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# Modeling net energy balance of ethanol production from native warm season grasses

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ABSTRACT

There has been an increasing interest in the use of perennial grasses as potential feedstock for ethanol production. The characteristics which make perennial grasses attractive for bioenergy feedstock development initiative are their high yield potential and the high contents of lignin and cellulose. The objective of the study is to model energy input and output and simulate Net Energy Value (NEV) of producing ethanol from native warm season grasses. According to simulated results, the mean NEV of ethanol production from native warm season grasses considered in the analysis was positive. Mean NEV for switchgrass and eastern gammagrass was higher compared to Indiangrass and big bluestem. Although the probability of having positive NEV is high, there is a risk of having negative energy balance under low output scenarios.

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## 1. Introduction

The increasing demand for energy in the U.S has ranked the U.S as the world's largest energy consumer, with increasing gasoline consumption as the single most important factor behind rising dependence on oil. At present gasoline has no major substitute fuel that can be quickly and broadly disseminated into widespread use across the United States during a major disruption or oil pricing shock (Alvarez et al., 2010). The absence of major substitutes called for efforts to ensure an ever increasing production of ethanol to substitute or compliment fossil fuel, which can only be achieved by exploring the economic competitiveness of other sources of biomass, especially the promising native warm-season grasses. The Federal Government has recently created various initiatives to push ethanol as a U.S transportation fuel. The Energy Independent and Security Act of 2007 (EISA) set the following targets: renewable fuels of 36 billion per year by 2022, corn ethanol production at 15 billion gallon per year or close to 1 million barrels a day by 2015, 16 billion gallons per year from cellulosic ethanol by 2022 (Alvarez et al., 2010).

According to Milbrandt (2005), the total biomass resources available in the United States are 423 million tons/year. The Southern states of Alabama, Kentucky, Louisiana, Mississippi, and Tennessee produce 12.3, 7.8, 13.1, 16.1 and 6.7 million tons of biomass per year respectively. Out of the Mid-South biomass resources of 56 million tons, dedicated energy grasses accounted for 21.1 million tons. Switchgrass on Conservation Reserve Program (CRP) land alone contributed 83.6 million tons to the total biomass resources in the United States (Pimental and Patzek, 2005). These figures justify the increasing interest in the use of perennial grasses as energy crops in the US. The characteristics which make perennial grasses attractive for biomass production are their high yield potential and the high contents of lignin and cellulose. Energy crops are produced with the express purpose of using their biomass energetically (Lewandowski et al., 2003). In the United States there are various candidate perennial grasses available which are considerable in their potential productivity, chemical and physical properties, environmental demands and crop management requirements. There has been an increasing interest in the use of perennial grasses as energy crops in the US and Europe. The characteristics which make perennial grasses attractive for biomass production are its high yield potential, the high contents of lignin and cellulose and generally anticipated positive

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**Table 1**
Estimated embodied energy in nitrogen, phosphorus and potassium.

| Source | Unit | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|---|
| FAO, 2000 | MJ/kg | 65 | 9 | 6 |
| Pimental and Patzek, 2005 | MJ/kg | 67 | 17.39 | 13.68 |
| Shapouri, 2001 | MJ/kg | 56.84 | 9.2 | 6.96 |
| Bhat et al., 1994 | MJ/kg | 55.48 | 4.52 | 4.80 |
| Shapouri et al., 2002 | MJ/kg | 42.71 | 2.17 | 12.45 |

environmental impacts (Lewandowski et al., 2003). Also, a number of studies have suggested recently that marginal and abandoned lands could potentially be converted to cellulosic feedstock production which would avoid a large scale conversion of current crop land to biofuel feedstock production (Tulbure et al., 2012).

