Chapter 6
Future Biofuel Production and Water Usage

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Abstract Biofuel in particular, together with the rising demands for food, have the highest prospects for an increase in agricultural water withdrawals. The water-biofuel relationship is being recognized as backbone of the factors fundamental for the future sustainable supply of water and biofuel. A better understanding of the subject is essential to adopt superior technologies that may improve use of water for biofuel production in efficient way. This chapter presents prospective and future trends of the water-biofuel relationship and impacts of additional water usage in future increased biofuel production. The importance of technological innovation to save water and future impacts on water quantity and especially on water quality will be assessed in terms of safe keeping the environment. The obligation of reusing wastewater and application of undiluted wastewater to grow feedstock for biofuel to save freshwater resources will be analyzed.

Keywords Climate changes · Future water availability · Biofuel production · Fresh water assessment

6.1 Introduction

Biofuel offer better answers to present world energy needs and economic crises, both as a sustainable energy source and through promoting economic development, especially in rural areas of developing countries (Joly et al. 2015; Arshad 2010; 2011; 2014a; 2017). Biofuel are regarded most promising renewable substitutes of fossil fuels to meet the aim to pull down CO_2 emissions (Farrell et al. 2006; Ragauskas et al. 2006; Arshad et al. 2008, 2014b). Share of biofuels for road transport in various countries has been presented in Fig. 6.1.

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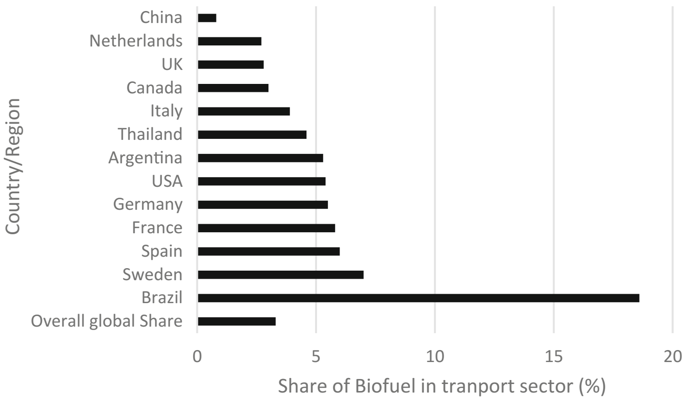

Fig. 6.1 Share of biofuels for road transport in 2011 (Raboni et al. 2015)

The expansion of the feedstock production for biofuel has been controversial due to potential adverse side effects on natural ecosystems and the services they provide (Gasparatos et al. 2011). Globally land and water hungry nature of biofuel feedstock has been matter of concern now. Not good choices in selection of feed stocks and agricultural practices may emasculate environmental goals of biofuel and resource sustainability. Certainly major water resources are used to irrigate the agriculture farming, employed to raise food. But other sector such as energy, electricity and fuel (biofuel) production also need increasing amounts of water (Macknick et al. 2012; Arshad and Ahmed 2016). In certain areas, this trend has forced to a struggle between various water uses (Cosgrove and Rijsberman 2014). Simultaneously the climatic variations can also shrink the availability of water with drop in the quality (Jiménez Cisneros et al. 2014). From now, the energy and transport fuel sources we select, can speed up the rising water requirements or offset such needs in future. Water is the vital natural resource. Its linkage between water use, energy requirement and food production is multifaceted, as the changes in the need of one resource in one sector can change its availability and that of another resource in another sector and vice versa.

Up till now, biofuel production cost comparison to fossil fuels has been remained focused with large scale agribusinesses of the crops investing heavy energy inputs, high pesticide, fertilizer, and water use. The need of the day is to calculate the ecological footprint caused by large-scale cultivation of a given biofuel energy crop, that includes different modes of processing the feedstock into a liquid fuel. Numerous factors are involved in ecological footprints of biofuel. Over all energy balance with energy efficiency in the complete life cycle of biofuel and generation from fuels produced per hectare impacts the whole ecological footprint. These factors impacts on the land required for growth of enough masses of biofuel to substitute fossil based fuels up to significant level. Carbon intensity of biofuels resulting from different feedstock and technology, compared to traditional fossil fuels has been shown in Fig. 6.2.

