Benefits and Costs of Shifts to Biomass Crops: Producer and Public Perspectives

Jim Fenton, President, Fenton and Associates, AB
Shahab Sokhansanj, University of British Columbia
Sudhagar Mani, University of British Columbia

March 2006

A BIOCAP
Research Integration Program
Synthesis Paper

BIOCAP
CANADA

www.biocap.ca

Table of Contents

Page

List of Tables

List of Figures

Executive Summary

There is a growing interest in sourcing additional biomass from agriculture as feedstock for energy and bioproducts. Potential benefits of this shift towards a bioeconomy include various environmental improvements as well as improved rural economies.

Using biomass for energy is particularly attractive with respect to Green House Gases (GHG's), in that it considered to be GHG neutral, and thus highly advantageous if it replaces fossil fuel as the energy source. While not as concentrated a form of energy as natural gas or coal, it is much more environmentally friendly, as shown below.

Energy cost and greenhouse gas emissions of different fuel sources (from Table 3.1).

Fuel source	Heating Value GJ/t dm	Fuel cost, $/GJ	GHG emissions, kg of CO_2 eqv /GJ
Natural gas	52	11.11	68
Coal	24	3.70	208
Dry biomass (hay)	18	4.67	9
Wood pellets	18	7.55	3

It is often assumed that much of the biomass could come from agricultural residues. Although there is good quality data on land use and grain and oilseed production in Canada, data on the availability of residues is limited, derived mostly from assumed mass ratios. Following this approach, it has been estimated that an annual average of 37 million tonnes of harvestable straw are produced on the Prairies, but this ranged over the years from a low of 20 million tonnes to a high of 52 million tonnes. Most of the straw is produced in Saskatchewan (19 million tonnes), followed by Alberta (13 million tonnes), and Manitoba (5 million tonnes). Demands on the residues come mostly from the livestock sector and conservation needs, which together may total 24-30 million tonnes. Thus, while there are large amounts of straw produced, there are also large demands on this straw, and implied periodic shortages; e.g., 20 million tonnes of harvestable straw versus a demand of 24-30 million tonnes.

The sourcing of agricultural residues has also been more difficult than was predicted. The reasons are many, including competition from livestock and soil conservation, changes in technology such as the shifts to semi-dwarf cereal varieties and rotary combines, changing crop mixes, and others. This raises the question of the potential for targeting biomass as a specific crop output; i.e., the production of biomass crops, or including biomass as a targeted component of selected cropping systems.

The energy content of alternate biomass crops varies, but through relatively narrow ranges, from about 18 GJ/t for hay to 25 GJ/t for canola. Larger differences are found with the crop yields. On a net basis, the energy content per ha ranges from a low of 28 GJ/ha for rye to a high of 164 GJ/ha for Switchgrass.

Yields and energy value of alternate crops (from Table 3.2 (Samson et al., 2005)).

Crop	Yield t/ha	Energy GJ/odt	Net Energy GJ/ha
Rye	2.0	19.0	28
Oats	2.2	19.1	32
Canola	1.7	25.0	32
Soybeans	1.9	23.8	39
Barley	2.8	19.0	43
Winter wheat	4.2	18.7	66
Tame Hay	4.6	17.9	78
Grain Corn	6.2	18.8	98
Switchgrass	9	19.0	164

The GHG emissions and the extent of carbon sequestration also vary by crop. For example, the GHG emissions from the production of dryland timothy is estimated to be less than half that of dryland barley, or a difference of about 300 kg/ha/yr of CO_2 equivalent. And, the total sequestration of carbon by Switchgrass is higher than that for corn by 400 kg C/ha/yr, which equates to 1.5 t/ha/yr of CO_2. The total reduction in greenhouse gases from switching from cereal to grasses would likely be in the order to 1.5-2.0 t/ha/yr.

Greenhouse gas emissions from production of timothy compared to wheat and barley (from Table 4.10).

Crop types	Crop yield, t/ha	GHG emissions, kg CO_2 eq/ha	GHG emissions, kg CO_2 eq/t
Timothy, dry land	5.75	363	63
Wheat, dry land	4.35	597	137
Barley, dry land	4.27	697	163
Timothy, irrigated	8.65	530	61
Barley, irrigated	5.36	813	151

Rate of carbon sequestration of three managed systems in Southwestern Quebec - t/ha/yr (from Table 3.3).

Ecosystem pool	Willow	Switchgrass	Corn
Biomass (above)	1.71	1.92	2.38
Root (below)	1.25	1.06	0.21
Soil	0.04	0.03	0.03

The producers' perspective relative to the opportunity to produce crops for bioenergy or bioproducts relates primarily to business economics. There are many influencing factors, including profit potential, machinery required, availability of markets, required expertise, government programs, and others. It takes more than an attractive farm budget to attract producer interest in a new crop. In the current setting, an over-riding consideration is the need to control risks, protect cash flows, and be able to respond quickly to new opportunities that may arise.

In the context of the Prairies, there is the potential for producers growing bioenergy crops for their own needs. Switchgrass or elephant grass would likely produce over 7 t/ha. With an energy value of 18 GJ/t dw, a conversion efficiency of 70%, and a natural gas cost of $10/GJ, the implied energy value of the crop is $800-900/ha. However, there are also significant costs involved in extracting this energy. At best, when all costs are considered, there may be an advantage over natural gas of $4/GJ. Still, this equates to a net benefit of $350/ha – which is attractive by today's standards.

Producer perspective:

- Urgently looking for ways to improve earnings.
- Intuitively interested in biomass crops, but concerned about technology.
- Preoccupied with the need to control risks and protect cash flows.
- Strong desire to maintain flexibility of future cropping patterns.
- Desire to participate in related value-added activities.

But there remains an important and outstanding issue with existing technology for converting biomass to energy. Based on actual trials, it appears that raw biomass may need to be converted to some intermediate form, such as pellets or cubes, before burning. This conversion may cost up to $80/t, and this brings the cost of energy from $50/t biomass to about the same as that for natural gas with a metered price of $10/GJ. If the metered cost of natural gas increased to $12/GJ, the biomass would have an advantage of $2/GJ, and a net benefit of $120/ha. Still this would be marginal considering the risks and management burden involved. But a natural gas cost of $15-20/GJ, as is predicted by many, would quickly result in major benefits to biomass energy systems.

The support of producers and rural communities is likely essential for the success of such ventures, and this support can often be related to their participation in the related value-added activities. Simply selling the agricultural products in raw form is often of little interest to producers, and will garner little enthusiasm or supply. While obtaining value-added services from producers or the rural community may or may not be the most efficient method, it may be required to make the sourcing of biomass possible; i.e., in some cases, it may be necessary to trade-off certain efficiencies in order to realize the larger potentials. (See Annex C for a more detailed discussion of this issue).

Industry perspective:

- Generally recognize the major risks of developing new crops and products.
- Only large firms can cope with the associated risks and cash-flow demands, and they may have other priorities.
- Smaller firms could play an important role if presented with adequate incentives and assistance.

Carbon credits for changing land use from cereals to forages, at the levels being discussed, would make only modest differences to the above scenarios. For example, a carbon credit of $10/t, or $15-20/ha, would not be sufficient to over-ride the basic economics of the situation. A stronger encouragement approach may be through risk reducing measures and improved technology.

From a public policy perspective, there do appear to be extra-market benefits in the production of bioenergy crops. Broadly, these benefits appear to include:

- limiting the growth of green house gases (GHG),
- assisting carbon sequestration in soils,
- perhaps limiting use of fertilizers and herbicides during the growth cycle of crops, and
- maintaining habitat for birds and wildlife.

Development of public policy assumes the ability to quantify such benefits, and assess the prices society is prepared to pay for them. The knowledge base on both the physical measurement and willingness-to-pay issues appears to be rising exponentially. But, while the economic and environmental case for paying growers for the extra-market benefits may be strong, the informational costs are high, and the change in public culture needed to initiate such payments may be profound.

There are other public initiatives that could provide some benefit to producers of biomass crops, such as improvements in systems of crop insurance. It is also be useful to note, however, that government seems increasingly to be moving toward 'whole-farm' approaches of support, which provides support to farmers based on changes in some 'whole-farm' measures of income. Hence, at least some aspects of biomass production may already be provided with public support.

In total, the strongest claim biomass crops have to public support has to do with the extra-market benefits they supply to society. While building the case for such supports will require added efforts in documenting the existence and value of benefits, it will also require a more environmental focus to public policy in agriculture. The issue is not likely to be resolved in the near-term, but it has the potential to help 'level-the-playing-field' in terms of support for annual versus multi-year types of production.

The above discussions respecting agricultural products are focused on good productive agricultural lands, likely producing cereals or oilseeds. Unfortunately it is not an easy matter to extrapolate these findings to marginal and under-utilized lands. While there are the common constraints such as inflexibility of long rotations, high reclamation costs, and delayed earnings, there are additional challenges with marginal lands due to the biophysical characteristics of the lands, competition for these lands, and public expectations specific to marginal lands. Still, marginal lands have relatively low opportunity costs and few options, and biomass crops could represent a significant opportunity for the operators of these lands. They should continue to be considered as a potential for producing biomass crops.

Policy implications:

- There are public benefits to be had, but public intervention is required.
- Carbon credits on their own, at the levels being discussed, are unlikely to impact on crop/product development on good lands.
- Candidates for intervention include: risk reducing measures, agronomic and engineering research, and subsidized technical assistance.

Acknowledgements

The authors wish to express their gratitude to BIOCAP Canada Foundation for making this project possible. The research topic is of increasing importance as Canada addresses concerns about greenhouse gases and the well being of rural communities.

Susan Wood, Associate Research Director, BIOCAP Canada Foundation provided overall direction to the research team, along with valuable guidance in identifying pertinent issues to be addressed in the study. Katie Lundy, Research Support, BIOCAP Canada Foundation ensured that the project management functions were adhered to, and this support was appreciated and well received.

The interest of the project review committee is appreciated. Members included:

Ken Arnold, President, Stonepoint Strategies.
Kurt Klein, Professor, Department of Economics, University of Lethbridge.
Dan McKenney, Chief, Landscape Analysis and Applications, Natural Resources Canada.

Comments provided during the formal review of the draft document resulted in an improved final document.

The study benefited from an invitation from Dr. Dan McKenny to attend a forestry workshop that dealt with several aspects of using poplar and willow as cropping options. Various parts of those deliberations have been incorporated in this report.

1. Introduction

1.1 Background

Increased attention to global climate change and green house gas mitigation has caused a growing interest in the sustainability of existing agricultural production systems. Crops, cropping systems, and agricultural management practices impact on private and public economics, but also on the environment, through such things as GHG emissions, soil carbon sequestration, soil conservation, wildlife habitat, and sources and uses of energy.

Crops and livestock dominate the agricultural industry of western Canada. Canada has about 36.4 million ha of croplands available for agricultural production, of which more that 85% (about 32 million ha) is located on the Prairies (Manitoba, Saskatchewan, Alberta) and a small portion of North East British Columbia (Campbell et al., 2002). Cereal crops, followed by oilseeds and pulse crops, dominate seeded area. Following grain harvesting, most crop residues are left in the field, or used for livestock feed or bedding. In some recent initiatives however, these residues have been used for the production of ethanol, composite boards, energy, and other bio-based products and chemicals. Each of these developments impacts on climate change, greenhouse gas mitigation, and green energy production. The sustainability of these systems is dependent on the availability of feedstock, much of which must come from agricultural lands. This, in turn, impacts on the sustainability of agriculture.

There have been changes in the amount of agricultural residue available. While cereal and oilseed production has generally been increasing, scientists have developed shorter stem cereal varieties, which considerably reduce the straw to grain ratio. New technology, such as the rotary combine, has reduced the amount of harvestable straw. As well, as the cropping of soils continues, a portion of the crop residues must be left on the field to maintain the soil fertility and avoid erosion. Agricultural residue as a source of biomass has its limits.

An option for increasing the supply of biomass from agriculture is to produce more crops specifically for biomass, or crops having biomass as one of the significant component outputs. Examples include biomass energy crops such as switch grass or short rotation poplar. Several energy crops increase soil organic carbon sequestration (carbon storage), reduce greenhouse emissions, promote bird habitation, and offer many other social and ecological benefits (Perlack et al., 1992; Graham et al., 1995; Paine et al., 1996). Another example would be dual purpose crops, such as hemp, that provide fiber for industrial applications as well as large quantities of core that can be used for energy.

Shifting of agricultural practices from traditional cereal crops to biomass crops requires participation and interest from the producers. This implies real private benefits, either available through the normal market mechanism or imparted through interventions. Movement in this direction requires information about the private and public benefits and costs of such cropping shifts, and information on the likely requirements to cause such shifts to occur.

1.2 Purpose of the Study

The purpose of the study is twofold:

1. To evaluate the economic and environmental impacts of potentials shifts from traditional cropping systems (food and feed) to crops for use as bioenergy or bioproducts.

2. To identify the major determinants of the potentials for such cropping shifts to occur.

Examples of significant crops that can be used for bioenergy or bioproducts, and that may have potential to be widely adopted by producers on the Prairies, include the following.

- Flax and Hemp
- Elephant grass and Switchgrass
- Sweet clover and other clovers
- Millet
- Short rotation poplar and willow.

While crop residues, including straw, have the potential to be targeted as specific crop outputs, the focus of this study is on crops specifically grown for purposes other than food and feed.

The study also has its focus on good agricultural lands, as opposed to marginal lands or under-utilized lands. The study examines the potential for “shifts” to biomass crops on productive and producing soils, typically shifting from an existing traditional crop such as cereal or oilseed to a biomass crop. An extension of these findings to marginal lands is discussed in the final chapter, but primarily to demonstrate the additional considerations involved.

1.3 Study Approach

1.3.1 General Approach

The study was conducted recognizing the following:

There have been successful introductions of new crops in recent years, and it is useful to fully understand the processes and conditions related to these introductions so as to better understanding the scope and requirements for introducing additional new crops.

The significant adoption of non-traditional crops by producers in western Canada has been slow and cautious. There are several reasons for this, including insecure markets and marketing channels, lumpiness of required investments, farm financing and cost structure, lack of government support, and a host of other economic and non-economic factors. It has been found that an attractive farm budget is far from a sufficient basis to judge the likely adoptability of a new crop.

