BIOCOST-CANADA: A NEW TOOL TO EVALUATE THE ECONOMIC, ENERGY, AND CARBON BUDGETS OF PERENNIAL ENERGY CROPS

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The ability of biofuels to generate positive energy balances and to reduce greenhouse gas emissions will strongly influence the role they will play in future energy portfolios. In a collaborative effort, REAP-Canada and Oak Ridge National Laboratory (ORNL) developed a software program to evaluate the economics, energy and carbon (C) balances associated with producing two perennial energy crops under eastern Canadian soil and climatic conditions. Energy and C budgets generated by the software include fossil fuel energy and C used during cropping activities and the manufacture of farm inputs. A key feature of the software is that the user is able to include a provision for soil organic carbon (SOC) sequestration resulting from crop production. Thus, the impact of modifying rates of organic C sequestration on the net C balance of each bioenergy supply system can be evaluated. Methods and defaults used to develop the software and results from recent simulations are presented.

1. INTRODUCTION

When growing perennial crops to produce energy and mitigate greenhouse gas emissions (GHG), the renewable nature and economic viability of the fuel produced are important concerns. In a joint effort between REAP-Canada and ORNL, a model evaluating economic costs and estimating energy and C balances associated with the production of switchgrass (*Panicum virgatum* L.) and short rotation forestry (SRF) (willows *Salix* sp.), under eastern Canadian agricultural conditions, was developed in 1998. Based on ORNL's BIOCOST software, first released in 1996, BIOCOST-Canada version 1.0 is a user-friendly, EXCEL-based software featuring pop-up windows allowing users to change selected parameters.

2. METHODOLOGY

2.1. Economic model

The economic models used in BIOCOST-Canada are based on the modeling effort performed by both REAP-Canada and ORNL. The economic models being developed by REAP-Canada since 1992 were updated with the latest information available and integrated into the existing models of BIOCOST. Approaches, methodologies and assumptions used by both sets of models were analysed and modified (when necessary) to develop a model that best reflects the conditions of eastern Canada.

BIOCOST-Canada's default values are set to estimate the full economic costs of growing switchgrass and SRF willows in eastern Canada. Estimates for western Canada can be generated by changing default values. Costs computed include variable cash expenses (seeds, chemicals, fertilizers, fuel and repairs), fixed cash costs (overhead, taxes, interest payments) and the cost of owned resources (producer's own labour, equipment depreciation, land rental and the opportunity cost of capital investments). The approach used is consistent with the methods used by the USDA to estimate the cost of producing field crops (Walsh, 1996). Full economic costs estimates are higher than when only variable cash expenses are used, the approach farmers traditionally use for making year-to-year planting decisions. BIOCOST-Canada provides the flexibility of computing costs on either basis, including other subsets. Full economic cost estimates are most useful for policy analysis and in evaluating the long term survival and expansion potential of a farm operation.

BIOCOST-Canada can be tailored to individual needs by changing input prices and quantities, fixed and owned resource costs, yields, and management operations. Production cost outputs are presented annually while per oven dry Megagram (odMg) costs are estimated as the net present value over the entire rotation. Costs are expressed in Canadian dollars ($). For more details on the assumptions used by the economic model, see Walsh (1996) and Girouard et al. (1999).

2.1.1. SRF willow default economic values

SRF willows are grown for a 20-year period with five harvests in a four-year harvest cycle. The crop is planted as 30-cm long cuttings and the default price per cutting and for planting ranges from 0.04-0.20$ and 0.01-0.20$, respectively. Establishment begins by spraying the site the previous fall with a broad-spectrum herbicide (Roundup®), followed by plowing. The site is harrowed twice and planted in the spring. A combination of pre-emergent (Simazine®) and post-emergent (Assure®) herbicides is sprayed for weed control during the growing season in addition to rotary hoeing and inter-row cultivation. No weed control is required in the second season. Chemical control thereafter is assumed to be necessary only in the year following harvest. Fertilizer doses are as outlined in Samson et al. (1995).

Willow harvest is by custom operation, using a Claas-Jaguar harvester that chips the trees as it harvests and blows them into a trailing wagon. Equipment productivity (h/ha) is adjusted for yield and is based on data collected in harvesting trials in the United Kingdom (Deboys, 1996). Additional business costs incurred by a custom operation, such as transporting equipment to the harvest site, storing equipment not in use, labor costs for mechanics and supervisory personnel, general overhead costs not already covered, a profit margin, and income taxes are included in the estimated harvesting costs. The default transportation cost of the chips to a conversion facility is estimated to be \$11.47/odMg.

