Changing the energy climate:

clean and green heat from grass biofuel pellets

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Abstract

Volatile energy markets, concerns over energy security and international agreements to reduce greenhouse gas (ghg) emissions have created unique opportunities for biofuel development. Feedstock for pelletized fuels from warm season grasses such as switchgrass (*Panicum virgatum)* can be grown for $3-4/GigaJoule (gj) and pelletized for $3/GJ with only minor emissions of CO_2. Assuming hay prices provide a shadow price for switchgrass, the price volatility of switchgrass appears low relative to the price volatility of fossil fuels. Using close-coupled gasifer combustion technology, switchgrass fuel pellets emit 85%, 91%, 87% and 89% less CO_2 than electricity, heating oil, natural gas and propane, respectively. Every 100 ha of switchgrass converted into pellet form and used to displace the same fuels in space-heating applications prevents the emission, on average, of 1800 tonnes of CO_2. Heating an average Ontario house with a 90GJ heat demand costs $1213 with switchgrass pellets compared to $2234, $1664, $882 and $2302 with electricity, heating oil, natural gas and propane, respectively. An estimated 23 and 130 million acres of agricultural land in Canada and the US, respectively, could be converted to perennial grass biofuel production. The depressed farm sector would benefit economically from energy farming through economic diversification and absorption of excess production capacity. Low-grade heat energy derived from grass pellets could displace some of the 30,000 GigaWatt Hours of electricity currently used for home heating in Quebec, Ontario and Manitoba. Surplus electricity could be exported where it would likely displace fossil-fired electricity. Pelletized grass biofuels could provide consumers without access to natural gas with less expensive heating options than fossil energy options. For consumers with access to natural gas, the price premium for switching to a much lower ghg emitting alternative would be modest, except during natural gas price spikes when switchgrass could be cheaper. Developing the switchgrass pellet market could help ease the political challenges in implementing the Kyoto Protocol.

Key words: switchgrass, biofuels, pellets, energy, CO2, greenhouse gases

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Introduction

The sharp increase in global oil prices, continental natural gas and propane prices and some regional electricity prices during 2000-2001 demonstrated consumer vulnerability to fluctuations in price and supply. Responding to concerns about the security of intercontinental energy supplies, U.S. government policy has focused on expanding fossil fuel production and conversion. This strategy runs counter to the recent ratification of a modified version of the 1997 Kyoto Protocol, the first international binding treaty to mitigate global warming by reducing greenhouse gas (ghg) emissions (the US was not a signatory). A dedicated effort to develop and promote clean sources of alternative energy would go a long way towards safeguarding the planet's energy and environmental security.

Biofuels derived from perennial grass crops are consistent with Canada's commitments to reduce ghg emissions by 5.2% from 1990 levels by 2008-2012 under the Kyoto Protocol (unfccc, 1997). Energy obtained from perennial plant biomass is considered closed loop carbon because carbon released during combustion is recycled into plant tissues through photosynthesis. The only net loading of CO_2 into the atmosphere takes place during production and processing operations. Some crops may also lead to carbon sequestration in the soil creating a carbon sink (Zan *et al*., 2001).

Wood, wood chips, and more recently wood pellets, are the most traditional and ubiquitous biofuels. Innovations in the production of corn ethanol, cellulosic ethanol and bio-diesel from oilseeds, as well as the efficient combustion of crop residues such as straw, mark significant advances in biofuel development. More recently, REAP-Canada has pioneered the development of biofuel pellets made from switchgrass (*Panicum virgatum*) for use in space heating applications. Warm season grasses such as switchgrass can be grown in many parts of North America at a cost of $3-4/GigaJoule (gj). Between 100-250 gj (the energy potential contained in 15-40 barrels of heating oil) can be harvested per hectare of farmland. About 88% of the original energy in a switchgrass crop is available for heating purposes (Samson *et al.,* 2000). Switchgrass pellet heating systems represent a tremendous opportunity to displace high grade energy forms such as natural gas, heating oil and electricity with a low grade, clean burning fuel. Large sections of the enormous North American agricultural land base are suited to producing herbaceous feedstocks.