All considerations about adoptability of the new crops must evaluated as to their technical feasibility, and the <u>private</u> financial, economic, environmental, and social changes that would result from their adoption.

The analysis requires, as a starting point, full farm budgets for each of the potential new crops being studied and for the crops they replace.

The potential for adding value at the farm or regional level is an important consideration in the adoptability of any new crop. These value-added activities generally would be in some form of preprocessing of the product for a subsequent use (see Annex C on preprocessing options).

The opportunity for obtaining multiple products from one crop plays an important role in sourcing additional biomass for bioenergy and bioproducts. This is a form of crop fractionation, closely related to the preprocessing discussions above.

The farm budget information also serves as the basis for interpreting and quantifying the public impacts of cropping shifts, inclusive of the economic and environmental impacts. Differences between the private and public impacts provide indicative information on the case for interventions.

1.3.2 Limitations

The value of the information will only be as good as the quality of data available to construct the farm budgets. This varies from good for crops such as flax, to poor for crops such as hemp.

Some of the limiting data is technical in nature, such as normal expected yields from elephant grass. Some is economic, such as the value of the core fraction of hemp. For poplar and willow crops, the implications of the wait for the harvest on the adoptability of the crop are conjectural.

Other limiting data includes producer perceptions about environmental stewardship. For some producers, there is a high priority attached to protecting the environment.

The length of adoption period for new crops is often critical to the success of the crop, with too slow a rate of adoption often negating the opportunity. Typically the markets and the crops must develop together, and this adds the complication of estimating the rate at which the value-added and marketing activities can develop. Experience has shown this to require a highly orchestrate process of modest incremental steps.

1.3.3 Use of a Case Study

To assist in coping with the lack of data on the potential new crops , it was decided to develop a baseline case for a well known and reasonably similar crop that has recently been introduced - to learn and to demonstrate the type of data and information required to make credible estimates of the potentials and impacts of the new crops being considered. This baseline information can then be used for making comparative statements about the potential new crops.

For this study, export timothy was used as the baseline crop. It was introduced in the 1980’s, and generally replaced cereals and oilseeds. Excellent technical, economic, and social data is available for both the new and the replaced crops. The development process and time-lines are well known, as are the critical development needs and hurdles that influenced the development process. With this information, we can better identify the critical information needs and considerations for assessing the potentials for other new crops. For example, with export timothy it was found that most producers expanded slowly into the new crop, in 25 ha increments, and most took 3 years to learn how to make a profit. The farm budgets suggested a net return of over $40/ha, or twice that of barley, and there was a ready market for the product, but it still took over 20 years to reach 300,000 t/annum of output.

1.4 Report Structure

The report is structured to provide an overview of the potential sources of biomass, followed by a description of the significant environmental and economic aspects that should be considered when evaluating the impacts of such crops. For illustrative purposes, these considerations are then applied to the specific case of export timothy in the Prairies, which is a new crop that has several strong parallels with the biomass crops being investigated.

The potential new biomass crops are reviewed against the above, to the extent permitted by the available data – which varies by crop. The final chapter reflects on the potentials for development of new biomass crops, and the major considerations involved in developing such crops.

2. Sources of Agricultural Biomass

While there are a variety of potential sources of agricultural biomass, the focus in this study is on crop biomass, which may be a crop, a crop fraction, or crop residues available following crop harvest.

2.1 Biomass From Crop Residues

The 32 million hectares of arable land on the Prairies are divided into five soil zones: the Brown soil zone (21%) and Dark Brown soil zone (22%) occupy the drier south and central regions of the Prairies. The balance of the soil falls in the Black, Dark Gray, and Gray soil zones that occupy the northern part of the region (Campbell et al. 2002). The collection and supply of adequate quantities of straw to a biomass conversion plant is affected by climate conditions, local demand for animal bedding, cereal variety, and cropping rotations (Johnston et al., 2005).

2.1.1 Residue Availability in the Canadian Prairies

Although there is good quality data on land use and grain production in Canada, data on the availability of straw residue is limited. Much of the information available on residue is derived from grain production, assuming a straw to grain ratio that varies from one estimate to another (Wood and Layzell, 2003).

Table 2.1 shows that, based on our calculations, roughly 37 million tonnes of straw were produced on the Prairies annually. But this annual production ranged from a high of 52.6 million tonnes to a low of 20.8 million tonnes. Most of the straw was produced in Saskatchewan (more than 19 million tonnes), followed by Alberta (roughly 14 million tonnes), and Manitoba (5 million tonnes). If 50% of the straw is left on the field for soil conservation and erosion control, the total straw available for collection would be about 18.5 million tonnes. But, most of the cattle in Prairies depend on straw for feed and bedding, which can account for 0.5-1.0 t/mature head (Alberta Agriculture, 2005). In 2004, there were nearly 12 million head of cattle on farms in the Prairies, suggesting a straw requirement of 6 – 12 million tonnes, as against the 18.5 million tonnes of available straw. While there are large amounts of straw produced, there are also major demands for the straw.

Table 2.1 Total crop residues available in the Canadian Prairies.

Cereal grains		Alberta		Saskatchewan		Manitoba		Total straw-Prairie	Straw yield
		1000 t	t ha^{-1}	1000 t	t ha^{-1}	1000 t	t ha^{-1}	1000 t	t ha^{-1}
Wheat	Avg	7,475	2.86	13,390	2.15	4,152	2.05	25,017	2.36
	Max	9,370	3.24	18,971	2.61	4,990	3.19	33,330	3.01
	Min	4,251	2.05	7,652	1.54	3,600	0.70	15,503	1.43
Barley	Avg	4,434	2.46	3,467	2.06	1,187	1.94	9,088	2.15
	Max	5,714	2.84	4,822	2.43	1,705	2.96	12,242	2.74
	Min	2,074	1.82	1,957	1.42	950	0.70	4,981	1.32
Oat	Avg	921	2.63	1,529	2.47	999	2.34	3,449	2.48
	Max	1,342	2.88	2,183	2.92	1,237	3.10	4,763	2.96
	Min	418	2.16	939	1.93	706	1.03	2,063	1.71
Flax	Avg	37	1.75	662	1.42	354	1.12	1,054	1.43
	Max	64	1.88	946	1.70	485	2.03	1,494	1.87
	Min	22	1.62	386	1.16	235	0.37	643	1.05
Overall	Avg total	13,618	2.81	18,736	2.09	4,993	1.92	37,347	2.27
	Max total	17,618	3.18	26,299	2.49	8,705	2.91	52,622	2.86
	Min total	8,057	2.13	11,113	1.55	1,614	0.72	20,784	1.47

Source: Team calculations based on grain yields reported by Statistics Canada.

2.1.2 Seasonal Variations in Residue Availability

One of the inherent problems with biomass from crop residues is its annual variation, which depends largely on weather conditions. The Prairie Agricultural Machinery Institute (PAMI) has shown that the amount of straw recoverable actually goes to zero at some low yield point due to the limitations of current harvest technology. For example, Figure 2.1 shows the fluctuations of wheat straw available in the three Prairie Provinces from 1994-2003. In a good year, such as 1999, the total wheat straw available in Alberta was 9 million tonnes. In the drought year of 2002, the amount fell to less than half - at ~ 4 million tonnes. Saskatchewan followed the same trend. Annual variations are also large for other crop residues such as barley, oat and flax (Sokhansanj et al., 2005). While the amount of production varies considerably from year to year, the demands for the residue for erosion control and livestock usage tend to remain quite stable.

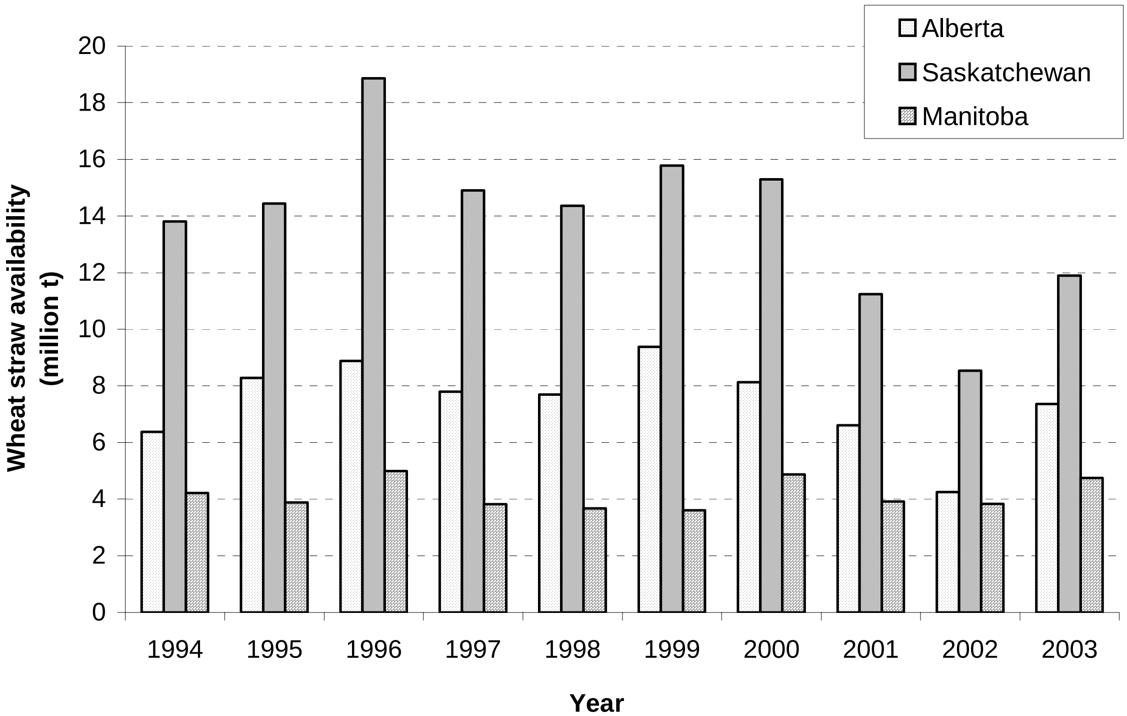


Figure 2.1 Annual variation of wheat straw availability in the three Canadian provinces. (From team calculations based on grain yields reported by Statistics Canada).

2.2 Biomass Energy Crops

Biomass energy crops, or bioenergy crops, are defined as any plant material used to produce bioenergy, but those grown specifically for the purpose are characterized by the capacity to produce large volumes of biomass, have high energy potential, and are adapted to any marginal and crop lands (Lemus and Lal, 2005). Biomass energy crops falls under two major categories; namely, herbaceous crops and short rotational wood crops (SRWC).

2.2.1 Herbaceous Crops

Herbaceous crops are plants that have little or no woody tissue, and mostly comprise bunch-type grasses, generally harvested like hay at the end of the growing season when important nutrients (especially nitrogen) have been translocated to the roots (Lemus, 2004). Some are annual crops with thick stems like sorghum, while others are perennial with thin-stems like switchgrass. Depending on conditions, the crops can be grown either monoculture or inter-seeded with other species. They can also be double-cropped with other energy crops or with conventional agricultural crops.

Herbaceous crops such as elephantgrass, kleingrass, buffalograss, switchgrass miscanthus, reed canary grass, tall fescue, eastern gamagrass and big bluestem have been identified as promising species for biofuel production (Madakadze *et al.,* 1999). These grasses regrow from their roots and do not require replanting for long periods of time (> 15 years). Also included are legumes such as alfalfa. birdfoot treefoil, crown vetch, flatpea, clover and sericae lespedeza. There are several advantages of using these crops for energy production. Management and production practices, and the equipment needed, are modest. Also, these crops can grow on marginal soils and still achieve moderate yields and protein levels. Fertilizer, energy, and water requirements are low, and year-round ground cover slows erosion. With recent advances in energy crops research, production of herbaceous crops for energy conversion is economically feasible.

In North America, the biomass yield of herbaceous crops varies from region to region. For example, in the Southern USA, biomass yields of more than 40 tonne/ha were obtained from elephantgrass, energy cane and coastal bermudagrass (Woodward and Prine, 1993). For other crops, the yield ranged from 10.8 to 25 tonne/ha, which includes kleingrass (6.6 to 11 tonne/ha), buffalograss (14.5 tonne/ha) and switchgrass (5.4 to 26 tonne/ha) (Sanderson et al.1996). In the Northern USA, biomass yields of 3 to 9 tonne/ha were achieved for big bluestem, 5.8 to 8.7 tonne/ha for indiangrass, and 7.7 to 12.3 tonne/ha for switchgrass (Jung et al., 1990). In Canada, Madakadze et al. (1999) studied the biomass yield of three different varieties of switchgrass grown in Canada. They estimated that the biomass yield of Cave-in-Rock, Pathfinder and Sunburst varieties were 12.2, 11.5 and 10.6 tonne/ha respectively.

2.2.2 Short Rotational Woody Crops (SRWC)

The short rotational woody crops (SRWC) are fast growing woody plants. The SRWC include hardwood species such as poplar, willow, cottonwood, sweetgum, sycamore, black locust, silver maple and Eucalyptus. The SRWCs can be grown for other uses also, such as paper production, and the waste can be utilized for energy (Brown, 2003). SRWC systems involve genetically improved plant material grown on open or fallow agricultural land. They require intensive site preparation, nutrient inputs, and short rotations (3 to 10 years). In northern temperate areas, woody crop development has focused on willow shrubs (*Salix* spp.) and hybrid poplar (*Populus* spp.). Eucalyptus (*Eucalyptus* spp.) has been a model species in warmer climates.

3. Benefit Cost Considerations

3.1 Environmental Perspective

There are several environmental and ecological benefits associated with the production of biomass energy crops. These crops can be easily established and maintained, they fix soil organic carbon above and below the ground, they reduce soil and water erosion, and they improve the quality of wildlife inhabitant.

3.1.1 Energy Supply and GHG Emissions from Different Fuel Sources

It is important to recognize that the energy content of alternate fuel sources varies, as does the efficiency and cost of alternate methods of extracting this energy. The cost of extracting energy from different fuel sources, namely natural gas, coal, wet biomass, dry biomass and fuel pellets, is shown in Table 3.1, along with the corresponding greenhouse gas emissions. Among the different fuel sources, coal has the lowest energy cost, but by far the highest GHG emissions.

