THE EMERGING AGRO-PELLET INDUSTRY IN CANADA

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ABSTRACT: Heat-related energy applications represent the largest energy demand in industrialized countries. Bioheat from densifying fast-growing energy grasses into fuel pellets represents one of the most economically efficient means to displace petroleum-based fuels and create a greenhouse gas-friendly heating fuel. The energy balance for switchgrass pellets in Ontario has been estimated at 14:1, distinctly superior to corn ethanol, switchgrass ethanol and biodiesel. Historically, the major constraint to the development of grasses for bioheat has been the difficultly associated with burning grasses in conventional boilers. These technical problems now appear to be largely resolved. Plant breeding and crop management can be used to reduce the chlorine, alkali and silica content in grasses, reducing clinker formation and corrosion. A new approach to optimize biomass yield and quality through fall mowing and spring harvesting appears highly promising. Utilizing advanced combustion systems which are specifically designed to burn high-ash fuels can also help resolve the problem of ash removal from boilers. In 2006/2007, Canadian farmers planted approximately 800 ha of switchgrass and other warm season grasses to expand the resource base for producing agro-pellets. The main market emerging for agro-pellets is commercial heating applications, particularly the greenhouse and food processing sector and export markets to Western Europe.

Keywords: switchgrass, pellets, combustion

1 INTRODUCTION

In most industrialized countries, heat-related energy applications represent the largest energy demand. Bioheat from wood energy is emerging as a promising option to replace natural gas and petroleum-based fuels in these countries. However, there is little scope for greatly expanding wood residue use to meet the increasing demand due to supply and ecological constraints associated with harvesting large volumes of woody materials. Burning corn or other feed grains for fuel is expensive and recognized to have significant social implications associated with food security and food prices in developing countries. Relative to other bioresource options, bioheat from densifying fast-growing energy grasses into fuel pellets represents one of the most economically efficient means to expand the bioheat industry. It is also the most socially and environmentally acceptable option available to create a new, abundant, clean burning, greenhouse gas-friendly fuel for heat-related energy applications. This paper will overview the current opportunities and constraints to the development of the grass pellet industry.

2 WARM SEASON GRASSES AS BIOENERGY FEEDSTOCKS

In North America, the warm continental climate has produced a diversity of native warm season (C_4) grasses that have a relatively high production potential on marginal farmlands. Warm season grass species that could be well adapted to Western Europe include switchgrass (*panicum virgatum*), prairie cordgrass *(spartina pectinata*), eastern gamagrass (*tripsacum dactyloides*), big bluestem (*andropogon gerardii vitman*) and coastal panic grass (*panicum amarum A.S. hitchc.*). All of these species are relatively thin stemmed, winter hardy, productive and are established through seed. Switchgrass, big bluestem and coastal panic grass in particular have modest seed costs. Prairie cordgrass and eastern gamagrass are more expensive to seed-establish due to their low seed production. As well, Prairie cordgrass produces a recalcitrant seed that has a short seed life.

Switchgrass was chosen as the model herbaceous energy crop species to concentrate development efforts on in the early 1990's by the U.S. Department of Energy. It had a number of promising features including its moderate to high productivity, adaptation to marginal farmlands, drought resistance, stand longevity, low nitrogen requirements and resistance to pests and diseases [1]; [2]. In central Canada, switchgrass produces 67% more net-energy gain per hectare than grain corn and 5 times more net-energy gain per hectare than canola prior to any conversion process (see Table I).

Table I: Solar energy collection and fossil fuel energy requirements of Ontario Crops per hectare [3]

Crop	Yield (ODT/ha)	Energy Content (GJ/ODT)	Fossil energy used (GJ/ODT)	Fossil energy used (GJ/ha)	Solar energy collected (GJ/ha)	Net energy (GJ/ha)
Canola	1.7	25.0	6.3	11	44.9	32.4
Soybean	1.9	23.8	3.2	6	44.9	38.9
Barley	2.8	19.0	3.9	11	53.6	42.6
Winter Wheat	4.2	18.7	2.9	12	78.2	66.2
Tame Hay	4.6	17.9	1.0	4.6	82.5	77.9
Grain Corn	6.2	18.8	2.9	18	116.3	98.3
Switch-grass	9	19.0	0.8	7.2	171.0	163.8