Mean annual biomass growth increments estimated to be realistic at the present time in eastern Canada range between 7-11 odMg/ha/yr. Productivity is lower during establishment years, therefore annual growth in the first and second years is assumed to be 15 and 65%, respectively, of the mean annual increment obtained over a 4-year cycle of an established crop. In the third and fourth years, annual growth is assumed to be 100%, resulting in the mean annual increment over the 1^{st} cycle to be 70% of what is achieved in subsequent cycles.

Annual production costs are totaled and discounted to provide the present value of these costs. The present value of each production year is summed to obtain the total present value of costs incurred during the life span of the crop. Annual harvestable biomass yields are also discounted to the present value and summed to estimate the total present yield value. Average production cost per odMg is computed by dividing total discounted costs by total discounted yield.

2.1.2. Switchgrass default economic values

The model assumes switchgrass is grown for a 10-year period. In the fall, prior to planting, fields are sprayed with a broad-spectrum herbicide (Roundup®) and plowed. In spring, fields are harrowed twice and planted with a cereal grain drill equipped with a forage seed box. Broadleaf weed control in the establishment year is achieved by spraying Laddock® herbicide. No weed control is assumed to be necessary for the following nine years.

Fertilizer requirements range from 50 to 75 kg of N/ha, and 10 kg P/ha for a spring harvest. No fertilization is required in the establishment year. For a fall harvest, fertilizer requirements are estimated at 70 kg N/ha, 15 kg P/ha, and 30 kg K/ha. Crop harvest is accomplished with a self-propelled haybine and a large square baler. Large square bales are stored on-farm, then delivered to a conversion plant located within a 60-km radius. No provision for storage costs is allowed in the budget. Off-farm transportation costs are estimated to be \$11.47/odMg.

Current annual harvestable yields once the crop is fully established vary between 6-10 odMg/ha for a spring harvest and 8-13 odMg/ha for a fall harvest. Since switchgrass fields usually become fully established in the third growing season, the model assumes that productivity during the establishment year is 35% of the full yield potential, 80% in the second growing season and attaining full productivity in the third growing season.

2.2. Energy model

A main concern of growing crops for energy production relates to the amount of fossil fuel energy required in the production process. BIOCOST-Canada's energy model is integrated into the economic and C emission models. Fossil fuel energy used in manufacturing farm inputs, diesel fuel energy used for cropping activities, and energy in oil and lubricants are taken into consideration.

2.2.1. SRF willow default energy values

The energy used to produce willow cuttings is estimated in Girouard et al. (1999). Annual doses of herbicide and fertilizer used in the economic model are automatically integrated into the energy model. Values from the literature determine the energy associated with the use of one elemental unit of N, P, and K fertilizers and one unit of active ingredient of herbicide.

Diesel fuel energy required (liters/ha) for each pre-harvest and harvest operation is estimated using a formula relating engine horsepower rating to fuel consumption. The values are then multiplied by the energy content of 1 litre of diesel fuel (0.03868 gigajoule [GJ]). For off-farm transport, fuel consumption per kilometer (km) traveled is estimated from a trucking cost study (see Girouard et al., 1999). Energy contained in oil and lubricants is assumed to be 15% of the diesel fuel energy required for each operation. Finally, the energy output:input ratio of the biomass produced is estimated using the higher heating value (HHV) of willow biomass (19.5 GJ/odMg).

2.2.2. Switchgrass default energy values

The switchgrass energy model is similar to the SRF model, with two exceptions. First, the amount of energy needed for seed production is 10% of the energy required for growing the crop during the first growing season, and second, switchgrass HHV is estimated to be 17.5 GJ/odMg.

2.3. Carbon model

BIOCOST-Canada's C model is integrated into the economic and energy models. Carbon released during the manufacture of farm inputs, from burning diesel fuel during cropping activities, and from the use of oil and lubricants, is accounted for in the budget.