Table 3.1 Energy cost and greenhouse gas emissions of different fuel sources.

Fuel sources	moisture content, % wb	fuel cost, $/t	Fuel cost, $/GJ of energy	Net GHG emissions, kg of CO_2 eqv /GJ
Natural gas	0	10/GJ	11.11	68.50
Coal	25	50	3.70	208.15
Wet biomass (wood chip)	50	40	7.41	17.70
Dry biomass (timothy)	15	50	4.67	8.52
wood pellets	8	100	7.55	2.80

Source: Annex A.

Looking at specific crops, the energy content varies from a high of 25 GJ/ODT for canola down to around 18 GJ/ODT for tame hay (Table 3.2).

Table 3.2 An example of solar energy collection and fossil fuel energy requirements, in GJ/ha (Samson et al., 2005.)

Crop	Yield (t/ha)	Energy Content (GJ/ODT)	Fossil Energy Consumed/t produced (GJ/ODT)	Fossil Energy Consumed (GJ/ha)	Solar Energy Collected/ha (GJ/ha)	Net Energy Production /ha (GJ/ha)
Rye	2.0	19.0	4.6	9	37.1	28.1
Oats	2.2	19.1	4.5	10	42.2	32.2
Canola	1.7	25.0	6.3	11	43.4	32.4
Soybeans	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
Switchgrass	9	19.0	0.8	7.2	171.0	163.8

Source: Samson et al., 2005.

3.1.2 Soil Carbon Sequestration

Soil carbon sequestration is a process in which plants remove CO_2 from the atmosphere and incorporate it into soil carbon pool along with other nutrients (N, P, and S). It is estimated that about 75 to 80 percent of the lost carbon can be re-sequestered in the soils (Wojick, 1999). Conversion of degraded agricultural soils to energy crops can improve soil quality by increasing carbon sequestration due to their perennially, high biomass production, and deep root systems (Ma *et al.,* 2000). Replacing fossil fuels with bioenergy crops has a potential to reduce the rate of enrichment of atmospheric CO_2 because of the cumulative effects due to high biomass accumulation (Bransby *et al.,* 1998). However, bioenergy crops provide net gains in carbon sequestration only if they replace annual row crops.

One of the advantages of bioenergy crops are that aboveground biomass can be used to produce energy through combustion without increasing net CO_2 emissions. Figure 3.1 shows the energy and carbon flow during production and combustion of energy crops and coal. When aboveground energy crop is harvested and burned for energy, carbon dioxide is returned to the atmosphere. Regrowth of the plants, in turn, remove the carbon dioxide from the atmosphere. In this way, carbon dioxide is recycled by the energy crops, making this process carbon dioxide neutral (or actually carbon-dioxide- negative if soil carbon sequestration is considered), as compared to fossil fuel use that continually adds carbon dioxide to the atmosphere (Zan *et al.,* 2001).

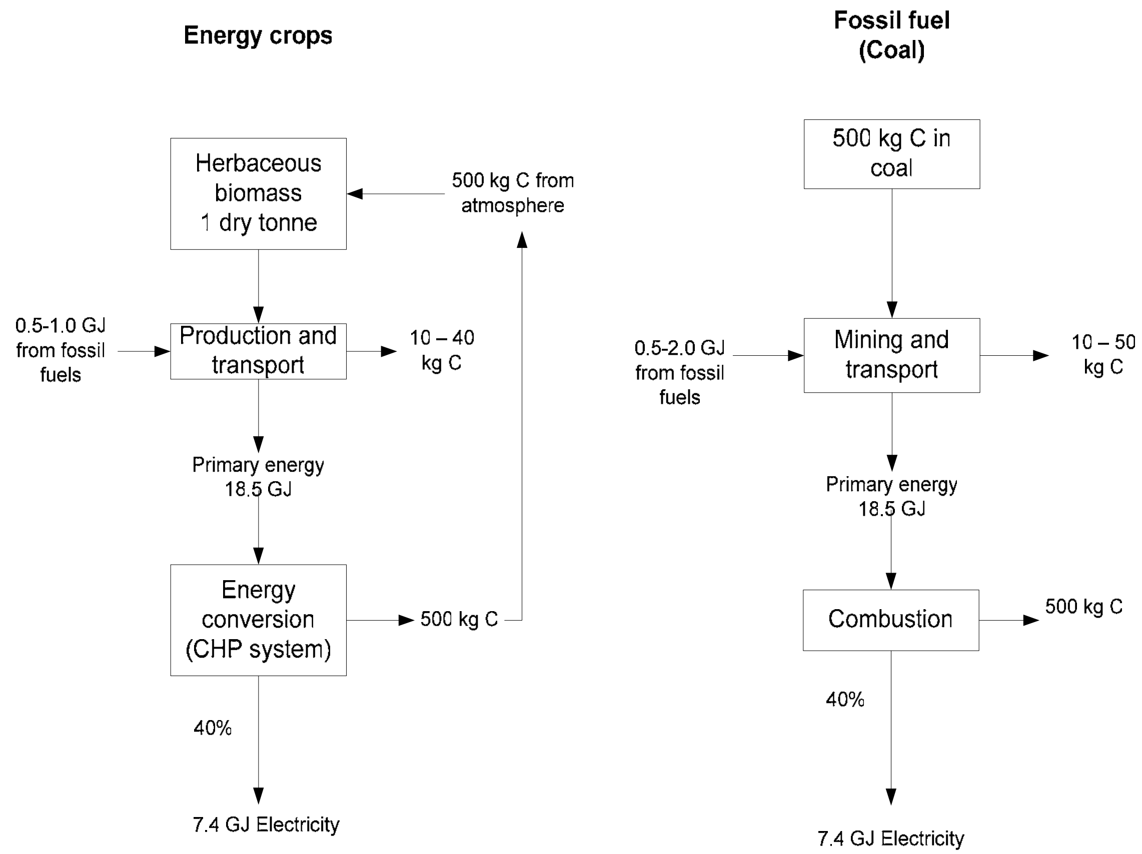


Figure 3.1. Comparison of energy and carbon (C) flow from energy crops and fossil fuels (Cannell, 2003).

Aboveground Biomass. The potential for soils to sequester carbon depends on the rates of biomass production relative to carbon exports controlled by microbial activity (Williams et al., 2004). Residue cover has a soil cooling effect and influences decomposition rates by moderating biological activity that could influence the incorporation of carbon into the organic-mineral complexes (Ingram and Fernandes, 2001). Cook and Beyea (2000) estimated biomass production of 5.4 tonne C/ha/yr by corn, 7.4 tonne C ha/yr by switchgrass, and 8.0 tonne C ha/yr by SRWC in a 3-year or 10-year rotation. The amount of biomass production by these cropping systems may reduce CO_2 emissions by sequestering 400 kg C/tonne of biomass in switchgrass, 500 kg C/tonne in willow, and 600 kg C/tonne in poplar, compared with only 300 kg C/tonne by corn residue (Lemus and Lal, 2005).

Belowground Biomass. Soil carbon sequestration below the ground is achieved by through the root systems. Switchgrass has four to five times more belowground biomass than corn, with additions of 2.2 tonne C/ha/yr *(*Zan et al., 1997). Thus, removal of switchgrass or other bioenergy crops may not severely exacerbate the erosion hazard nor adversely affect the soil organic carbon (SOC). Perennial crops maintain considerable biomass below the typical cutting height, and also their fibrous root network close to soil surface aids in soil stabilization and SOC sequestration (Kort et al., 1998).

Detailed information regarding the profiles of root system for different energy crops compared to corn can be obtained from Lemus and Lal (2005).

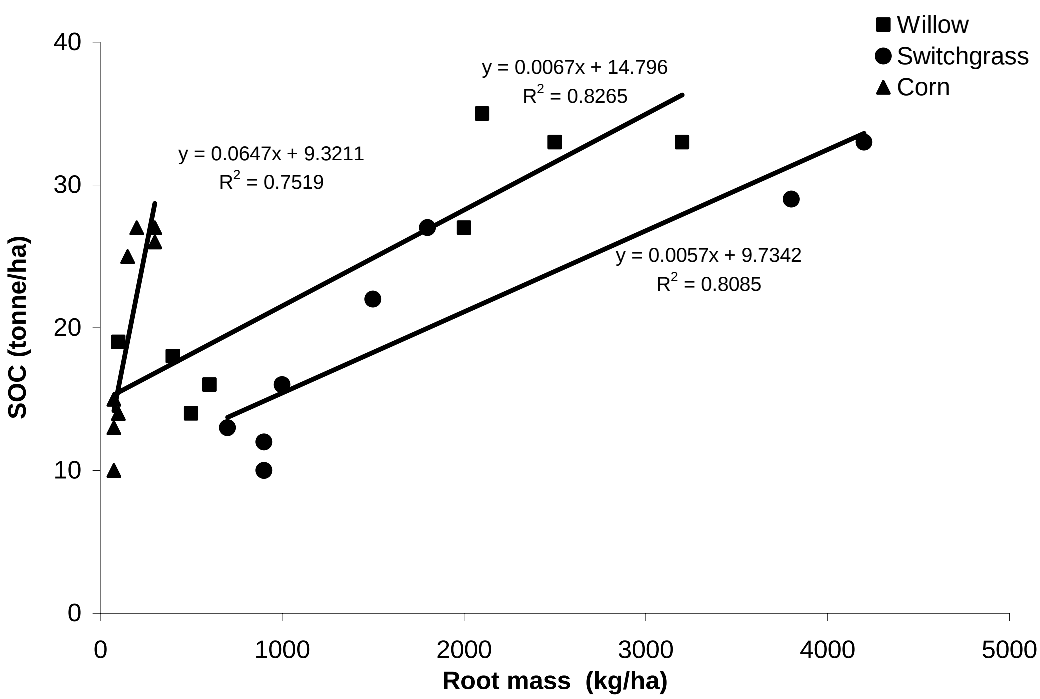


Figure 3.2 Relationship between soil organic carbon (SOC) and root mass of annual and energy crops (data extracted from Mehdi et al., 1998).

Mehdi et al. (1998) reported the soil carbon sequestration for three different ecosystems (switchgrass, willow and corn) in southeastern Quebec, and found that willow and switchgrass have greater soil organic carbon and nitrogen content than corn. Switchgrass had a higher root carbon below 30 cm depth than corn or willow. The SOC present under bioenergy crops (willow and switchgrass) is related to great root mass in the soil profile when compared to traditional crops like corn (Figure 3.2). As the depth of the root system increases, the oxidation of carbon decreases due to the reduction in microbial activity. Therefore, deep-rooted crops are more likely to have a stable SOC pool (Grigal and Berguson, 1998). Table 3.3 shows the soil carbon sequestration of willow, switchgrass and corn. From Table 3.3 corn has greater aboveground biomass carbon, while willow sequestered more carbon in the soil. However, in the total biomass system, both willow and switchgrass sequestered more carbon than corn.

Table 3.3 Rate of carbon sequestration (tonne/ha/year) of three managed systems in Southwestern Quebec, Canada (Zan et al., 2001).

Ecosystem pool	Willow	Switchgrass	Corn

Biomass (above) Root (below) Soil	1.71 1.25 0.04	1.92 1.06 0.03	2.38 0.21 0.03
Changes with reference to corn			
Total biomass Soil	+0.37 +0.01	+0.39 0.00	-- --

3.1.3 Management of Cropping Systems Affecting Carbon Sequestration

Increase in the carbon dioxide content in the atmosphere is mainly associated with emissions from the use of fossil fuels and agricultural systems. Soils lose about 15 to 40 tonne carbon/ha from their original carbon pool, and can sequester 60 to 70 percent of the depleted C pool with the adoption of species capable producing high biomass (Lal, 2002). The sequestration of carbon from the emitted carbon pool depends on crop variety, fertilization, and harvest management.

Crop variety. Plant species differ in biomass production, and soil carbon storage is primarily controlled by two fundamental processes: net primary productivity (NPP) and decomposition. Increase in NPP results in an increased carbon storage, whereas increased decomposition has an opposite effect (Yang and Hsieh, 2002). Maintaining plant species with good vegetation cover and deep root systems, such as perennial grasses, are important to increasing the SOC pool in deeper soil layers (Sommer et al., 2000). Management of eroded croplands with more perennial crops (grasses and SRWC) can enhance soil quality and improve SOC sink capacity by improving plant productivity, soil structure, pH, and nutrient pool, and increasing the amount of biomass returned to the soil and incorporated into the SOC pool (Lal, 2003).

Fertilization. Soil fertility influences the amount of biomass produced and the rate of soil carbon sequestration. The SOC pool depends on the amount of biomass returned to the land and the amount of N present in the soil. Several studies have shown that regular application of fertilizers leads to an increase in SOC (Schuman et al., 2002; Rice, 2000; Reeder et al., 1998). Most degraded lands utilized for bioenergy crops are deficient in N and can increase biomass production and water-use efficiency in response to N fertilization (Lemus, 2000). Fertilization stimulates biomass production and, therefore, enhances C accumulation (Schuman et al., 2002). Rice (2000) reported that N fertilization increased biomass production in a tall grass prairie with a 1.6 tonne C/ha sequestered in the soil over a 5-year period. Management practices such as N fertilization, row spacing, and harvest frequency do not affect C sequestration by switchgrass (Ma et al., 2000). Improving fertilizer use efficiency in bioenergy crops is a key element in increasing the SOC pool. Fertilization rates for herbaceous crops usually range from 50 to 100kg N/ha depending on species, region, soil nutrient status, and climate. Fertilization is required to maintain the rapid growth rates in SRWCs, especially after the second rotation (three years after planting).

Harvest Management. The NPP and plant growth capacity of bioenergy crops increase with harvest management. An increase in biological capacity has a higher demand for atmospheric CO_2, which may be incorporated into different plant components. Herbaceous crops *(e.g.,* switchgrass) are usually harvested once a year in late fall when most leaves are still intact. Large switchgrass biomass production can significantly increase C sequestration, with C concentration of 39-41% (Tufekcioglu et al*.,* 2003). These concentrations can be higher under multiple harvests where new growth requires more sequestered C for tissue formation (Lemus, 2004). Harvest management also affects C sequestration, since cutting may shift the allocation of C from active root biomass to regrowth of leaves and in this way alter the SOC profile associated with root activity (Ma *et al.,* 2000). Therefore, SOC sequestration in herbaceous crops largely depends on root dynamics (Bransby et al*.,* 1998). Most SRWCs grown for bioenergy purposes are harvested on a 3-10-year rotation, and are generally harvested during the dormant season (winter) when significant quantity of nutrients are translocated to the roots and most of the leaf deposition contributes to SOC sequestration. Willows are more efficient at sequestering C on an annual basis than trees grown in native temperate forests, and production per ha can exceed that of the row crops (Ranney et al*.,* 1991).