Warm season grasses function well as perennial energy crops as they mimic the biological efficiency of native tall-grass prairie plants. They produce significantly more energy than grain corn while at the same time requiring minimal fossil energy inputs for field operations and less fertilizers and herbicides. Further reductions in fossil energy requirements for warm season grasses may be achieved through breeding for improved seedling vigour during establishment, selection of cultivars for biological nitrogen fixation and/or use of native warm season legumes such as Tick-Trefoil (*desmodium canadense*) in mixed seedings with warm season grasses. Cool-season forage legumes are too competitive early in the growing season for use with warm season grasses.

3 THE FUEL CYCLE OF WARM SEASON GRASS PELLETS

The grass pellet industry represents a major new agro-industrial opportunity because of its superior net energy gains and greenhouse gas (GHG) mitigation potential compared to other energy crop and bioconversion options. Focusing on bioheat development from domestically produced and imported agro-pellets could be major strategy for Europe to meet its GHG and renewable energy targets. The energy balance for switchgrass pellets in Ontario has been estimated at 14:1, which is distinctly superior to liquid biofuel options in temperate regions. Corn ethanol and switchgrass ethanol have been identified as having energy output to input ratios of 1.2:1 and 3.4, respectively [4], while biodiesel from rapeseed has an energy balance of 1.47:1 [5]. The thermodynamics of converting grass into a fuel pellets is superior to converting grass into other energy forms such as green power through co-firing with coal or conversion into cellulosic ethanol (see Table II). Warm season grasses likely have good potential for biogas applications if effective cultural management and optimized biogas conversion systems are developed. Big bluestem and eastern gamagrass may prove more suitable for this application than switchgrass as they have improved digestibility for livestock. Densification processes for energy grasses are similar to those used for sun-cured alfalfa hay or wheat straw. The length of grind and die selection are important aspects to consider to enable adequate retention time of the material and properly form a pellet. Optimizing the densification of grasses has been previously reviewed by Samson [6].

4 OPTIMIZATION OF FUEL QUALITY FOR COMBUSTION

Historically, the major constraint to the development of grasses for bioheat applications has been biomass quality and the difficultly associated with burning energy grasses efficiently in conventional boilers. In particular, the relatively high alkali and chlorine contents of herbaceous plants can lead to clinker formation and corrosion of boilers. These biomass quality problems have resulted in slow commercialization of grass feedstocks as agro-pellets in small scale boilers [7]; [8]. However, these technical problems now appear to be efficiently resolved through a strategic, dual approach. Plant breeding and delayed harvest management can be used to reduce the chlorine, alkali and silica content in native grasses, reducing clinker formation and corrosion. In addition, utilizing advanced combustion systems which are specifically designed to burn high-ash fuels can help resolve the problem of ash removal from boilers [10].

Table II. Energy analysis of biomass fuel transformation pathways [7]

	Switchgrass fuel pellets	Co-firing switchgrass with coal	Cellulosic switchgrass-ethanol & electricity	Grain corn ethanol
Biomass yield per hectare (ODT)	10	10	10	6.5
Direct biomass energy yield (GJ/ha)	185	185	185	136.5
Energy yield after conversion (GJ/ha)	175.8	58.3	73.0 (67.2 ethanol + 5.8 electricity)	64.2
Energy consumed in production & conversion (GJ/ha)	12.7	11.1	15.9	42.8
Net energy gain (GJ/ha)	**163.1**	**47.2**	**57.1**	**21.4**

The silica, potassium and chlorine contents of grasses and other herbaceous biomass feedstocks are affected by many factors including: time of harvest, soil type, fertilizer type and rate, thickness of the stems, the relative stem to leaf ratio of cultivars, the relative water use efficiency of C_4 versus C_3 species and the rainfall to evaporation ratio where the crops are grown [11]. In eastern Canada, the ash content of switchgrass grown on a sandy loam soils was 15% below that of a clay loam soils [12]). However, delayed harvesting of the grass (overwintering the grass and harvesting the following spring) had an even bigger influence than soil type by reducing ash content by 39% [13].

