Changing the energy climate: clean and green heat from grass biofuel pellets

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Abstract

Uncertain energy supplies and international agreements to reduce greenhouse gas (GHG) emissions have created unique opportunities for biofuel development. Pelleted fuels from warm season grasses such as switchgrass (*Panicum virgatum)* can be grown for $3-4/GigaJoule (GJ) with only minor emissions of CO_2. Using close-coupled gasifer combustion technology, switchgrass fuel pellets emit 86%, 91%, 71% 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 fossil fuel for space-heating prevents the emission of 1000 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 $3251 with electricity, heating oil, natural gas and propane, respectively. An estimated 23.4 million acres of agricultural land in Canada could potentially be converted to perennial grass biofuel production. The depressed farm sector would benefit economically from energy farming. 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 or used to replace nuclear or coal burning plants. Contrary to prevailing beliefs that reducing GHG emissions will raise societal energy costs, pelletized grass biofuels could provide consumers with less expensive and more GHG-friendly heating options than most fossil energy sources. If the political support and direction exist to implement the Kyoto Protocol as intended, grass pellets could well become a heating fuel of choice in North America.

Key words: switchgrass, biofuels, pellets, energy, CO_2, greenhouse gases

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Introduction

The sharp increase in energy prices during 2000-2001 served as a reminder of the global dependence on diminishing supplies of fossil fuels. Although oil and natural gas prices have eased somewhat from their peaks, consumers remain vulnerable to fluctuations in price and supply. Increased demands for electricity and widespread blackouts in California have heightened concerns about the security of energy supplies. Although the response of the U.S. government has been to promote increased production of oil, coal and nuclear energy, this strategy should be seen as a short-term option with unacceptable long-term consequences. The recent ratification of a modified version of the 1997 Kyoto Protocol is the first international binding treaty to mitigate global warming by reducing greenhouse gas (GHG) emissions. A dedicated effort to development 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 essentially carbon neutral because carbon released during combustion is effectively 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 sinks (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 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 heat contained in 15-40 barrels of heating oil) can be harvested per hectare of farmland and about 88% of the original energy in a switchgrass crop can be captured as usable heat (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. Sweden and, to a lesser extent, Spain and Portugal, are currently export markets for Canadian wood pellet processors. Densification creates a clean burning, convenient and concentrated fuel from fibrous waste. 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 (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 1988 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, 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 as the planet enters a period of global warming. In addition, efficient water use produces biomass with reduced ash levels which improves the combustion quality of the fuel (Samson and Mehdi, 1998). Switchgrass is one of three grass species native to the North American tallgrass prairie and numerous ecotypes grow wild from Mexico to Labrador. In cool regions, more chilling tolerant 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 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, assuming a feedstock energy content of 18.5 GJ/t (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 as heat 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, 2001).

- 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

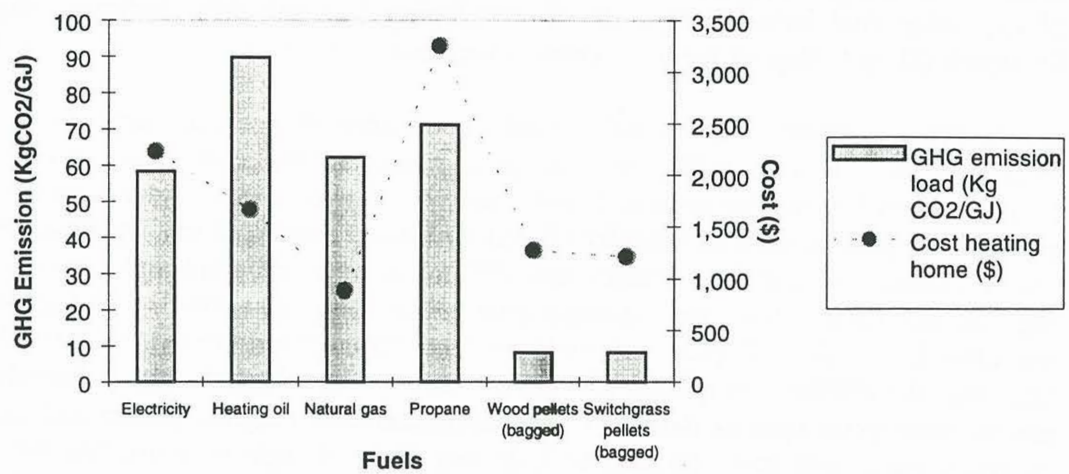

Figure 1 Heating cost and GHG emissions in Ontario for major fuel types

Assumptions:

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 CO_2 loading value of 58.32 kg CO_2/GJ and is converted at 100% efficiency. The approximate electrical mix for Ontario is: 59% hydro-power, 12% nuclear, 16.1% coal, 7% oil, 5% natural gas and 1% other (NRC, 2000).

