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The potential of sustainable algal biofuel production using wastewater resources

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Abstract

The potential of microalgae as a source of renewable energy has received considerable interest, but if microalgal biofuel production is to be economically viable and sustainable, further optimization of mass culture conditions are needed. Wastewaters derived from municipal, agricultural and industrial activities potentially provide cost-effective and sustainable means of algal growth for biofuels. In addition, there is also potential for combining wastewater treatment by algae, such as nutrient removal, with biofuel production. Here we will review the current research on this topic and discuss the potential benefits and limitations of using wastewaters as resources for cost-effective microalgal biofuel production.

Introduction

As the demand for energy continues to increase globally, fossil fuel usage will likewise continue to rise. There is still a plentiful supply of fossil fuels at reasonably low cost, although this is likely to change in the future, but more critically a rising use of fossil fuels is unlikely to be sustainable in the longer term principally due to the attributed increase in greenhouse gas (GHG) emissions from using these fuels and the environmental impact of these emissions on global warming (Hill et al., 2006). There is therefore significant interest in identifying alternative renewable sources of fuel that are potentially carbon neutral (Demirbas, 2009, Hill et al., 2006, Rittmann, 2008). The majority of the current commercially available biofuels are bioethanol derived from sugar cane or corn starch or biodiesel derived from oil crops including soybean and oilseed rape. Although biofuels have the potential to be environmentally beneficial compared to fossil fuels, there is some dispute as to whether these crop-based biofuels are economically competitive compared to fossil fuels. Furthermore, there is even more concern over the impact that the use of these crops for biofuels might have on food availability (Demirbas, 2009, Hill et al., 2006). Biofuels derived from the cultivation of algae have therefore been proposed as an alternative approach that does not impact on agriculture.

Algae, particularly green unicellular microalgae have been proposed for a long time as a potential renewable fuel source (Benemann et al., 1977, Oswald and Golueke, 1960). Microalgae have the potential to generate significant quantities of biomass and oil suitable for conversion to biodiesel. Microalgae have been estimated to have higher biomass productivity than plant crops in terms of land area required for cultivation, are predicted to have lower cost per yield, and have the potential to reduce GHG emissions through the replacement of fossil fuels (for reviews and further analysis see Benemann and Oswald, 1996, Brennan and Owende, 2010, Brune et al., 2009, Chisti, 2008, Dismukes et al., 2008, Huntley and Redalje, 2007, Rittmann, 2008, Schenk et al., 2008, Sheehan et al., 1998, Stephens et al., 2010).

As with plant-derived feedstocks, algal feedstocks can be utilised directly or processed into liquid fuels and gas by a variety of biochemical conversion or thermochemical conversion processes (reviewed by Amin, 2009, Brennan and Owende, 2010, Demirbas, 2009, Rittmann, 2008). Dried algal biomass may be used to generate energy by direct combustion (Kadam, 2002) but this is probably the least attractive use for algal biomass. Thermochemical conversion methods include gasification, pyrolysis, hydrogenation and liquefaction of the algal biomass to yield gas- or oil-based biofuels (McKendry, 2002a, McKendry, 2002b, Miao and Wu, 2004). Biochemical conversion processes include fermentation and anaerobic digestion of the biomass to yield bioethanol or methane (McKendry, 2002a, McKendry, 2002b). In addition, hydrogen can be produced from algae by biophotolysis (Melis, 2002). Finally, lipids, principally triacylglycerol lipids can be separated and isolated from harvested microalgae and then converted to biodiesel by transesterification (Chisti, 2007, Hu et al., 2008, Miao and Wu, 2006).

This latter process, the use of microalgae for biodiesel production has attracted a significant amount of interest. Research as part of the Aquatic Species Program funded by the US Department of Energy extensively analysed the oil production capabilities of microalgae and suggested that potential productivity of oil from microalgae may be significantly greater than oilseed crops such as soybean (Sheehan et al., 1998). This and subsequent research has focussed on identifying microalgae strains that are capable of synthesising significant quantities of lipids and in identifying cultivation conditions that will provide the greatest lipid productivities (Griffiths and Harrison, 2009, Hu et al., 2008). Many studies have focussed on identifying conditions that induce high accumulation of neutral lipids (particularly triacylglycerol) in the microalgae cells, like a nutrient stress such as nitrogen (N) or phosphorus (P) limitation (Converti et al., 2009, Dean et al., 2010, Li et al., 2008, Rodolfi et al., 2009). However, a major limitation of this approach is that despite inducing very high lipid yield, biomass productivity of the cells is often very low and so lipid productivity will not be high. Cultivation conditions that focus on providing high biomass productivity instead may ultimately be more beneficial and may be a more efficient means of increasing total lipid productivity (Griffiths and Harrison, 2009). Furthermore, with large quantities of algal biomass it may be more economically viable to generate energy via the production of the other types of biofuel.

One of the attractions of microalgae as a biofuel feedstock is that they can be effectively grown in conditions which require minimal freshwater input unlike many plant-based biofuel crops, and utilise land which is otherwise non-productive to plant crops, thus making the process potentially sustainable with regard to preserving freshwater resources. For example, microalgae could be cultivated near the sea to utilise saline or brackish water. There has therefore been significant interest in the growth of microalgae for biofuels under saline conditions (e.g. Rodolfi et al., 2009, Takagi et al., 2006). However, another potentially sustainable growth medium for algal feedstock is wastewater.

