R.E.A.P. Canada Research Reports

Bioenergy Opportunities from Agriculture

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(*Presented at the,* **International Conference incorporating the 24th Annual Conference of the Solar Energy Society of Canada Inc., SESCI. Techniques des énergies renouvelables dans les climats froid 1998. Renewable Energy Technologies in Cold climates '98; 4-6 May 1998; Montreal, Quebec, Canada**)

ABSTRACT

Solar energy collection in the form of agricultural biomass can play an important role mitigating climate change. Crop residues and dedicated biomass energy crops can be used to meet a diversity of energy needs including electricity, space heating and liquid transportation fuels.

Perennial grasses appear to be the most promising dedicated feedstocks for energy production in regions with limited crop residues. Perennial grasses are well adapted to marginal soils, intercept sunlight throughout the growing season, have low maintenance requirements and a low cost of production. As a greenhouse gas offset strategy they can help reduce $C0_2$ buildup in the atmosphere by sequestering carbon in the soil and by producing biofuels with closed loop carbon cycles.

In northern regions with cool summers, reed canary grass, a C3 species, appears to be the most promising dedicated agricultural feedstock. ln areas with warmer summer temperatures, switchgrass, a warm season (C4) prairie grass, is the lowest cost dedicated agricultural feedstock with costs of S38-$51 per oven dry tonne (odt) or $2.17-$2.91per gigajoule (GJ) of energy. Warm season (C4) grasses have several agronomic advantages and energy conversion advantages over C3 grasses.

Sustainably grown agricultural biofuels combined with energy efficient end use technologies can play an important role to facilitate the implementation of a sustainable energy economy. Recent breakthroughs *in cellulosic ethanol and gasifier pellet stove technology currently allow for extended opportunities; in agriculturally derived biofuels as a means of meeting greenhouse gas reduction targets.

INTRODUCTION

Biomass can be considered unique amongst renewable energy sources in that it can be used for power generation, converted into solid fuels for space and process heating applications, or transformed into liquid fuels for the transportation industry.

Biomass from forest residues continues to be the most important source of biomass in cold climate regions. However, forest residues suffer from supply constraints for the large-scale development of biofuel industries and are generally not located near densely populated regions. As well, forest residues are increasingly being recycled within the forest product industry as new wood processing technologies are developed.

1.0 Plants as Solar Collectors

Grains or oilseeds for energy production have been the entry point for agricultural feedstocks as renewable energy fuels There are nonetheless, serious limitations to the long term viability of this strategy, which include; the high costs of raw materials, the low energy yield per hectare, the modest net energy gains, and the long term conflict with the food production sector due to the use of high quality agricultural soils.

There are two main ways that farm production can be used to produce energy on a larger scale; i) crop residues can be used, provided surplus quantities are available, and ii) dedicated biomass energy crops can be grown, ideally on marginal agricultural land.

1.1 Crop Residues

The main opportunities for using crop residues exist in productive regions where substantial acreage of cereal grain is grown. In Canada, surplus volumes of cereal straw (beyond livestock and soil sustainability requirements) are available in higher rainfall cereal growing regions of western Canada, such as southern Manitoba. In eastern Canada cereal straw is in very limited supply and therefore, only corn residues could theoretically be collected (mostly in southern Ontario and southwestern Quebec).

Even in large cereal straw surplus regions, the location of conversion plants must be carefully studied to secure access to sufficient raw materials in drought years. Since straw is a bulky raw material collection from a larger radius would quickly become prohibitive, precluding economic viability. Furthermore, in the case of corn residue harvesting, climatic factors must be taken into consideration, to ensure the thick stemmed material is completely dry at the time of late fall harvest.

The quality of crop residues for energy conversion is another concern. For combustion purposes, agricultural residues can create serious problems with clinker and slag formation due to their high ash content, particularly the potassium and chlorine components. Perhaps the best bioenergy use of cereal straw is to use it as a feedstock for cellulosic ethanol conversion.

1.2 Dedicated Agricultural Feedstocks

Research in North America and Europe has been ongoing since the oil crisis of the 1970's to develop crops specifically for bioenergy. Much of the early effort examined die potential of short rotation forestry. In the 1980's research increasingly focused on herbaceous species. In the 1990's efforts focused on perennial grass species because of their high productivity, good adaptation to marginal agricultural lands, relative low fertility requirements, and their low energy and economic production costs.

Switchgrass (Panicum virgatum L.) was identified by the United States Department of Energy as a model herbaceous bioenergy feedstock (McLaughlin, 1992). In northern Europe, reed canary grass *(Phalaris* arundinacea), miscanthus *(Miscanthus sinensis),* and switchgrass are currently under assessment as biofuels.

Ile major advantages identified with C4 perennial grasses (e.g. switchgrass and miscanthus) over C3 grasses (e.g. reed canary grass) are that they convert solar radiation 40% more efficiently under optimal conditions, use only 1/2 as much water per tonne of biomass produced, have lower fertility requirements, lower ash and silica contents, and are deeper rooted (Samson et al., 1997). However they are not as well adapted as reed canary grass to cooler northern regions. Further research in regions with cooler summers is required on more cold tolerant C4 grasses.

In 1991, REAP-Canada began working with C4 perennial grasses, primarily switchgrass, as dedicated biomass feedstocks for both the bioenergy and the agri-fibre markets. The program has emphasized all aspects of commercialization of the crop, including small plot cultivar evaluations, quasi commercial size plantation comparisons with short rotation forestry and corn as energy crops, field scale plantations, harvesting and storage studies, energy and carbon storage studies, economics and plant breeding.

