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Life cycle assessment of green diesel production from microalgae

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ABSTRACT

Many LCA based viability studies have already been done for the production of green diesel from microalgae, still a comprehensive LCA, has not yet been undertaken. Current study aims to find out if the Net Energy Balance(NEB) can further be increased by using a combination of many available agronomical practices & the techniques of production of green diesel from microalgae. The results show that neither open raceway pond nor Photobioreactor routes (Wet and dry routes) yield positive energy balance. The production of green diesel via open raceway pond, both in dry as well as wet route, have less negative NEB and comparatively higher NER than the photobioreactors. Comparison says that open raceway pond dry route has slightly higher value for NER than the wet route. Even with the best possible route (open raceway pond dry route), the total energy use is almost 5 times more than the energy produced, with a negative NEB of 4.07 MJ & very low NER value of 0.20. Study concludes that R & D in the area of green diesel production from microalgae has yet to go a long way & has a huge scope to further lower its input energy demand for biofuel production.

1. Introduction

Depletion of fossil fuels and climate change concerns [1], have led to increasing interest in new sustainable alternatives [2] and clean energy sources [1]. Among the various forms of alternative energy currently under study, biodiesel exhibits particular promise [2].

In recent years, 'Algae for fuel' concept has gained renewed interest [3]. Microalgae store energy in their cells in the form of lipid droplets [4]. The algal oil industry, though presently in its infancy, has tremendous potential to provide future liquid transportation fuels that can improve national energy security by providing less dependence on imported oil. Photosynthetic activity of microalgae is highly efficient [5]. Advantages of algae over other energy crops includes rapid growth rate [2], higher CO_2 fixation [6] and high lipid content [7]. Moreover, the production of microalgae does not require high quality arable land, and therefore does not compete with food crops [5].

2. Life cycle energy balance

2.1. Goal, scope and system boundaries

Every activity involved in the production of biofuels from microalgae is energy intensive and also produces greenhouse gases. Many LCA (Life cycle assessment) based viability studies, with net energy balance (difference of energy input and energy output) or net energy ratio (ratio of energy output to energy input) as the viability indicators, have already been attempted for the production of liquid fuels from microalgae [6,8].

In an LCA study of *Nannochloropsis* sp., though Jorquera et al. found a positive energy demand for biomass production, but the study did not consider harvest, post-harvest and conversion to fuel stage [6]. Clarens et al. in a similar kind of study did not include post biomass production stages. Razon et al. did net energy analysis of the production of biodiesel and biogas from *Haematococcus* and *Nannochloropsis* sp., wherein his results showed large energy deficit for both the species. The scope of the study included only two harvesting techniques, i.e. gravitational settling and microfiltration, of many available techniques. For oil processing only trans-esterification was considered [9]. Even Lardon et al., in his life cycle assessment study of biodiesel production from microalgae found a very low value for energy balance. The production system included only open raceway pond for culture, and trans-

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esterification process for oil processing. The study did not include oil cake processing, but did recommend further processing of oil-cake to reduce external energy demand [8]. In another LCA study, Khoo et al. calculated a total energy demand of 4.44. MJ per MJ biodiesel produced. The scope of the study included an integrated photobioreactor raceway system for algae culture, trans-esterification for oil processing and did not take oil cake into account [10].

It is clear, from the above review of various LCA studies on microalgae, for liquid fuel production, that most of the studies have either found a very low value [8] or negative values for energy balance [9,10]. A few though have found a positive energy balance; have not included the entire value chain [6]. Moreover, almost all of them have considered only a few of the many available methods and techniques of biofuel production from microalgae [8–10].

The net energy ratio depends on the type of techniques used for cultivation, harvesting and oil processing (conversion) [11]. Through a combination of different techniques several different routes can be formed for green diesel production from microalgae. Considering the same, the current study aims to find out if the net energy balance can further be increased by using a combination of many available agronomical practices and the techniques of biofuel production from microalgae.

The functional unit of the study is one hectare. Fig. 1 shows the system boundary with various possible combinations and routes for green diesel production from microalgae. Energy requirements for items with many years of useful life have not been included in the study.