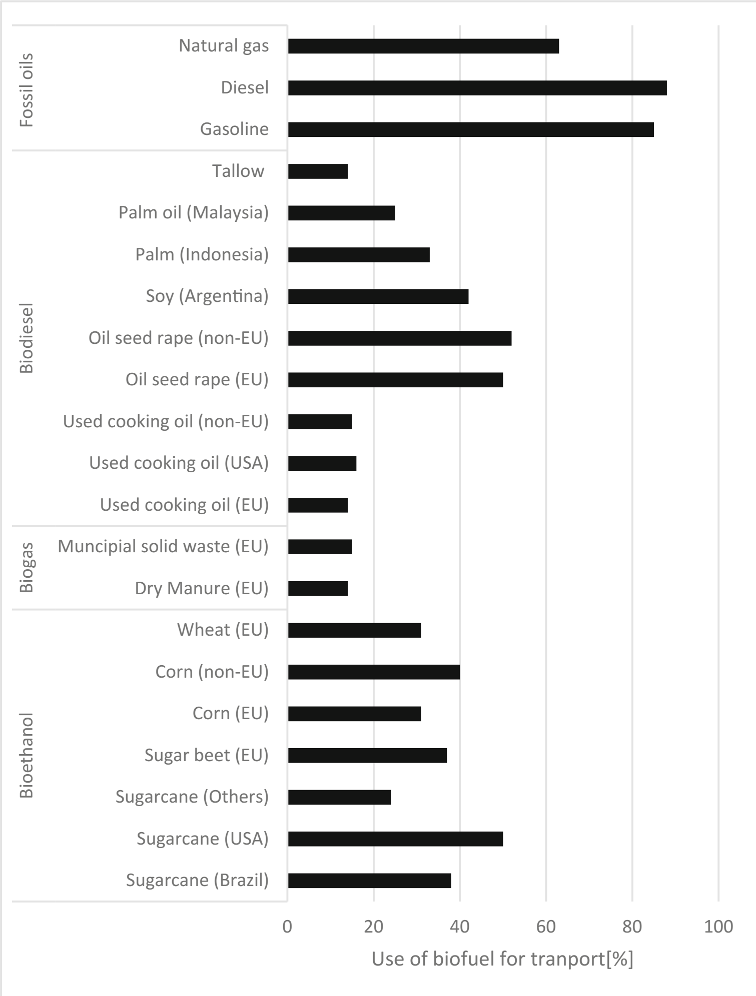

Fig. 6.2 Carbon intensity of biofuels resulting from different feedstock and technology, compared to traditional fossil fuels (Raboni et al. 2015)

The amount of water, pesticide and fertilizer utilized, energy required in farming of the feedstock and greenhouse gas emissions over the life cycle of the product are included in estimation of ecological footprint of a biofuel. Groom et al. (2008) estimated these variables for presently leading biofuel feedstock. This chapter deals largely with the effects of future expansion in feedstock production of biofuel on water, land and ecosystem. It has been also focused on proactive solutions to avoid or minimize potential adverse impacts.

6.2 Vision 2050 and Water Requirements

Climatic changes will create more doubts in the accessibility of freshwater ensuring drinking quality. It is firm scientific believe that human induced emissions of CO_2 are assembling swiftly in the atmosphere. Now it is the fact that the global water resources will be under pressure in 2050 as world population will reach up to 9 billion (Bakker and Morinville 2013). Water need is foreseen to upsurge by 55% globally between 2000 and 2050, demand in certain industries, such as manufacturing will be increased by 400% and electricity production by 140% (OECD 2012). Sources of fresh water as part of total water on earth have been presented in Fig. 6.3. The world may see a 40% deficit between forecasted water requirements and available supplies (2030 Water Resources Group 2009). The core associations among water security and the world's rapidly growing needs for food and fuel make this challenge more complicated.

As the 60% increased food production is required by 2050 to fulfill the growing population's feed demand (Alexandratos and Bruinsma 2012). Simultaneously, climate change will impact agricultural farming, and biofuel demands will contest with food for the same water and land use. In effect, food, biofuel, fiber and ecosystems are all going to screech for more water. The water biofuel competition related to climate changes has been depicted in Fig. 6.4.