3.1.4 Soil Erosion

Soil erosion in croplands impacts negatively on crop productivity, including soil water holding capacity, soil nutrients, soil density and soil organic matters. Production of biomass energy crops on the cropland significantly decreases soil and water erosion and preserves soil productivity (Graham and Dawning, 1993; Ranney and Mann, 1994). Figure 3.3 shows cropland erosion reduction in Nashville, TN due to shifting croplands to switchgrass. Significant reduction in soil erosion and nitrogen losses was observed when 20% of the cropland was cultivated with switchgrass.

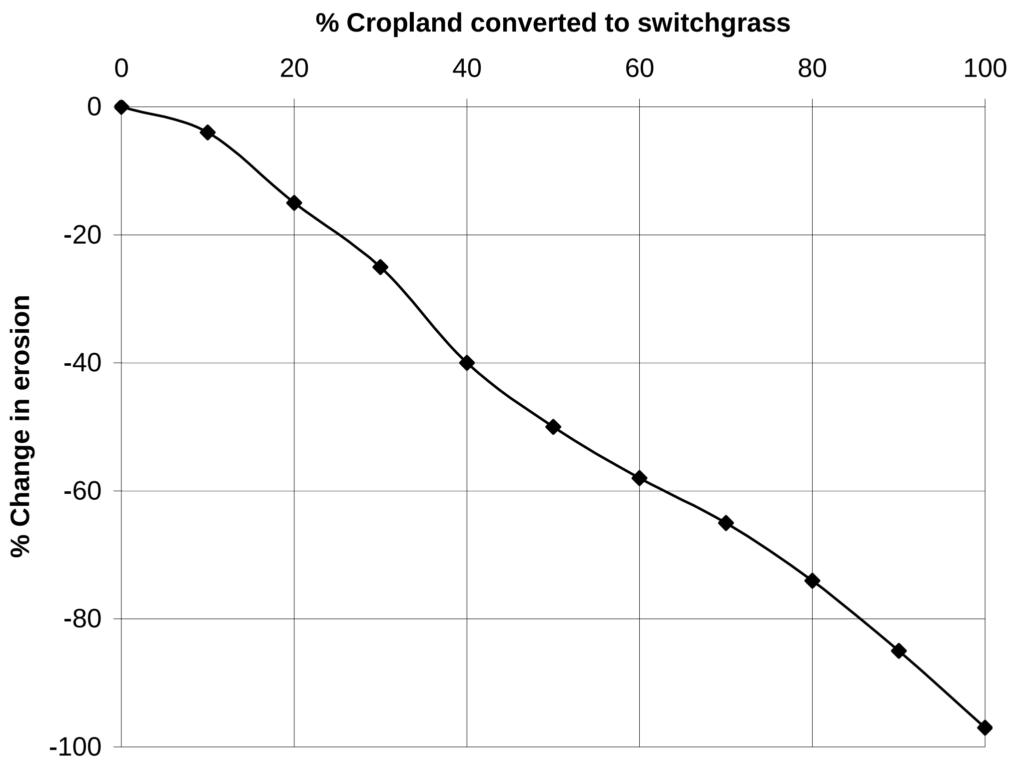


Figure 3.3 Cropland erosion reduction in Nashville, Tennessee (Data extracted from Graham and Downing, 1993).

3.1.4 Wildlife Habitat

Perennial grasses can provide extensive habitat for grassland wildlife, similar to the short rotational woody crops. SRWC provide a transitional habitat, with a great deal of change in habitat structure over a relatively short period. From Table 3.4, herbaceous crops significantly promote the breeding bird density and bird species compared to row crops. Thus, converting land currently planted to corn and soybeans to energy crops would increase the density and diversity of birds, and change the wildlife community dynamics (Paine et al., 1996). Roth et al. (2005) reported the response of grassland birds during harvesting seasons. They found that strategic harvesting management schedule is important for the value of wildlife habitat in grasslands.

Table 3.4 Breeding bird density and species richness of row crops and grassland in Wisconsin, USA (Paine et al., 1996).

Habitat type	No. of breeding pairs/40 ha	No. of breeding species
Reed canary grass	246	9
Dense switchgrass	182	10
Poor switchgrass	178	9
Mixed warm season grasses	126	13
Corn	32	5
Beans	22	2

3.2 Economic Perspective

3.2.1 Production potentials of biomass for energy

There is a wide range of grasses, trees and/or shrubs that seem well adapted to the agricultural areas of Alberta. At least some of these are potential sources of bioenergy, and some may also be suitable for bioproducts such as building materials, construction materials, or fabrics. From this perspective, the potential bioenergy uses must also compete with other non-food and non-feed uses.

Most potential bioenergy crops have characteristics that make their adoption difficult. A common suggestion is the use of straw (the residue from grain or oilseed production) as a feedstock for bioenergy uses. Indeed, it has been suggested that the amount of straw, and the economics of scale of large bioenergy producing plants, are so persuasive that more than one large-scale producer of energy from straw would be economic within the province (Flynn 2006). To date, these potentials have not been borne out in relation to straw used for production of building materials. While strawboard plants have tended to local scale, all such plants to date have been financially unsuccessful. Their inability to access sufficient straw at prices they consider affordable may be due to a combination of circumstances on the agricultural side as well as on the plant scale side. Included in the former would be the longer-term decline in straw due to varietal shifts (primarily to semi-dwarf varieties of crops), an increasing need for straw due to growth of the livestock industry, and what may be a long-term decline underway in the economics of producing barley, traditionally the major source of straw on Alberta farms. On the plant scale side, it may be (as Flynn argues for bioenergy) that the economics of scale for such plants is simply too small to permit them to command straw from a larger area. Intuitively at least, the scale economy argument for a plant producing building products does not seem nearly as persuasive as it might for an energy plant, since energy plants currently tend to be very large.

Other crops such as flax and hemp have potentials for use off the farm, but are difficult to process with typical farm equipment. Grasses such as elephant grass or switchgrass may have potential as bioenergy sources, although basic agronomic information for prairie locations appears sketchy. Here, too, issues of handling arise, since height and stem size appear to be directly related, and (like hemp) these plants can become very tall. Woody plants also have a potential to fit into a bioenergy system, but harvest and handling issues remain, although at least some of these are being addressed (Savoie 2006). Rapid introduction of such plants (either herbaceous or woody) for producing biomass would likely require a) remunerative price guarantees, b) centralized or cooperative purchase of suitable harvest/processing equipment, and c) assurance of the agronomic suitability of the source of the biomass.

3.2.2 Private and public socio-economic impacts

There are at least two separate issues that impact on the socio-economic consequences of shifting production toward crops that provide biomass for energy or provide carbon sequestration benefits. Some production shifts toward grasses or woody plants have occurred over recent decades, and those changes provide clues to what are the social and economic factors associated with the shift toward increasingly conservation-oriented farming patterns. The second issue is the consequences at the community, regional or national level of moving toward multi-year crops from the annual cropping patterns characteristic of prairie farms. This is a function of a host of issues; the basic on-farm economics of new multi-year crops, the perceptions that farmers hold about economic opportunities in the years ahead, and the policy choices that governments make.

Production shifts to multi-year crops. One example of the trend away from annual cropping has been the founding in the mid-1980s, the subsequent rapid growth, and now perhaps a winding-down of the export timothy hay market. During the 1990s, the industry expanded annually, and appeared to meet a strong overseas demand. Farmers responded to the opportunity, and the industry had an impressive history for a number of years. With the strengthening of the Canadian dollar, however, the industry faltered.

The area in which the timothy export business grew was a part of the relatively productive black-soil zone. A typical part of the crop rotation in this area might be, for example, canola, wheat, barley, or canola, wheat, wheat, barley. The most adventurous farmers might even increase the number of years of canola in the rotation. Few, however, would actively lobby to increase the number of years of barley in a typical rotation. The reasons are not hard to understand. No. 1 Feed Barley typically provides a gross return of $300 to $500 per ha. Wheat, as long as it got into the 3CWRS or higher category, was likely to provide $400 to $800 per ha, and canola (at least until the collapse of 2005-06), was likely to provide a wide range of outcomes, but within a range that could be expected to bottom at $600 or so an ha, and probably top out at near $1,200 per ha. While the costs for canola production at the implied yields is higher (perhaps $50-$100 per ha) than for wheat or barley, the costs for the other two crops are similar. Result: farmers attempt to maximize canola acres, and there is typically a lack of enthusiasm for barley. If the lack of enthusiasm for barley is really true, however, why is barley acreage relatively insensitive to the option provided by multi-year grasses?

This answer is almost surely that farmers view returns as an average over a typical rotation. If so, they recognize that shifting to a long-lived crop means that there is a need not only to compete with barley, but also to compete with the wheat and canola that will be part of a typical rotation. One of the issues in the current environment of a highly valued Canadian dollar and relatively depressed commodity prices, is that the returns from the overall rotation are sinking, and that may be shifting the balance of financial viability toward multi-year crop plants, whose financial attractions may be less affected by a rising Canadian dollar. One growing competitor for the timothy acreage, however, is what appears to be a growing interest in silage. A growing, but unknown, part of barley acreage is ensiled for cattle feed. Especially in the milk sheds of growing urban centers, silage for dairy animals is a major issue, and the rapid rates of growth in Alberta especially make this a further threat to straw availability, especially on cultivated lands in the Edmonton-Calgary-Lethbridge corridor. In addition, there is increased reliance on silage by cattle feeders, making it likely that forages for bioenergy will continue to meet sharp competition from silage as well as grain crops in the black-soil areas, even while the grain economy faces serious cost-price issues.

In turn, if bioenergy is likely to be subject to significant competition in the black-soil zones, what are the prospects in the other soil zones within the prairie region? While the issues are complicated by a dearth of basic agronomic information on the new crop options involved, some considerations in the economics of bioenergy on, say, the thin-black region are the following: 1) what, if any, yield penalty is paid for moving to these regions? 2) is there a transport cost differential to move these products to some use point or transport location? 3) do different input cost regimes exist? Intuition alone suggests that comparing black soil zone and other soil zone outcomes might lead to similar input costs but somewhat lower yields outside the black soil zone. All long-lived plants carry with them added costs of returning the land to its original cultivated state at the end of the rotation. While the cost is probably not excessive for long-lived crop plants, it escalates rapidly with the introduction of woody plants. Similarly, the annual or periodic harvest cost also escalates as growers shift land to woody crops and these added costs are a further deterrent to shifting to bioenergy systems.

There is a further reason why growers may be reluctant to shift to longer crop rotations involving a number of years of a bioenergy crop such as grass. There is a history of dashed expectations in many rural communities. Timothy was planted on the basis of price relationships that held true for many years. Eventually however, related in large part to the value of the Canadian dollar relative to importer currencies, timothy prices declined, and budget expectations of earlier years simply did not materialize. The current budgets appear to show timothy as less profitable than wheat or silage, even given current prices of small grains. Another lesson, this one focused on the attractions of crops other than forage, occurred in the early 1970s. At that time, many farmers signed long term contracts with the Federal Government to commit their land to forages for a defined period of time, the goal being to cut back crop production in the face of large backlogs of unsold grain on farms (the so-called LIFT – Lower Inventories for Tomorrow – program). As a result, farmers who committed themselves to the forage option missed at least some of the years of strong grain prices in that early 70's period (pleas to permit breaking contracts were eventually met by the government of the day). Although these events took place several decades ago, many farmers or their parents, continue to resonate to the issues involved. Partly as a result of the recollections of the past, many will gauge their involvement in new bioenergy production not just on price plans for the biomass itself, but also based on their expectation of prices of traditional annual crops.

Aggregate Effects. Assuming that a significant shift to production of biomass for energy purposes can be made to happen, what are likely to be the aggregate consequences of such a shift? At least two issues stand out: one is how likely it is for such a shift to occur, and another is the impact on the overall economy should one or more herbaceous or woody plants become a significant part of the agricultural production scene.

Issues surrounding the prospect of a new innovation finding its way to market or into widespread use have long been studied by behavioral scientists. The so-called innovation-diffusion process attempts to explain the process of introduction of a new concept, technique or product in terms of the way various people react to new ideas; there are those who adopt early, those who adopt late, and those who wait until almost everyone else has tried the product or innovation. Gladwell's 'Tipping Point' theory borrows from the diffusion literature, but also introduces a kind of mass psychology, in which something becomes fashionable enough that at some 'tipping point' it suddenly becomes widely accepted. In applying these concepts to agricultural products, however, it seems important to recognize that the basic economics have to be there in the first instance. But beyond that, people gradually learn about an innovation and are tempted to try it. This is particularly so if the costs of the experiment are low, and even more so if the potential benefits are also significant. In the early 1990's, the Federal Government introduced a plan known as GRIP (Gross Revenue Insurance) that provided a combination of price and yield insurance leading to guaranteed levels of gross returns from a crop, irrespective of yields or prices at harvest. In a few cases of crops with relatively little price or yield history, these crops guaranteed total returns that made their production very attractive. One such crop was field peas, not widely grown in dryland prairie agriculture prior to that time. The acreage of peas rose sharply in those years, and remained at significant levels for some time. For a range of reasons that have little to do with the way in which peas were introduced to prairie farmers, the production of peas has lost much of its earlier interest. But it continues to be a cropping alternative, and likely would never have so become but for the effects of that particular farm program, a program that permitted farmers a cost-free (and in some cases very profitable) experiment with a new crop.