In partnership with the pulp and paper industry, and Natural Resources Canada, switchgrass has been identified as a promising agri-fibre feedstock for the production of fine papers (Radiotis et al., 1996). In terms of energy production, the crop is producing a fall harvest of 10-13 odt of biomass per hectare in southern Quebec, which is similar to results from the more northerly corn growing regions in the US. Later maturing varieties have been found to be more efficient interceptors of solar energy than earlier maturing varieties.

With a 12 odt per hectare yield, the crop was found to have a radiation use efficiency of total incoming solar radiation of 1.0 g per MJ and a solar energy recovery of 1.8% of photosynthetically active radiation (Madakadze, 1997). With an average energy content of 17.5 GJ per tonne a 12 odt ha^{-1} crop produces the energy equivalent of 36 barrels of Oil per hectare and has an energy output to input efficiency ratio of approximately 25: 1. This compares favorably with grain corn in Quebec, which has a ratio of approximately 5:1 (Hill and Nault, 1995) and whose land base is restricted to high quality soils.

2.0 Future Production Outlook

Very little effort has gone into breeding perennial grass crops to improve biomass production. Grass breeding has long been in decline in North America and any efforts prior to the early 1990's have been primarily to improve forage quality for livestock. Perennial grass crops have drawn little commercial interest from seed companies because of the low seed costs, and the longevity of the stand. Efforts to develop higher yielding grass crops will have to come from government or energy company support. Some public funded research is currently underway in northern Europe with reed canary grass, and in the United States with switchgrass, to increase yields and quality of these crops for biomass markets.

3.0 Further Yield Increases?

The process of biomass accumulation is based on photosynthesis, where carbon dioxide and water are converted into carbohydrates and water in the presence of sunlight. Most biomass scientists now agree that water is the main factor constraining biomass productivity.

In Quebec the maximum light restricted yield has been calculated to be 33.6 odt ha^{-1} for perennial C3 species such as willow or reed canary grass and 64.8 odt ha^{-1} for switchgrass (Samson and Chen, 1996). However, the water limited yield potential is much lower. The upper yield limit of C4 perennial grasses (e.g. switchgrass) was estimated to be 20 odt ha^{-1} whereas for C3 perennial crops it was 10 odt ha^{-1} This was based on 40% (400 min) of the annual rainfall (1,000 mm) in southern Quebec being available for crop growth, and on the C3 and C4 species using 40 min and 20 min of water, respectively, per tonne of biomass produced.

It is clear that water plays a much more important role than solar radiation in restricting yields, therefore plant breeders working with C4 species have ample potential to increase future productivity.

4.0 What do Biomass Crops Cost to Grow?

In Quebec, the cost of growing switchgrass plantations was compared to short rotation forestry willow using side by side plantations. Switchgrass, yielding 8-12 odt ha^{-1} was estimated to cost $38-$51 per odt or $2.18-$2.91 per GJ of energy, while SRF willow had production costs of $63-$95 per odt ($3.20-$4.82 per GJ).

On an equivalent yield basis switchgrass cost approximately 40% less to produce than short rotation forestry willow. Cost reductions for both crops will mainly come from increasing crop productivity and by reducing machinery and transportation costs, which represent almost 50% of the production costs (Girouard et al., 1996).

5.0 Agricultural Biofuels for $C0_2$ Abatement

Research is currently being undertaken to assess the carbon balance of bioenergy crops and the end use energy conversion requirements. In the case of switchgrass, research by REAP in partnership with McGill University, indicates that switchgrass can be considered a closed loop carbon biofuel. The small amount of fossil energy consumption used in the production of the crop is offset by the increased carbon sequestered in the soil, and *in the above and below ground plant.

The demand for these raw materials should increase in response to the event of new energy efficient technologies.

In November 1997, Iogen Corporation, a Canadian enzyme manufacturer, in partnership with PetroCanada, announced plans to build a 15-30 million dollar, 120 tonne per day cellulosic ethanol demonstration plant. This will be the first ethanol plant in the world to use cellulosic agricultural feedstocks as opposed to starch as raw material. The plant will test a range of cellulosic agricultural feedstocks to enable larger plants to be built throughout North America, using various feedstocks specific to each region.

Another recent technological development has been the commercialization of a new high efficiency gasifier pellet stove capable of burning higher ash containing fuels which was developed by Del-point Technologies of Blainville, Quebec, in conjunction with Natural Resources Canada. The stove has an operating efficiency of 85% which compares favorably to the modest efficiencies of 40-69% being achieved by the first generation of pellet stoves on the market.

As wood reserves are becoming more expensive, agricultural residues are being considered as alternatives. Switchgrass should be favored in the residential fuel pellet market due to its lower ash content. There appears to be significant opportunity to expand the home heating fuel market with the introduction of agriculturally derived fuels from the pellet industry. Increasing market shares of pellets produced from agricultural feedstock could have significant impacts on greenhouse gas emission reductions, especially if oil or electricity were targeted. In provinces of Canada, such as Ontario, where coal fired electricity generation is making a comeback it should be a high priority to keep emissions low. Used in this context, I million hectares of switchgrass would replace the equivalent of 36 million barrels of oil per year as the new gasifier pellet stove technology would have the same energy end use efficiencies as oil furnaces

SUMMARY

In the past ten years significant research progress has been made in developing low cost perennial grasses as bioenergy feedstocks. Parallel progress has been made in energy efficient end-use technologies such as cellulosic ethanol and gasifier pellet stoves. The impending challenge is to commercialize the opportunities so that industrialized nations can meet their greenhouse gas reduction targets.

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