

Biofuel: Concepts and Considerations¹

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Introduction

Biofuel can be described as "any fuel made from organic materials or their processing and conversion derivatives" (USEPA 2018). This publication serves as an introduction to biofuels for Extension educators and anyone interested in learning basic terminology, concepts, and impacts of biofuels as a replacement for fossil fuels.

Simply, biofuels are combustible fuels derived from recently produced biomass, as opposed to ancient biomass, which is the source of petroleum products. The term biofuel usually refers to liquid fuels used as replacements for or additives to petroleum-based liquid fuel. In the literature, the term bioenergy has been used interchangeably with biofuel, though it is more commonly used to describe any energy source based on recently produced biomass—everything from food, fiber, wood, grasses, crop residues, and even industrial and municipal wastes. Nevertheless, biofuel can be categorized into two broad groups—bioethanol (more commonly referred to as ethanol) and biodiesel. The basic difference between the two is that ethanol is an alcohol, the same as in beer and wine (although biofuel-ethanol is undrinkable), and biodiesel is an oil. World-leading ethanol- and biodiesel-producing countries are listed in Table 1 (REN21 2018).

Classification

Based on the type of feedstock used to produce either ethanol or biodiesel, biofuels are grouped into three categories—first generation, second generation, and third generation (Lee and Lavoie 2013). Additionally, "Advanced Biofuels" is a term generally used to describe comparatively new biofuel production technologies that use waste such as garbage, spent cooking oil, and animal fats as feedstock.

- **First-generation** ethanol/biodiesel is produced directly from biomass that is generally a food

source. Ethanol is produced by fermenting sugar or starch in food-crop sources that are biochemically categorized as carbohydrates. The major source of sugar is sugarcane, while corn is the major source of starch (USEPA 2010). Besides cane and corn, first-generation ethanol is produced from but not limited to other less popular sources like wheat, barley, and sugar beet (Table 2). The sources of first-generation biodiesel are soybean, rapeseed (canola), sunflower, and palm, which are edible oil crops (USEPA 2010).

- **Second-generation** ethanol/biodiesel is produced from non-edible biomass sources. The sources of second-generation ethanol include dedicated biofuel grasses, crop residues, and wood chips, which are biochemically categorized as lignocellulosic materials (Table 2). Second-generation biodiesel is produced from non-edible oils, and most comes from jatropha (Bhuiya et al. 2014). Other minor sources include jojoba, karanja, moringa, castor, soapnut, and cotton seed oil (Atabani et al. 2013).
- **Third-generation** ethanol/biodiesel is commonly produced from algae, a single-cell organism. Generally, algae are categorized based on their habitat, such as freshwater algae, marine algae, or wastewater algae. Based on its characteristics, a specific alga is chosen for either ethanol or biodiesel production (Wilkie et al. 2011).

Production

Ethanol and biodiesel are produced through different biochemical/chemical pathways. Fermentation and transesterification are the major pathways for ethanol and biodiesel production, respectively (Lee and Lavoie 2013). Thus, ethanol is produced by fermenting any biomass high in carbohydrates (sugar/starch/cellulose) through a process similar to beer brewing (Figure 1). In first-generation ethanol production, starch is enzymatically hydrolyzed to fermentable sugar before

going through the fermentation process. In second- and third-generation ethanol production, cellulose is extracted from the lignocellulosic structure by different pretreatments and then enzymatically hydrolyzed to fermentable sugar. Compared to ethanol production,

biodiesel production is theoretically more straightforward. Basically, all three types of biodiesel feedstocks are first extracted to get oil, and then the oil is converted to biodiesel through a process known as transesterification (Figure 2).

