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Biofuels: A sustainable choice for the United States' energy future?

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ABSTRACT

In the United States and elsewhere, climate change, peak oil, and other political and socioeconomic factors have spurred the development of alternate energy sources. Biofuels, derived from living organisms rather than petroleum-laden rock, are the focus of current energy research. To better understand the future composition and sustainability of biofuels within the U.S. energy portfolio the authors conducted an environmental scanning methodology and futures analysis. The authors developed a model representing the relationships between many important economic, environmental, political, and social factors to illuminate potential future trends in cellulosic and algal biofuel over the next twenty years. This innovative, flexible approach compared the sustainability of biofuel sources in many areas over time. The resulting analysis identifies environmental degradation as the most influential adverse factor. The environmental scanning exercise suggests that cellulosic biofuel may be a more sustainable option than algal biofuel under the model's assumptions. This analysis yields insightful trends that predict the sustainability of two biofuel sources over the next twenty years in relation to other important socio-politico-economic factors. In the future, this methodology can be applied to other biofuel sources and energy problems.

1. Introduction

The earth contains a wide variety of energy resources, although many of these are limited. Energy infrastructure around the world largely relies upon these inadequate supplies (Lianos, 2013). The United States and many other countries are still dependent upon nonrenewable resources, despite modest research, industrial, economic, and political initiatives (Driesen, 2009). Regardless, resource depletion could play a large role in the condition of human populations around the world (Lima and Berryman, 2011; Cellarier and Day, 2011). Motesharrei, Rivas, and Kalnay (Motesharrei et al., 2014) suggest that the world will face a population collapse unless resources are consumed sustainably. This can be achieved in a variety of ways. In the United States, energy is derived through many techniques; some of which are more sustainable than others (Santoyo-Castelazo and Azapagic, 2014). In particular, it relies upon oil and related products for many energy needs (Reynolds, 2014). Yet, some scientists have suggested that society has (or will soon reach) peak oil, or the maximum level of oil production (Hallock et al., 2014; Hubbert, 1962). After this point, oil production will begin to decline (Brandt et al., 2013). Renewable energy options provide answers to resource depletion, including peak oil.

The U.S. Energy Information Administration's (EIA) Annual Energy Outlook 2013 predicts that the national energy portfolio will be dominated by renewable energy sources by 2040 (U.S. Energy Information Administration, 2014a). Biofuels are one example of renewable energy (Yue et al., 2014). While biofuels only account for a small portion of renewable energy currently, production is predicted to increase by 1.4% annually, or near 40% by 2040 (see Table S1) (U.S. Energy Information Administration, 2014a). This trend could encourage political, industrial, and technological progress for biofuels in the United States.

Biofuel resources are processed through biochemical and thermochemical means, such as sugar fermentation, cellulose hydrolysis, pyrolysis, and gasification (Hoekman, 2009; Sims et al., 2010). These processes yield ethanol, biodiesel, and other fuel types that can be used in spark-ignition and compression ignition engines (Fig. 1) (Nigam and Singh, 2011; Bennion et al., 2015). Cellulosic biomass, microbes and algae, soybeans, corn, and sugarcane are common biofuel feedstocks. Each feedstock is processed differently to produce fuel. Infrastructure must exist to support each process and fuel type. One example of a biofuel limited by current infrastructure, corn ethanol, is discussed below.

Corn ethanol is the most well-known form of biofuel in the United States (Hoekman, 2009; Baeyens et al., 2015). Policies (e.g. renewable fuel standards) have encouraged corn ethanol production, yet infrastructure and demand issues have hindered its ultimate success (Anderson and Coble, 2010). Namely, the "E10 blend wall", or the 10% maximum amount of ethanol allowed in conventional fuel, significantly limits the future growth of this biofuel type (Qiu et al., 2014). This is because ethanol is produced at a rate with meets the highest potential

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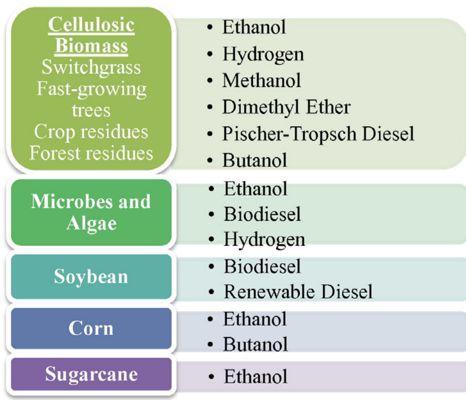

Fig. 1. Popular biomass resources in the United States and the fuels produced from them. Adapted from data in Nigam and Singh (2011), Argonne National Laboratory (2010) and Adenle et al. (2013).

demand of the industry. Ethanol is already produced at a high enough level to meet the 10% demand for conventional fuel blends. Therefore, ethanol demand can increase only through the use of higher ethanol blends like 15% (E15) and 85% (E85). Yet, vehicle fuel infrastructure is not capable of handling these high ethanol blends. Extensive fuel system changes would involve huge financial and temporal investments. In other words, ethanol demand is likely to stay stagnant until infrastructure can meet the demands of high ethanol blends (Strogen and Zilberman, 2014; Zhang et al., 2010). Consequently, current corn ethanol research focuses on limiting greenhouse gas (GHG) emissions, securing infrastructure, and improving vehicle technology, but further growth is unlikely (Hoekman, 2009; Tyner, 2011).

