Science of the Total Environment 609 (2017) 205–214

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Restoring low-input high-diversity grasslands as a potential global resource for biofuels

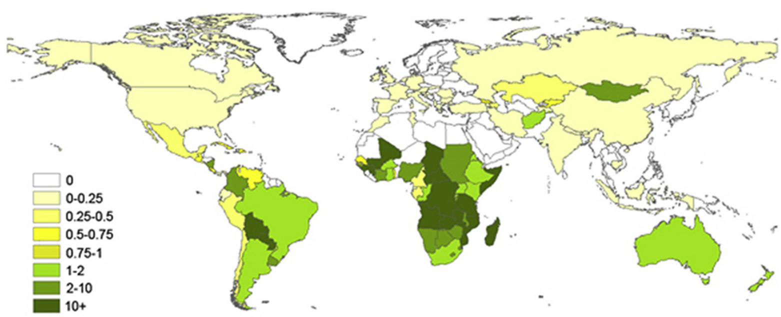
Brian Machovina [a,c,*], Kenneth J. Feeley [a,b]

[a] Department of Biological Sciences, Florida International University, Miami, FL 33199, USA
[b] Department of Biology, University of Miami, Miami, FL 33146, USA
[c] Fairchild Tropical Botanic Garden, Coral Gables, FL 33146, USA

HIGHLIGHTS

- Carbon-neutral/negative energy sources are needed.
- Livestock-free global grasslands could be valuable biomass energy source.
- Biofuel production is estimated via cellulosic ethanol and IGCC-FT processing.
- Biofuel capacity from livestock croplands are estimated for the USA and Brazil.
- Over 40 nations could meet ≥100% of their domestic electric and fuel demands.

GRAPHICAL ABSTRACT



Ratios of potential energy production of pastures from IGCC-FT processing vs. domestic demand for diesel.

ARTICLE INFO

Article history:
Received 5 April 2016
Received in revised form 9 July 2017
Accepted 12 July 2017
Available online xxxx

Editor: Simon Pollard

Keywords:
Biofuel
Grasslands
Restoration
Fischer-Tropsch
Syngas

ABSTRACT

Reducing meat consumption by humans and shifting to more efficient plant and animal protein sources could potentially free up large areas of pasture and feedcrop agricultural land for restoration or conversion to low-input high-diversity (LIHD) grasslands. LIHD grasslands improve biodiversity, carbon sequestration, erosion control, water storage, while also providing opportunities to produce biofuels. We examined the potential of converting pastures globally, and animal feedstock agricultural lands in the USA and Brazil, to LIHD biomass sources and the capacity of these systems to meet national energy demands via (1) cellulosic ethanol and (2) integrated gasification and combined cycle technology with Fischer-Tropsch hydrocarbon synthesis (IGCC-FT) processing. Our analyses, which we argue are conservative, indicate that large amounts of energy, far in excess of many country's current demands, can potentially be produced from IGCC-FT processing of grassland biomass grown on converted pastures, especially in tropical developing countries. Over 40 countries could meet ≥100% of their domestic demands for electricity, gasoline, and diesel. If energy products were shared between countries, the 95 countries with positive energy production yields could meet 46%, 28%, and 39% of their combined electricity, gasoline, and diesel demands, respectively. While it is clearly unrealistic to propose a 100% conversion of pasture lands to biofuel production, these analyses highlight the potential gains in ecosystem services and energy production that could theoretically be achieved on already-managed lands.

* Corresponding author at: Department of Biological Sciences, MMC, Florida International University, Miami, FL 33199, USA.
E-mail address: brianmachovina@gmail.com (B. Machovina).

http://dx.doi.org/10.1016/j.scitotenv.2017.07.109

1. Introduction

Fossil fuels supply approximately 80% of the primary energy consumed in the world (Nigam and Singh, 2011), and the projected rise of global atmospheric CO_2 concentrations (IPCC, 2007; Lawler et al., 2009) driven primarily by the use of these fossil fuels could cause widespread climate-related stresses on natural and human systems (Rosenzweig and Parry, 1994; Machovina and Feeley, 2013; Rosenzweig et al., 2014; Bakun et al., 2015) that far exceed recent documented effects (McCarty, 2001; Walther et al., 2002; Anthony et al., 2008; Feeley et al., 2011). Biomass-derived fuels, (Charles et al., 2007; Escobar et al., 2009), including carbon negative sources (Tilman et al., 2006; Mathews, 2008), can replace fossil fuels for many uses. Further examination and development of economical, high-efficiency and high-capacity biofuel systems is vital for efforts to help reduce net greenhouse gas emissions and consequent changes to climate.

Ethanol, derived primarily from the fermentation by yeast of sugars in sugarcane and corn following hydrolysis of starch in the grain, is the leading biomass-based fuel in the world (Pimentel and Patzek, 2008). Biodiesel can also be produced directly from vegetable oils of oleaginous plants such as soybean oil, rapeseed oil, and palm oil. However, these sources include problems such as limited life-cycle energy efficiencies (resulting in part from utilization of only a small fraction of total plant biomass), extensive use of chemical fertilizers and biocides, high levels of soil degradation and loss, limited to no soil carbon sequestration, low-biodiversity of monoculture production areas, and potential competition with food production (Demirbas, 2008; Havlík et al., 2011).

