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An economic assessment of the use of short-rotation coppice woody biomass to heat greenhouses in southern Canada

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ABSTRACT

This study explores the economic feasibility of fossil fuel substitution with biomass from short-rotation willow plantations as an option for greenhouse heating in southern Ontario, Canada. We assess the net displacement value of fossil fuel biomass combustion systems with an integrated purpose-grown biomass production enterprise. Key project parameters include greenhouse size, heating requirements, boiler capital costs and biomass establishment and management costs. Several metrics have been used to examine feasibility including net present value, internal rate of return, payback period, and the minimum or break-even prices for natural gas and heating oil for which the biomass substitution operations become financially attractive. Depending on certain key assumptions, internal rates of return ranged from 11–14% for displacing heating oil to 0–4% for displacing natural gas with woody biomass. The biomass heating projects have payback periods of 10 to >22 years for substituting heating oil and 18 to >22 years for replacing a natural gas. Sensitivity analyses indicate that fossil fuel price and efficiency of the boiler heating system are critical elements in the analyses and research on methods to improve growth and yield and reduce silviculture costs could have a large beneficial impact on the feasibility of this type of bioenergy enterprise.

1. Introduction

Growing concerns over energy security, volatility of fossil fuel prices, global CO_2 emissions and the need to revitalize rural economies have all added to the desire and urgency of developing biomass feedstock options for bioenergy. Bioenergy plantations have been identified as an approach to offset greenhouse gases produced through the use of fossil fuels for both industrial and domestic heating purposes [1–3]. The basic idea is that woody crop biomass sequesters carbon from atmospheric CO_2 and can also be used as a carbon-neutral substitute for fossil fuels [4]. However, while the possible use of biomass fuels as an alternative energy source is well recognized, perspectives on the costs and benefits of the fossil fuel substitution are still required. In Canada there has been growing interest in economic assessments of the attractiveness of fast-growing plantations as a source of bioenergy and fossil fuel substitute for small and medium-size regional projects [5–7].

Indeed the development of more efficient biomass energy heating systems has had appeal since the time of increasing fossil fuel prices in late 1970s. In Canada and the US the

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number of wood-burning facilities has increased significantly since 1993 [8]. For example, in 2005 renewable fuels, such as hydro, wind and biomass, contributed 16% of total primary energy consumption in Canada. Of this 0.59 EJ were supplied by biomass, or 4.83% of total primary energy. However, most of this capacity is in the pulp and paper industries where bioenergy now constitutes more than 55% of the total energy needs [9].

This study explores the potential of using woody biomass from short-rotation willow plantations as an alternative heat source for greenhouse or other small industrial building operations. The idea of a more integrated biomass supply and utilization cycle is appealing because the supply could in principle be derived from a local, renewable resource base. Greenhouses can also support food production and food security in colder climates and are already a significant component of horticulture and agriculture operations in Canada, particularly in southern Ontario. Approximately 634 ha of cucumber, peppers and tomatoes are grown in Ontario greenhouses representing 58% of total such vegetable acreage in Canada [10]. Greenhouse heating fuel costs (e.g. heating oil and natural gas) typically represent 20–35% of total production costs and arguably represent the highest single proportion of production costs for greenhouse operators in Ontario [11]. Security of feedstock supply is also a factor of interest for industrial bioenergy systems [12]. Reliance on mill or agricultural residues as well as other wood wastes may increase uncertainties in supplies especially in situations where purpose-grown feedstocks are not available [13]. In more populated areas such as southern Ontario, the costs of biomass supply may also increase if transportation distances are large [14].

In principle short-rotation coppice (SRC) plantations used in solid fuel-fired biomass boilers could provide a self-sustaining local energy supply. SRC willow production does have some history in Canada, starting in the 1980s [15,16], again through Canada's "Energy from the Forest" program in 1990s [17] and more recently through other federal initiatives, such as the Canadian Biomass Innovation Network and the ecoENERGY Technology Initiative (http://www.cbin-rcib.gc.ca) [18]. Willow clones have several characteristics that make them attractive including the potential for high and consistent biomass production in short time periods, ease of vegetative propagation from dormant hardwood cuttings, a broad genetic base and ease of breeding, and the ability to resprout after multiple harvests [19–22]. They can also provide environmental and other co-benefits, such as offsetting greenhouse gas emissions, improving ground water and soil quality, expanding some forms of wildlife habitat while potentially revitalizing rural economies [23].

This study specifically examines the economic feasibility or attractiveness of using purpose-grown short-rotation willow biomass to displace fossil fuels for greenhouse heating needs in southern Ontario. We include/integrate both biomass production and its utilization in greenhouse boiler systems in a single simulation model. Besides the standard economic metrics, such as of Net Present Value (NPV) and Internal Rate of Return (IRR), we also estimate payback periods, probabilities of the project generating positive net returns, break-even unit prices for displacing fossil fuels in natural gas or heating oil systems. Break-even prices provide a useful reference because individual entrepreneurs and other decision makers often have their own sense of future price paths. These price expectations are critical, but unknown, inputs to cost-benefit studies. We also conduct sensitivity analyses to determine the most important variables in our model and scenario formulation. This interpretation can help to identify research needed to both reduce uncertainty in the results and also enhance the attractiveness of this type of biomass enterprise [24].

2. Methods and data

2.1. Model

We have developed a spreadsheet-based Short-Rotation Coppice–Greenhouse Heating Model (SRC–GHM). The model incorporates establishment, management and land rental costs for growing the biomass, as well as transportation costs, capital and maintenance costs for a solid fuel-fired biomass boiler. Results are presented in the form of net present value (NPV) and internal rate of return (IRR) estimates at the end of the project lifetime. We also calculate the payback periods and plantation area requirements for given fossil fuel price expectations. Benefits are calculated as the value of displacing heating oil or natural gas with woody biomass. For simplicity we assume fixed prices for natural gas and heating oil through the lifecycle of the project. Fixed prices are more transparent and less demanding for interpretation than, for example, making additional assumptions about inflation, more complex price paths and differing relative prices. Fig. 1 summarizes the basic elements of the model including the various biophysical and greenhouse components and output metrics. NPV is the primary performance metric and includes the following cost and revenue streams over the project cycle:

$$NPV = PV_{Benefits} - PV_{Cost} = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \quad (1)$$

where $PV_{Benefits}$ is the present value of displacing fossil fuel; PV_{Costs} is present value of the SRC establishment and maintenance costs, boiler system, land rental, harvest and other annual costs; n is the project life span (21 years here); r is the real discount rate (6% and 12% in this study). While these rates may seem high for longer-term forest plantation investments our analyses are intended to provide insights to private sector investors or entrepreneurs with generally higher hurdle rates. This was the original policy interest motivating the study. The IRR is the discount rate which results in the NPV equaling zero [25]. The payback period is the length of time required for the project NPV to equate to zero for a given set of assumptions and break-even prices are derived for both heating oil and natural gas scenarios. The break-even value indicates what the oil or natural gas price would have to be for the biomass enterprise to be equally profitable, again for the given set of assumptions. We have represented principal model parameters in the form of probability distributions thus generating mean, minimum and maximum expected values of model parameters and the output metrics. The simulations were performed using @RISK [26], a spreadsheet tool that allows for