The comparative advantage of grass biofuels

Densification of wood residues into pellets for space and water heating has been used in Europe since the 1970s. Pelletizing creates a clean burning, convenient and concentrated fuel from fibrous waste such as sawdust. Sweden and, to a lesser extent, Spain and Portugal, are currently export markets for Canadian wood pellet processors. Wood pellet heating systems are considered an essential component of European plans to reduce ghg emissions and are targeted by incentive programs in countries such as Germany, Norway and Sweden (Malisius *et al*., 2000). In North America there are an estimated 500,000 pellet burning stoves and furnaces with wood pellet production totaling about 650,000 tonnes of annual consumption (PFI, 2001). However, further expansion is hampered by shrinking supplies of wood residues, partly a result of the more efficient use of the waste fraction of delivered roundwood. For example, between 1990 and 1998, the volume of wood residues declined by almost 50% across Canada with the exception of Quebec (Hatton, 1999). The bulk of residues in Quebec are bark, an inferior product due to a high ash content. Many pellet manufacturers believe the declining feedstock supply is critical and that further expansion of the pellet fuel industry depends on developing a sustainable, dedicated supply of feedstock (Greg Gillepsie, Shaw Resources, personal communication).

Warm season grasses offer a substantial opportunity to generate large quantities of herbaceous feedstock. This high yielding plant group includes corn (*Zea mays*), sorghum (*Sorghum bicolor)* and sugarcane (*Saccharum sp.),* as well as switchgrass. In contrast to cool season grasses such as timothy (*Phleum pratense)* and reed canary grass (*Phalaris arundinacea)*, warm season grasses are 50% more water efficient and respond well to high temperatures. These are desirable qualities if the planet continues warming. In addition, efficient water use produces biomass with reduced ash levels and improves biofuel combustion quality (Samson and Mehdi, 1998). Switchgrass is one of three dominant tallgrass species native to the North American tallgrass prairie and numerous ecotypes grow wild from Mexico to Labrador. In cool regions, more chilling tolerant warm season grasses such as prairie sandreed (*Calamovilfa longifolia*) and prairie cordgrass (*Spartina pectinata)* may be more productive energy crops.

The comparative advantage of switchgrass as a pelleted biofuel stems from technical, economic and environmental factors. These include:

- Switchgrass is adapted to marginal soils typified by drought and low fertility, which generally do not support cash crops such as corn and soybean.
- Switchgrass stands have a lifespan of at least 6-10 years and fossil fuel inputs are limited to field operations necessary for establishment, annual maintenance and harvesting operations. The net energy output to input ratio, including processing and transportation costs, is 14.6:1, (Girouard *et al*., 1999; Samson *et al*., 2000).
- Pelleting is a relatively simple and inexpensive means for upgrading energy quality. About 88.2% of the original biomass energy is recovered in a usable energy form after proicessing versus 25.5, 30.9 and 15.7% for switchgrass co-fired with coal, cellulosic ethanol from switchgrass and grain corn ethanol, respectively (Samson *et al.,* 2000).

- The Dell-Point "close-coupled gasifier" stove is capable of burning switchgrass pellets with fuel conversion efficiencies in the same range as modern oil furnaces (80-85%). Each gj of grass pellet energy delivered to consumers thus directly substitutes for one GJ of delivered oil and can be utilized without significant air pollution. Switchgrass pellets have a CO_2 loading value of 8.17 kg CO_2/gj (Figure 1) compared to 62.13, 89.67 and 58.32 kg CO_2/gj for natural gas, heating oil and electricity, respectively (nrc, 2001b).
- Biomass, a low grade heat source, is used to displace high grade heat forms such as oil, gas and electricity for space and water heating, effectively adding value to the biomass and freeing energy for transportation and electrical applications.

Heating Costs and CO_2 emissions

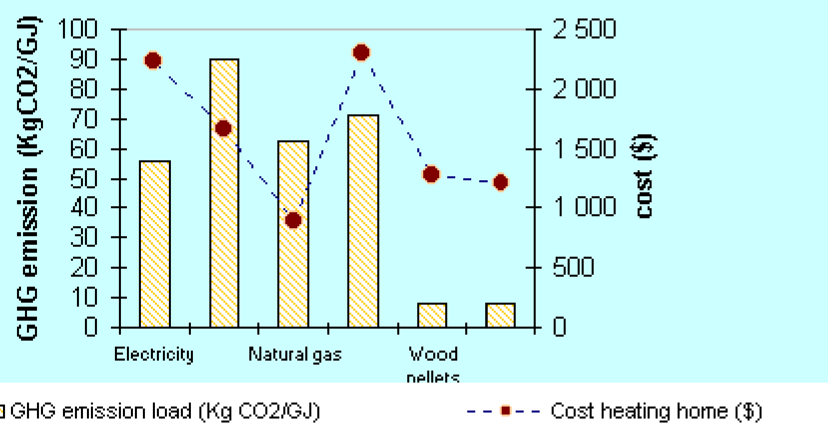

Figure 1.Heating costs and GHG emissions in Ontario for major fuel types

<u>Assumptions:</u>

The heating costs of fuel types are unrelated and the dotted line connecting the different heating costs is for illustrative purposes only.