The potassium and chlorine contents of grass species at harvest is affected by resident levels of these elements in the soil, the rate of potassium fertilizer applied to the crop, the type of potassium fertilizer applied, the content of these elements at crop maturity, and the rate and duration of leaching of these elements that occurs in the period following maturity until harvest time [14]. An effective way to reduce potassium content in the fall is to use early maturing varieties that have a longer period to leach out material prior to late fall [15]. Plant morphology can also have a significant effect on biomass quality. Lowland types of switchgrass are characterized by tall, coarse stems with rapid growth and are adapted to poor drainage and often found in floodplains. They differ notably from upland types which are characterized by short, fine stems with a high drought tolerance [16]. Upland types have generally been found to have higher ash concentrations than lowland types; but as they have finer stems, they also tend to have lower chlorine and potassium levels and lower water contents. This is likely a function of the thin-stemmed cultivars having a larger surface area exposed to the elements.

Overwintering material is extremely effective in improving biomass quality for combustion with up to 95% of the potassium leached out of the switchgrass fibre over winter [17]. November harvested material in eastern Canada typically has a potassium content of about 0.35% and chlorine content of about 0.5%. The content of potassium and chlorine can be reduced to about 0.06% and 0.02% respectively through overwintering [18]; [19]. Potassium and chlorine levels after overwintering are very similar to the average levels of potassium and chlorine in wood pellets, 0.05% and 0.01% respectively [20]. REAP-Canada has successfully burned overwintered switchgrass pellets in a 9 kw small scale gasifier pellet stove over an extended period with no clinker formation [21].

Productivity studies indicate harvesting of switchgrass is best delayed not just until biomass growth has ceased, which may be in August or September but after shoots have essentially all senesced and died, which may not be until November or December [22]. Previous studies reported yield declines of approximately 15% from August to November [23]; [24], a decline that represents the transfer of nutrients from above ground to below storage [25]; [26], which is vital for stand sustainability. Therefore the best management strategy for switchgrass in northern latitudes is a single harvest taken after the tops have completely died back [27].

Overwintering switchgrass, although beneficial for biomass quality, has historically reduced the total biomass yield obtained, with losses mainly due to breakage over winter. Spring harvested switchgrass yields were found to be approximately 24% lower in south-western Quebec than that of early October harvested switchgrass [28]. This was likely due to both the late season translocation of materials to the root system in winter [29], as well as the physical loss of materials, mainly from leaves and seed heads during overwintering [30]. In Quebec, the loss of dry matter through overwintering switchgrass compared to fall harvesting was found to be 4% from the stem component of the plant, 11% from leaf sheaths, 30% from leaves and 80% from seed heads [31]. Other studies on fully established switchgrass stands in Quebec have found spring yields 15% below late October fall harvests where the crop is fully dormant [32].

Biomass loss also occurs during field operations including cutting, baling and transport. Sanderson [33] reported a 5% biomass loss from conventional fall harvesting (mowing and baling) of switchgrass. A study conducted by REAP-Canada found that conventional spring harvesting of switchgrass with a mower and baler resulted in a 45% loss of biomass, 32% of that as mowing losses and 13% as baling losses [34]. Losses of this magnitude were also witnessed by Hemmings [35] with reed canary grass where a mower conditioner was used in the spring. A subsequent comparison in Quebec between spring mowing and baling versus spring swathing and baling found biomass losses of approximately 25.3% and 12.5%, respectively [36]. However, a follow up study witnessed a decline of 3% in biomass losses with the swathing and baling method [37]. This reduction in losses was attributed to the lowering of the cutting height from 16 cm to 13 cm which enhanced recovery of the lodged material.

In 2006/2007, REAP-Canada began to assess a new approach consisting of a conventional mow in late fall (typically mid November) followed by a spring harvest. The intention was to minimize biomass losses by leaving the material in a swath overwinter while also maintaining the advantageous biomass quality associated with overwintering materials. Furthermore, the fall mowing and spring harvesting approach would avoid spring swathing, which is a relatively slow field operation that often delays soil warming and soil drying because the entire field is covered in mulch. Preliminary field results from the May 2007 harvest indicate this new delayed harvest approach for warm season grass pellet production is highly effective. Both recovered field yields and spring soil temperatures were found to be higher in the fall versus spring mowed switchgrass plots. The material was harvested at below 12% moisture. Reductions in winter breakage were evident in the fall mown treatments where the material laid in a windrow over winter. It is anticipated this approach will become the main harvest strategy to improve biomass quality while maximizing yield and efficient harvest operations. Raking may be avoided if the windrow is sufficiently narrow to fit between the front rows of the tractor during baling operations.

