



A geographical assessment of vegetation carbon stocks and greenhouse gas emissions on potential microalgae-based biofuel facilities in the United States



Carlos Quiroz Arita^{a,*}, Özge Yilmaz^b, Semin Barlak^b, Kimberly B. Catton^b, Jason C. Quinn^a, Thomas H. Bradley^a

^a Mechanical Engineering, 1374 Campus Delivery, Colorado State University, Fort Collins, CO 80524, USA

^b Civil and Environmental Engineering, 1372 Campus Delivery, Colorado State University, Fort Collins, CO 80523, USA

HIGHLIGHTS

- Direct land use change (DLUC) is evaluated for microalgae biofuel systems.
- Previous LCA of algae to biofuel have overestimated GHG benefits by excluding DLUC.
- GHG emissions due to DLUC of $\leq 20 \text{ gCO}_2\text{eq MJ}^{-1}$ are observed in 85% of potential algal sites.
- DLUC negates positive GHG benefit of algae systems when barren land is not used.

ARTICLE INFO

Article history:

Received 17 June 2016

Received in revised form 1 September 2016

Accepted 2 September 2016

Available online 13 September 2016

Keywords:

Microalgae facilities

Carbon stocks

Direct land use change

Greenhouse gas emissions

ABSTRACT

The microalgae biofuels life cycle assessments (LCA) present in the literature have excluded the effects of direct land use change (DLUC) from facility construction under the assumption that DLUC effects are negligible. This study seeks to model the greenhouse gas (GHG) emissions of microalgae biofuels including DLUC by quantifying the CO₂ equivalence of carbon released to the atmosphere through the construction of microalgae facilities. The locations and types of biomass and Soil Organic Carbon that are disturbed through microalgae cultivation facility construction are quantified using geographical models of microalgae productivity potential including consideration of land availability. The results of this study demonstrate that previous LCA of microalgae to biofuel processes have overestimated GHG benefits of microalgae-based biofuels production by failing to include the effect of DLUC. Previous estimations of microalgae biofuel production potential have correspondingly overestimated the volume of biofuels that can be produced in compliance with U.S. environmental goals.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

The cultivation of microalgae-based biofuel feedstocks have various advantages compared to conventional biofuels feedstocks including higher solar efficiency, high production rates, and utilization of low quality land (Wijffels and Barbosa, 2010). However, the conversion of undeveloped or low-quality land to microalgae cultivation has the potential to be a disadvantage relative to conventional biofuels due to the environmental cost associated with land use change. For conventional biofuels, direct land use changes (DLUC) are a relatively minor component of the biofuels' life cycle greenhouse gas (GHG) emissions because conventional biofuels are

often cultivated on preexisting dedicated croplands (Kendall and Chang, 2009). For example, the DLUC effects of switching from feed corn cultivation to ethanol corn cultivation are very small. In comparison, microalgae cultivation facilities are typically assumed to require the conversion of marginal agricultural, range, or undisturbed land, for which DLUC must be quantified to understand the impact on the life cycle emissions of the biofuel product.

A variety of research efforts have quantified the productivity potential and life cycle environmental impacts of microalgae biofuels. The results of these assessments are found to be highly sensitive to the siting of the modeled facility. Researchers have subsequently considered geographically-specific inputs to these LCAs including meteorological data, land types and availability, carbon dioxide (CO₂) accessibility, and more. The results of these efforts have been an evaluation of the localized life cycle impacts

* Corresponding author.

E-mail address: carlos.quiroz@fulbrightmail.org (C. Quiroz Arita).

of microalgae-based biofuel facilities in the U.S. (Batan et al., 2013; Brentner et al., 2011; Frank et al., 2011; Quinn et al., 2013; Quinn and Davis, 2015; Sills et al., 2013; Vasudevan et al., 2012; Venteris et al., 2013; Wigmosta et al., 2011; Woertz et al., 2014). Sustainability results currently in the literature show algal based systems to have great potential. Combining land and CO₂ availability microalgae has the capability to produce 44 billion gallon per year in the U.S. (Quinn et al., 2013). The water footprint of microalgae biofuels when optimally sited is comparable to that of other biofuels 80–291 m³·GJ^{−1} (Batan et al., 2013; Dominguez-Faus et al., 2009; King and Webber, 2008; Mekonnen and Hoekstra, 2011; Wu et al., 2009; Yang et al., 2011). The environmental impact of algal systems as assessed through net energy ratios and net GHG emissions of microalgae of well-developed facilities are favorable relative to petroleum-derived and biofuels ranging between −0.74 and 0.93 MJ consumed·(MJ produced)^{−1}; and between −95.7 and 534 gCO₂eq MJ^{−1} (Adesanya et al., 2014; Azadi et al., 2014; Batan et al., 2010; Brentner et al., 2011; Campbell et al., 2011; Collet et al., 2014; Frank et al., 2013; Grierson et al., 2013; Handler et al., 2014; Liu et al., 2013; Passell et al., 2013; Ponnusamy et al., 2014; Quinn et al., 2014; Shirvani et al., 2011; Sills et al., 2013; Soh et al., 2014; Vasudevan et al., 2012; Woertz et al., 2014). None of the cited studies have taken into consideration the DLUC associated with the construction of the biofuel facilities. Canter et al. (2014) investigated the emissions associated with the actual construction of the facility but do not consider emissions associated with the disruption of the soil. Ignoring DLUC in these analyses represents a discrepancy in boundary assumptions between microalgae life cycle assessments (LCAs) and the state of the art for conventional biofuels.