Electricity has an energy content of 0.0036 GJ/kWh, a delivered fuel value of 8.93 cents/kWh, a $C0_2$ loading value of 55.46 kg $C0_2$/GJ and is converted at 100% efficiency. The approximate electrical mix for Ontario is: 27% hydro-power, 39% nuclear, 13% coal, 13% oil, 6% natural gas and 2% other (NRC, 2000).

Heating Oil has an energy content of 0.0387 GJ/l, a delivered fuel value of 58.64 cents/l, a $C0_2$ loading value of 89.67 kg $C0_2$/GJ, and is converted at 82% efficiency.

Natural Gas has an energy content of 0.03723 GJ/m^3 ,a delivered fuel value of 31 cents/ m^3, a $C0_2$ loading value of 62.13 kg $C0_2$/GJ, and is converted at an average efficiency of 85%

Propane has an energy content of 0.0253 GJ/l, a delivered fuel value of 55 cents/l, a CO2 loading value of 71.14 kg CO2/GJ, and is converted at an efficiency of 85%.

Wood Pellets (bagged) have an energy content of 19.8 GJ/tonne, a delivered fuel value of $230/tonne, a $C0_2$ loading value of 8.17 kg $C0_2$/GJ, and are converted at 82% efficiency

Switchgrass Pellets (bagged) have an energy content of 19.0 GJ/tonne, a delivered fuel value of $210/tonne (based on a $70/t feedstock cost, $60/t pelleting costs, $20/t transport, plus 40% retail mark-up) and a $C0_2$ loading value of 8.17 kg $C0_2$/GJ, and are converted at 82% efficiency.

[b] Heat estimates made for a new detached 2000 sq. foot home with a 90GJ heat requirement (Natural Resources Canada, 1997). The analysis does not include capital costs associated with equipment.

Switchgrass pellets offer significant savings over the costs for electricity (46%), heating oil (27%) and propane (47%) in Ontario (Figure 1). Grass pellet heating systems may also be attractive in regions such as Manitoba and Quebec where electricity use for space heating is high, and in Atlantic Canada where heating oil is widely used. Although the domestic heating market for propane is relatively small, switchgrass could be very cost-effective in rural markets where propane is widely used for crop drying and heating swine and poultry barns. It is clear that among the major heating fuels natural gas is currently the most economical heat source. However, it is worth noting that natural gas prices have decreased by about 60% in recent months, and that further price fluctuations could occur. The gap between grass pellets and natural gas could be narrowed further if bulk pellets were distributed for $175/t. The cost of heating a house with a 90 GJ annual heat demand would decrease from $1213 to $1011. Bulk pellet handling using pneumatic systems and trucks is being introduced in Europe to improve convenience and lower costs to the consumer (Malisius *et al.,* 2000).

The 'closed coupled gasifier' technology used in the Dell-Point stove is a product of a partnership between Dell-Point Technologies (http://www.pelletstove.com/) and Natural Resources Canada's Advanced Combustion Laboratory to design a high efficiency, low emission pellet stove capable of burning fuels with moderate ash levels such as bark and switchgrass. The stove's high efficiency compares favourably with the more modest efficiencies of 35-69% for most pellet stoves on the market. The design is such that a lower operating temperature exists in the bottom of the gasifier where the first stage of combustion occurs, allowing the ash to fall through a grate into an ash pan, reducing the formation of clinker (fused residues). A gaseous combustion stage then occurs in the top of the gasifier. The stove's efficiency stems from a reduced and carefully regulated in airflow.

Switchgrass pellets burned in the Dell-Point stove produce 86-91% fewer CO_2 emissions than electricity, heating oil, natural gas or propane, respectively (Figure 1). Substituting energy crops such as switchgrass for fossil fuels used in space heating can be a highly effective ghg reduction strategy. For example, every 100 ha of switchgrass converted to pellets and used to displace heat derived from fossil fuels would save, on average, about 1800 t of CO_2 from being released to the atmosphere (Table 1).