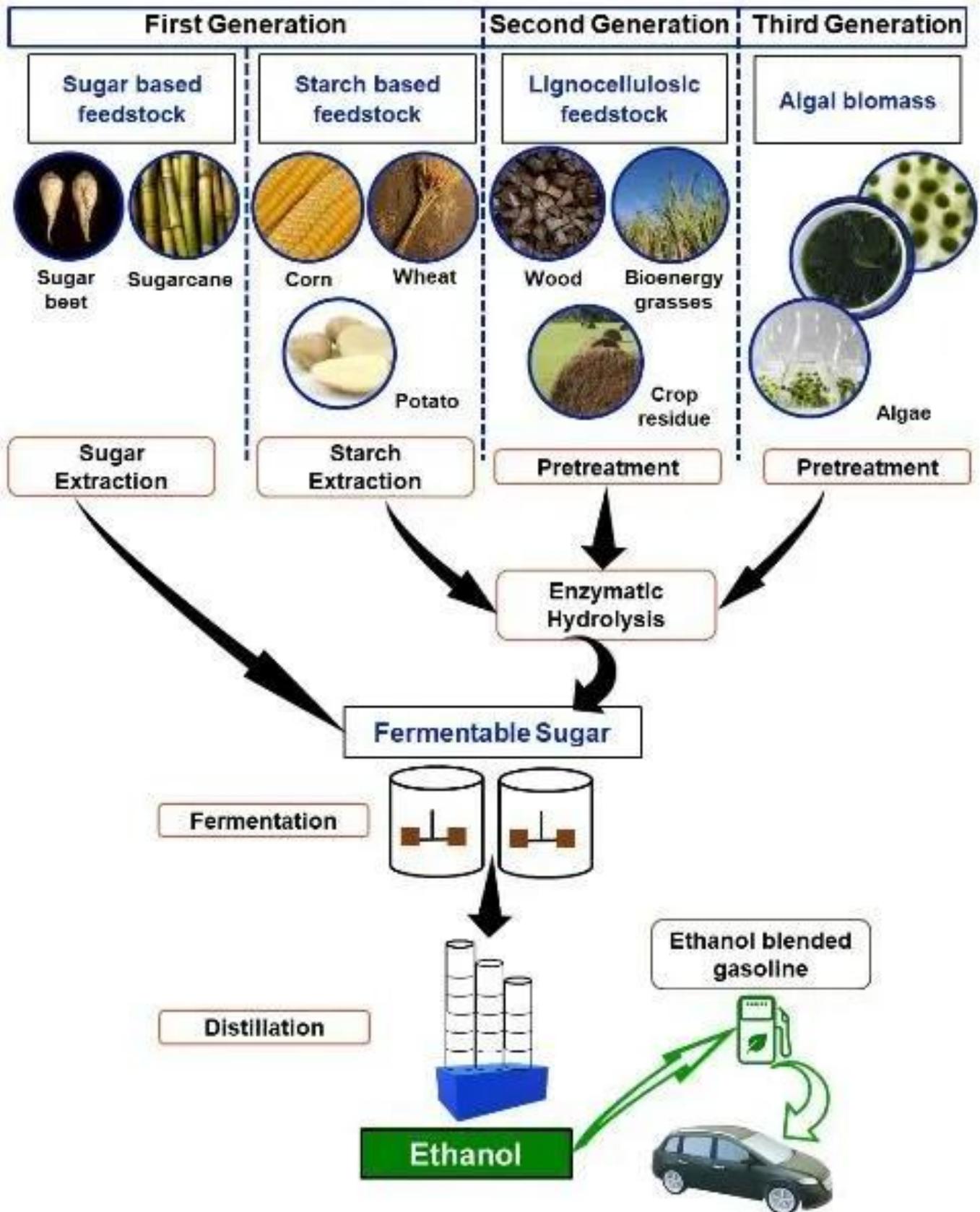


Figure 1. Schematic pathways of first-, second-, and third-generation ethanol production.