5 GRASS PELLET MARKETS

The main markets emerging for warm season grass pellets are commercial heating applications in North America and export market pellet markets to Europe. In particular, the North American greenhouse industry is a promising entry market, as profitability of this sector is greatly impacted by rising heating costs. As well, rural energy users are familiar with the use and handling of feed pellets for livestock farming operations. Six Canadian boiler manufacturers are now selling commercial boilers capable of burning pellets made from crop milling residues and delayed harvest energy grasses to the greenhouse industry.

The main feedstocks used to develop the agro-pellet industry in Canada are currently oat hulls and wheat bran made into pellets. Other milling products used for bioheat applications in Canada include barley hulls, flax shives, and sunflower hulls. The addition of 1% lime to agro-pellets is used by some pellet manufacturers to help further ease concerns regarding clinker formation. In total, approximately 1.4 million tonnes of crop milling residues are available in Canada for use in the agro-pellet industry [38].

Approximately 800 hectares of switchgrass were seeded by farmers in Eastern Canada in 2006/2007 as they recognized the commercial potential of the emerging Bioheat industry. Agri-fibre pellet producers are planning to integrate warm season grasses to scale up agro-pellet production. This may include use of energy grasses in mixtures with crop milling residues for the commercial pellet market. Some interest by wood residue pellet producers has also been expressed in using switchgrass as a blended feedstock for residential pellet markets. In the pulp and paper industry there has been research conducted on grass fractionation to recover the low ash stems for paper applications in northern Europe. As the stems of warm season grasses typically contain 1% ash, successful fractionation techniques will likely be used to expand the use of grass stems for residential pellet markets with the leaves, seed heads and leaf sheaths of the plants utilized for commercial pellet markets. Fractionation of grasses may improve the economic viability for energy grass cultivation in pellet markets as bulk residential pellets have about a 50% premium over bulk commercial fuel pellets.

6 OUTLOOK

There are no significant technical barriers to be overcome in the development of grass pellets for the bioheat industry. The main barrier to the emergence of this industry in North America is a lack of parity in biofuel incentives. REAP-Canada estimates corn ethanol and wind energy producers are currently subsidized in Ontario, Canada, through various federal and provincial incentive schemes at an estimated 16 cents per litre and 5.5 cents per kwh. This creates a GJ equivalent subsidy of $7.27/GJ and $15.28/GJ for the ethanol and wind energy industries. If a $7.27 GJ subsidy was applied to BioHeat pellets the pellet producers would receive $(CAN) 135 in incentives. There currently exists no United States or Canadian federal incentives for the BioHeat industry. The most logical approach would be to create a green carbon incentive or “bounty” for bioenergy fuels for a set market price per tonne of CO_2 mitigated or GJ of renewable energy produced to create parity in the bioenergy market. An amount such as $25 CAD/tonne of CO_{2e} would go a long way in supporting the development of this industry in North America. Unfortunately there is no political vision within Canada or the US presently to create policies enabling market forces to work to facilitate bioheat development, either through carbon taxes or green carbon incentives. Carbon taxes and trading systems are in place in Europe, representing a strategic opportunity for Western Europe to readily access low-cost, sustainably grown, greenhouse gas friendly fuels from North America. This could be a means for Europe to efficiently reduce its carbon emissions. It would also provide the leadership for North America to follow in making the transition from a fossil fuel economy to an economy driven by renewable energy. The scale of the grass bioheat industry could become very large in North America given its large agricultural land base. If 20% of Canadian and US farmland was put into energy grass cultivation, REAP-Canada has estimated that 80 million and 611 million tonnes of energy grass pellets could be produced in the two countries respectively.

7 REFERENCES

[1] Samson, R.A. and J. Omielan. 1994. Switchgrass: A potential biomass energy crop for ethanol production. In Wickett, R.G., P.D. Lewis, A. Woodliffe and P. Pratt. Proc. 13th North American Prairie Conference. Dept. of Parks and Recreation, Windsor, Ontario, Canada, p. 253-258.

