

Biocomplexity Analysis of Alternative Biomass Routes for Power Generation: Environmental, Economic, and Technical Assessment

Xiaoyun Qin, Tanya Mohan, Mahmoud El-Halwagi

Department of Chemical Engineering

Gerald Cornforth and Bruce McCarl

Department of Agricultural Economics

Texas A&M University

College Station, TX 77843

USA

Abstract- This paper reports on a study employing an integrated approach to analyze the environmental, energy, economic, and technological aspects of using switchgrass (*panicum virgatum*) as a replacement for coal in power generation. We utilize an environmental biocomplexity approach and examine the agricultural, technological, economic, and environmental aspects of such a substitution. In particular, we use the lifecycle analysis approach to examine the environmental aspects (mainly focusing on the greenhouse gas (GHG) implications and their relationship to economic cost and energy use. The lifecycle analysis mainly concentrates on three stages –On farm switchgrass production, conveyance to power plant and utilization in power generation. Economics, emissions and energy consumption during the on farm stage of all processes between the transformation of switchgrass to electricity are being quantified using material and energy balances.

Biocomplexity Analysis of Alternative Biomass Routes for Power Generation: Environmental, Economic, and Technical Assessment

Today biomass has not achieved a great deal of market penetration largely due to its cost relative to the availability of cheap fossil fuel energy sources. This cost is a function of crop yields, biomass to energy conversion rates, usage of production inputs, hauling and harvesting costs and a lack of rewards for environmental improvements in terms of reduced GHG emissions or lessened air pollution loadings. Thus, if the role of biomass were to expand some mix of technological, market and policy developments would need to occur. Several societal trends and developments portend an expanded role for biomass to energy. These involve:

1. A desire to manage greenhouse gas (GHG) emissions globally and the role that biomass through carbon recycling or GHG emissions management might play.
2. A continued desire for rural income support and the bolstering of farm prices and or income opportunities as well as a desire to increase the stability of rural incomes.
3. An enhanced desire for a cleaner environment and a move to reduce emissions from liquid fuel consumption and emissions from coal fired power plants.
4. Continued concern over the degree of energy dependency on foreign sources of petroleum.

In the face of these trends and developments policies could be formulated to promote biomass production and use in energy generation. However, in doing this, policy makers must be careful to insure that viable cost effective strategies are developed that do not switch out one environmental problem for another or one source of GHG emissions for another. In this regard, analysis is needed of the associated economic, environmental, energy and GHG implications of biomass related actions. An environmental biocomplexity approach (e.g., El-Halwagi, 2003) provides an attractive means for delivering such an analysis since it requires a holistic understanding of the interactions that arise in terms of biological, physical, and social components of the Earth's diverse environmental systems.

Perennial, herbaceous energy crops such as switchgrass can be used for developing Bioenergy and Bioproducts. In the United States, switchgrass is considered the most valuable native grass on a wide range of sites. It is noted for its heavy growth in late spring and early summer. It is also valuable for soil stabilization, erosion control and is used as a windbreak.

In order to be profitable, energy crops need to produce high yields of biomass, that are characterized by low concentration of water, nitrogen and ash, but high concentrations of lignin and cellulose. The quality of switchgrass for fuel depends on concentration of energy, primarily derived from cell walls and particularly from lignin and cellulose. Also, it should have low concentrations of elements like potassium, sodium, chlorine, silica, etc. since they cause problems when burned (erosion, slagging and fouling) decreasing efficiency and increasing maintenance costs [Sami *et al*, 2001].

At present, coal is simply a cheaper power plant feedstock when one considers biomass product, hauling, and associated capital costs for plant modifications. However, farm policy, energy security or GHG emission reduction policy options could promote the biomass as an energy feedstock. (note this suggests two additional sensitivity analyses what happens if coal gets more expensive and what happens if ag production costs are reduced)

APPROACH

The use of switch grass means it must be raised on the farm involving establishment, and maintenance then harvested and transported to the power plant and finally combusted with any resultant post combustion wastes hauled away. All of the above-mentioned steps include subcategories and comprise of various activities. The overall process involved with switchgrass from farm level production through delivery to the power plant is shown in Fig.1.