2.2. Open pond description

The design specifications of the raceway ponds considered for the current study comprise of 10 units of open ponds, each 100 m long, 10 m wide and 30 cm in depth.

2.3. Photobioreactor description

Flat -plate airlift photobioreactors have been considered for the current study. Two cases have been studied:

Case 1: The design specifications comprise of 20 flat reactors, each with 105 units. Each unit is 4.53 m long, 1 m high and 10 cm thick. Reactors are 1 m apart from each other to avoid shading. A part of the light energy required for illumination was from sunlight, and the rest was from the fluorescent tubes on both sides of the reactors.

Case 2: The design specifications comprise 39 flat reactors each with 105 units. Each unit is 4.53 m long, 1 m high and 10 cm thick. The reactors were illuminated on both the sides using fluorescent tubes.

The culture conditions for flat plate reactors were kept similar to that by Pruvost et al., 2011 [12]. For all reactors the temperature was controlled at 25 °C and pH was set at 7.5 by air and CO_2 injections. The incident photon flux density was 270 μmol m^{-2} s^{-1}. The number of fluorescent tubes was adjusted accordingly to provide the required photon flux density. In addition, algae was grown under stressful condition of nitrogen depletion, which increased the total lipid content from 20% to 23%.

2.4. Microalgae (*Chlorella vulgaris*)

Chlorella vulgaris is a freshwater species, and is also known for lipid accumulation [12]. Chlorella is a single celled, spherical non-motile green alga 2.0–10.0 μm in diameter. Chlorella occurs in both fresh and marine water. Due to its occurrence in various different habitats it is also called ubiquitous [13].

According to various studies on *Chlorella vulgaris*, it is an ideal

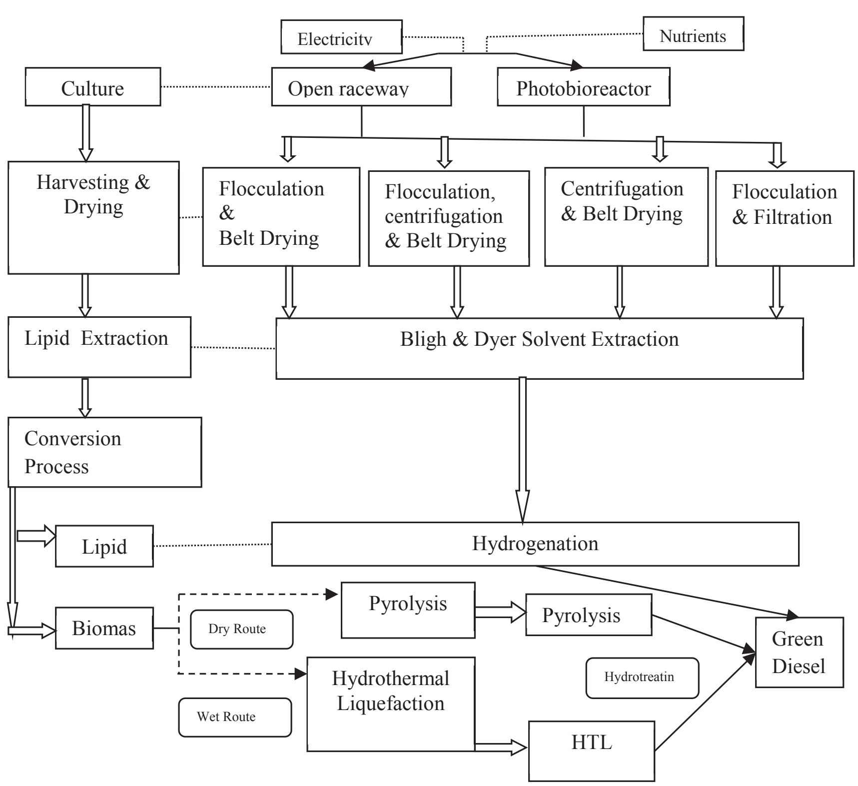

Fig. 1. System boundary, showing the various possible combinations and routes for green diesel production from Microalgae.