Heating Oil has an energy content of 0.0387 GJ/l, a delivered fuel value of 58.64 cents/l, a CO_2 loading value of 89.67 kg CO_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 CO_2 loading value of 62.13 kg CO_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 77.68 cents/l, a CO_2 loading value of 71.14 kg CO_2/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 CO_2 loading value of 8.17 kg CO_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, a CO_2 loading value of 8.17 kg CO_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 of electricity (26%), heating oil (27%) and propane (63%) 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 heating greenhouses and 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). Another option for cost reduction currently being developed by VIFAM Pro-Services Inc., Montreal, is a mobile pellet system for direct, on-farm use.

The 'closed coupled gasifier' technology used in the Dell-Point stove is a product of a partnership between Dell-Point Technologies (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. 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%, 87% and 89% 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 1000 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

Fuel Type	*Kg CO_2 Emitted per 19,000 GJ*	*CO_2 emissions (tonnes) avoided by displacing fossil energy with switchgrass*
Electricity	1.1 million	945
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.

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 help increase soil carbon. Zan *et al.* (2001) found that accumulation of soil carbon was dependent on soil type and fertility levels and that switchgrass plantations did not always function as a carbon sink. 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 credits for 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.

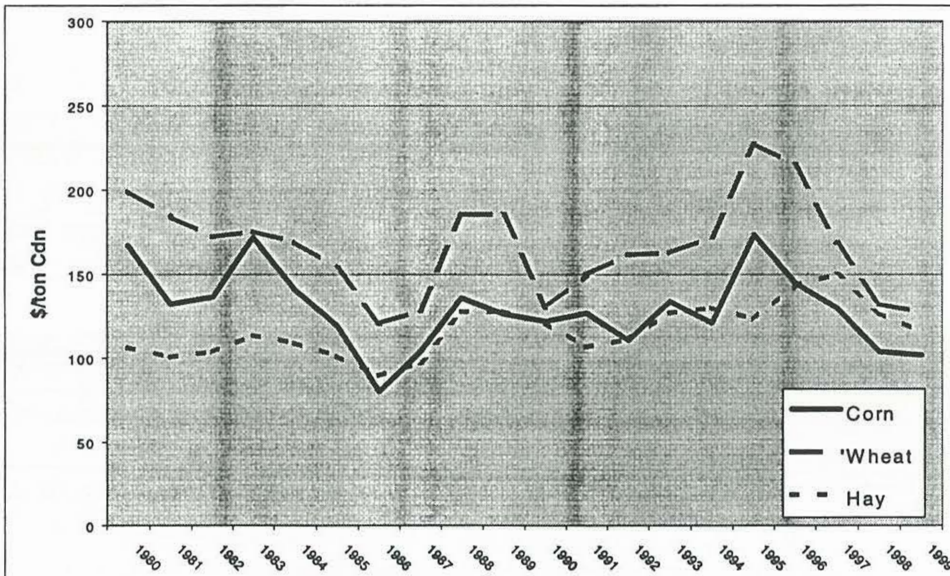

Figure 2 Average price of Corn, Wheat and Hay (1980-1999) - Source USDA

In contrast, fossil energy prices have been gradually increasing. 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).