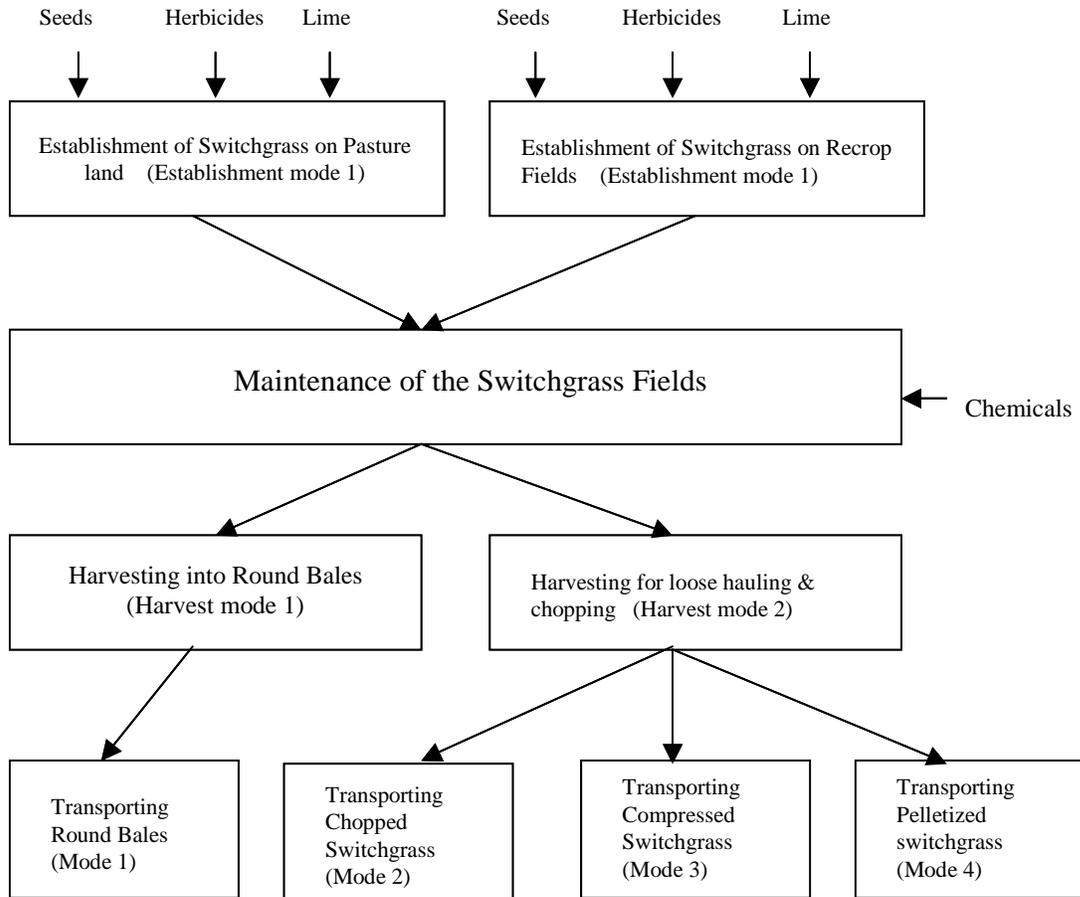


Fig.1: Overall approach for switchgrass preparation including delivery to power plant.

Figure 2 illustrates the key life-cycle stages and processes associated with GHG emission and energy consumptions for switchgrass as an alternate feedstock for power generation