Hence, some sorts of risk reduction schemes can greatly aid the introduction of new crops such as those that are bioenergy related. At this time, however, typical farm programs have few if any benefits for those raising bioenergy crops, and there are few ways for growers to shift some of the price or yield risk to other parties. Crop insurance would of course be attractive, but few farmers seem to be content even with the current coverage for forages, and crop insurance has tended not to work well for crops that are defined as exotic. Of course, the problems are particularly acute for bioenergy derived from trees. Here, the grower must focus on product prices that may be years in the future. Typically, there is no salable output until the end of that period, and there are major costs associated with a change of crop plans during the growing process. Contracts may be possible, but there are risks to all parties from such arrangements.

4. The Case of Export Timothy in the Prairies

4.1 Nature of the Industry

While export timothy does not fall within the realm of a new crop for maximizing biomass, it is a useful case to examine for several reasons. There are strong resemblances of timothy with the production characteristics of the most likely crops for higher biomass, such as switchgrass or elephant grass. Timothy was also a new crop that was introduced without an established market, and with limited knowledge of production or marketing methods. It was targeted on good lands, thus requiring some other crops to be replaced. It was launched in Alberta, but successfully introduced in all of the Prairie Provinces. There was little government support. All of the above may apply to any new crop being introduced as a source of additional biomass. Lessons learned in the export timothy experience are instructive in terms of planning for, or assessing the potentials for, a new crop.

We will refer to the crop as export timothy, and the industry as the modern export hay industry, to emphasis that the crop being discussed is new and unique. Timothy itself is an ancient crop, which is grown widespread as a component of hay mixes or for seed. As well, there have been earlier exports of timothy and other hays. However, the timothy export market as discussed here involves a different type of timothy, different processes, and different markets than those of the past.

4.1.1 Development Path

The modern export timothy industry was started in Alberta in 1981, with a trial shipment of 17 t in a container to Japan. By 1986, the shipments still amounted to only 9 containers and 165 t, but the growth continued, and in 1987, 74 containers with 1,252 t were shipped (Table 4.1). The product came from several different producers is different parts of central and southern Alberta, none of whom had much knowledge or connection to the market. The product was compressed using mobile equipment, and loaded in containers at the farm. Only in 1988 was a central compressing/loading facility developed.

Although growth of the industry was slow, it was continuous (except for the disastrous drought of 2002 which is discussed later). During the early years, all of the product came from Alberta. Saskatchewan started shipping in 1996, and Manitoba in 1997. Alberta continues to dominate, accounting for over 85% of the current shipments.

Table 4.1 Shipments of Export Hay, 1986-2004, t

1986	165
1987	1,498
1988	3,620
1989	5,719
1990	10,973
1991	25,232
1992	38,366
1993	38,878
1994	63,486
1995	97,158
1996	90,410
1997	104,906
1998	138,716
1999	149,502
2000	184,823
2001	229,431
2002	256,608
2003	203,782
2004	313,778

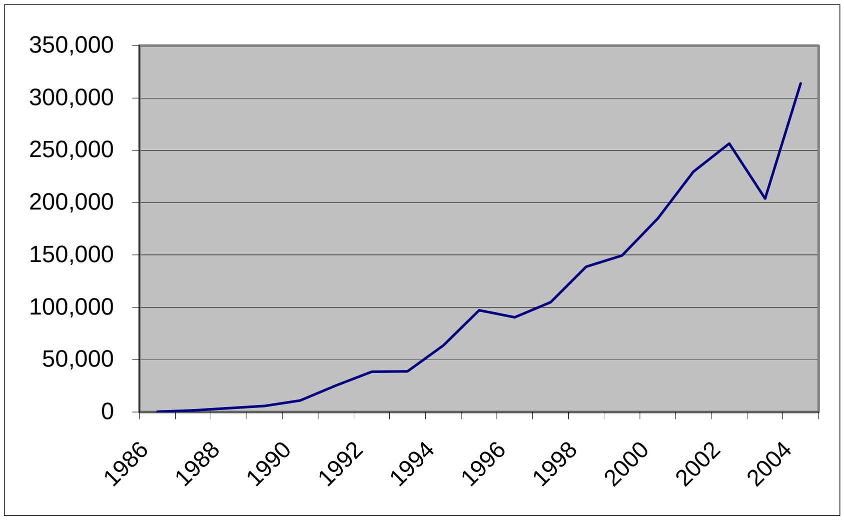


Figure 4.1 Shipments of Export Hay, 1986-2004, t

Sources: data for alternate years from various sources, including: Agriculture Canada Phyto-Certificates; Canadian Hay Association; Unicoop, Japan; Alberta Agriculture.

4.1.2 Nature of the Product

Export timothy is produced and harvested to maximize its fiber quality as a component in high quality ruminant and horse feeds. However, there remains much speculation about what constitutes high quality timothy. The export timothy market does not require or expect routine chemical analysis of the products prior to shipment. Customers buy timothy because of its palatability, and its apparent effect on factors such as animal health, milk yield and milk quality. Conventional feed analysis does not demonstrate these values. It has been observed that end-users buy forages that are readily devoured or “cleaned-up”, rather than hay that is “picked over” or sorted and thereby wasted. As well, timothy customers in hot humid climates look for feed material that their animals will consume readily, since appetites of these animals tend to be depressed with higher temperatures and humidity.

What has traditionally been a yardstick is that the ideal timothy plant is immature, has a course stalk, a large head, and is celery green in color. End-users normally evaluate the quality on its visual appearance, and it is rare to laboratory analysis as a part of quality evaluation or feed formulation. Different customers want different things in the feed. Initially the producers of the crop had no good guidelines for how to produce a crop with particular characteristics, and no good method for knowing if they had achieved any particular standards. In consequence, the grading system was relatively arbitrary.

Over the years, as the knowledge of the Canadian product grew, so did the body of anecdotal evidence of what the customers and their cows preferred. Laboratory analysis of selected samples was initiated by some processors, and related to apparent customer wants. This process continues, and information to relate products to customers is gradually getting better. But many questions remain. For example, a worrisome and inexplicable problem is the occasional hay lots that cows refuse to eat, despite the forages having the normal look, feel, and smell of good quality hay. The penalty for these situations is that the shipments are returned, and the processor suffers the losses.

4.1.3 Product Pricing

There are some 6 major grades of timothy, each with ranges, thus there are many price potentials. With the subjective nature of matching products to consumer wants, the pricing becomes somewhat of an art. From the producer's perspective, most good producers during the startup period planned in terms of averaging $150/t, with the high-end hay being worth well over $200/t, and the low-end something below $100/t – perhaps being sold in the domestic market.

The exported product has always been sold in $US. A rule-of-thumb used in the industry was that the price in the export market (c.i.f.) was approximately equal to the producer price in $Cdn/t plus $100, and stated in $US/t; i.e., $Cdn 150/t to the producer would have a c.i.f. value of $US 250/t. The following sample price profile reflects this price structure.

Table 4.2 Sample Price Profile – Export Timothy, 2000

Port price at destination, cif		255	$US
Marketing costs		12	$US
Shipping	800	32	$US
Vnc'r price, fob		211	$US
Cdn Exchg	0.65		
Vnc'r price, fob		325	$Cdn
Shipback/claims insurance (self)		7	
Rail to port		28	
Trucking, plant to rail		12	
Phytos, export fees		2	
Plant output, ex plant		276	
Profit, risk		10	
Processing costs			
Variable		70	$Cdn
Fixed		40	$Cdn
Shrink	4%	6	$Cdn
Plant input, del'd		150	$Cdn

Prices in the export markets (in $US/t) were relatively constant over the years, and primarily set by other supplying nations – notably the US. Canada, with 5-10% of the market, was essentially a price taker, able to extract only some special consideration for the quality of its products. Price risks related mostly to exchange rates and ocean shipping costs. The exchange rates were relatively constant during the major growth years of 1994-2002 (Table 4.3). Shipping rates did fluctuate from year to year, but a 50% increase in shipping rates still amounted to only $US 16/t, and there were usually opportunities to absorb this change in other cost components.

Table 4.3 Cdn/US Exchg Rates, 1986-2005

1986	0.72
1987	0.75
1988	0.81
1989	0.84
1990	0.86
1991	0.87
1992	0.83
1993	0.78
1994	0.73
1995	0.73
1996	0.73
1997	0.72
1998	0.67
1999	0.67
2000	0.67
2001	0.65
2002	0.64
2003	0.71
2004	0.77
2005	0.83

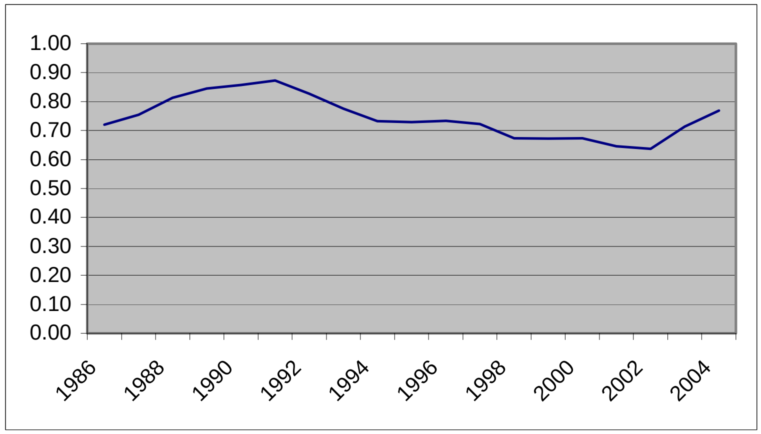


Figure 4.2 Cdn/US Exchg Rates, 1986-2005

Source: Bank of Canada.

4.1.4 Processing Industry

Being a new and developing industry, the export hay processing industry was relatively inefficient during its development years. Processing costs were high, in part reflecting the ongoing research and development efforts. There were no templates to follow, and no parallel research efforts to copy or to learn from. For example, the high-pressure compressing systems were developed exclusively by and for the export hay industry, all of which was funded from day-to-day operating budgets. The innovators in the industry bore the brunt of these costs, and the others followed.

Capital costs were reasonable high, amounting to over $50/t of output. It was generally accepted that a plant needed to produce a minimum of 15,000 t/annum to be viable, implying a capital investment of over $750,000. A bigger cost, however, was the cost of hay inventory, which would total over $2,000,000 for this size of operation. Banks tended to be very cautious about lending to this type of a new industry, and innovative financing methods were required.

In total, the industry was characterized by low profit margins per tonne (as reflected in the pricing structure above which indicates a profit of $10/t on a Vancouver price of $325/t), high capital and inventory costs, but relatively stable market prices. The major risk was with foreign exchange rates, but these were easy to ignore as long as they were relatively stable and the industry was growing. In spite of the low margins, the gross profits were attractive.

Exchange rates started a significant change in 2002, going from $0.64 to the present $0.86. The difference per tonne is $75 (Vancouver), a huge amount in relation to the low margins being earned. Although the industry was started when exchange rates were greater than $0.80, the majority of acres were developed when the rates were closer to $0.65. The overall efficiencies and expectations were geared to $0.65. As indicated below, the processors could not adjust or absorb the change due to exchange rates, with dire consequences for the industry and the producers.

4.1.5 Producer Returns

Producers initially viewed the industry with some skepticism. Hay had traditionally been a somewhat inferior product, often produced on inferior lands for the producer's own needs. There was not a well-developed hay market, and hay prices were traditionally low. While there were some producers of high-end hay for the high-end horse markets, these were viewed as exceptions. The advent of the higher priced export market needed to first overcome these traditional attitudes.

Target returns for producers remained steady at 5-6 t/ha and $150/t during much of the main development period of the 1990's (Table 4.4). It was recognized, however, that this was a reasonable target for a mature producer. A common expression amongst producers was that the first year would be a failure, the second year would be half a failure, and the third year would be a success. Most of the problems of succeeding related to getting acceptable quality of product.

Target net returns over a normal 5-6 year rotation were more than $375/ha, an attractive return compared to other cropping options and opportunities (Tables 4.4 – 4.7). But there were risks, uncertainties, and unknowns. Most producers started with one field, perhaps 25 ha, and expanded slowly as they learned, and gained confidence in being able to produce an exportable crop. Most producers continued, however, to view the crop as a diversification option. It would be unusual to find any producer with more than 1/3 of their croplands in export hay.

The change in US/Canadian exchange rates that started in 2002 had a huge impact on producer returns. The export price (Vncr) dropped by an average of $75/t over a 2-year period, directly as a result of changes in exchange rates. The processing plants had only a small profit margin to forfeit, and very rigid plant and equipment that could not adjust to the new pricing. In consequence, most of the price change was passed on to the producer, essentially leaving them at break-even for target returns. Large amounts of export timothy lands were changed to other crops in 2005, and several processing plants closed.

Table 4.4 Farm Budget, Export Timothy, 2000

Revenue	**$/acre**		
Yield - t/ac	2.30		
Price - $/t	150.00		
Crop sales		345.00	
Direct Costs			
Establishment	16.00		seeded with cereal cover crop; $80/ac (net loss) over 5 crops
Seed	0.60		$6.00/ac * 10% infill
Fertilizer	32.10		75 lb N * $0.36; 15 lb P * $0.34; incl application
Chemicals	12.00		including application
Crop insurance	0.00		
Trucking	23.00		$10/t to deliver
Fuel	12.00		32 l * $0.37/l
Repairs: equip/impr	17.00		
Utilities	2.00		nominal
Custom work	10.00		varying with producer equipment
Paid labor	30.00		mostly harvest labor, may include some bale picking
Operating interest	2.00		nominal
Other	32.00		$10/t shed storage; twine, rentals
Total direct costs		188.70	
Net - after direct costs		156.30	

* Indirect costs: land, interest on capital, capital leases, depreciation, taxes, insurance, prof services.
** Incremental capital costs: equipment, misc: $30,000 for 160 acres of timothy.

Table 4.5 Farm Budget, Wheat, 2000

Revenue			
Yield - t/ac	1.74		64 bu/ac
Price - $/t	141.00		$3.84/bu
Crop sales		245.34	
Direct Costs			
Seed	12.63		
Fertilizer	46.65		80 lb N * $0.36; 40 lb P * $0.34; 25 lb K * $0.17: incl application
Chemicals	32.21		including application
Crop insurance	11.86		
Trucking	8.65		$5/t
Fuel	7.40		20 l/ac * $0.37/l
Repairs: equip/impr	6.67		
Utilities and misc	5.34		
Custom work	13.26		
Paid labor	1.10		
Operating interest	8.66		
Other			
Total direct costs		154.43	
Net - after direct costs		90.91	

* Indirect costs: land, interest on capital, capital leases, depreciation, taxes, insurance, prof services.