Table 1. Reduction in CO_2 emissions (tonnes) per 100 ha of switchgrass used to displace fossil fuel derived heat in Ontario.		
Fuel Type	*Kg CO2 Emitted* *per 19,000 GJ*	*CO_2 emissions (,000 tonnes) avoided by displacing fossil energy with switchgrass*
*Electricity*a	3.5 million	3.35
Heating Oil	1.7 million	1.55
Natural Gas	1.2 million	1.05
Propane	1.4 million	1.25
Switchgrass	0.155 million	

19,000 GJ is the heat equivalent of 100 ha of switchgrass yielding 10 t dry matter/ha converted to pellets.

a Based on a marginal fuel mix for electricity generation of 50% coal and 50% natural gas.

Switchgrass for carbon sequestration

Perennial grasses have the potential to sequester carbon in terrestrial carbon sinks by virtue of continuous soil cover, reduced tillage, prolonged root growth and repeated above ground biomass production. It is not clear, however, whether high yielding biomass crops with low fertilizer applications such as switchgrass cause soil carbon to increase. Zan *et al.* (2001) found that soil carbon accumulation under a fall switchgrass harvesting regime was highly dependent on soil type and fertility levels. Spring harvested switchgrass, on the other hand, a favoured option for biofuel production, might increase soil carbon due to plant leaf and tissue loss over winter. A more telling indicator of the overall carbon balance of a switchgrass crop may be a comprehensive accounting of carbon cycling resulting from management inputs such as fertilizer and machinery use. Although soil carbon storage may help limit CO_2 emissions, sequestration does little to address the fundamental problem of society's high reliance on fossil fuels. Displacing fossil fuels with grass-based biofuels, on the other hand, should have a much more immediate and long lasting impact on reducing ghg emissions than "buying time" strategies such as carbon storage.

Comparative costs of perennial grass energy crops

Perennial grass crops have an advantage over other energy sources in that feedstock costs should follow long-term agricultural commodity prices. North American hay, corn and wheat prices have remained relatively stable over the past 20 years (Figure 2), and because crops such as switchgrass share many of the same production characteristics as hay, this trend bodes well for keeping the long-term cost of grass biofuels low.

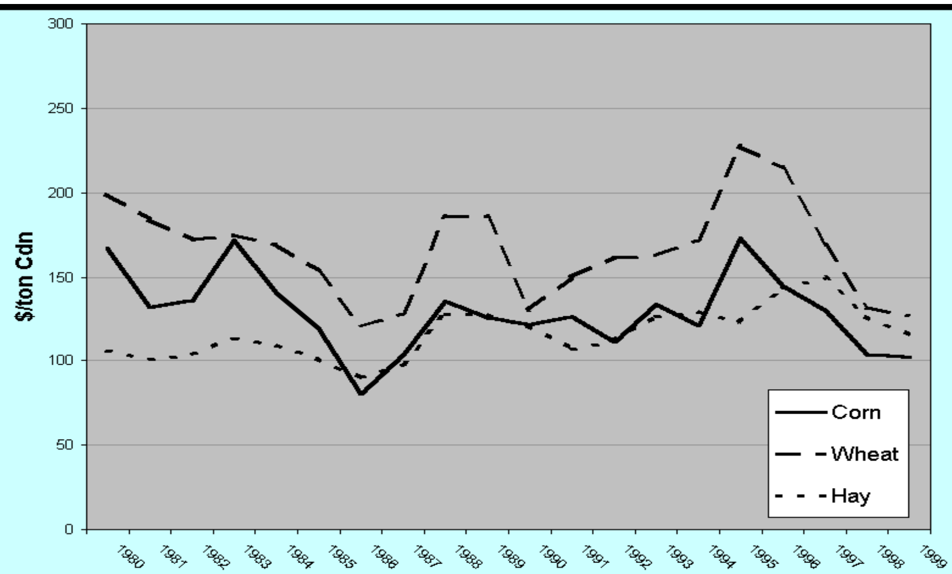

Figure 2 Average price of Corn, Wheat and Hay (1980-1999) - Source USDA

In contrast, fossil energy prices have fluctuated considerably. In Manitoba, for instance, domestic energy costs have steadily increased over the past two decades whereas long-term hay prices measured in $/GigaJoule have remained stable (Figure 3).

