Assessment of Economic Aspects of CO_2 Sequestration in a Route for Biodiesel Production from Microalgae

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Abstract: *The photosynthetic microalgae are unicellular organisms that can fix carbon dioxide efficiently from various sources including the air and exhaust gases from industrial processes during its cultivation. This feature can bring economic benefits in the production process of biodiesel through the Clean Development Mechanism for which may be granted carbon credits for environmental benefits and thus contribute to reducing costs in the production process. This study sought to quantify the contribution of carbon credits in the operating costs of a route for biodiesel production from microalgae proposed by Davis (2011). The results showed a significant reduction in annual operating costs by around 7%. This value can be considered conservative, since the production process based on Davis (2011) can be optimized to reduce operating costs and thus increase the contribution margin of carbon credits to reduce costs.*

Keywords: biodiesel, microalgae, carbon credits, costs.

Introduction

Climate change, what is happening on the globe during the last decades, has attracted international attention by research and search for alternative sources of renewable energy that could be better role and to play with regard to emissions of greenhouse gases.

Therefore, mitigation strategies have become the focus of intense studies, becoming one of the main goals of international environmental policy.

In this scenario, an alternative source to replace fossil diesel is the production of biomass rich in oil for biodiesel production. Thus, oleaginous microorganisms are currently an alternative plausible by short cycles of growth, high lipid content and can be genetically modified by biotechnology. In this context, microalgae have an opportunity of increasing viability, either by cultivation or characteristics of the potential mitigation of environmental impacts associated with energy conversion and utilization.

Due to a higher conversion efficiency of light energy into chemical energy and, consequently, higher carbon capture by the biomass, and also high growth rates compared to other energy crops, resulting in higher productivity of biomass, microalgae emerge as the only renewable source for biodiesel production that will be able to meet global demand, replacing fossil diesel.

Microalgae are unicellular or multicellular organisms that perform photosynthetic functions and can fix carbon dioxide from various sources efficiently. Among them may be mentioned the atmosphere, exhaust gases from combustion sources, among others.

This work intends to evaluate the potential of microalgae have, through their ability to fix CO_2, to impact economically a given productive route to get biodiesel using the benefits of obtaining carbon credits through the Clean Development Mechanism (CDM).

Microalgae - CO2 fixation

The microalgae can fix CO_2 from different sources, among them we can mention the CO_2 from the atmosphere, CO_2 from exhaust gases of combustion from industrial chimneys, and also in the form of soluble carbonates (Wang et al, 2008).

Traditionally, the microalgae are grown in open or closed systems. Closed systems are supplied with air and in the case of open systems, they are naturally exposed to the atmosphere to allow the microalgae capture of carbon dioxide atmosphere for growth of cells. The atmosphere contains between 0.03 and 0.06% CO_2, and this amount is a limiting factor for the cell growth of microalgae (Chelf et al, 1993). Thus, it appears necessary whenever possible the addition of CO_2 in the culture medium of the richest sources of carbon dioxide for example the chimney exhaust gases of industrial combustion sources which contains approximately in average 15% CO_2, providing a more rich environment of this gas in the cultivation of microalgae and offering a potentially more efficient route for CO_2 fixation.

A alternative route is the fixation of CO_2 by chemical reaction to produce carbonates to be used as carbon source for the microalgal cultivation. However this route will not be focus of this work, but will be considered the enrichment of medium with industrial exhaust gases of combustion (Emma Huertas et al. 2000).

Some advantages can be cited for the use of exhaust gases from industrial sources of combustion to CO_2 enrichment on microalgal culture medium.

Such sources of exhaust gases are responsible for more than 7% of total CO_2 in the world (Sakai et al, 1995), and therefore its use in the cultivation of microalgae becomes an agent reducing emissions of greenhouse emissions.

A second advantage that can be cited is that these gases are available with minimum cost or even no cost.

Therefore, certainly higher tolerance of microalgae environments rich in CO_2, the greater the setting of this gas and the better the efficiency of growth microalgal (Maeda et al. 1995).

Matsumoto et al (1997) reported that their studies indicated that high levels of CO_2 were tolerated by many microalgal species and that moderate levels of SO_x and NO_x (150 ppm) were also very well tolerated. Levels of up to 40% of CO_2 were cited by Iwasaki et al (1998) and Ikenouchi & Murakami (1997) for marine microalgae *littorale Chlorococcum.*

Table 1 shows some microalgal species that has been studied for bio-mitigation of CO_2.