Table 4.6 Farm Budget, Barley, 2000

	$/acre		
Revenue			
Yield - t/ac	1.73		80 bu/ac
Price - $/t	120.00		$2.60/bu
Crop sales		207.60	
Direct Costs			
Seed	12.32		
Fertilizer	37.20		75 lb * $0.36; 30 lb P * $0.34; incl application
Chemicals	21.51		including application
Crop insurance	7.14		
Trucking	8.65		$5/t
Fuel	7.40		20 l/ac * $0.37/l
Repairs: equip/impr	10.86		
Utilities and misc	11.81		
Custom work	3.21		
Paid labor	4.46		
Operating interest	0.94		
Other			
Total direct costs		125.50	
Net - after direct costs		82.10	

* Indirect costs: land, interest on capital, capital leases, depreciation, taxes, insurance, prof services.

Table 4.7 Crop Returns Comparisons – ($/ac)*

	1996	1998	2000	2000	2001	2002	2003	2004	2004	2005
Dryland										
Timothy										
Revenue	**300**	362	340	**386**	**345**			267	**310**	266
Direct Expenses	**92**	105	181	**203**	**141**			184	**185**	186
Net	**208**	257	159	**183**	**204**			83	**125**	80
Wheat										
Revenue	**269**				245		200	192		175
Direct Expenses	**134**				151		91	145		144
Net	**135**				94		109	47		31
Feed Barley										
Revenue	**261**						192	187		180
Direct Expenses	**136**						120	140		139
Net	**125**						72	47		41
Cereal Silage										
Revenue			175		221		235	210		210
Direct Expenses			90		147		140	123		122
Net			85		74		95			
Irrigated										
Timothy										
Revenue			600	**808**	**712**	**810**	**614**	504	**438**	504
Direct Expenses			351	**540**	**435**	**573**	**375**	418	**308**	421
Net			249	**268**	**277**	**237**	**239**	86	**130**	83
Wheat										
Revenue					340		408	276		266
Direct Expenses					198		204	220		222
Net					142		204	56		44
Feed Barley										
Revenue					348		260	256		247
Direct Expenses					204		186	215		217
Net					144		74	41		
Cereal Silage										
Revenue			270		302					320
Direct Expenses			150		164					233
Net			120		138					87

* Bold numbers indicate actual farm budgets, others are consensus estimates.

4.1.6 Industry Issues

The Canadian export hay industry is largely a price taker in the export markets, and must compete with other producing nations having lower costs. Western Canada is disadvantaged by its weather, which impacts directly on production costs and risks, processing costs, and marketing costs and risks. As well, it faces higher transportation and infrastructure costs than found in competing countries, and it functions almost entirely without external assistance. Its major economic advantage is its natural resource base, which is relatively low cost and enables a marketing perception of pristine growing conditions. By world standards, however, productivity per ha is not high.

Practical options facing the industry for improving profitability and helping to ensure long-term viability include new product development and improved cost efficiencies through new technology. Current products and existing markets are being exploited near their potential, and additional investments in conventional systems yield only marginal returns. Given the limited ability to force more profits from conventional systems poses the danger of Canada falling behind vis-à-vis competing nations, and touching off a final downward spiral in the industry. The business axiom of "grow or perish" is increasingly relevant to the industry, a recent example being the alfalfa industry in western Canada.[1] Attempting to squeeze more from the same will buy some short-term security, but long-term viability will require focused efforts in research and development, and significantly improved efficiencies.

The industry has a strong history of research and development, and several new initiatives are underway. Some relate to new products, some to new packaging, some to new processing methods, and others to various aspects of marketing and market development. The industry has developed due to the persistence of its key companies in research and development, allowing others to follow and benefit. Funding the research, however, has been difficult.

One industry improvement that has proven to be extremely elusive, but which could yield major returns, relates to product drying. The potential benefits of drying have long been recognized in the industry, and various efforts have been underway virtually since its beginning. All attempts have met with their own successes, but none have yielded the hoped-for results. This search goes on, and perhaps is the most important opportunity facing the industry. A successful drying system would result in major benefits to all industry participants, including the producers who would realize higher marketed yields and substantially reduced risks.

Directly, in response to the drastic consequences of the change in foreign exchange rates, and the inability to convert existing plant and equipment to more efficient systems, new operations are developing. More efficient systems and equipment are available, and it is cheaper to start over than it is to adjust existing systems and equipment. Processing costs are being reduced by half, and the new operations are not burdened by the high sunk costs.[2] The industry survival will likely depend on these "startup" operations, whether they are new or a rejuvenated part of an existing operation.

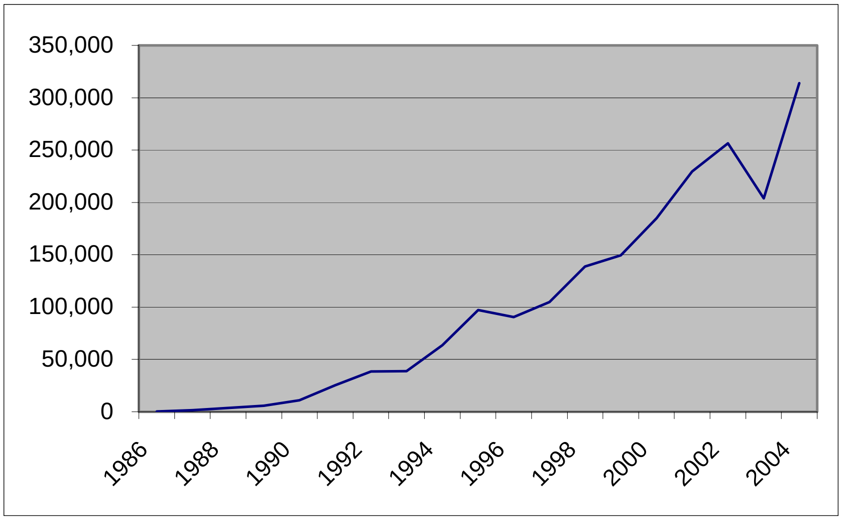
It is interesting to relate the change in acreage to the change in exchange rates, and note the lag in producer response with a multi-season crop, as shown in Figure 4.3. As discussed elsewhere, long

---

[1] Many business economists go further, believing that growth must be at an increasing rate for survival; i.e., even steady state growth is not sufficient.

[2] The situation is similar to the "theory of disruptive technologies", which describes the way startup firms successfully enter established industries.

rotation crops face their own constraints and limitations, and these have direct impacts on adoptability of the crops.



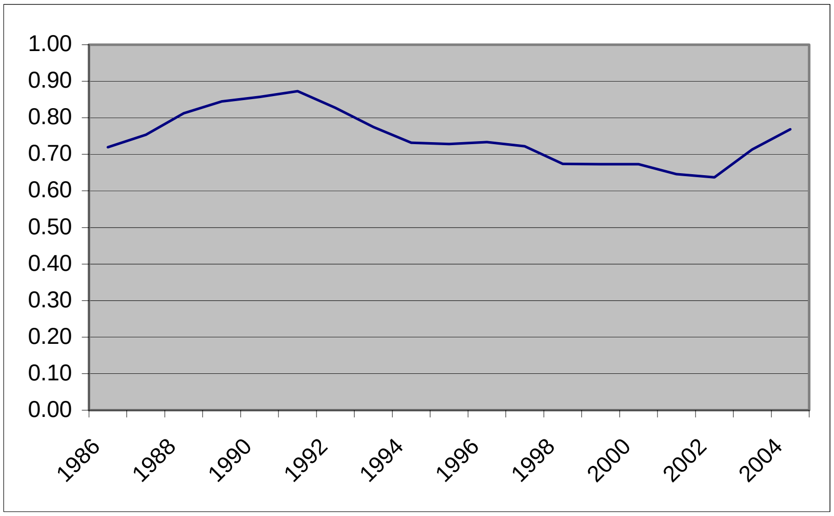


Figure 4.3 Relation of hay shipments with Cdn/Us Exchange Rates (from Figures 4.1 and 4.2)

4.2 Environmental Impacts

4.2.1 Greenhouse Gas Emissions

Greenhouse gas emissions from production of timothy can be estimated based on the emissions from fertilizer use, machinery operations and emissions from croplands. Greenhouse gases such as carbon dioxide, carbon monoxide, and nitrous oxide are represented in terms of carbon dioxide equivalents (Table 4.8).

Table 4.8 Carbon dioxide equivalent factors for different greenhouse gases

SL. No	Greenhouse gases	CO_2 equivalent factors
1	Carbon dioxide	1
2	Carbon monoxide	1
3	Methane	21
4	Nitrous oxide	310

GHG emissions from fertilizer use. Application of different fertilizers emits nitrous oxides to the atmosphere. Emission of N2O from nitrogen fertilizers is estimated from the following equation (CEEMA 2.0, 2002).

Emissions from fertilizers (kg of N_2O/ha) = $N*EF_N*44/28$

where N is the amount of nitrogen in the fertilizers in kg/ha; EFN is the fraction of nitrogen evolved as nitrous oxide (which is assumed as 0.0125), and the factor (44/28) is the used to convert nitrogen into nitrous oxide.

GHG emissions from diesel fuel. Farm machineries for various farm applications emit green house gases due to the combustion of diesel fuels. Table 4.9 shows the emission factors for the diesel fuel (EPA, 1995).

Table 4.9 Emission factors for the diesel fuel

Greenhouse gases	Emission factors (kg/l of fuel)
Carbon dioxide	0.6992
Carbon monoxide	0.0041
Methane	N/A
NOx	0.0188

GHG emissions from crop residues. Crop residues left on the field emit nitrous oxides due to decomposition and fermentation processes. The nitrous oxide emissions depend on the amount of nitrogen in the crop residues and the amount of crop residues left on the land. It was assumed that no nitrous oxide from timothy cropland is emitted due to complete removal of all the biomass from the field. In the case of barley and wheat, all the crop residues are assumed to be left on the field. The emission of nitrous oxide for the given crop is estimated as follows (CEEMA 2.0, 2002)

Nitrous oxide emission (kg of N_2O/ha) = $Y*N_B*CF*EF$

where Y is the crop residue in kg/ha, N_B is the proportion of crop biomass containing nitrogen (for example, wheat = 0.855; barley =0.85), CF is the crop factor for a non nitrogen-fixing crop (0.0165), and EF is the emission factor to convert N into N_2O (0.01964).

Comparison of Crops. Table 4.10 shows the greenhouse gas emissions from production of different crops. Timothy produces lower greenhouse gases than does cereal crops. Higher emission of greenhouse gases from cereal crops was due mainly to large emission of nitrous oxides from crop residues. Crops such as timothy grass do not require any residual grasses left on the field for soil conservation and soil erosion. In the case of cereal crops, at least 50% of the crop residues are required for soil conservation and erosion control. Growing timothy would reduce the greenhouse gas emissions in the range of 234-334 kg of CO_2 equivalent/ha as compared to wheat and barley.

Table 4.10 Total greenhouse gas emissions from production of timothy compared to wheat and barley.

Crop types	Crop yield, t/ha	Greenhouse gas emissions, kg CO_2 eq./ha	Greenhouse gas emissions, kg CO_2 eq./t of yield
Timothy, dry land	5.75	363	63
Wheat, dry land	4.35	597	137
Barley, dry land	4.27	697	163
Timothy, irrigated	8.65	530	61
Barley, irrigated	5.36	813	151

4.2.2 Carbon sequestration.

Soil carbon sequestration of bioenergy crops is much higher than that for cereal crops. Although no published data on soil carbon sequestration for timothy grass is available, bioenergy crops such as switchgrass showed higher soil carbon sequestration compared to corn crop of about 400 kg of C/ha/yr (see Table 3.3). Soil carbon sequestration from forest ecosystems are much higher compared to cereal crops, ranging from 0.4 to 1.3 tonne of C/ha/y (Papaport and Lind, 2003). As discussed in chapter 3, following strict cultural practices and management strategies can further increase the soil carbon sequestration.

4.2.3 Total Greenhouse Gas Impacts.

In total, timothy is positive in its impact on GHG as compared to cereals. Based on the above, we can safely assume that timothy versus cereal improves sequestration by at least 0.4 tonne of C/ha/yr, equivalent to 1.5 tonne of CO_2/ha/yr. (One tonne of carbon equates to about 3.67 tonne of CO_2). As well, based on the above, timothy versus cereal production reduces GHG emissions by an average of 280 kg/ha of CO_2 equivalent. The total reduction of greenhouse gasses from timothy production as compared to cereal crops is thus about 1.8 t of CO_2 equivalent per ha.

4.2.4 Other Environmental Impacts.

The various other environmental impacts of biomass crops, as discussed in Chapter 3, all apply fully to timothy. Of particular importance are the erosion control and habitat benefits, which are well understood by the producers, though not necessarily in a quantifiable sense.

4.3 Economic Impacts

Some of the direct economic impacts of export timothy are as follows. It is emphasized that these impacts are only the direct impacts, with no consideration to loop-back and associated impacts; e.g., the industry does create employment, but the value of this employment in the broader context can be debated. The broader context discussion is the subject of the final chapter of this report.

Producer returns. During the industry development period the available returns were higher than those for cereals, by at least $125/ha; capital investments were modest; risk was reasonably high during the learning process, but then only slightly higher than for other crops. The subsequent increases in foreign exchange rates removed most or all of the profit margins.

Cash crop. Producers, who in need of cash could sell their crop, and be paid full in 30 days. Most processors paid cash advances, some approaching the market value of the crop. This provision proved to be very important to many of the younger farmers.

Income diversification. Most new producers were producing cattle, cereals and oilseeds. Most were aware of the benefits of this relatively unrelated source of earnings; i.e., one that operated on an somewhat independent business cycle.

Workload diversification. The major tasks associated with export hay occur during July-August, fitting well with the major workload of cereals.

Crops replaced. The most likely crops being replaced are wheat, barley, and canola. To be more profitable, the returns to timothy must be superior to that of typical rotations involving grains and canola. This was the case during the expansion years.

Value-added. Plant in/plant out value of the product increases by over 80%, as compared to 30-35% in beef packing industry. This will change to 40-50% with the new more cost efficient operations.