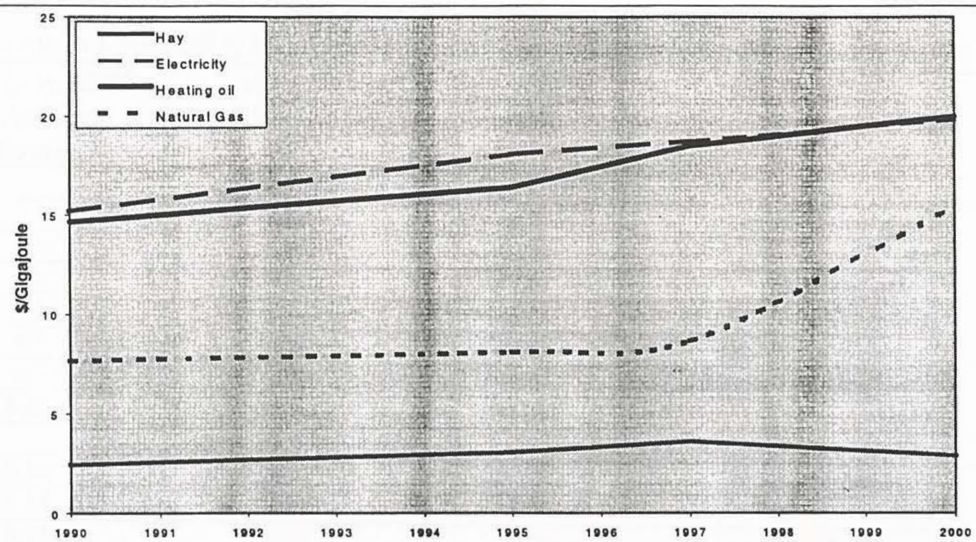

Figure 3 Comparative Costs of Hay Prices vs. Residential Heating in Manitoba

The rising prices of fossil fuels means a major agro-industrial opportunity has developed to convert low cost, solar energy into GHG-friendly biofuels. The comparative advantage of biomas should increase in the future because two factors will contribute to long-term price stability. Historically, agricultural commodity prices have declined in real dollars as a result of advances in crop production and mechanization. Secondly, plant breeding and the introduction of improved plant materials has increased crop productivity. 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

The potential 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 values are derived from 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 and the province has few fossil energy reserves. 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 production costs are approximately $65/t due to higher land rents and production costs. The highest productions costs are in Quebec ($75/t) where heavy 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 States 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	
	Hay	2.3	30	0.69	
	Seeded pasture	0.86	30	0.26	
			Total	**1.53**	**6.12**
Quebec					
	Annual crops	2.06	10	0.21	
	Hay	2.29	30	0.67	
	Seeded pasture	0.48	30	0.15	
			Total	**1.04**	**3.95**
Manitoba					
	Annual crops	9.54	10	0.95	
	Hay	2.02	30	0.60	
	Seeded pasture	0.88	30	0.26	
			Total	**1.83**	**3.66**

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

*Based on yields of 4.0, 1.8, 2 and 3 t/a 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. Thirty-six percent of the residential heat demand in Quebec (average for 1990-98) and 32% in Manitoba is currently met by electricity (NRC, 2001). 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). 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 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 move Canada a long way towards meeting its obligations under the Kyoto Protocol.

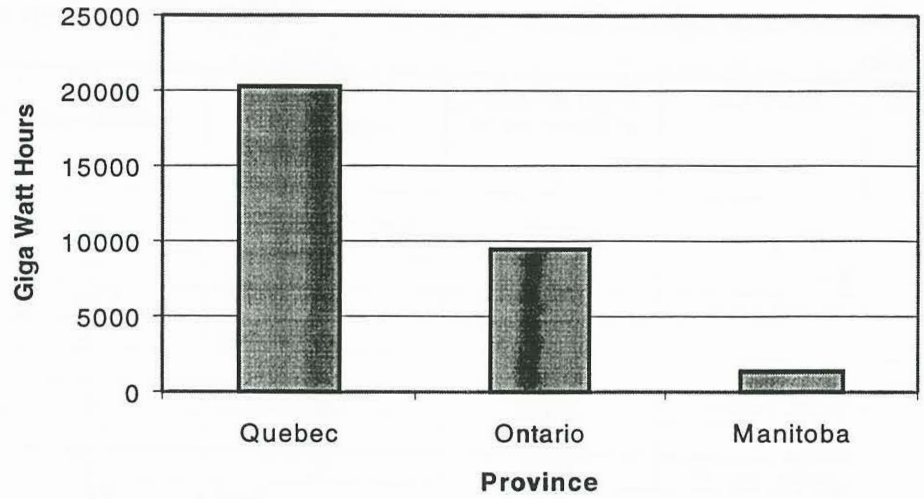

Figure 4. Potential savings from avoiding electricity use in residential heating applications in three provinces.

The prospects for pellet biofuels

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 others in Ontario have expressed interest. Production of multi-fuel pellet stoves (grass pellets, wood pellets, corn) by Dell-Point Technologies 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 pelleting infrastructure close to switchgrass production zones. Currently pelleting capability exists at alfalfa pelleting 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 are being modeled after the livestock feed industry. Crop yields could be improved by breeding varieties with earlier maturity and better over-wintering qualities. 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, low prices and increasing input costs could be partly alleviated by diverting a 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.

Future energy prices will undoubtedly affect the development of the pellet fuel heating sector. Current predictions are 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 foosil 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

Pelleted 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 combustion system and increasing prices for fossil fuels. CO_2 emissions can be reduced by 1000 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, pelleted biofuels can provide consumers with lower cost and more secure heating options than many conventional sources. As energy prices continue to rise and the global warming becomes more pronounced, grass biofuel pellets will become an increasingly attractive heating option in North America

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