Table 1

Microalgae	**CO2%**	**T °C**	***P* g / L.day**	**P_{CO2} g / L.day**	
Chlorococcum littorale	40	30	n / a	1 A	
Chorella kessleri	18	30	0.087	0.163 [a]	
Chorella sp. UK001	15	35	n / a	> 1	
Chorella vulgaris	15		n / a	0.624	artificial wastewater
Chorella vulgaris	air	25	0.04	0.075 [a]	
Chorella vulgaris	air	25	0.024	0.045 [a]	low N
Chorella sp.	40	42	n / a	1 A	
Dunaliella	3 3	27	0.17	0.313 [a]	
Haematococcus pluvialis	16-34	20	0.076	0.143	
Scenedesmus obliquus	air		0.009	0.016	winter
Scenedesmus obliquus	air		0.016	0.031	summer
Botriococcus braunii		25-30	1.1	> 1.0	
Scenedesmus obliquus	18	30	0.14	0.26	
Spirulina sp.	12	30	0.22	0.413 [a]	

[a] calculated as the biomass productivity according to the equation:
P = 1.88 x CO_2 *biomass productivity P (Chisti, 2007)*

Li et al (2006), cited in their work that the growth rate for *Spirulina* is 30 g / m$^{2.}$ day and has been determined to 1 g of biomass produced from microalgae was used 1.8g of CO_2 in agreement with the factor used in the above table.

Route Considered for Biodiesel Production

For the evaluation proposed in this study, was chosen as reference the work of Davis et al (2011), which assesses economically two routes of biodiesel production from microalgae using a set of assumptions which may be perfectly attainable in a panorama of the next five years. The routes chosen by Davis (2011), include the production system via open and closed systems (fotobioreator), however, for this study will only be considered the economic analysis of open system due to lower cost implication associated with this case.

Some assumptions have been imposed for the analysis in question, including some assumptions related to microalgal growth which is summarized in Table 2.

Table 2

Assumed Conditions	**Open System**
Scale (MM gallons per year of algal oil)	10
Algal Productivity (g / m^2 / day)	25
Cell Density (g / L)	0.5
Lipid Yield (dry wt.%)	25
Days of Operation	330

In order to reach the production of 10 MM gal / year established as a target for the production of lipid, has been assumed that the plant receives radiation suitable to achieve its productivity shown in Table 2 and the plant operates 330 days per year .

The open system focus of this analysis was assumed to reach a stable cell density of 0.5 g / L in the culture medium, the default value found in the literature. It is also important to mention that the process used by Davis (2011), has no intention of saying that is the best or optimal, but it is one of the options most likely to become feasible on a commercial scale using the latest technology available in industrial processes today.

Carbon dioxide enrichment as used in the process of the culture medium is concentrated from waste gases from a source near the plant. The cost of the CO_2 purification was considered $ 40 / t.

The production process used by Davis (2011) is shown in Figure 1.

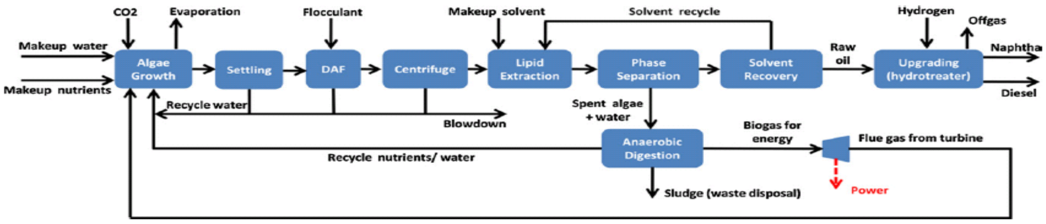

Fig. 1. Schematic of algal biofuel process modeled in Aspen.

Basically, the microalgae are grown in tanks with a depth of 20 cm to maximize the use of sunlight. Microalgae grow in a steady state as shown in Table 2, and are collected continuously at a rate equal to the growth rate to maintain the continuity of the production process. Firstly there is a simple and natural deposition in the tank which holds the microalgae to 1% (10g / L) via auto-flocculation. This stage is followed by flocculation with chitosan and collection by flotation leading to a concentration of 10% (100 g / L). Thereafter, a new concentration is carried out on centrifuge with the material leaving at about 20% concentrate (200g / L).

The extraction process is composed of a combination of mechanical and chemical means using butanol as solvent. This process assumes a 90% efficiency. The residual biomass and the water removed is sent to a treatment station that uses anaerobic digestion to produce biogas that is used as energy source.