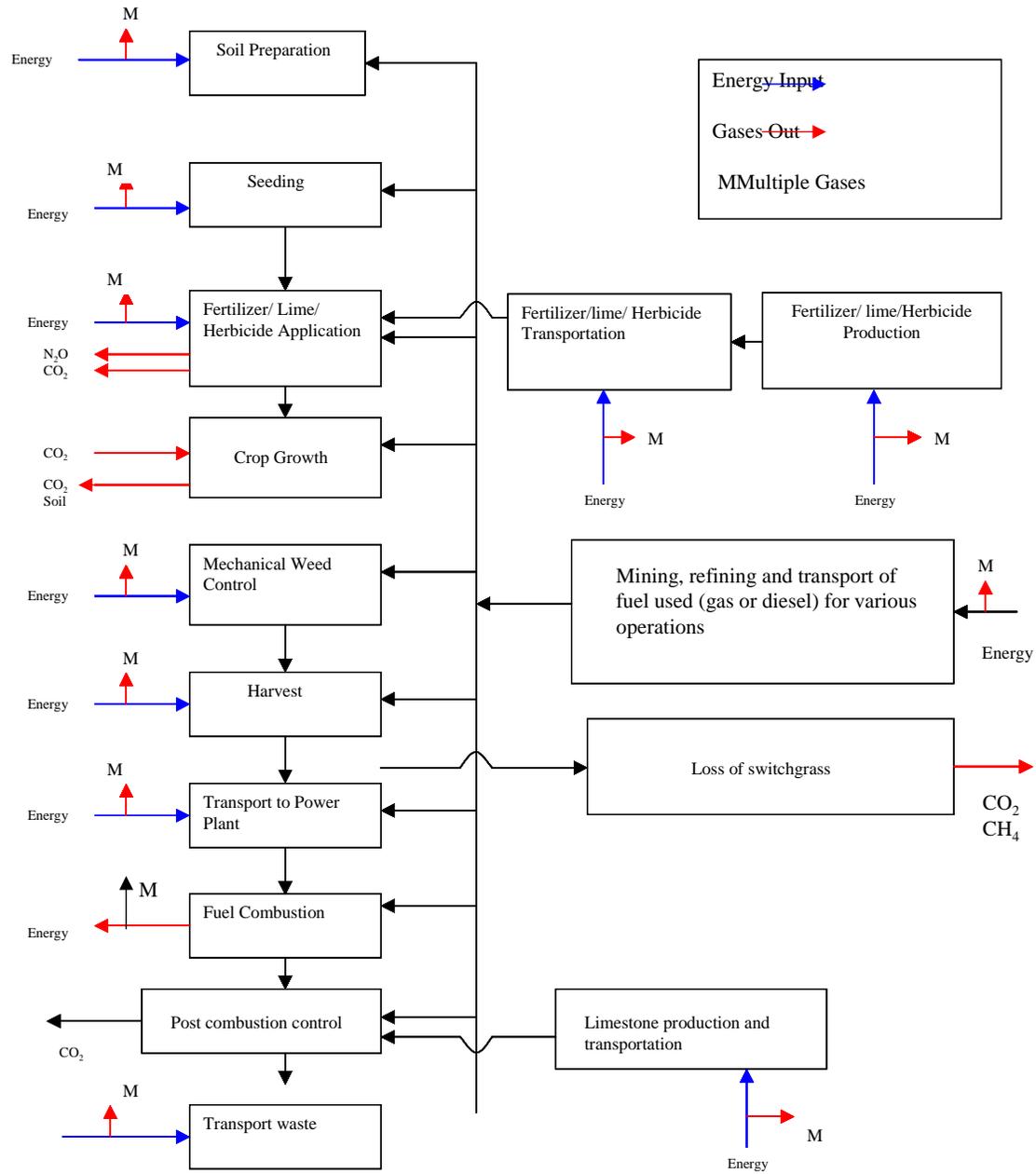


Fig. 2: Emission and energy Pathways for Switchgrass

Switchgrass Data used for this analysis

In this paper, the switchgrass composition used as a basis for computations of the GHG emissions is taken as shown in Table 1.

Table 1: Switchgrass proximate analysis.

Component	% By weight (kg)
Water	11.99
Ash	4.61
Carbon	42.04
Hydrogen	4.97
Oxygen	35.44
Nitrogen	0.77
Sulfur	0.18

The higher heating value (HHV) of switchgrass can be estimated by the following equation:

$$\text{HHV} = 35160\text{C} + 116225\text{H} - 11090\text{O} + 6280\text{N} + 10465\text{S}$$

Where, HHV is the higher heating value in kJ/kg, and C, H, O, N and S represent the mass fractions on a dry ash free basis for carbon, hydrogen, oxygen, nitrogen and sulfur in the fuel respectively. Calculated HHV for switch grass is 16,694 kJ/kg. The tested HHV for switchgrass, which is employed in this model, is 15991 kJ/kg [Sami *et al*, Aerts *et al*, 1997].

The agronomic traits and cell wall constituents for the switchgrass used for analysis is listed below [Lemus *et al*, 2002].

Table 2: Cell wall constituents of switchgrass.

Constituent	% By bone dry weight base
Cellulose	37.10
Hemi cellulose	32.10
Fixed Carbon	13.60
Lignin	17.20

The carbon content of the cellulose and hemi cellulose is found by using their respective structural monomers as shown in Figs. 3 and 4.

respectively. The GHG mitigation during co-firing is better than switchgrass fired alone with the GHG effects of 90.5 grams CO₂-Eq /kWh for switchgrass fired alone and 58.1 grams CO₂-Eq /kWh for 5% switchgrass co fired with coal. This paper discussed several aspects of CO₂-Eq offset as a function of co-firing ratio, hauling distance, yield, and stand life. It indicates that enhancing switchgrass yield is more important than any other alternative method of reducing CO₂ offset, and cofiring is more favorable than Switchgrass firing alone for power generation in most aspects.

REFERENCES

- Aerts D.J., Bryden K.M., Hoerning J.M., Ragland K.W., Co-firing switchgrass in a 50 MW pulverized coal boiler. In: Proceedings of the 1997 59th Annual American Power Conference, Chicago, IL, vol. 59(2), 1997. p. 1180-1185.
- El-Halwagi, M. M., 2003, "Industry and environmental biocomplexity: impact, challenges, and opportunities for multidisciplinary research" J. Clean Technologies and Environmental Policy, 4(3), 135
- Lemus R., Brummer E.C., Moore K.J., Molstad N.E., Burras C.L., Barker M.F., Biomass yield and quality of 20 switchgrass populations in southern Iowa, USA, Biomass and Bioenergy 23, 2002. p. 433-442.
- Sami M., Annamalai K., Wooldridge, Co-firing of Coal and biomass fuel blends, Progress in Energy and Combustion Science 27, 2001. p. 171-214.