Almost 165 billion m^3 of wastewater is collected globally and treated, but just 2% is reused. It shows the potential of reusing wastewater as the same water can be used several times before being discharged into the natural environment. All types of water cannot be used for recycling, so water quality standards should be adapted to the desired end use. Globally almost 1.3 billion tons of eatable food is wasted every year (Conforti 2011). Similarly 7.5 million tons of food waste is guided to landfill in Australia (Mason et al. 2011). Along with the problems associated with waste disposal, we are consuming vast amounts of water as embedded in these losses (Chartres and Sood 2013).

Worldwide water availability may be reduced and limited water resources for agriculture, over the coming decades will be available (Hanjra and Qureshi 2010). Chartres and Sood (2013) analyzed the water demand for food production until 2050 using the WATERSIM model. An increase in global water demand for agriculture from 2400 km^3/yr in 2010 to between 3820 and 7230 km^3/yr in 2050 were forecasted. An increase from 1425 km^3/yr irrigation (blue) water demand for crop production in 2000 to 1785 km^3/yr in 2050 in their baseline scenario was forecasted by Sulser et al. (2010) using IFPRI's IMPACT model. Many water availability analysis have been performed in previous years (Khan et al. 2009; Perrone et al. 2011; Scott et al. 2011; Hardy et al. 2012; Larson 2013; Lele et al. 2013; Rasul 2014). All were agreed that water availability is expected to decline due to rising demands and simultaneous adverse ecological changes.

The energy in the form of scaling up biofuel production in the future need water and land requirements, with their potential adverse effects on food security and water availability has been summarized by (Dominquez-Faus et al. 2009; Yang