The references to financial analysis used by Davis (2011) are as follows:

- Fixed costs

  - Labor: 50 tanks per operator

  - All other costs based on NREL's Aden et al. (2002) (2002)

  - Administrative costs and overheads: 60% of the workforce

  - Maintenance: 2% of the cost of equipment installed

  - Insurance and fees: 1.5% of the total installed

- Indirect costs of capital

  - Contingencies: 30% (due to uncertainties in the production of microalgae in a commercial scale)

  - Working capital: 25% of operating costs

- 10% IRR (internal rate of return)
- Lifetime of the plant 20 years
- Average rate of tax 35%
- Depreciation in 7 years

Table 3 shows the process indicators, and economic resources for the system considered.

Table 3

Data Process, Economic and Resource for Production in Open System

Production Scale	
Production of lipids (MM gal / year)	10
Production of diesel (MM gal / year)	9.3
Land Use	
Pond (acre)	4820
Total Plant (acre)	7190
Resources	
Water demand (MM gal / year)	10000
Evaporated water (gal / gal lip)	570
Water treatment / disposal (gal / gal lip)	430
Demand CO_2 (tons / year)	145000
NH3 for algal cultivation (ton / year)	5100
DAP for algal cultivation (ton / year)	4800
Energy (MM kWh / y)	80
System Costs	
Total Capital Cost ($ MM)	390
Operating Cost ($ million / year)	37
Credit co-products ($ MM / year)	6

Analysis and Valuation of CO_2 Sequestration

For analysis and valuation of CO_2 sequestration, were considered the prerogatives of the study of Davis (2011), and taken into account some data from the study of Xu et al (2011), which present an evaluation in terms of energy balance of the two routes of production of biodiesel from microalgae and it brings some considerations useful and valid for the analysis object of this study, in line with the proposals and conclusions of Davis (2011).

In these terms, Xu et al (2011), show in their energy balance for the dry route that the energy contained in biodiesel produced is 14,706 MJ, from where it can be obtained through the typical calorific value of biodiesel from 9500 kcal / kg the quantity produced by this route, and by this, the yield of conversion of biomass which is represented by:

$$1 \text{ t of dry biomass} \rightarrow 370 \text{ kg of biodiesel}$$

From this value and using the data given by Davis (2011), it is possible to reach the amount of biomass to be produced to achieve the desired annual production of biodiesel and consequently the amount of CO_2 sequestered by the method of cultivation of microalgae.

Having the quantification of CO_2, it is possible to calculate the values to be credited to the annual operating costs of the procedure proposed by Davis (2011), using the market value per ton of CO_2 as the proposed by CDM.

Market value considered for credit per ton of CO_2 is $ 15 / t.

Table 4 shows the references used for the calculation and the values obtained.

Table 4

Calculation of Credit from C to CO2 Sequestration

Density of Biodiesel	0.88	kg / l
Calorific Value	9500	kcal / kg
Annual production	9.3	MMgal/ year
Annual production	30,979,811	kg / year
	30979.8	t / year
1 gal	3.785412	l
1 t dried microalgae	370	kg biodiesel
	0.37	t biodiesel
Annual production of dry biomass	83729.2	t dry weight
Rate Fixing 1.88 x productivity		
Productivity	25	g/m2/day
	0.125	g / L / day
Density of the medium	0.5	g / l
Volume of water for growing	2 x 10^9	l
P CO2	0.235	g / L / day
P CO2 daily	470	ton / day
P CO2 annually	155100	t / year
Market Value of Carbon Credits	15	U.S. $ / t
Credit value for C Annual Production of Biomass	**2326500**	**U.S. $**

Conclusion

The CO_2 fixation by microalgae in the growing stage of the process of biodiesel production from its oil, is presented as a very promising alternative to be explored in order to reduce operating costs of the production process, by obtaining carbon credits for the mitigation carbon known as the main gas that causes global warming. The savings achieved by using carbon credits considering the productive route proposed by Davis (2011), is approximately U.S. $ 2.3 MM / year corresponding to approximately 7% of total annual operating costs. This value is relatively significant considering that the result obtained in this study is conservative of the technological point of view taking into account that the production route can be simplified and streamlined, and so, the contribution of carbon credits on the cost savings can be even more significant.

It is very important that studies and research in this area are encouraged to continue because of strategic importance that the economic and environmental issues represent in the feasibility of using microalgae to produce biodiesel.

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