[2] Parrish, D.J and J.H. Fike. 2005. The biology and Agronomy of Switchgrass for Biofuels. Critical Reviews of Plant Sciences. 24:423-459.

[3] Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, D., Urquiaga, S., Reis, V., and C. Ho Lem. 2005. The potential of C_4 perennial grasses for developing a global BIO-HEAT industry. Critical Reviews in Plant Science 24: 461-495.

[4] McLaughlin, S.B. and Walsh, M.E. 1998. Evaluating environmental consequences of producing herbaceous crops for Bioenergy. Biomass and Bioenergy 14(4):317-324.

[5] Armstrong, A.P., J. Barro, J. Dartoy, A.P. Groves, J. Nikkonen and D.J. Rickeard. 2002. Energy and Greenhouse Gas Balance of Biofuels for Europe-An Update. CONCAWE Ad Hoc Group on Alternative Fuels, European Community, Brussels.

[6] Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, D., Urquiaga, S., Reis, V., and C. Ho Lem. 2005. The potential of C_4 perennial grasses for developing a global BIO-HEAT industry. Critical Reviews in Plant Science 24: 461-495.

[7] Elbersen, H.W., D.G. Christian, W. Bacher, E. Alexopoulou, V. Pignatelli, and D. van den Berg. 2002. Switchgrass Variety Choice in Europe. Final Report FAIR 5-CT97-3701 “Switchgrass”.

[8] Obernberger, I. and G. Thek. 2004. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behaviour. Biomass and Bioenergy 27:653-669.

[9] Samson, R., Drisdelle, M., Mulkins, L., Lapointe, C. and Duxbury, P. 2000. The use of switchgrass as a greenhouse gas offset strategy. Proceedings of the Fourth Biomass Conference of the Americas, Buffalo, New York, Oct. 15.

[10] Obernberger, I. and G. Thek. 2004. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behaviour. Biomass and Bioenergy 27:653-669.

[11] Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, D., Urquiaga, S., Reis, V., and C. Ho Lem. 2005. The potential of C_4 perennial grasses for developing a global BIO-HEAT industry. Critical Reviews in Plant Science 24: 461-495.

[12] Samson, R., P.Girouard, B. Mehdi. 1999. Establishment of commercial switchgrass plantations. Final report prepared for Domtar Inc., Noranda & Natural Resources Canada.

[13] Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, D., Urquiaga, S., Reis, V., and C. Ho Lem. 2005. The potential of C_4 perennial grasses for developing a global BIO-HEAT industry. Critical Reviews in Plant Science 24: 461-495.

[14] Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, D., Urquiaga, S., Reis, V., and C. Ho Lem. 2005. The potential of C_4 perennial grasses for developing a global BIO-HEAT industry. Critical Reviews in Plant Science 24: 461-495.

[15] Elbersen, H.W., D.G. Christian, W. Bacher, E. Alexopoulou, V. Pignatelli, and D. van den Berg. 2002. Switchgrass Variety Choice In Europe. Final Report FAIR 5-CT97-3701 “Switchgrass”.

[16] Cassida, K. A., J. P. Muir, M. A. Hussey, J. C. Read, B. C. Venuto and W. R. Ocumpaugh. 2005.

Biofuel Component Concentrations and Yields of Switchgrass in South Central U.S. Environments. Crop Sci. 45:682-692 (2005).

[17] Goel, K., R. Eisner, G. Sherson, T. Radiotis and J. Li. 2000. Switchgrass: A potential pulp fibre source. Pulp & Paper-Canada 101(6):51-45.

[18] Goel, K., R. Eisner, G. Sherson, T. Radiotis and J. Li. 2000. Switchgrass: A potential pulp fibre source. Pulp & Paper-Canada 101(6):51-45.

[19] Christian, D.G., Riche A.B., Yates N.E. 2002. The yield and composition of switchgrass and coastal panic grass grown as a biofuel in southern England. Bioresour Technol. 2002 Jun;83(2):115-24.

[20] Obernberger, I. and G. Thek. 2004. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behaviour. Biomass and Bioenergy 27:653-669.