In general, DLUC has been shown to be a significant contributor to world-wide GHG emissions through the transport of CO₂ to the atmosphere from carbon stocks stored in soil and above ground biomass (AGB). Currently approximately 30% of anthropogenic carbon emissions are generated by deforestation and forest degradation (Goetz et al., 2009). Although DLUC is considered negligible in evaluating the environmental impacts of many 1st generation biofuels, for some particularly land-disruptive applications, DLUC has been demonstrated to have a significant effect on lifecycle emissions. For an example, gasoline and diesel produced from Canadian oil sand crude is estimated to result in 18–21% higher GHG emissions than U.S. conventional crudes, with the differences due primarily to DLUC (Cai et al., 2015). Recent remote sensing research has resulted in the development of datasets that can broadly represent the AGB and soil organic carbon (SOC) for not only forested, but also for the shrubland, and scrubland that are expected to be utilized for microalgae-based biofuel production facilities (Kellndorfer et al., 2012; Quinn et al., 2013). There is a need to integrate available carbon stock data with microalgae based LCA to have a more holistic understanding of the environmental impact associated with biofuels derived from microalgae.

This study integrates AGB and SOC datasets with microalgae biofuels LCAs into a geographical assessment of the effect of DLUC on the life cycle GHG emissions of microalgae biofuels. The results and quantified sensitivities of this assessment allow insight into the relative importance of DLUC in assessing the sustainability of microalgae based biofuels facilities. Geographically resolved results can be used to quantitatively exclude environmentally-disadvantageous lands from consideration for microalgae biofuels cultivation. These methods and results represent the next level of fidelity in the critical assessment of microalgae biofuels on the metrics of environmental impact and will support long-term investment planning.

2. Materials and methods

To evaluate the life cycle GHG emissions from microalgae-based biofuel facilities, inclusive of DLUC, carbon fluxes from microalgae cultivation and industrial processes must be taken into account (Batan et al., 2010), along with the carbon associated with disturbed AGB and Soil SOC release due to facility construction activities. The modeling workflow, illustrated in Fig. 1, integrates the equivalent CO₂ emissions from these disturbances by applying the Intergovernmental Panel on Climate Change (IPCC) method simulated spatially across the U.S. By adding the effects of DLUC to the results of microalgae biofuels LCAs in literature, we can develop a more comprehensive assessment of the net GHG emissions of potential microalgae-based biofuel facilities in the U.S.

2.1. Spatial inputs to life cycle assessment and direct land use change modeling

The AGB dataset is derived from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) for biogeochemical dynamics, National Aeronautics and Space Administration (NASA) (Kellndorfer et al., 2012). The AGB, which is comprised of the dried matter of living organisms above ground (Mitchard, 2013), was utilized to obtain the land cover carbon, which is measured as tonnes of dried matter per hectare. The AGB maps of the U.S. and the potential microalgae-based biofuel facilities areas processed in our research is included in the [Supplementary material](#) for three scenarios described below.

The potential locations for microalgae-based biofuel facilities and their lipid productivities are derived from previous research on siting of microalgae biofuels facilities as reported in Quinn et al. (2013). Only facilities of more than 400 contiguous hectares are considered. Three scenarios of land use constraints, each with progressively lower restrictions on siting, for locating microalgae biofuels facilities are considered wherein the facilities are only located on 1) barren land with slope of less than 1%, 2) barren land with slope of less than 2%, and 3) forest or pasture or barren areas with slopes of less than 5% (see [Supplementary material](#)). The projection used for this geographical assessment is the North America Albers Equal Area Conic and the datum is the North American 1983.

To take into account the carbon disturbance in the soil due to the potential change in the land use, the total SOC estimated by the U.S. Department of Agriculture (USDA) in the total soil profile at 30 meters resolution has been incorporated in the carbon stocks balance of this assessment. These SOC maps are included in the [Supplementary information](#). By utilizing minimum microalgae facilities sizes of 400 Ha, the carbon stocks liberated by facility construction can be well represented using AGB and SOC datasets at resolutions of 240 m and 30 m, respectively.

2.2. Spatial analysis of direct land use change and related emissions

With these inputs, we use geographical information systems (GIS) tools to synthesize the spatial GHG emissions and environmental impacts of microalgae-based biofuels production across the US. This assessment incorporates the methods of the *Good Practice Guidance for Land use, Land-use Change and Forestry* of the Intergovernmental Panel on Climate Change (IPCC, 2014). Map-algebra was applied to calculate the carbon stocks from the attribute values of the AGB and the microalgae-based biofuel facilities:

$$L_{OL} = A_d * B_w * (1 - f_{BL}) * CF + SOC \quad (1)$$

Download English Version:

<https://daneshyari.com/en/article/4998057>

Download Persian Version:

<https://daneshyari.com/article/4998057>

[Daneshyari.com](https://daneshyari.com)