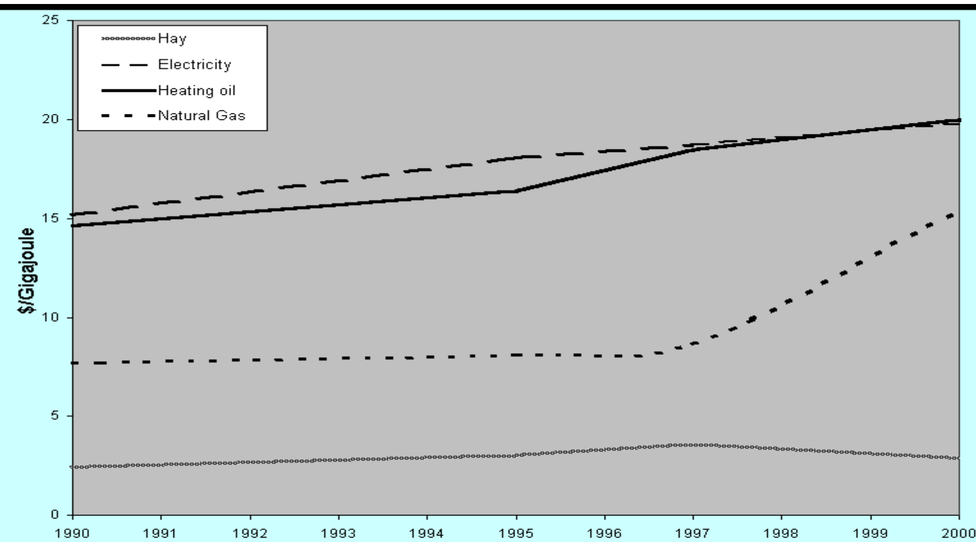

Figure 3 Comparative Costs of Hay Prices vs. Residential Heating in Manitoba

The rising prices of fossil fuels means a major agro-industrial opportunity will develop to convert low cost, solar energy into ghg-friendly biofuels. The comparative advantage of biomass should increase in the future and several factors will contribute to the long-term price stability of grass biofuels. Historically, agricultural commodity prices have declined in real dollars as a result of advances in crop production, mechanization and plant breeding efforts. These traditions are expected to continue. Modest price increases can be expected from rising input costs (fuel and fertilizer) and possibly higher land costs should large areas be converted to switchgrass production. However, the net impact on biofuel prices will, in all likelihood, be a fraction of the rate of increase in fossil fuel prices.

Estimating the potential North American land base for energy farming

An estimate of the land area available for biofuel production from perennial grasses in Canada and the U.S. is 23 and 130 million acres, respectively (Table 2). The estimates are based on the assumption that 10% of the major annual cropland, 30% of hay land and 30% of seeded pasture could be planted to switchgrass. For the U.S., 10% of the nation's massive pasture/rangeland acreage is also included. The projected biofuel acreage represents about 14 percent of the agricultural land base in both nations.

Table 2 Farmland in North America and Potential Acreage for Biofuel Production

	Land Use	***Millions of Acres***	***Percent Converted***	***Millions of acres of Biofuel Production***
Canada				
	Major annual crops	70.9	10%	7.1
	Hay	15.3	30%	4.6
	Seeded pasture	10.7	30%	3.2
	Summerfallow	15.5	30%	4.6
	Pasture & rangeland	38.6	10%	3.9
	Woodland and other land	16.9	0%	0.0
	Total	167.9	13.9%	**23.4**
U.S.A.				
	Major annual crops	240.2	10%	24.0
	Hay	60.8	30%	18.2
	Seeded pasture	64.7	30%	19.4

	Orchards & vegetables	8.8	0%	0.0
	Idle cropland & fallow	56.9	50%	28.5
	Pasture & rangeland	396.0	10%	39.6
	Woodland & other land	104.4	0%	0.0
	Total	931.8	13.9%	**129.7**

Potential biomass production in Canada could total approximately 14 million tonnes (Table 3). The most promising regions to develop a grass pellet fuel industry are those where hay production costs are low (generally indicated by low land rents) and heating costs are high. Based on hay prices, land costs, switchgrass performance and winter heating costs, the best regions in North America are the states of North Dakota, South Dakota, Nebraska, Minnesota, Wisconsin, and the provinces of Manitoba, Ontario, and Quebec.