[21] Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, D., Urquiaga, S., Reis, V., and C. Ho Lem. 2005. The potential of C_4 perennial grasses for developing a global BIO-HEAT industry. Critical Reviews in Plant Science 24: 461-495.

[22] Parrish, D.J and J.H. Fike. 2005. The biology and Agronomy of Switchgrass for Biofuels. Critical Reviews of Plant Sciences. 24:423-459.

[23] Sanderson, M.A., J.C. Read and R.L. Read. 1999. Harvest management of switchgrass for biomass feedstock and forage production. Agron. J. 91:5-10.

[24] Vogel, K.P., J.J. Brejda, D.T. Walters and D.R. Buxton. 2002. Switchgrass biomass production in the Midwest USA: Harvest and nitrogen management. Agron. J.94:413-420.

[25] Parrish, D.J. and D.D. Wolf. 1992. Managing switchgrass for sustainable biomass production. In: Proc. Symp. Liquid Fuels from Renewable Resources. Pp 34-39. Nashville, TN, 13-14 December 1992. ASAE, St. Joseph, MI.

[26] Parrish D.J. and D.D. Wolf. 1993. Switchgrass as a biofuels crop for the upper Southeast. In: Proc First Biomass Conference of the Americas, Burlington, VT. 1:248-253. National Renewable Energy Lab, Golden CO.

[27] Parrish, D.J and J.H. Fike. 2005. The biology and Agronomy of Switchgrass for Biofuels. Critical Reviews of Plant Sciences. 24:423-459.

[28] Goel, K., R. Eisner, G. Sherson, T. Radiotis and J. Li. 2000. Switchgrass: A potential pulp fibre source. Pulp & Paper-Canada 101(6):51-45.

[29] Parrish D.J., D.D. Wolf, J.H. Fike and W.L. Daniels. 2003. Switchgrass as a biofuel crop for the upper southeast: Variety trials and cultural improvements. Final Report for 1997 to 2001, ORNL.SUB-03-19SY163C/01. Oak ridge National Laboratory, Oak Ridge, TN

[30] Goel, K., R. Eisner, G. Sherson, T. Radiotis and J. Li. 2000. Switchgrass: A potential pulp fibre source. Pulp & Paper-Canada 101(6):51-45.

[31] Goel, K., R. Eisner, G. Sherson, T. Radiotis and J. Li. 2000. Switchgrass: A potential pulp fibre source. Pulp & Paper-Canada 101(6):51-45.

[32] Girouard, P., R. Samson, B.B. Mehdi. 1998. Harvest and Delivered Costs of Spring Harvested Switchgrass: Final Report. REAP-Canada final report to Domtar Inc., Noranda Inc. and Natural Resources Canada. Ottawa Ontario. 12 pp.

[33] Sanderson, M.A., R.P. Egg and A.E. Wiselogel. 1997. Biomass losses during harvest and storage of switchgrass. Biomass & Bioenergy. 12(2):107-114.

[34] Girouard, P. and R. Samson. 1996. Evaluation of conventional haymaking equipment for spring harvesting switchgrass. REAP-Canada report prepared for Domtar Inc., Noranda Inc. and Natural Resources Canada. Ottawa, Ontario. 12 pp.

[35] Hemmings, M.S. 1995. Spring Harvest of Reed Canary Grass (Phalaris arundinacea). In: Proc. Biomass for Energy, Environment, Agriculture and Industry. 8th E.C. conference. October 3-5, 1994. Vienna, Austria. 708-711.

[36] Girouard, P. and R. Samson. 1997. Evaluation of haymaking equipment to harvest switchgrass/Part II. REAP-Canada internal report. Ste-Anne-de-Bellevue, QC. 12 pp.

[37] Girouard, P., R. Samson, B.B. Mehdi.1998. Harvest and Delivered Costs of Spring Harvested Switchgrass: Final Report. REAP-Canada final report to Domtar Inc., Noranda Inc. and Natural Resources Canada. Ottawa Ontario. 12 pp.

[38] Samson, R.A., S. Bailey and C. Ho Lem. 2006. Biomass resources options: Creation a BIOHEAT supply for the Canadian greenhouse industry. Phase I research report to Natural Resources Canada. 38 pp.