Potential alternative strategies include processing complex cellulosic components of biomass into simpler sugars prior to ethanol fermentation or the conversion of biomass into electricity, gasoline, and diesel synfuels via integrated gasification and combined cycle technology with Fischer-Tropsch hydrocarbon synthesis (IGCC-FT). Fischer-Tropsch liquids (FTLs) are produced by first gasifying carbon-based materials under high temperature and pressure to produce CO and H_2, which are then catalytically combined to produce straight-chained hydrocarbons that resemble semi-refined crude oil. FTLs can be shipped to conventional petroleum refineries for processing or refined on-site into diesel, gasoline, or jet fuel (Nigam and Singh, 2011). FTLs can be handled by existing transportation, storage, and refueling infrastructure for petroleum products, are largely compatible with current combustion engine technology, and can be blended with petroleum fuels (Takeshita and Yamaji, 2008). FTLs can also be further distilled, hydro-cracked, cleaned and refined into a variety of raw materials for chemical industries.

Several FTL plants operate today utilizing natural gas or coal as feedstocks. The use of biomass feedstocks is currently limited to several small-scale experimental plants and commercialization is limited by technological challenges and especially competition with cheaper fossil fuels. Most oil companies have initiatives to further explore FT technology (IEA/AMF, 2007). In addition, small scale biomass gasification energy platforms are being developed (e.g., All Power Labs; Berkeley, California; allpowerlabs.com) which could supply small communities in underdeveloped areas of the world with local biomass-based energy sources (Nagaraja et al., 2015).

FTLs from biomass are "high quality" in that they are free of sulfur, nitrogen, aromatics, and other contaminants typically found in petroleum products (Takeshita and Yamaji, 2008), greatly reducing emissions causing smog and acidification and eutrophication of ecosystems. In addition, biomass FTLs are estimated to reduce the emissions of greenhouse gases by 60–90% vs. fossil fuels (IEA/AMF, 2007). Indeed with some feedstock production systems with high levels of soil carbon sequestration, such as low-input high-diversity (LIHD) mixtures of native grassland perennials, FTLs can be carbon negative (Tilman et al., 2006). LIHD biomass converted via IGCC-FT can yield 51% more usable energy per hectare of degraded infertile lands than corn-derived ethanol from fertile soils (Tilman et al., 2006). LIHD feedstocks also have low nutrient requirements due to increased soil nitrogen levels from the presence of legumes, require little or no pesticides or herbicides, and can provide valuable plant and wildlife habitat (Tilman et al., 2006). Diversity of the plant species in a grassland is positively correlated with diversity of insects (Murdoch et al., 1972), birds (Vickery et al., 2001), NPP, and biofuel production (Tilman et al., 2006).

Harvesting biomass can be done annually after senescence (and allocation of nutrients into below-ground biomass) without decreasing quantity or quality. However long-term harvesting could require some reintroduction of exported nutrients, especially if harvesting in locations where plant growth is year-round or not performed post-senescence (Jungers et al., 2013). Annual production-scale biomass harvesting from LIHD grasslands has been shown not to affect plant taxonomic or functional diversity (Jungers et al., 2015). In addition, agricultural fields that were previously utilized for crop production can be restored to functioning grasslands by sowing seeds of a few competitive grass species. This, combined with facilitation of the immigration of grassland specialist species by further management, can potentially lead to the restoration of LIHD grasslands suitable for biomass harvesting from converted agricultural fields and species-poor grasslands (Török et al., 2010).

A leading concern with increasing the production of biofuels is the effects on food supplies and prices (Baka and Roland-Holst, 2009; Escobar et al., 2009; Rathmann et al., 2010; Tirado et al., 2010; Ajanovic, 2011; Harvey and Pilgrim, 2011; Taheripour et al., 2011; Duke et al., 2013). An important factor when examining the land requirements for biofuel vs. food production is the type of food being produced. Today, livestock production is the single largest anthropogenic land use - accounting for up to 75% of all agricultural land and 30% of the Earth's ice-free land surface (Steinfeld et al., 2006). Livestock consume 58% of human-appropriated biomass (Krausmann et al., 2008) and one-third of global cereal production (Foley et al., 2011; Alexandratos and Bruinsma, 2012). However, substituting meat with soy protein in the human diet would reduce biomass appropriation in 2050 to a level 94% below 2000 baseline levels (Pelletier and Tyedmers, 2010) and greatly reduce other environmental impacts related to the use of water, fertilizer, fossil fuel, and biocides (Reijnders and Soret, 2003; Machovina et al., 2015). This highlights the potential to greatly reduce the area required to produce food for humans by increasing proportional plant-based protein on a global scale.

Shifting away from ruminant meat sources to more plant-based protein sources and metabolically efficient animal protein sources (i.e. chicken) could potentially free up large areas of current agricultural lands (Machovina et al., 2015) to be restored or converted to LIHD grasslands to produce biofuels. Here we investigate the potential of converting existing pastures and animal feedstock agricultural lands to LIHD biomass sources and the capacity of these systems to meet global energy demands via cellulosic ethanol and IGCC-FT processing. We examine the theoretical capacity of pastures to produce energy via cellulosic ethanol and IGCC-FT processing for all countries worldwide. We also assess the potential conversion of feedstock agricultural lands to IGCC-FT biomass sources in the USA and Brazil. The USA and Brazil are the two leading producers of biofuel and feedcrops, have extensive transportation demands, and contrasting temperate and tropical feedstock production systems.

2. Methods

In order to estimate biomass production potential of land used to support grazing animals, we downloaded the global Pastures, v1 (2000) Map dataset (Pasture Map; Fig. 1) and Global Patterns in Net Primary Productivity, v1 (1995) Map dataset (NPP Map; Fig. 2) from NASA Socioeconomic Data and Applications Center (SEDAC) (Ramankutty et al., 2000; Imhoff et al., 2004) for analysis in ArcGIS 10 (ESRI, 2011). The Pasture Map was created by combining agricultural inventory data with satellite data from Moderate Resolution Imaging