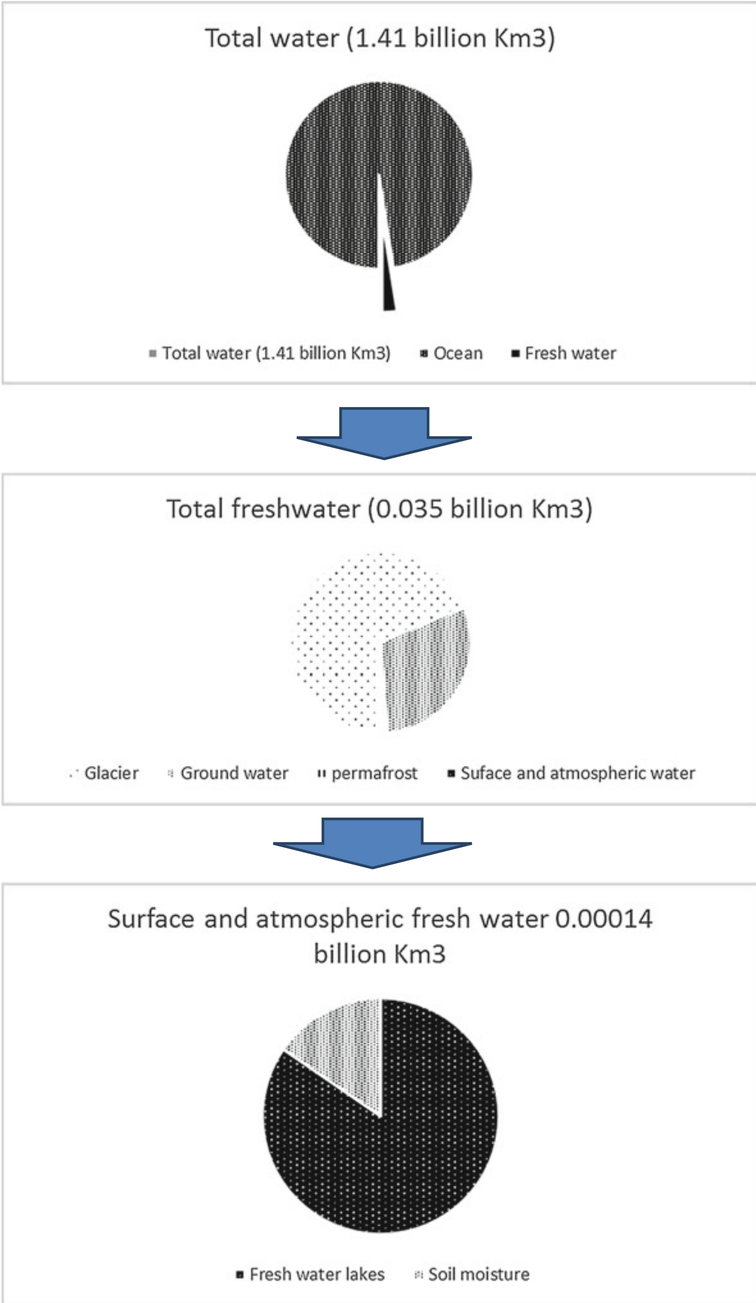

Fig. 6.3 Sources of freshwater as part of total water on earth

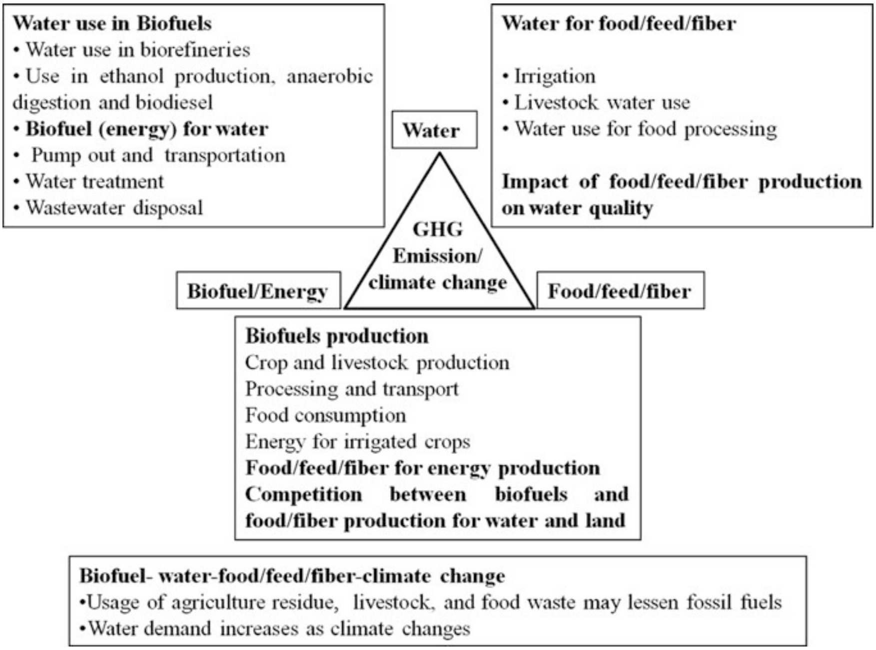

Fig. 6.4 The water biofuel compitition related to climate changes

et al. 2009; Fingerman et al. 2010).Water needed for maize as energy crop in the US, and its harmful effects regarding water availability and environmental health were analyzed by Dominquez-Faus et al. (2009). Fingerman et al. (2010) reported that huge quantity of water (5100 L/L) will be needed for ethanol production. The water and land necessities for biofuel production in China were summarized by Yang et al. (2009).

6.2.1 Increase in First-Generation Biofuel

The water feeding for biofuel (energy) can be increased up to 2012 from 74 km^3/yr in 2050 (97% will be used for growing biomass), if worldwide per capita fuel requirement would reach OECD levels and 7% of the need should be met by first generation biofuel. First generation biofuel are produced in every corner of the world from common energy crops and quantity of water may equal the amount of water required for increased food supply.

An analysis of global biofuel policies and their consequences on water requirements in agricultural sector worldwide was performed. As China and India, are rapidly rising economies and will require more water from limited water resources. It may lead to a tough resource rivalry in the future, if biofuel were

Table 6.1 EU biofuel production and use for transport in 2012 (keto $^{y-1}$) (Raboni et al. 2015)

Country	Bioethanol		Biodiesel	
	Production	Use of transport	Production	Use of transport
Germany	387	403	2861	2191
France	600	209	1910	2268
Spain	191	101	925	1899
Italy	75	40	706	1264
Poland	106	77	370	669
Austria	108	34	289	390
Other member states	952	538	2509	2980
Total	2418	1401	9570	11,661

employed as major transport fuels. Worldwide irrigation water withdrawals for bioethanol production may reach to 128.4 in 2030 from 30.6 km^3/yr in 2005.