Employment. Export hay, as it was developed, is labor intensive. The earlier farm budgets indicated $75/ha for timothy, versus $3-10/ha for cereals. Much of this cost relates to harvesting with small square bales, but this will reduce as producers adjust to the new prices – through such measures as moving to large square bales. Plant operations in the past employed up to 1 worker per 2,000 t of output, but plants in the future will reduce this by half.

Transportation. The industry has reasonably large transportation requirements. Farm output volumes increase by 35% as compared to cereal production. A 50,000 t plant has 3,500 loads arriving and 2,000 loads leaving each year, or 22-25 loads per working day.

Regional impacts. The most significant regional impact is on labor, much of which is drawn from local farms and small urban centers. The additional municipal taxes resulting from the industry likely do little more than pay for the higher municipal costs.

Trade. Most of the product is exported, thus making a greater direct contribution to trade surplus on a per ha basis than would be obtained from the crops replaced (wheat, feed barley).

Government programs and subsidies. There has been some government support for the industry in the form of co-funding of research and development, perhaps totaling some $0.5 million. Until 2006, crop insurance was not used due to it being based on quantity rather than quality of product, and the major crop risk is with quality. A new quality of product program has recently been introduced, and will be tested. The industry was successful in 2004 in having export hay qualify under the crop advance program, which includes the standard interest-free component. Being a fuel demanding industry, it gained proportionately more from the farm fuel subsidy. As well, it qualifies under the regulated rail rates for export products going to port; i.e., it pays about $28/t for rail service from Calgary to Vancouver. There are no other obvious subsidies or supports for the industry.

All of the above must be interpreted in a total sense rather than as individual items, which is discussed in Chapter 6.

5. Examples and Sample Data for Other Crops

5.1 Herbaceous Crops

Table 5.1 Establishment cost of herbaceous crops (Hallam et al., 2001)

Items	**Alfalfa**	**Reed Canary grass**	**Switch grass**	**Big bluestem**
Years of production	4	10	10	10
Revenue				
Yield (tonne/ha)	6.15	5.97	8.10	6.80
Price ($/tonne)	71.65	66.14	60.63	60.63
Total Revenue ($/ha)	440.64	394.84	491.07	412.26
Operating expenses				
Fertilizer				
Phosphorous ($/ha)	98.84	19.77	19.77	19.77
Potash ($/ha)	262.54	39.49	39.49	39.49
Herbicides				
Atrazine 4L ($/ha)			9.76	9.76
2, 4-D ($/ha)		11.42		
Eptom ($/ha)	20.83			
Seed ($/ha)	74.13	100.08	62.27	266.87
Operator labor ($/ha)	32.91	22.68	22.68	22.68
Fuel ($/ha)	18.91	13.57	13.57	13.57
Repair and Maintenance				
Implements ($/ha)	32.02	21.00	21.00	21.00
Tractors ($/ha)	22.16	16.04	16.04	16.04
Interest ($/ha)	31.06	12.97	11.94	17.07
Transportation ($/ha)	25.83	25.07	34.02	28.56
Total operating expenses	618.93	282.09	250.53	454.82
Allocated overhead				
Implements ($/ha)	41.29	29.78	29.78	29.78
Tractors ($/ha)	39.39	28.52	28.52	28.52
Land ($/ha)	284.17	284.17	284.17	284.17
Total allocated overhead ($/ha)				
Total expenses($/ha)	364.84	342.46	342.46	342.46
Net expenses($/ha)	983.78	624.55	592.99	797.28
Allocated Establishment cost ($/ha)	543.13	229.70	101.92	385.01
	158.54	31.95	14.18	53.56

Table 5.2 Production cost of herbaceous crops at Ames, Iowa (Hallam et al., 2001).

Items	**Alfalfa**	**Reed Canary grass**	**Switch grass**	**Big bluestem**
Operating expenses				
Fertilizer				
Phosphorous ($/ha)		19.77	19.77	19.77
Potash ($/ha)		49.49	49.49	49.49
Nitrogen ($/ha)		37.07	37.07	37.07
Herbicides ($/ha)	8.95			
Operator labor ($/ha)	21.82	28.29	15.00	15.00
Fuel ($/ha)	10.77	14.38	7.66	7.66
Repair and Maintenance				
Implements ($/ha)	22.66	26.46	13.64	13.64
Tractors ($/ha)	13.15	17.49	9.32	9.32
Interest ($/ha)	1.66	10.87	10.80	9.88
Transportation ($/ha)	42.74	34.55	46.73	39.80
Total operating expenses	121.73	118.37	199.73	191.62
Allocated overhead				
Implements ($/ha)	23.80	30.17	15.77	15.77
Tractors ($/ha)	23.35	31.06	16.53	16.53
Land ($/ha)	284.17	284.17	284.17	284.17
Total allocated overhead ($/ha)				
Establishment cost ($/ha)	331.32	345.40	316.47	316.47
	158.54	31.95	14.18	53.56
Total expenses($/ha)	611.59	605.73	530.10	561.64
Average yield(t/ha)	10.18	8.23	11.13	9.48
Breakeven price ($/t)	60.11	73.64	47.65	59.28

5.2 Woody Crops

5.2.1 Willow

The willow biomass production system is an agricultural-based system similar to perennial cropping systems. Experimental yields of short-rotation willow were as high as 24 to 30 dry tones/ha/y in Sweden and North America (Adegbidi et al., 2001; Labrecque et al., 2003). Typical yields are more often in the range of 10 to 12 dry tonne/ha/y.

Keoleian and Volk (2005) reported a life cycle energy, emissions and economic performance of willow crops. They concluded that a commercial willow enterprise will not be viable unless the biomass price, including incentives and subsidies, is comparable to currently used fossil fuels, and parties involved in growing, aggregating and converting the biomass, are able to realize a reasonable rate of return on their investment. There are two pathways to make willow biomass crops economically viable. One is to lower the cost of production by reducing operating costs and increasing yields. The other is to value the environmental and rural development benefits associated with the system.

Table 5.3 Greenhouse gas emissions flow per ha over seven rotations of willow crop (Keoleian and Volk, 2005)

	CO_2 emissions (tonne/ha)	Other GHG (tonne of CO_2 eq./ha)	Total (tonne of CO_2 eq./ha)
Diesel fuel	3.12	0.06	3.18
Ag. Inputs	2.97	0.4	3.37
N_2O from applied N		+3.97	3.97
N_2O from leaf litter		+7.28	7.28
C Sequestration			
Belowground biomass	-14.1		-14.1
Soil carbon	0		0
Net total	-8.01	+11.7	3.7
Harvested biomass	-499.2		-499.2

Current costs to produce and deliver SRWC are $43–52/dry tonne (Walsh et al., 1996).

5.2.2 Poplar

Table 5.4 Energy use and emissions for a 5-year rotational hybrid poplar (Updegraff et al., 2004)

Practices	Energy use (GJ/ha)	Carbon emissions (kg C/ha)
Establishment	3.10	51.9
Fertilization	15.02	251.7
Weed control	5.33	107.4
Harvest	15.03	251.9
Total	39.24	657.5

5.3 Observations of Others Respecting Crop Adoption

5.3.1 Profit Potential

The primary attraction for the farmers to grow energy crops depends on the net profit possible from the crop. The net return for growing corn in Wisconsin, USA varies from over $300/ha to close to zero on poor lands. In Canada, the net return from growing wheat or barley would be about $250/ha.

Switchgrass can produce between 4 and 14 dry tonne/ha. Production cost estimates range from $380/ha to over $600/ha. To simply recover production costs, a yield of 8 tonne/ha would be required (Turhollow, 1994). Power producers operating a plant with SRWCs expect a feedstock cost in the range from $40-50/tonne of biomass. This cost would only cover the production cost of SRWCs.

5.3.2 Improving Economics with Co-products

The development of by-products or co-products in conjunction with biomass production can provide economic incentives for landowners to put land into energy crop production. In the Northern Minnesota, alfalfa was grown for producing power. In this case, alfalfa stem material was supplied for power generation after separating leaves (co-product) from the plant. The high protein leaves were sold for $145/tonne as a livestock feed. If the co-product profit is included, the alfalfa stem for power generation costs about $1.6/GJ as compared to $2.7/GJ for switchgrass (Morris, 1994). Chemical and pharmaceuticals industries may require a number of chemical compounds found in some plant tissues and it may be possible to extract these without reducing the value of the biomass for production of energy.

5.3.3 Sustainable Production

The use of disease- and pest-resistant varieties of grass seed or tree stock improve both the environmental and economic sustainability of biomass crops. Switchgrass and other native herbaceous species tend to be less prone to disease and pest problems than are many conventional crops.

In the case of short-rotation woody crops, several species are being bred specifically for biomass production. Production of trees for SRWC plantations, using cuttings or other cloning methods, can result in the creation of large monocultures with little genetic variability that can be very susceptible to disease or insect attacks. Efforts are being made to address these concerns through breeding for disease and pest resistance.

5.3.4 Harvesting, Storage and Transportation

Harvesting, storage and transportation issues for biomass feedstock differ greatly from those of other fuels because biomass feedstocks are perishable. Protection of feedstocks from mold, rot and fire damage, is required during storage and transportation. Woody biomass is less perishable than herbaceous material, but few landowners possess the equipment to harvest and prepare SRWC for energy production. As well, a major limitation of biomass crops is their low bulk density and resultant high transportation costs. Transportation of biomass crops more than 80 km is not economically feasible (Paine et al. 1996).

6. Private and Public Perspectives Related to the Prairies

6.1 Private Perspective

There are many factors influencing a producers' decision to grow a new crop to replace an existing cropping system. Some include profit potential, machinery required, availability of markets, farmer expertise, and government programs, but there are many other objective and subjective considerations. As noted earlier, and as evidenced by the experience with export timothy, it takes far more than an attractive farm budget to determine the potential for introducing a new crop.

In the context of the Prairies, there is a potential for producers growing bioenergy crops for their own needs. Switchgrass or elephant grass would likely produce over 7 t/ha. With an energy value of 18 GJ/t dw, a conversion efficiency of 70%, and a natural gas cost of $10/GJ, the implied energy value of the crop is $800-900/ha (see Annex A – Energy and Emissions Calculations).

However, while the energy value of biomass crops is attractive, there are also significant costs involved in producing this energy. Firstly is the value of the biomass. In the Switchgrass example, the raw biomass must be valued at $50/t or more, to cover production costs or opportunity costs (see Annex B – Alternate Fuel Systems Calculations). Adding other operating costs, and provision for repairs and maintenance, brings the total non-capital costs to approximately $6/GJ Capital costs add another $2/GJ, for a total of $8/GJ. Following the same approach for natural gas, and assuming a meter cost of $10/GJ, the corresponding cost for natural gas is $12/GJ. A savings of $4/GJ is significant for some higher users of energy. The implied net benefit to the producer would exceed $250/ha – which is attractive by today's standards.

An important issue is that, with existing technology, and based on actual trials, it appears that the raw biomass may need to be converted to some intermediate form, such as pellets or cubes, before burning. This conversion may cost up to $80/t[1]. This brings the energy cost to approximately $12/GJ – about the same as that for natural gas. Work is continuing on finding ways to burn biomass in its raw form. For example, a British firm is promoting a system that will burn large bales. Others are trying mixtures of coal and biomass. But many experts in the area are skeptical of anything other than a processed product being successful.

The above referenced cost margins are based on natural gas having a metered cost of $10/GJ. On this basis, and assuming the biomass must be converted to some alternate form before burning, biomass and natural gas are about equal in cost. If the metered cost of natural gas increased to $12/GJ, the biomass would have an advantage of over $2/GJ, and an implied net benefit of $120/ha. Still this would be marginal considering the risks and management burden involved. But a natural gas cost of $15-20/GJ, as is predicted by many, would quickly result in major benefits to biomass energy systems.

The above is based on producers producing energy for their own needs, likely in the form of heat for product drying or heating buildings. There is growing evidence of this happening in the Prairies, with various suppliers of small-scale biomass burners reportedly not being able to keep up with the demand. As energy costs continue to increase, this trend is expected to continue. An option to biomass as fuel

[1] An interesting comparison is that the greenhouse industry in BC plans in terms of $8/GJ for processed biomass fuel.

is coal, but there is growing skepticism about the future of coal in small-scale operations. Clean-burning technology for coal is getting better, but is only feasible for large-scale operations.

The possibility of producers producing energy for use by others is much more remote. Selling electricity into the grid would reduce the above referenced benefits by half, and the incentive would be lost. This reality has also been borne out by experience on the Prairies. Producing feedstock for another party is also questionable with today's technology. Storage, transportation and management costs could easily add $3-5/GJ, and remove any incentive. Still, it all depends on the future cost of natural gas. We know that biomass is about breakeven with natural gas at a metered cost for natural gas of $10/GJ, and the merits of biomass for energy will hinge directly on this cost in the future.

As discussed in Chapter 4, today's producers are not in a strong mood for risk taking. Earnings are low, and their highest priority is protecting their cash flow. Increasing risk is simply not possible. Even highly attractive options will be viewed with caution, and changes will be gradual. Policy considerations directed at the producer must recognize these constraints.

Carbon credits for changing land use from cereals to forages, at the levels being discussed, would make modest differences to the above scenarios. In relating grasses to cereals, the carbon sequestering difference is approximately 1.5t/ha (CO_2 equivalent), and the emission benefits about 0.3 t/ha. A carbon credit of $10/t, or $18/ha, would not be sufficient to over-ride the basic economics of the situation. A stronger encouragement approach may be through risk reducing measures and improved technology.

6.2 Public Perspective

With today's costs and prices, the on-site production economics of producing biomass for energy appear at best marginally attractive in the absence of payment for extra-market benefits. Evidence to date suggests, however, that were growers to be paid for benefits associated with forest production, such as carbon sequestration, at least some land on the margins of agricultural production would find production of forest biomass to be economically attractive (Yemshanov, et al, 2005).

Unfortunately for those interested in seeing the development of a biomass industry on agricultural lands, there is a history of unfulfilled expectations in similar ventures. One of these is the demise of strawboard plants in western Canada. The question arises whether there is anything public policy can or should do to provide a brighter future for production of biomass crops on cultivated lands.