Manitoba is a good location for a biofuel pellet industry because hay prices are among the lowest in North America. The gap between delivered heat costs of conventional energy sources and hay costs is rapidly growing. In real dollars, long-term hay prices remain flat at $3/GJ ($55/tonne) while delivered heat costs for natural gas, oil and electricity are rising. With current pellet production costs estimated to be $3.2/GJ ($60/tonne) and a conversion efficiency at combustion of 80%, delivered heat costs for grass pellet fuels are projected to be in the $10-$14.00/GJ range.

Ontario has the largest production potential for fuel pellets due to the province's large land base and good productivity, but feedstock costs are approximately $65/t due to higher land rents and production costs. The highest production costs are in Quebec ($75/t) where subsidies in the agricultural sector have inflated land and crop values. Major factors influencing the economic viability of pellet biofuels will be market proximity and competing market prices of fossil fuels. Both Ontario and Quebec have the advantage of large energy markets relatively close to feedstock production areas. However, Quebec has a relatively inexpensive supply of electricity whereas natural gas is used to heat about half the detached homes in Ontario (nrc, 2000).

Table 3 Farmland in Selected Provinces and Potential for Biofuel Production

Location	***Land use***	***Total acreage*** *(millions acres)*	***Percentage converted***	***Area*** *(millions acres)*	***Potential Production*** *(million tonnes)**
Ontario					

	Annual crops	5.8	10	0.58	**6.12**
	Hay	2.3	30	0.69	
	Seeded pasture	0.86	30	0.26	
			Total	**1.53**	
Quebec					
	Annual crops	2.06	10	0.21	**3.95**
	Hay	2.29	30	0.67	
	Seeded pasture	0.48	30	0.15	
			Total	**1.04**	
Manitoba					
	Annual crops	9.54	10	0.95	**3.66**
	Hay	2.02	30	0.60	
	Seeded pasture	0.88	30	0.26	
			Total	**1.83**	

Values derived from agricultural statistics (1997-2000, OMAFRA, MAPAQ, Manitoba Agriculture, Statistics Canada).

*Based on yields of 4.0, 1.8, and 2 t/ha for Ontario, Quebec, Manitoba, respectively.

Hydro-rich provinces such as Quebec and Manitoba may consider increasing electricity exports by encouraging domestic energy users to switch from electrical heating to biofuels. Heat from biomass represents an excellent opportunity to displace high-grade electric energy with an energy form that is more appropriate to its final application. Energy substitution could be a major opportunity to reduce GHG emissions while increasing energy exports.

Substituting switchgrass biofuels for electricity currently used for space heating in Quebec, Ontario and Manitoba could make an estimated 30,000 gwh of power available for export (Figure 4; source, NRC, 2001a). This would produce a substantial increase in sales given that the national electric energy exports totaled 18,779 gwh between January and May, 2001, and earned revenues of $2.8 billion (Strange, 2001). Alternatively, the energy could be used for shutting down aging nuclear plants or displacing production from high CO_2 loading coal plants. Regardless of the electricity's end use, displacing even a small portion of the Canadian electrical heat demand with grass pellet biofuels would produce significant economic returns and help Canada meet its obligations under the Kyoto Protocol to reduce ghg emissions.

The prospects for pellet biofuels

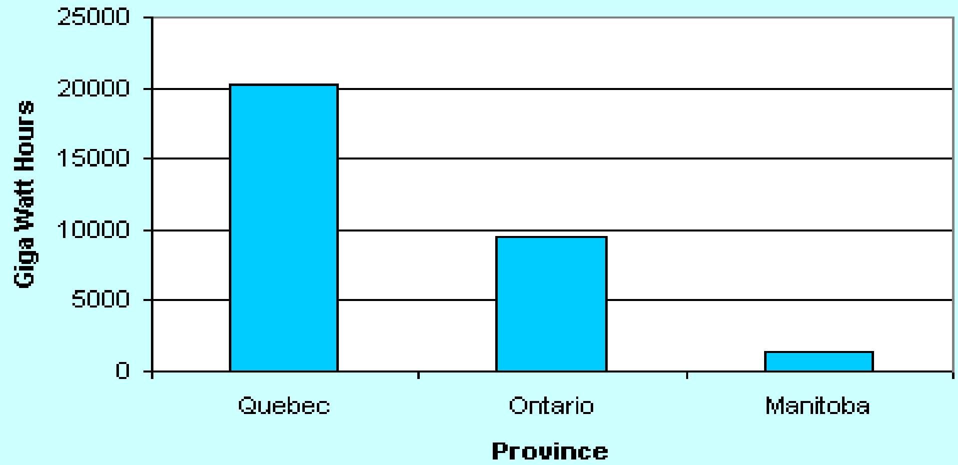

Figure 4. Potential savings from avoiding electricity use in residential heating applications in three provinces.

