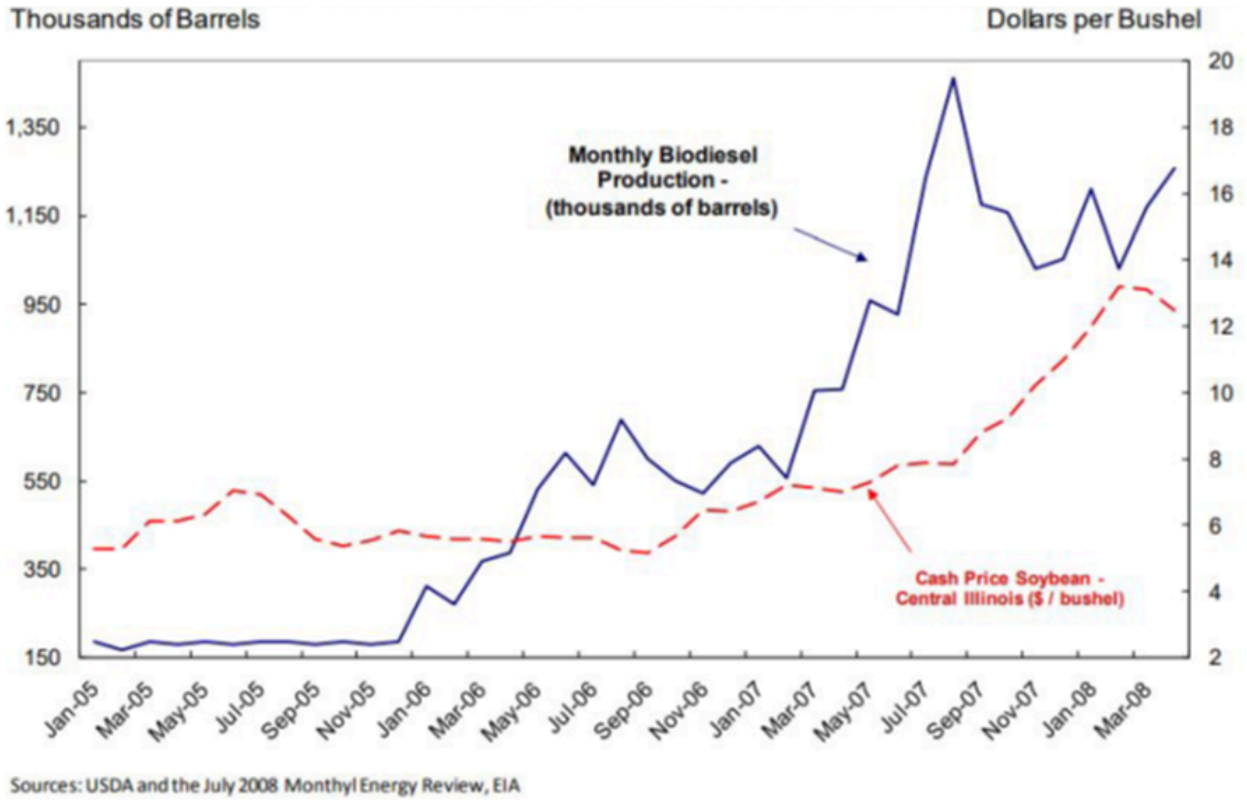

Figure 3. Soybean prices and US biodiesel production, Jan. 2005 – Mar. 2008 (Baier et al., 2009)

Alternative Approaches to Biofuels

Although there are many drawbacks to Biofuel production and use, there are solutions to the disadvantages.

Microalgae can be cultivated in wastewater and used as a raw material for biofuel production. Studies have found microalgae to have higher lipid productivity and energy efficiency while requiring minimal freshwater input (Pittman et al., 2011). Neochloris oleoabundans, a particularly lipid dense algae, has a high oil content of 29% and can reach up to 56% after cultivation (Gouveia & Oliveira, 2009). The use of microalgae to produce biofuels addresses both the economic and environmental limitations of biofuel production in that it will serve as wastewater treatment and reduce the costs of production.

Genetically modified crops can address the food availability crisis due to plant-based biofuel production, increase crop yield (which causes less planting area and pesticides to be used), and can also be designed to be resistant to pesticides, which would decrease the use of conventional pesticides (Foong et al., 2022). Integrated pest and weed management can control pest and weed populations without heavy use of pesticides (Foong et al., 2022). It can prevent

algal grazers and weeds through mixed-species algal assemblages or grazer-predator introduction (Foong et al., 2022).

Internet of Things (IoT) technologies can guide agroforestry decisions, e.g., nano-sensors reporting the need for fertilizer, water, and pesticides based on soil conditions (Foong et al., 2022). Education can educate farmers on pesticide use and preventing water contamination through activities, demonstrations, and group discussions (Foong et al., 2022). The use of food waste for biofuel production and biopesticides promotes circularity and is less toxic than synthetic pesticides while having similar performance (Foong et al., 2022).

Conclusion

As a renewable energy source, while biofuels present a promising, sustainable alternative to traditional fossil fuels, their production in the U.S. faces significant social, environmental, and economic challenges. This study examined existing research publications and summarized the opportunities and challenges currently faced by biofuel production in the U.S. from three perspectives: social, environmental, and economic.

Despite the many benefits of biofuels, major limitations include food shortages, high cost of production, and greenhouse gas emissions during the process. To address these challenges, an alternative approach is proposed, which involves growing algae-based biofuels from wastewater, genetically modified crops, integrated pest and weed management, as well as the potential use of food waste for biofuel production and biopesticides. Algae-based biofuels use wastewater, which not only reduces the reliance on arable land but also helps in treating wastewater. Genetically modified crops can be designed to yield higher energy content or to grow in non-arable lands to reduce the competition between food crops and fuel production crops. Integrated pest and weed management practices can further enhance the sustainability of biofuel crops by minimizing the need for chemical based pesticides. Finally, utilizing food waste as a feedstock for biofuel production not only helps to mitigate the issue of food waste but also provides a low-cost and abundant resource for biofuel production.

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