To calculate the water utilization in food as well as for first-generation biofuel production, data from the global Water Footprint (WFP) Network was utilized by Damerau et al. (2016). The volume of fresh water taken to yield a product, including the water quantity utilized and polluted in the all the steps of the supply chain are defined as Water Footprint. Gerbens-Leenes et al. (2008) listed blue and green water consumption for production of bioenergy. Fresh surface and ground-water is blue water while the gray water is the quantity of water needed to dilute pollutants. Water coming precipitation on land that does not run off or re-charge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation is called green water (Ridoutt and Pfister 2013; Sulser et al. 2010).

First generation biofuel can have large negative ecological impacts, not only with regard to water (Creutzig et al. 2014). So the European Union revised their biofuel targets until 2020, limiting first-generation biofuel to a share of 7% (Eggert and Greaker 2014). EU biofuel production and use for transport in 2012 has been shown in Table 6.1. An increase in first-generation biofuel can easily lead to huge needs of extra water and demand for cropland would also rise, which might lead to additional competition for landwith food production (Rathmann et al. 2010).

6.3 Future Impacts on Ecosystems

Ecosystems are affected due to agricultural activities, either to raise food and fiber or biofuel. One of major impact related to biofuel is the land-use change. The required land to raise feedstock for biofuel production may come rightly after clearing new land, but mostly as a consequence of replacing the one crop with another (Hertel et al. 2010; Searchinger et al. 2008). The ecological effects of biofuel are interceded the impact on land, water, air complexly connected with the economics of worldwide agricultural markets. Ecology is an emergent part of biology that has to lead us towards the sustainable production of biofuel in a cost effective and environmentally safe way. It may be employed to produce large quantities of feedstock keeping the desired chemicals composition. If feedstock for biofuel are raised through sustainable means then biofuel can be sustainable source of energy and may be promoted with smallest ecological footprint. The Ecological Footprint measures the amount of biologically productive land and water area required to produce all the resources that an individual, a population, or an activity consumes, considering also the absorption of residues they generate. This can be compared to the biocapacity, the amount of productive area that is available to generate these resources and to absorb the residues (Wang 2005).

6.3.1 Land Use Change

According to Fargione et al. (2010), the land needed for biofuel production can be easily estimated by dividing the biofuel quantity with the conversion efficiency multiplied by crop yield and un-harvested correction. Few biofuel also generate byproducts and coproducts that can substitute many other products in the market place, decreasing the net amount of food displaced. Resultantly, the quantity of land needed to produce such biofuel can be lesser. Therefore the impact of co-product/byproduct must be incorporated. It is estimated that 15.9 million ha were used to produce ethanol and 17.4 million ha were cultivated for biodiesel production in 2008. It approaches to 2.2% of worldwide cropland.

Assuming biofuel expand by 170% in 2020, as under a business as usual scenario (Fargione et al. 2010), cropland required for biofuel production would be 72–82 million ha if biofuel production efficiencies (that is, crop yields and conversion efficiencies) increased by 10–25%. Our estimates of the land required to produce biofuel do not include co-products effects due to lack of data. Research on coproduct effects could help guide biofuel producers toward processes and coproducts that reduce the amount of new land required for biofuel production.

6.4 Possible Solution

6.4.1 Polyculture Versus Monoculture

The type of agriculture farming growing more than one crop at a time on the same space is called polyculture. It provides crop diversity to maintain the natural ecosystems. Biofuel feedstock needing some inputs, consuming innate species or that emphasize perennial species, mostly in polyculture can be better biodiversity friendly as compared to energy intensive monocultured yearly crops. The value of biofuel crop in terms of biodiversity can be increase through polyculture technique.