Switchgrass fuel production in Eastern Canada is positioned for the early stages of commercialization. Production methods are well established (Girouard *et al.,* 2000) and plantations are established in Ontario, Quebec, and, more recently, in Manitoba. One pellet plant in southwest Quebec is currently processing small quantities of pellets, and several alfalfa dehydrators in Ontario have expressed interest. Production of multi-fuel pellet stoves (grass pellets, wood pellets, corn) by Dell-Point Technologies (www.pelletstove.com) is about to undergo a major expansion. The establishment of a pellet fuel industry will probably proceed incrementally as alternative heat markets and production capability evolve. A major constraint to pellet production is accessing pelletizing infrastructure close to switchgrass production zones. Currently pelleting capability exists at alfalfa or wood pellet plants, but these are not always located in the most favorable regions (areas with marginal soils, low land rents) for switchgrass production. Plants in eastern Canada have relatively low outputs of approximately 10,000 tonnes/yr. New plants with a 100,000 tonne capacity could considerably reduce production costs.

Other important areas of research and development include the production of consistently high quality fuel (low dust, durable pellets), efficient transportation, delivery and storage techniques, and increasing overall convenience to the consumer. Europe is the industry leader in this area and various innovations such as pneumatic delivery trucks are being modeled after the livestock feed industry. Crop yields could be improved by breeding varieties with greater seedling vigour, earlier maturity and better over-wintering qualities. Demonstration projects, dissemination of information, marketing, advertising and gaining consumer acceptance are essential steps to promote widespread implementation of pellet heating systems. Pellet fuel development would be further advanced by applying close coupled gasification technology to the design and manufacture of larger capacity pellet furnaces. This would spur a more rapid demand for feedstock and greenhouse operators and livestock farmers reliant on propane could grow their own fuel and considerably reduce their fuels costs.

A viable pellet industry would contribute ancillary benefits to the depressed farm sector. The farm crisis caused by surplus production capacity and low prices could be largely alleviated by diverting a significant portion of the agricultural land base into energy farming. Farmers would benefit by utilizing marginal farmlands to increase energy self-reliance or by producing a marketable crop. Construction and operation of pellet plants would also boost non-farm employment in rural areas.

The development of the pellet fuel heating sector will be driven in part by future energy prices and environmental considerations. Current prices in the futures market suggest that natural gas will remain the most economical heating fuel in the short-term. Pellet heating appears to be most attractive in rural areas not serviced by natural gas, and areas where prices for electricity, heating oil and propane are high. The volatile energy market, however, means there is no guarantee that gas prices will stay low. Moreover, the environmental costs associated with CO_2 emissions must be factored in to the economic equation. For instance, the prospect of accumulating carbon credits for clean burning fuels or the imposition of a carbon tax on fossil fuels would considerably narrow the economic gap between switchgrass pellets and natural gas. If the political support and direction exist to implement the Kyoto Protocol as intended, grass biofuel pellets may well become a heating option of choice.

Conclusion

Pelletized warm season grasses such as switchgrass have enormous potential as a biomass fuel even though the current share of the heat energy market filled by wood fuel pellets is small. The potential exists because of high crop productivity, a large and underutilized agricultural land base, an efficient energy conversion system and increasing prices for fossil fuels. CO2 emissions can be reduced by approximately 1800 tonnes for every 100 ha of switchgrass converted to pellets and substituted for fossil fuels used to generate heat. Replacing high-grade energy forms such as oil, natural gas and electricity with grass biofuels is a logical and necessary step in developing a cost-effective and environmentally responsible energy supply. Contrary to prevailing beliefs that reducing GHG emissions will raise societal energy costs, pelletized biofuels can provide consumers with lower cost and more secure heating options than many conventional sources. As energy prices continue to be volatile and mitigation of global warming becomes more urgent, grass biofuel pellets will become an increasingly attractive heating option in North America.

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