# Densified Grasses for Heat-Related Energy

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## Introduction

In most industrialized countries, heat-related energy applications represent the largest energy demand. Relative to other biofuel options, BioHeat from fuel pellets represent one of the most economically efficient means to displace natural gas and petroleum based fuels in industrialized countries. However, there is little scope for greatly expanding the wood pellet industry due to supply and ecological constraints associated with harvesting large volumes of forest floor wood residues. 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. Within the bioenergy sector, densifying fast growing energy grasses represents the most socially and energetically acceptable option available to creating a new abundant low cost, clean burning, greenhouse gas friendly energy source for heat-related energy applications. This paper will overview the current opportunities and constraints to the development of the grass pellet industry.

### 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 relatively high production potential on marginal farmlands. Warm season grass species that could likely 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 in the early 1990's by the U.S. Department of Energy to concentrate development efforts. 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 (Samson and Omielan, 1994; Parrish and Fike 2005). In central Canada, prior to any conversion process, switchgrass produces 67% more net-energy gain per hectare than grain corn and 5 times more net-energy gain per hectare than canola (Table 1). Warm season grasses as perennial energy crops mimic the biological efficiency of native tall grass prairies and produce significantly more energy than grain corn with 1/10th the investment in seed and herbicide and 1/6th the investment in chemical fertilizers. Further reductions in fossil energy requirements for warm season grasses may be achieved through breeding for improved seedling vigor 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 extremely competitive early in the growing season for use with warm season grasses.

**Table 1: Solar energy collection and fossil fuel energy requirements of Ontario Crops per hectare** (Samson et al., 2005)

| Crop | Yield (ODT/ha) | Energy Content (GJ/ODT) | Fossil energy consumed/ tonne produced (GJ/ODT) | Fossil energy consumed (GJ/ha) | Solar energy collected/ ha (GJ/ha) | Net energy production/ha (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 |
| Switchgrass | 9 | 19.0 | 0.8 | 7.2 | 171.0 | 163.8 |

## The Fuel Cycle of Warm Season Grass Pellets

The grass pellet industry represents a major new agro-industrial opportunity because of its outstanding fuel cycle. Focusing on BioHeat development from grasses is advantageous from both a fossil energy and greenhouse gas displacement standpoint as it requires modest levels of energy to grow the crop and transformation into heat-energy is the biggest energy application in most western economies. The energy balance for switchgrass pellets in Ontario has been estimated at 14:1, which is distinctly superior to liquid fuel products. Corn ethanol and switchgrass ethanol have been identified as having an energy output to input ratios of 1.2:1 and 4.3:1, respectively (McLaughlin and Walsh, 1998) while biodiesel from rapeseed has an energy balance of 1.47:1 (Armstrong et al., 2002). The thermodynamics of converting grass into a fuel pellet is superior to its conversion to other energy forms such as green power through co-firing with coal or conversion into cellulosic ethanol (see Table 2). 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 to this application than switchgrass as they have improved digestibility for livestock. Densification processes for energy grasses are similar to that used for sun cured alfalfa hay or wheat straw. The main important points are the length of grind and die selection to enable adequate retention time of the material to properly form a pellet. Details on optimization of densification of grasses have been previously (Samson et al., 2005).

**Table 2. Energy analysis of biomass fuel transformation pathways** (Samson *et al.*, 2000)

| | Switch-grass fuel pellets | Co-firing switch-grass with coal | Cellulosic switch-grass-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+ coproducts |
| Energy consumed in production & conversion (GJ/ha) | 12.7 | 11.1 | 15.9 | 42.8+ coproducts credits |
| **Net energy gain (GJ/ha)** | **163.1** | **47.2** | **57.1** | **21.4** |
| **Recovery of original biomass energy (%)** | **88.2** | **25.5** | **30.9** | |

## Optimization of Fuel Quality for Combustion

The major historical constraint to developing grasses for BioHeat applications has been biomass quality characteristics as they were difficult to burn efficiently in conventional boilers. In particular, the relatively high alkali and chlorine contents of herbaceous plant species leads to clinker formation and corrosion of the boilers. This has resulted in slow commercialization of these feedstocks and limited the use in small scale boilers (Elbersen et al., 2002; Obernberger and Thek, 2004). This technical problem can now be resolved in a number of ways. Plant breeding and crop management can be used to reduce the chlorine, alkali and silica content in native grasses. As well, utilizing combustion systems of advanced design which are specifically designed to burn higher ash fuels can help resolve the problem (Obernberger and Thek, 2004). This dual strategy to improve biomass quality as well as improved boiler technology appears to be the most efficient approach to resolve the previously mentioned concerns.

The silica, potassium and chlorine contents of grasses and other herbaceous 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 $C_4$ and $C_3$ species and the rainfall to evaporation ratio where the crops are grown. In eastern Canada, the ash content of switchgrass grown on a sandy loam soils was 15% below that of a clay loam soils (Samson et al 1999). 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%.

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 occur in the period following maturity until harvest time (reviewed in Samson et al., 2005). 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 harvest (Elberson et al., 2002). 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 (Cassida et al., 2005). Upland types have also 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 thin stemmed cultivars having a larger surface area exposed to the elements. Overwintering material is extremely effective in improving biomass quality for combustion with 95% of the potassium leached out of the switchgrass fibre over winter (Goel et al., 2000). 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 (Goel et al 2000; Christian et al 2002). These levels are very similar to average levels in wood pellets of 0.05% and 0.01% for potassium and chlorine respectively (Obernberger and Thek, 2004). 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 (Samson et al., 2005).