It may decrease the pest and soil fertility issues (Tilman et al. 2006). Conservative biologists may give better input by estimating the biodiversity costs and advantages in cultivation of major portion of land through polyculture technique.

6.4.2 Less Input Feedstock

One possibility to reduce the water requirements for first-generation biofuel production would be a shift towards energy crops that show lower water demands but are currently less often used. However, a general restriction of first-generation biofuel as well as the deployment of freshwater-cooled thermal energy technologies in the future would also limit the additional water (and land) demand in the energy sector, an increase that could be more than offset by changes in the food sector. Due to this potential trade-off, an overall increase in water demand in both sectors is not necessarily an unavoidable trend. Our results provide valuable new insights and information for integrated natural resource management and policy, in particular with respect to biofuel targets. Mitigation measures as discussed in previous studies can further improve water efficiency, especially in regions where water availability might decline over the next decades as a consequence of climate change and other potential ecological changes.

Whether the biofuel crop can give better energy yields per hectare under less input techniques; switchgrass that is grown with much less fertilizer inputs than other crops, especially corn can be the better answer (Graham et al. 1995; Parrish and Fike 2005). The switchgrass has been investigated more comprehensively as compare to any other feedstock. Therefore it can well lead towards advances in best farming practices with high yield and energy extraction (Parrish and Fike 2005). Switchgrass seizes carbon below ground, resulting in a negative greenhouse gas balance (Adler et al. 2007). Other perennial prairie grasses that can serve as biodiversity friendly feedstock must be explored. Wood, crop residues and other perennial species can be ecologically better than grain and grass feedstock for biofuel production. Municipal or industrial wastewater irrigated, poplar and willow plant can also be better feedstock as these can decrease waste streams while achieving inputs needed for high yields (Powlson et al. 2005). Aptness of woody biomass also based on either the native species are used and plants were grown in sustainable style. Conversion of forests to tree plantations with short rotation tree species can be most appropriate for biofuel production, especially Populus species (Popular) and Salix species (willows). The tree energy crops can enhance biodiversity. If biofuel production from woody biomass becomes profitable, it might serve to motivate land restoration and to avoid conversion of native habitats. Meeting current global demand for petroleum via current-generation biofuel would require a doubling of the human share of net primary productivity, which would threaten species and habitats with extinction and sharply decrease global food security (Junginger et al. 2006). Thus, many look to high-efficiency extraction of hydrocarbons from lignocellulosic biomass as a necessary precondition to successful use of biofuel (EEA 2006). Still there exist some practical difficulties in conversion of lignocellulosic biomass to ethanol for production of fuel ethanol at commercial scales. Thus far the conditions are not well defined under which biofuel derived from woody biomass are biodiversity-friendly.

Lal (2006) stressed that crop residues mostly play their role in maintenance of soil fertility and in reduction of soil erosion from rain and wind, and suppress weed growth. Therefore the use of agriculture residue in biofuel production may affect the agriculture. Health of the soils is gauge of crop yields grown for energy or for food. Biofuel crops differ in soil fertility and fertilizer requirements, and in types of soil management or conservation practices compatible with high yields. Switchgrass is better as it takes nitrogen efficiently from soils as compared many other species as corn and other grasses (Parrish and Fike 2005). Very less inputs of fertilizer are needed when mixed native prairie grasses were grown on degraded soils (Tilman et al. 2006). In contrast, corn and soy is cultivated under significant fertilizer quantity (Griffing et al. 2014). That results in major nitrogen overspills into surrounding and distant waterways. Thus greenhouse gas emissions (Powlson et al. 2005; Hill et al. 2006) are increased.

Present energy harvesting efficacies compels to grow energy crops on a massive spatial scale to replace even half of U.S. transportation fuel demands. That has huge consequent effects on biodiversity. Over 20–50% portion of the land in terrestrial biomes has been reserved for food production for increasing world population (Millennium Ecosystem Assessment 2005). Such worldwide losses of habitat are puffed up by increasingly large areas being cleared to meet the demand for biofuel, converting biodiverse lands into monocultures. Extensive tracts of tropical rainforest have been cleared to create oil-palm plantations for biodiesel in Indonesia and Malaysia (Dennis and Colfer 2006). Land to grow corn is increasing very fast to provide fodder for ethanol production in In the U.S. Midwest. More cerrado habitats are being replaced by soybean and sugar cane crops in Brazil (de Cerqueira Leite et al. 2009).