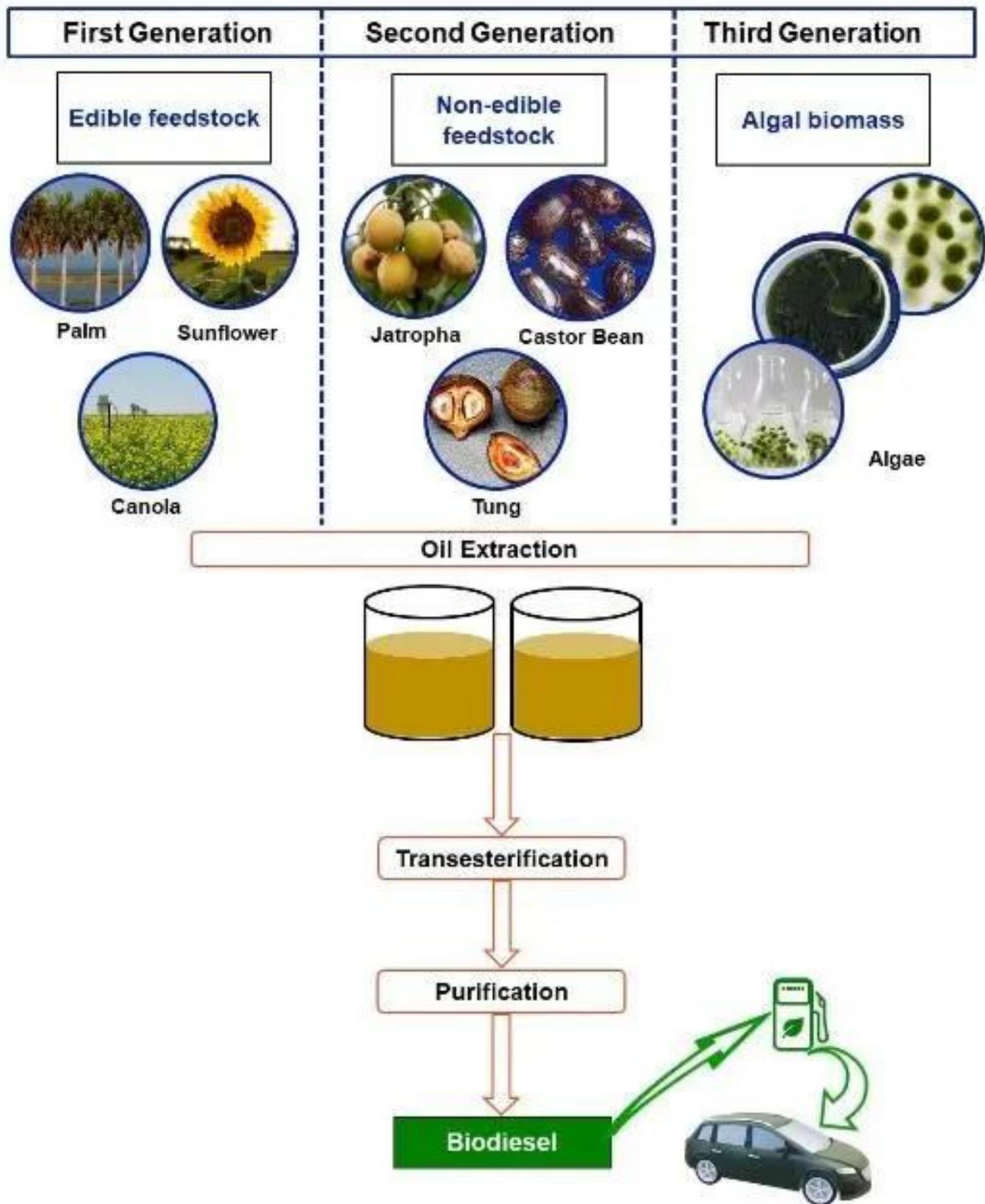


Figure 2. Schematic pathways of first-, second-, and third-generation biodiesel production.

Potential Benefit

Biofuel production has a number of potential benefits for replacing finite fossil fuels that are being depleted day by day (Figure 3). Theoretically, biofuel is a renewable energy source compared to nonrenewable

fossil fuel (Table 3). In its first triennial report to congress, USEPA (2011) had predicted that biofuel from corn or soybean could have lower lifecycle greenhouse gas (GHG) emissions than gasoline. Specific economic modeling studies also suggested lower lifecycle GHG

emissions from biofuel production and use than from conventional petroleum-based fuel (Huang et al. 2013). Biofuel produced from non-edible sources (i.e., second- and third-generation biofuel) has added advantages. Most of the second- and third-generation biofuels are either produced on marginal or extra land, or are the co-products of agricultural production systems with no added cost of production and with little or no alternate uses. Biofuels also reduce environmental pollution by

decreasing CO₂ emissions and improving air quality (USEPA 2010). However, biofuel production and consumption by themselves still have impacts on conventional pollutant emissions (like CO₂). Biofuel has advantages over petroleum-based fuel provided that biofuel production and consumption do not increase environmental pollution or augment demand for resources like arable land, water, fertilizer, and pesticides.