Productivity studies indicate harvesting of switchgrass is best delayed not just until biomass growth has ceased, which may be in August or September but until shoots have essentially all senesced and died, which may not be till November or December (Parrish and Fike 2005). Previous studies (Sanderson et al., 1999; Vogel et al., 2002) reported yield declines of approximately 15% from August to November, however this decline represents the transfer of nutrients from above ground to below storage (Parrish and Wolf, 1992, 1993). The transfer of nutrients below ground is vital for stand sustainability and therefore the best management strategy for switchgrass in northern latitudes is a single harvest taken after the tops have completely dies back (Parrish and Fike 2005). Overwintering switchgrass, however, reduces the biomass yield obtained mainly due to breakage over winter. Spring harvested switchgrass yields were found to be approximately 24% lower in southwestern Quebec than that of early October harvested switchgrass (Goel et al., 2000). This was likely due to both the late season translocation of materials to the root system in winter (Parrish et al., 2003), as well as the physical loss mainly from leaves and seed heads during overwintering (Goel et al., 2000). Through overwintering in Quebec, the loss of dry matter was 4% from the stem component, 11% from leaf sheaths, 30% from leaves and 80% from seed heads compared to fall harvesting (Goel et al., 2000). Other studies in Quebec have found on fully established switchgrass stands spring yields 15% below late October fall harvests where the crop is fully dormant (Girouard et al. 1998).

Losses of biomass also occur during field operations (eg. cutting, baling, transport), however the goal is to minimize as much of these losses as possible. Sanderson *et al.* (1997) reported a 5 percent biomass loss from conventional fall harvesting (mowing and baling) of switchgrass. A study conducted by REAP- Canada (Girouard and Samson 1996) found that conventional spring harvesting (mower and baler) of switchgrass resulted in a 45% loss of biomass (32% as mowing losses and 13% as baling losses). Losses of this magnitude were also witnessed by Hemming (1995) with reed canary grass where a mower conditioner was used. A subsequent comparison in Quebec between spring mowing and baling with spring swathing and baling found biomass losses of approximately 25.3 and 12.5 percent, respectively (Girouard and Samson 1997). However, in a follow up study Girouard et al. (1998) witnessed a decrease of biomass loss to 3% with the swathing and baling method. This reduction in losses was attributed to the lowering of the cutting height from 16 cm to 13 cm which enhanced recovered of the lodged material. In 2006, REAP-Canada began to assess a fall mowing technique and spring baling approach to minimize overwintering losses. The main known disadvantage of delayed harvest is overwintering losses due to winter breakage of seed heads and leaves. Spring swathing is also a relatively slow field operation and soil warming and soil drying is often delayed because the entire field is covered in a mulch. A new approach to delayed harvest for warm season grasses is presently being optimized in Canada to ease mowing operations and reduce winter breakage by laying the material into a windrow overwinter. It consists of use of a conventional mowing in late fall (typically mid November) followed by a spring harvesting. It is anticipated this will become the main harvesting strategy to improve biomass quality while optimizing yield and harvest conditions.

## Grass Pellet Markets

The main market emerging for agri-fibre fuel pellets is commercial heating applications. In particular the greenhouse industry is a promising early market, as profitability of this sector is greatly impacted by heating costs. As well, rural energy users are familiar with the use and handling of feed pellets for livestock farming operations. The main feedstocks used to develop the agri-fibre fuel pellet industry in Canada are currently oat hulls and wheat bran pellets. Other milling products used for BioHeat applications in Canada include barley hulls, flax shives, corn fibre, and sunflower hulls. In total approximately 1.4 million tonnes of crop milling residues are available in Canada for use in the agri-fibre fuel pellet industry (Samson et al 2006). The addition of 1% lime to agri-fibre fuel pellets is used by some pellet manufacturers to help further ease concerns regarding clinker formation. 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. Approximately 500 hectares of switchgrass was seeded by farmers in Eastern Canada in 2006 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 agri-fibre fuel pellet production. This may include use of energy grasses in mixture 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, successfully fractionation techniques will likely be used to expand the use of grass stems for residential pellet markets. The leaves, seed heads and leaf sheaths would be utilized for commercial pellet markets. Fractionation of grasses may improve the economic viability for energy grass cultivation for pellet markets as bulk residential pellets have about a 50% premium over bulk commercial fuel pellets.

## Outlook

There are no significant technical barriers to be overcome for 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. Ethanol from corn is currently subsidized at approximately US$6-10/GJ in the US and Canada through various incentives and grants. This is equivalent to a $110-185/tonne subsidy for BioHeat pellets. There currently is no US or Canadian federal subsidies for the BioHeat and biogas industries. The most logical approach would be to create a green carbon incentive or "bounty" for bioenergy fuels for a set market price such as $25/tonne of $CO_2$ mitigated (or alternatively per GJ of renewable energy produced) to create parity in the bioenergy market. Unfortunately there is no political vision within Canada or the US presently to create policies enabling market forces to work to facilitate BioHeat or biogas 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 to a renewable energy driven economy. 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 80 million and 611 million tonnes of energy grass pellets could be produced in the two countries respectively.

## References

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.

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).

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.

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".

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.

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.

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.

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.

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

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.

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

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. Nashwille, TN, 13-14 December 1992. ASAE, St. Joseph, MI.

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

Parrish D.J., D.D. Wolf, J.H. Fike and W.L. Daniels. 2003. Switchgrass as a biofuels 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

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.

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.

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

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.

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 Amercian Prairie Conference. Dept. of Parks and Recreation, Windso Ontario, Canada, p. 253-258.

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

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