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Environmental indicators for sustainable production of algal biofuels

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ABSTRACT

For analyzing sustainability of algal biofuels, we identify 16 environmental indicators that fall into six categories: soil quality, water quality and quantity, air quality, greenhouse gas emissions, biodiversity, and productivity. Indicators are selected to be practical, widely applicable, predictable in response, anticipatory of future changes, independent of scale, and responsive to management. Major differences between algae and terrestrial plant feedstocks, as well as their supply chains for biofuel, are highlighted, for they influence the choice of appropriate sustainability indicators. Algae strain selection characteristics do not generally affect which indicators are selected. The use of water instead of soil as the growth medium for algae determines the higher priority of water- over soil-related indicators. The proposed set of environmental indicators provides an initial checklist for measures of algal biofuel sustainability but may need to be modified for particular contexts depending on data availability, goals of stakeholders, and financial constraints. Use of these indicators entails defining sustainability goals and targets in relation to stakeholder values in a particular context and can lead to improved management practices.

1. Introduction

Sustainability considerations influence the development of alternative sources of energy, including algal-based bioenergy. Algae hold promise as a future source of liquid fuel in part because of anticipated sustainability benefits such as the use of degraded, non-agricultural land (Gao et al., 2012; NRC, 2012), high productivity per land area (Clarens et al., 2010), potential net greenhouse-gas (GHG) emissions benefits (Sander and Murthy, 2010), and potential use of wastewater as a nutrient source (Woertz et al., 2009; Craggs et al., 2012). However, technologies, scenarios, and supply chains are still under development, and sustainability costs and benefits are influenced by the choice among many options (e.g., open pond versus photobioreactor, the latter being a closed device for generating biological products that uses sunlight or sugars for energy).

Progress toward sustainability can be estimated using indicators, which represent environmental or socioeconomic elements of sustainability (NRC, 2010a; McBride et al., 2011). The focus of this paper is on environmental indicators of sustainable biofuel production.

The evaluation and selection of environmental sustainability indicators for algal biofuels have not kept pace with those activities for other feedstocks. Indicators of the sustainability of bioenergy pathways have been proposed by many institutions and researchers [e.g., Roundtable on Sustainable Biomaterials (RSB, 2010), Global Bioenergy Partnership (GBEP, 2011), McBride et al. (2011)] and are under development by others such as the International Organization for Standardization (ISO, 2010). Most indicators, principles, and standards for bioenergy have focused on terrestrial, vascular plant feedstocks such as corn, switchgrass, and forest products (CSBP, 2012). Some compilations of indicators and standards mention algae in the context of potential risk from genetically modified organisms (RSB, 2010; Fritsche, 2012). The U.S. National Research Council (NRC, 2012) published potential environmental impact and resource requirement metrics for the sustainable development of algal biofuels and listed the most important potential sustainability concerns but did not identify the most likely benefits or a practically measurable set of environmental sustainability indicators. Hence, technology development for algal biofuels is moving rapidly in the absence of clear means to define and quantify its sustainability.

A practical set of sustainability indicators is needed for algal biofuel processes and site-specific applications for several reasons. Indicators can be used to compare effects of different circumstances under which biofuels are produced, including different initial conditions. Alternatively, algal biofuel systems may be compared with business-as-usual fossil gasoline (Harto et al., 2010) or alternative diesel systems (Dinh et al., 2009; Harto et al., 2010). Indicators can be used to screen technologies for feasibility. Furthermore, indicators may be used to help with facility siting

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