2.3.1. SRF willows default carbon values

To determine C emissions resulting from the use of one elemental unit of N, P, and K fertilizers, the quantity of each type of fossil fuel required to manufacture each fertilizer is retrieved from the energy model and multiplied by the C released during combustion of 1 GJ of each fuel (Girouard et al., 1999). The same procedure is used to estimate C emitted from herbicide use. Carbon emissions from diesel fuel used for cropping activities are computed by multiplying fuel amount in GJ/ha required for a specific operation by 19.28 kg C/GJ. Emissions related to oil and lubricants are 15% of the estimates for diesel fuel for each farming activity. Carbon emissions during the production of cuttings use the estimate from Girouard et al. (1999).

Total estimated fossil fuel C emissions are then analyzed in terms of their intensity compared with the quantity of biomass energy produced. The analysis involves three levels, in each of which total kg of fossil fuel C emitted is divided by total number of GJ of harvestable biomass energy produced, a ratio known as the C requirement. The first level analysis (C1) estimates the C requirement of the crop with no provision for soil or biomass C changes resulting from introducing the crop to a piece of land. The second level analysis (C2) introduces the concept of SOC accumulation in the computation of the C requirement. The third level analysis (C3) includes changes in biomass carbon stocks in addition to changes in SOC. The complete details of the carbon requirement analysis are presented in Girouard et al. (1999).

2.3.2. Switchgrass default carbon values

Carbon emission calculations follow the same methodology discussed for SRF willows, except for emissions related to seed production which are assumed to be equivalent to 10% of the carbon emitted in the establishment year.

A summary of the information taken into consideration or generated by BIOCOST-Canada is presented in Table 1.

Table 1
Summary output information generated by BIOCOST-Canada

1a: Economic ($/ha)	1b: Energy (GJ/ha)	1c: Carbon (kg C/ha)
Variable cash costs	Diesel - on farm & transportation	Diesel - on farm & transportation
Fixed cash costs	Fertilizers	Fertilizers
Owned resources	Herbicides	Herbicides
	Seeds/Cuttings	Seeds/Cuttings
Total Economic Cost	Total Energy Required	Total Carbon Input Required

2. Energy Ratio: (Total harvestable biomass energy [GJ/ha])/(Total energy used [GJ/ha])

3. Carbon Requirement Estimates:

$$C1: \frac{\text{Fossil fuel carbon required (kg C/ha)}}{\text{Total harvestable biomass energy (GJ/ha)}}$$

$$C2: \frac{\text{Fossil fuel carbon required - SOC accumulation}}{\text{Total harvestable biomass energy}}$$

$$C3: \frac{\text{Fossil fuel carbon required - SOC accumulation - Change in biomass carbon stocks}}{\text{Total harvestable biomass energy}}$$

3. SIMULATION RESULTS

The simulations performed on SRF willows and switchgrass (Table 2) indicate that SRF willows are more expensive to grow than switchgrass but would have a slightly higher energy balance and lower carbon requirement (C1). All three scenarios investigated have largely positive energy balances along with carbon requirements (C1) in the order 1 kg C GJ^{-1} of biomass energy produced, delivered to a conversion facility. Even taking into consideration carbon emissions resulting from conversion and distribution activities, the resulting biofuels will still most probably emit much less carbon than do fossil fuels, as gasoline for instance releases 18.54 kg C GJ^{-1}.

In the event that soil organic carbon can be increased while growing these crops, these crops could be become a carbon sink as shown by the negative carbon requirement values

(C2) in Table 2. Assuming that both switchgrass and SRF willows are established on a land previously cropped with corn, a preliminary analysis suggests that the carbon requirement (C3) of the bioenergy crops could be further improved. A complete analysis of these simulations can be found in Girouard et al. (1999).

Table 2
Results summary of simulations performed using BIOCOST-Canada

	SRF Willows		Switchgrass			
			Spring Harvest		Fall Harvest	
Yield (odMg/ha/yr)	7	11	6	10	8	13
Total Variable Cost ($/odMg)	74	55	35	30	34	31
Total Economic Cost ($/odMg)	108	76	81	61	71	57
Energy Ratio	18	24	16	19	17	18
Carbon Requirement Estimates						
C1 (kg C/GJ)	0.99	0.74	1.05	0.89	1.04	0.97
C2[a] (kg C/GJ)	-2.90	-1.74	-4.15	-2.22	-2.85	-1.43
C3[a, b] (kg C/GJ)	-7.28	-4.53	-6.54	-3.65	-4.64	-2.53

[a]assumes a SOC accumulation rate of 500 kg C ha^{-1} yr^{-1}.
[b]see Girouard et al. (1999) for more details.

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