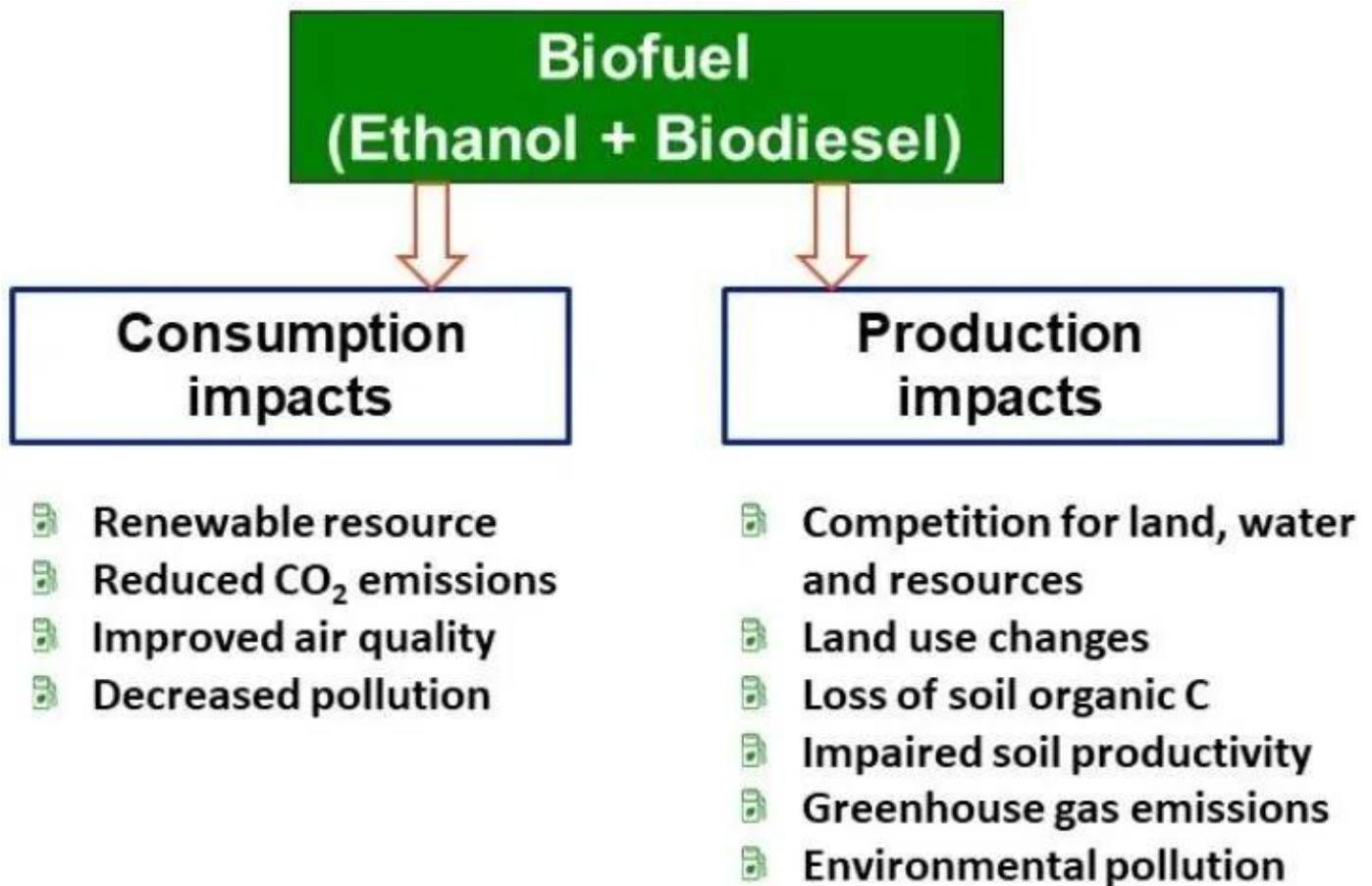


Figure 3. Impacts of biofuel.

Considerations

Though biofuel provides an attractive alternative to current petroleum-based transportation fuel, its production impacts cannot be overlooked (Figure 3). The major challenges for long-term sustainability of biofuel production are mainly twofold: economic and environmental. Most biofuel feedstocks are agricultural products, which is a point of major concern. The key economic issue is that if food crops are used for biofuel production (which is the case for first-generation ethanol and biodiesel), then there will be a shortage of food grains in the market, leading to higher dietary costs (Hill et al. 2006). To address this concern, second-generation biofuel production, which relies on either

the biomass residues or non-edible agricultural products, has been developed.

However, second-generation biofuel production is also subject to environmental and economic concerns. Removing residues from the field for second-generation biofuel production aggravates environmental problems due to reduction of soil organic carbon that otherwise would accumulate in soil when crop residues are retained (Lal 2005). Loss of soil organic carbon leads to a vicious cycle of increased soil erosion, increased GHG emissions, lower soil productivity, higher mineral fertilizer input, increased cost of production, and impaired water quality due to surface runoff (National

Research Council 2011). Growing dedicated crop biomass only for first- or second-generation biofuel production either competes with agricultural and pasture land or leads to deforestation with increased GHG emissions (Fargione et al. 2008, Melillo et al. 2009).

Production of crop biomass for biofuel on marginal lands also increases the use of fertilizer, water, and pesticides, which impacts the environment negatively (Searchinger et al. 2008). Despite these concerns, the future of biofuel production is not entirely bleak. The solution could involve producing biofuel in substantial quantities from feedstocks that have low environmental impact and little or no competition with food production. The application of biofuel industry by-products back to soil could be a complementary strategy to increase soil quality (Bera et al. 2019) and possibly mitigate the potential impacts of biofuels.