Other biofuel types avoid the “blend wall” issue, require less land and water use, and involve lower greenhouse gas emissions (although they do have other limitations like limited numbers of refineries and complex processing requirements). For example, alternative biomass resources include cellulosic forest resources (as shown in Fig. 1), including fast-growing trees, residues from logging, crop and wood processing (Hoekman, 2009). Cellulosic materials produce a variety of fuels, including ethanol and butanol. While many potential biofuel crops, such as cellulosic products are not typically consumed as food, they can use land that would otherwise cultivate food products (Baffes, 2013; Ajanovic, 2011). Sugarcane and soybean are also biofuel resources, yielding ethanol, biodiesel and butanol (Swapna and Srivastava, 2012; Ziolkowska, 2013). Alternatively, algae and microbes can be used to produce biofuel and do not typically require as much land or compete with food markets. While algae and microbe-based biofuels have yet to be applied on commercial scales, there are around thirty cellulosic biofuel projects in over twenty U.S. states (Nigam and Singh, 2011; Scheel and Lütke-Eversloh, 2013; Advanced Ethanol Council, 2013). As interest in renewable fuels increases, more projects using the above-mentioned resources will likely begin (Algieri, 2014).

1.1. Driving forces in the U.S. biofuel portfolio

Many factors will determine which biofuels dominate the U.S. energy portfolio in the next 30 years. For example, energy security, economic productivity, environmental impacts, political viability, and technological feasibility guide the production and distribution of biofuels (Table 1). Biofuels that maximize beneficial factors while minimizing negative ones will likely be more successful. Currently, socioeconomic and political challenges limit the market penetration of biofuels (Szulczyk and McCarl, 2010). Energy security is also a major issue for the United States; the nation imports over 11 quadrillion British thermal units (btu) each year (U.S. Energy Information Administration, 2014a). In 2013, the United States received 33% of its petroleum and 50% of its crude oil from foreign countries (U.S. Energy Information Administration, 2014b). Widespread biofuel production could increase the domestic supply of energy significantly, and provide additional reliability and distribution of fuels within the country (Kruyt et al., 2009). A rise in energy security could also increase economic growth, price stability, and global competitiveness (Demirbas, 2009).

Dominant biofuels are also driven by political viability and technological concerns (Table 1). Sustainable biofuel portfolios depend upon sufficient funding through a strong policy framework, an environment in which policy can function effectively and efficiently, and a clear idea of potential effects on U.S. welfare (Koh and Ghazoul, 2008; Cui et al., 2011). Technology, in combination with policy, drives the success of particular biofuels by supporting development and applicability. In addition, transportation and production infrastructure and the lack thereof, optimization of resource processing and storage facilities will determine whether a particular biomass product will be more economically and environmentally sustainability compared to another (Nigam and Singh, 2011; Taylor, 2008; Bauen, 2006).

Research suggests that climate change influences how energy security, economic productivity, political viability, and technological feasibility drive biofuel portfolio pathways (Fig. 1) (He et al., 2015; Jian-Kun, in press; Uddin and Taplin, in press). The most significant GHG, carbon dioxide (CO_2), is now nearly double the global average before the Industrial Revolution at around 400 ppm (Tans and Keeling, 2014). The accumulation of CO_2 in the atmosphere has increased intense climate activity (i.e. stronger storms and heat waves, and decreased air quality). In addition, climate change has triggered ocean acidification and warming, and sea level rise (Lenton et al., 2008; Zeng et al., 2015). The change in ocean and atmosphere temperatures reduces plant and animal biodiversity (United Nations Environment Programme and World Meteorological Organization, 2011). Because gases causing climate change are largely released during the burning of fossil fuels, and fuel use increases with population, these events are predicted to intensify over time (Intergovernmental Panel on Climate Change, 2013). If this prediction stands, consequences would be devastating to the Earth and all of its inhabitants. To mitigate the progression of climate change, many scientists have focused on limiting fossil fuel consumption (Bauen, 2006).

Table 1
Driving factors of biofuel composition. Potential driving factors in the composition of biofuels within the U.S. energy portfolio. These factors include sustainability indicators such as land and water use. The critical issues listed under each factor impact biofuel success over time. A particular biofuel will be most effective in a varied energy portfolio when it limits negative factors (e.g. high land and water use) and maximizes positive factors (e.g. infrastructure availability).
Adapted from data in Hoekman (2009), Nigam and Singh (2011) and Cui et al. (2011).

Driving factors					
	Improved energy security	Economic productivity	Environmental impacts	Political viability	Technological feasibility
Critical issues	Domestic fuel supply Distributed fuel resources Fuel supply reliability Petroleum reduction	Fuel price stability Rural development Trade equality Global competitiveness	Land and water use Criteria air pollutants Greenhouse gases Wildlife habitat Biodiversity Carbon sequestration	U.S. welfare Political climate Funding accessibility	Infrastructure availability and stability Technological optimization Storage facilities

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