It has been appreciated for some years now that microalgae can be potentially utilised for low-cost and environmentally friendly wastewater treatment compared to other more commonly used treatment processes (de la Noue et al., 1992, Green et al., 1995, Oswald et al., 1957). The major problem with most wastewaters is the very high concentrations of nutrients, particularly total N and total P concentration as well as toxic metals, which require costly chemical-based treatments to remove them during wastewater treatment (Gasperi et al., 2008). Total N and P concentrations can be found at values of 10–100 $mg L^{-1}$ in municipal wastewater and >1000 $mg L^{-1}$ in agricultural effluent (de la Noue et al., 1992). The ability of microalgae to effectively grow in nutrient-rich environments and to efficiently accumulate nutrients and metals from the wastewater, make them an extremely attractive means for sustainable and low cost wastewater treatment (de-Bashan and Bashan, 2010, Hoffmann, 1998, Mallick, 2002). However, it has also long been proposed that wastewater-grown algae could be used for energy production (Benemann et al., 1977, Oswald and Golueke, 1960).

There have been contrasting assessments as to the economic viability of algal biofuels. A number of studies have argued that biofuel production from algae, particularly biodiesel production is both economically and environmentally sustainable (Brune et al., 2009, Chisti, 2008, Huntley and Redalje, 2007, Stephens et al., 2010), although there have been some sceptical views of the long term viability and economics of biofuels from algae (Reijnders, 2008, van Beilen, 2010, Walker, 2009). One frequent criticism is that the use of fossil fuels in the biofuel production process, in the construction of algal growth facilities, supply of nutrients for algal growth, harvesting of algae and biomass processing, is not often considered in the evaluation of algal biofuel viability and would in fact give rise to a net negative energy output. The use of wastewater resources may be a viable means to enhance the sustainability of algal biofuel production, both by providing a dual use process, an effective growth medium for algal cultivation, and freely available nutrient (particularly N and P) input (Fig. 1). This review will describe the ability of algae to grow in wastewater conditions, the uses of algae in wastewater processes, and the current research on the use of wastewater resources for potentially cost-effective microalgal biofuel production.

Section snippets

Algae and wastewater

Many species of microalgae are able to effectively grow in wastewater conditions through their ability to utilise abundant organic carbon and inorganic N and P in the wastewater. The use of microalgae in wastewater treatment has been long promoted (Oswald et al., 1957), however, chemical processing of waste or the generation of activated sludge is the conventional treatment method. Although the application of microalgae in the wastewater industry is still fairly limited, algae are used…

Use of wastewater for biofuel generation

The ability of microalgae to grow well under certain wastewater conditions, as described above, has indicated the potential of these resources as suitable sustainable growth medium for biofuel feedstock. In this section we will briefly assess in more detail how effective wastewater resources are in providing significant algal biomass and whether this biomass can generate high amounts of lipids for biodiesel production.…

Potential, limitations and future needs of algal wastewater biofuel production

The high biomass productivities and in some cases high lipid productivities that have been demonstrated in many of the reviewed studies of wastewater-grown microalgae suggests that there is real potential in the utilisation of these high nutrient resources for cost-effective biofuel production. However, there are some limitations that need to be addressed.…

Conclusions

Based on current technologies algal cultivation for biofuel production alone is unlikely to be economically viable or provide a positive energy return. Dual-use microalgae cultivation for wastewater treatment coupled with biofuel generation is therefore an attractive option in terms of reducing the energy cost, GHG emissions, and the nutrient (fertiliser) and freshwater resource costs of biofuel generation from microalgae. The high biomass productivity of wastewater-grown microalgae suggests…

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References (76)

S.S. Ahluwalia *et al.*
Microbial and plant derived biomass for removal of heavy metals from wastewater
Bioresour. Technol. (2007)

S. Amin
Review on biofuel oil and gas production processes from microalgae
Energy Convers. Manag. (2009)

S. Aslan *et al.*
Batch kinetics of nitrogen and phosphorus removal from synthetic wastewater by algae
Ecol. Eng. (2006)

L. Brennan *et al.*
Biofuels from microalgae – a review of technologies for production, processing, and extractions of biofuels and co-products
Renew. Sust. Energy Rev. (2010)

S. Canovas *et al.*
Seasonal development of phytoplankton and zooplankton in a high-rate algal pond
Water Sci. Technol. (1996)

S. Chinnasamy *et al.*
Microalgae cultivation in a wastewater dominated by carpet mill effluents for biofuel applications
Bioresour. Technol. (2010)

Y. Chisti
Biodiesel from microalgae
Biotechnol. Adv. (2007)

Y. Chisti

Biodiesel from microalgae beats bioethanol

Trends Biotechnol. (2008)

A. Converti *et al.*

Effect of temperature and nitrogen concentration on the growth and lipid content of *Nannochloropsis oculata* and *Chlorella vulgaris* for biodiesel production

Chem. Eng. Process. (2009)

L.E. de-Bashan *et al.*

Immobilized microalgae for removing pollutants: review of practical aspects

Bioresour. Technol. (2010)