Third-generation biofuels from cultured algal biomass or advanced biofuels from domestic and industrial wastes have certain advantages over biofuels from agricultural feedstocks. Nevertheless, production of biofuels from algae also has the potential for significant resource use and negative environmental impacts, though this is true for all forms of energy production (Georgianna and Mayfield 2012). However, biofuel production from algae that are highly productive and less resource intensive is considered an economically viable biofuel production pathway at present (National Research Council 2012). Ultimately, any new kind of biofuel production technology needs to be environmentally sustainable and economically profitable.

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Tables

Table 1. Global biofuel production by country in 2017.

Countries	Biodiesel production (billion liters)	Ethanol production (billion liters)
United States	6.0	60.0
Brazil	4.3	28.5
European Union-28	11.8	4.1
Argentina	3.3	1.1
China	1.0	3.3
Thailand	1.4	1.5
Indonesia	2.5	0.1
Canada	0.5	1.7
India	0.2	0.8
Colombia	0.6	0.3
World Total	30.7	105.5

Data are from Table R15, REN21 (2018).

Table 2. Average yield of ethanol and biodiesel from different feedstocks.

	First generation		Second generation	
		Yield (L t ⁻¹)		Yield (L t ⁻¹)
Bioethanol Feedstock (Rajagopal and Zilberman 2007)	Rice	430	Switch grass	330
	Corn	400	Miscanthus	330
	Sorghum	390	Crop residue	290
	Wheat	340	Sugarcane bagasse	280
	Cassava	180		
	Sugar beet	110		
	Sugarcane	70		
	Sweet sorghum	70		
		Yield (L ha ⁻¹ y ⁻¹)		Yield (L ha ⁻¹ y ⁻¹)
Vegetable Oil* Feedstock (Atabani et al. 2012)	Palm oil	5950	Jatropha	1892
	Olive oil	1212	Jogoba oil	1818
	Rapeseed	1190	Castor bean	1413
	Peanut oil	1059	Tung oil	940
	Sunflower	952	Rice bran oil	828
	Sesame oil	696	Cotton seed oil	325
	Soybean	446		

*The table contains the vegetable oil yield instead of biodiesel yield. However, an approximate biodiesel yield can be calculated by applying a factor of 90% for conversion of vegetable oil to biodiesel, as mentioned by Atabani et al. (2012).

Table 3. Fuel properties comparison among traditional gasoline, biodiesel, and ethanol (USDOE 2014).

Property	Gasoline/E10	Biodiesel	Ethanol/E100
Chemical Structure	C ₄ to C ₁₂ and Ethanol = 10%	Methyl esters of C ₁₂ to C ₂₂ fatty acids	CH ₃ CH ₂ OH
Fuel Material (feedstocks)	Crude Oil	Fats and oils from sources such as soy beans, waste cooking oil, animal fats, and rapeseed.	Corn, grains, or agricultural waste (cellulose)
Gasoline Gallon Equivalent	97%–100%	B100 has 103% of the energy in one gallon of gasoline or 93% of the energy of one gallon of diesel. B20 has 109% of the energy of one gallon of gasoline or 99% of the energy of one gallon of diesel.	1 gallon of E85 has 73% to 83% of the energy of one gallon of gasoline (variation due to ethanol content in E85). 1 gallon of E10 has 96.7% of the energy of one gallon of gasoline.
Energy Content (lower heating value)	112,114–116,090 Btu/gal	119,550 Btu/gal for B100	76,330 Btu/gal for E100
Energy Content (higher heating value)	120,388–124,340 Btu/gal	127,960 Btu/gal for B100	84,530 Btu/gal for E100
Physical State	Liquid	Liquid	Liquid
Cetane Number	N/A	48–65	0–54
Pump Octane Number	84–93	N/A	110
Flash Point	-45°F	212°F to 338°F	55°F
Autoignition Temperature	495°F	~300°F	793°F
Maintenance Issues		Hoses and seals may be affected by higher-percent blend. Lubricity is improved over that of conventional diesel fuel.	Special lubricants may be required. Practices are very similar, if not identical, to those for conventionally fueled operations.
Energy Security Impacts	Manufactured using oil, of which nearly ½ is imported.	Biodiesel is domestically produced, renewable, and reduces petroleum use 95% throughout its lifecycle.	Ethanol is produced domestically. E85 reduces lifecycle petroleum use by 70% and E10 reduces petroleum use by 6.3%.

¹This document is SL475, one of a series of the Department of Soil, Water, and Ecosystem Sciences, UF/IFAS Extension. Original publication date September 2020. Visit the EDIS website at <https://edis.ifas.ufl.edu> for the currently supported version of this publication.

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