6.4.3 *Microalgae, a Possible Solution*

Microalgal can be ultimate most efficient source of biofuel production, in terms of land use and energy conversion (Chisti 2007; Lawton et al. 2016). Although the technical capacity to create large volumes of biofuel from microalgae have not yet been achieved (Ragauskas et al. 2006), we find this by far the most promising type of alternative, deserving of far greater attention and research. Among energy crops for which commercial-scale refining or demonstration projects are established, cellulosic ethanol and some biodiesels have shown strong energy returns, whereas much-less-developed alternative fuels derived from microalgae have astounding potential for high energy returns. Cellulosic ethanol is derived from grasses, crop and wood residues, and fastgrowing trees (such as poplar or willows) and typically yields >10 times as much energy as is needed to produce the fuel (Powlson et al. 2005).

Similarly, biodiesels have a high carbon content and return 2–6 times the energy used in production (Powlson et al. 2005; Hill et al. 2006).

With second-generation fuel-refining technology, cellulosic ethanol is expected to have much higher yields and consequently could have a much lower ecological footprint (Dien et al. 2003; Gray et al. 2006). The use of microalgae to produce biomass of high energy content has enormous potential for much higher energy yields and a much smaller ecological footprint (Sheehan et al. 1998; Kalscheuer et al. 2006; Chisti 2007). At present, microalgal biofuel are 4–10 times as expensive to produce as petroleum-derived fuels or other biodiesels (Chisti 2007). Nevertheless, only algal or microbial biofuel could be produced with a truly small ecological footprint because the space requirements for conventional crops or tree crops are 1–2 orders of magnitude greater. Even when grown in the least space-efficient manner (in large open ponds), only 200,000 ha would be needed to produce 1 quadrillion BTU from microalgae biodiesel (Sheehan et al. 1998), which is vastly less than the land area needed to produce a similar quantity of corn-derived ethanol (approximately 40 million ha) or soy biodiesel (approximately 20 million ha).

If microalgae were to reach its full potential, dedicating just 1.1% of U.S. cropland to microalgal production could replace half of the country's transportation fuel needs (Chisti 2007). Furthermore, many of the most promising species are diatoms and green algae that tolerate brackish or salt water and thus can be grown without use of increasingly scarce freshwater resources (Sheehan et al. 1998). Given the potential for much higher energy returns with microalgae, relative to other biofuel, this is an area that should be pursued actively.

In contrast to these higher potential yields, most estimates of energy returns from corn-derived ethanol show only a slight benefit, with a net energy balance of only 25%, or 1.25 times the energy needed to produce the fuel, because of the typically high inputs needed to grow the crop and the relatively low energy yield from this feedstock (Farrell et al. 2006; Hill et al. 2006). Thus, the current push to increase use of biofuel primarily through corn-based ethanol is clearly employing the least beneficial alternative fuel. Finally, biofuel may compete with arable land for growing food. In developing countries, this trade-off could result in social and economic problems. In the United States increased corn prices due to ethanol mandates have resulted in wide spread concern about impacts on livestock and other agricultural sectors, as well as on consumers.

6.5 Conclusion

Global water resources are more and more under pressure and the situation will be worse, as the demand for water accelerates due to expanding biofuel production. To acquire energy security and to meet sustainability in 2050. A sustainable biofuel production system must be built on the contemporary infrastructure and current technology, with the implementation of water saving innovative concepts. Obviously there is no single energy source that can sustainably fulfill future energy requirements entirely; however, biofuel are only choice that can meet the energy needs. Biofuel and bioproducts obtained from algal biomass will fulfill the future needs on industrial scale with the technologies for transforming biomass into biofuel that are economically feasible and environmentally friend. Mitigating the land use change impact, requires targeting biofuel production to degraded and abandoned cropland and rangeland; increasing crop yields, use of wastes, residues and compensatory offsite mitigation for residual direct and indirect impacts.

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