The contribution of renewable energy resources is vital for economic growth as well as an effective tool for the confrontation of climate change (Zafeiriou et al., 2016). However, to qualify as a viable supplement to fossil fuel, an alternative fuel should not only have superior environmental and economic benefits and potential of high production but also has energy gains over the energy sources used to produce it (Hill et al., 2006). Net energy production has been constantly used to determine energy efficiency of ethanol production from cellulosic as well as grain crops such as corn (Hammerschlag, 2006). In order to qualify for a promising alternative to fossil fuel, it is necessary for the biofuel to have a potential of offsetting cost of extracting and burning fossil fuel. The net energy benefit of replacing the fossil fuel will be determined by not only energy contained in biomass but also energy required to grow the biomass feedstock and convert in to usable form of energy (McLaughlin and Walsh, 1998). Among the tools available for determining energy efficiency of ethanol production, Net Energy Value (NEV) is an important tool. NEV for ethanol production can be defined as the difference between output energy obtained from ethanol production and energy required to produce ethanol (Schmer et al., 2008). Life-cycle analysis is use to estimate energy requirements and demands to determine the environmental and societal risk/benefits (Schmer et al., 2008). Net Energy Value (NEV) is widely used to evaluate net gain; however the estimates are not consistent due to different reasons (Shapouri et al., 2002; Ferrel et al., 2006).

The variation in the net energy gains among different studies could partially be explained by the difference in the biomass yield. Biomass yield of native warm season grasses are sensitive to environmental factors hence could vary significantly from region to region. Also, the incremental biomass losses during harvest and storage can decrease effective yield at refinery gate. These losses will result in increased input used to produce per unit of ethanol (Emery et al., 2014). However, Pimental (2003) reported a negative net energy or an energy loss for ethanol production from both grain crops and cellulosic feedstocks. These studies have further been criticized by other authors for using obsolete data, and incorrectly ignoring some important co-products (Ferrel et al., 2006).

## 2. Methodology

The modeling of Net Energy Value (NEV) was based on direct and indirect energy use for feedstock production and processing. Direct energy is the energy that is used directly on crop production while indirect energy is the energy that embodies in inputs to a process. Energy embodied in a process is the direct energy required in manufacturing of a particular input plus energy embodied in inputs required in manufacturing that particular input (Treloar, 1998). Energy input can be further segregated as follows (see Bansal et al., 2016; Romanelli and Milan, 2004 for details).

Total energy used in biofuel production (input energy)

$$E_{In} = E_L + E_S + E_I + E_M + E_F + E_{La} + E_T + E_P \quad (1)$$

where:

$E_{In}$ total energy input (MJ/ha).
$E_L$ energy used in land preparation (MJ/ha).
$E_S$ energy embodied in grass seeds (MJ/ha).
$E_I$ energy embodied in applied inputs (MJ/ha).
$E_M$ energy embodied in farm machinary (MJ/ha).
$E_F$ energy embodied in fuel used By farm machinary (MJ/ha).
$E_{La}$ energy embodies in farm labor (MJ/ha).
$E_T$ energy used in transporting feedstock to biorefinery (MJ/ha).
$E_P$ energy used in processing cellulose in to ethanol (MJ/ha).

### 2.1. Energy used in applied inputs

Energy used in applied input can be further divided in to energy used in solid input (fertilizer) and liquid input (pesticides).

$$E_I = E_s + E_l \quad (2)$$

where:

$E_s$ energy of solid inputs (MJ/ha).
$E_l$ energy of liquid inputs (MJ/ha).

Energy in solid input can be can be derived as follows:

$$E_s = Q \times E_C \quad (3)$$

where:

$Q$ quantity applied (kg)
$E_C$ energy embodied per unit of fertilizer (MJ/kg).

Accordingly, estimated embodied energy in nitrogen, phosphorous and potassium from various sources is given in Table 1.

**Table 2**
Energy embodied in fertilizers for native grass production.

| Fertilizer and herbicide quantity needed/ha | | | Energy embodied/kg of fertilizer and herbicide | | Energy required (MJ/ha) |
|---|---|---|---|---|---|
| Category | Quantity (kg/ha) | Source | Value (MJ/kg) | Source | |
| Nitrogen | 68.03 | UT Extension, 2009 | 65 | FAO, 2000 | 4421.63 |
| $P_2O_5$ | 45.35 | | 9 | | 408.15 |
| $K_2O$ | 90.70 | | 6 | | 544.20 |
| Herbicide | 12.5 | FAO, 2000 | 240 | | 3000 |
| | | | | Total | 8373.98 |

Source: Bansal et al., 2016.