There do appear to be extra-market benefits in the production of bioenergy crops. Where extra-market benefits are produced, the producer of those benefits is, by definition, not compensated for providing them. Thus, if bioenergy crops do indeed provide extra-market benefits, and growers could be compensated for the production of those benefits, how significantly would that change the economics of biomass production?

Part of the answer doubtless lies with the extent of the environmental benefits provided by growing multi-year grasses. Broadly, those benefits appear to include the following:

- limiting the growth of green house gases (GHG),
- assisting carbon sequestration in soils,
- perhaps limiting use of fertilizers and herbicides during the growth cycle of crops, and
- maintaining habitat for birds and wildlife.

In addition to quantifying such benefits, it is necessary to assess the prices society is prepared to pay for the benefits.

The knowledge base on both the physical measurement and willingness-to-pay issues appears to be rising exponentially. Whether there is an adequate informational base for estimating the extra-market benefits provided by a particular grower is an question that government may need to address. There are, of course, non-agricultural methods for reducing GHG emissions as well. For example, the typical approach to encouraging conservation in the natural resources sector relies on regulation rather than providing incentives. Government may view paying for carbon credits in agriculture as opening the door to significant costs in other industries, which may in turn be viewed as leading to major budget expenditures. Thus, while the economic and environmental case for paying growers for the extra-market benefits they produce is strong, the informational costs are high, and the change in public culture needed to initiate such payments may be profound.

There are other public initiatives that could provide some benefit to producers of grassy plants, such as improvements in systems of crop insurance. But these benefits appear small. Also, there are regulated rates benefiting export crops, but less so for crops intended for local markets. Whether the export preference persists into the future is uncertain – current lower rates may reflect an unintended but gradual ‘re-regulation’ of rates that were deregulated when the Western Grains Transportation Act ceased to exist in the mid-1990s. It may also be useful to point out that government seems increasingly moving toward ‘whole-farm’ approaches to support, which provide support to farmers based on changes in some ‘whole-farm’ measure of income. Hence, at least some aspects of grassy crop production may already be receiving public support somewhat parallel to that of annual crop production.

These kinds of considerations suggest that the strongest claim grassy crops have to public support has to do with the extra-market benefits they supply to society. While building the case for those supports will require added efforts in documenting the existence and value of benefits, it will also require a more environmental focus to public policy in agriculture. The issue is not likely to be resolved in the near-term, but has the potential to help ‘level-the-playing-field’ in terms of support for annual versus multi-year types of land-based production. The conclusions of the Yemshanov et al. (2005) study suggest the existence of a carbon credit is crucial to afforestation on lands that are marginal for agriculture. It could also be crucial for grassy production on agricultural lands, if the assumptions of relatively high yields and relatively high environmental benefits of grasses versus annual crops do indeed hold true for good agricultural lands.

Assuming that a major grass- or herbaceous-type plant does indeed make it into the ‘major’ or ‘significant’ category of crops, such a crop could then be compared with timothy, about 300,000 tonnes in 2004, or with flaxseed at 500,000 tonnes in the same year. What would it mean to have a new ‘timothy’ established in Canada?

1. Would it affect foreign exchange earnings? This is unclear. While first impressions suggest that shifting from an export crop (such as wheat) to a domestic crop (such as biomass for energy) will lead to fewer exports, there may be substitution relationships at work that could overwhelm those effects. For example, if the crops were used to create energy, permitting more gas, oil or electricity to be exported, or less to be imported, it could even increase foreign exchange earnings.

2. Would it lead to large shifts out of major crops such as wheat, barley or canola? In order to qualify as a significant crop, the amounts suggested are probably in the range of 100,000 to 500,000 acres. This remains a relatively small part of the Canadian cropland mix, and does not seem to suggest that, in aggregate at least, the effects on farmers, farm technology, or aggregate net incomes would be major.

3. Could it have an effect on rural communities in Canada? This may depend upon how regionally concentrated the production of the new biomass source becomes. There could be farm community effects within certain regions, which might lead to changes in regional prosperity based on principles associated with some of Community Economic Base Studies carried on in regional development divisions of government. Were the innovative crop reasonably widely distributed within the country or within a province, however, the effects would likely too widely distributed to be noticeable. The general rule for area development is that one should not count on agricultural well being as the main base of support, because even in rural areas much of the economic activity takes place away from the farm. Hence, targeting on processing, distribution or other non-farm activities tends to have a larger impact on community wealth and community viability (see Annex C – Preprocessing Agricultural Products).

4. What about the cost of government support or stability programs? In general, of course, most new products are excluded from such programs, and their introduction could lead to slight reductions in cost. However, once a product reaches acreages such as those discussed above, it is almost certain that it becomes included in government programs such as crop insurance, and perhaps even in programs (often at the provincial level) to support and assist its introduction and establishment. As well, often a range of new or exotic crops are included in programs (CAIS, former NISA) that use tax-based information on farm incomes rather that specific production records as the basis for estimating farm support payments. Hence, at least some aspects of exotic agricultural crops may already be within the purview of government programs.

The above discussion respecting agricultural products is focused on good productive agricultural lands, likely producing cereals or oilseeds. It is useful to reflect on these findings as related to marginal and underutilized lands. As noted previously, it appears that if growers were paid for the extra-market benefits, at least some marginal lands would be economical in the production of forest biomass (Yemshanov et al., 2005). But would they be economical in the production of agricultural crops?

The use of marginal lands for producing agricultural biomass faces certain constraints not encountered with good agricultural lands. There are the common constraints related to inflexibility due to long rotations, reclamation costs, and delayed earnings. But there are also challenges due to the nature of marginal lands, competition for these lands, and public expectations. These characteristics and related constraints are as follows:

1. Much is in grazing uses, and crucial for summer pasture, and sometimes for hay harvest for livestock.

2. Much is privately owned, and used for livestock. Livestock and biomass uses tend to co-exist poorly.

3. Much has topographic features that do not bode well for machine planting and harvesting.

4. Use of public marginal lands for biomass crops may be opposed by the ‘green’ lobby due to non-native species and practices.

5. Many public marginal lands, while underdeveloped, are in grazing leases to nearby farmers. These tend to be valuable to these farmers, as evidenced by the values commanded in leasehold transactions. In consequence, there would be a major cost involved in transferring the lands to biomass production, and there would be a major resistance from the leaseholders (who constitute one of the strongest lobby groups in the prairies).

6. There may be an issue of yields on marginal lands, but basic yield data is lacking for the crops being considered.

Still, marginal lands have relatively low opportunity costs and few options. Biomass crops could represent a significant opportunity for the operators of these lands.

References

Adegbidi, H. G., T. A. Volk, E. H. White, L. P. Abrahamson, R. D. Briggs and D. H. Bickelhaupt. 2001. Biomass and nutrient removal by willow clones in experimental bioenergy plantations in New York State. Biomass and Bioenergy, 20(6):399–411.

Bransby, D. I., S. B. McLaughlin and D. J. Parrish. 1998. Soil carbon changes and nutrient cycling associated with switchgrass. Biomass and Bioenergy, 14:379-384.

Brown, R. C. 2003. Biorenewable resources: Engineering new products from agriculture. Ames, IA: Iowa State Press.

Campbell, C. A., R. P. Zentner, S. Gameda, B. Blomert and D. D. Wall. 2002. Production of annual crops on the Canadian Prairies: trends during 1976 – 1998. Canadian Journal of Soil Science 82:45-57.

Canadian Economic and Emissions Model for Agriculture (CEEMA). 2002. Technical Documentation. Version 2.0. Center for Studies in Agriculture, Law and the Environment (CSALE), University of Saskatchewan, SK, Canada.

Cannell, M. G. R. 2003. Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. Biomass and Bioenergy, 24(1):97-116.

Cook, J. and J. Beyea. 2000. Bioenergy in the United States: Progress and possibilities. Biomass and Bioenergy, 18:441—445,

Flynn, Peter. 2006. The impact of scale on biomass project economics. Discussion paper presented at the Northern Forest Research Centre, February 7, 2006.

Environmental Protection Agency (EPA). 1995. The compilation of air pollutant emission factor: stationary point and area sources. EPA No.: AP-42, Vol. 1 (5th edition). Washington, DC: U.S. Environmental Protection Agency.

Graham, R. L., W. Liu and B. C. English. 1995. The environmental benefits of cellulosic energy crops at a landscape scale.: Proceedings of the Environmental Enhancement Through Agriculture Conference, November 15-17, Center for Agriculture, Food and Environment, Tufts University, Medford, MA.

Graham, R.L., and M. Downing. 1993. Renewable biomass energy: Understanding regional scale environmental impacts. In: Proceedings of the First Biomass Conference of the Americas, Burlington, Vermont, August 1993. NREL/CP-200-5768. National Renewable Energy Laboratory, Golden, Colorado. pp. 1566-1581.

Grigal, D. F. and W. E. Berguson. 1998. Soil carbon changes associated with short rotation systems. Biomass and Bioenergy, 14(4):371-374.

Hallam, A., I. C. Anderson and D. R. Buxton. 2001. Comparative economic analysis of perennial, annual and intercrops for biomass production. Biomass and Bioenergy, 21:407-424.

Hallam, A., I. C. Anderson and D. R. Buxton. 2001. Comparative economic analysis of perennial, annual and intercrops for biomass production. Biomass and Bioenergy, 21:407-424.

Information Systems (CIS) Inc. 2004. Alberta straw availability survey. A report for Alberta Agriculture, food, and rural development. Prepared by the CIS Research Center. http://www.pivotalresearch.ca/clients.html (2005/03/15).

Ingram, J. S. I. and E. C. M. Fernandes. 2001, Managing carbon sequestration in soils: Concepts and terminology. Agriculture, Ecosystems and Environment, 87:11l-l17.

Johnston, A. M., H. R. Kutcher and K. L. Bailey. 2005. Impact of crop sequence decisions in the Saskatchewan parkland. Canadian Journal of Plant Science 85:95-102.

Jung, G. A., J. A. Shaffer, W. L. Stout and M. J. Panciera. 1990. Warm season grass diversity in yield, plant morphology and nitrogen concentration and removal in northeastern USA. Agronomy Journal, 82:21-26.

Keoleian, G. A. and T. A. Volk. 2005. Renewable energy from willow biomass crops: life cycle energy, environmental and economic performance. Critical Reviews in Plant Science, 24:385-406.

Kort, J., M. Collins and D. Ditsch. 1998. A review of soil erosion potential associated with biomass crops. Biomass and Bioenergy 14(4):351-359,

Labrecque, M., and T. I. Teodorescu. 2003. High biomass yield achieved by Salix clones in SRIC following two 3-year coppice rotations on abandoned farmland in southern Quebec, Canada. Biomass and Bioenergy, 25(2):135–146.

Lal, R. 2002. Soil carbon dynamics in crop and rangeland. Environmental Pollution, 116:353-362.

Lal, R. 2003. Global potential of soil carbon sequestration to mitigate the greenhouse effect, Critical Review in Plant Science, 22(2):151-184.

Lemus, R, 2004. Switchgrass as an Energy Crop: Fertilization. Cultivar, and Cutting Management. Ph.D Dissertation, Virginia Tech. Blacksburg, VA.

Lemus, R. 2000. Cultivar and Fertility Effects on Switchgrass Biofuel Production in Southern Iowa. M.S. Thesis. Ames, Iowa: Iowa State University.

Lemus, R. and R. Lal. 2005. Bioenergy crops and carbon sequestration. Critical Reviews in Plant Science, 24(1):1-20.

Ma, Z., W. C. Wood and D. I. Bransby. 2000. Soil management on soil C sequestration by switchgrass. Biomass and Bioenergy, 18:469-477,

Madakadze, L. C., K. A. Stewart, P. R. Peterson, B. E. Coulman, and D. L. Smith. 1999. Switchgrass biomass and chemical composition for biofuel in eastern Canada. Agronomy Journal, 91: 696-701.

Mehdi, B., C. Zan, P. Girouard and R. Samson. 1998. Soil Carbon Sequestration under Two Dedicated Perennial Bioenergy Crops. Research Report. Resource Efficient Agricultural Production (REAP)-Canada. Online: http://www.reap-canada.com/Reports/reportsindex.htm

Morris, D. 1994. Biological Energy: Opportunity and Obstacles. Institute for Local Self-Reliance, Washington, DC.

Paine, L. K., T. L. Peterson, D. J. Undersander, K. C. Rineer, G. A. Bartelt, S. A. Temple, D. W. Sample and R. M. Klemme. 1996. Some ecological and socio-economic considerations for biomass energy crop production. Biomass and Bioenergy, 10(4):231-242.

Papaport, E and T. Lind. 2003. Steps towards integrating carbon dioxide sources and sinks into local environmental planning. Journal of Environmental Planning and Management, 46(6): 803-816.

Perlack, R.D., J.W. Ranney, and L.L. Wright. 1992. Environmental emissions and socioeconomic considerations in the production, storage, and transportation of biomass energy feedstocks. ORNL/TM-12030. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Ranney, J. W., L. L. Wright and C. P. Mitchell. 1991. Carbon storage and recycling in short-rotation energy crops. In: Proceedings of a seminar organized by International Energy Agency Bioenergy Agreement and National Energy Administration of Sweden on Bioenergy and Greenhouse Effect. Vol. I, pp. 39-59. Mitchell, C.P. (Ed.), NUTUK B, Stockholm.

Ranney, J.W. and L. K. Mann. 1994. Environmental considerations in energy crop production. Biomass and Bioenergy,6:21l-228.

Rice, C. W. 2000. Soil organic C and N in rangeland soil under elevated CO2 and land management. In: Proceedings of Advances in Terrestrial Ecosystem Carbon Inventory, Measurement, and Monitoring. October 3-5, 2000. pp. 83. USDA-ARS. USDA-FS. USDA-NRCS, US Dept, Energy. NASA, and National Council for Air and Stream Improvement.

Roth, A. M., D. W. Sample, C. A. Ribic, L. Paine, D. J. Undersander and G. A. Bartelt. 2005. Grassland bird response to harvesting switchgrass as a biomass energy crop. Biomass and Bioenergy, 28:490-498.

Samson, R., S. Mani, R. Boddey, S. Sokhansanj, D. Quesada, S. Urquiaga, V. Reis, and C. Ho Lem. 2005. The Potential of C_4 Perennial Grasses for Developing a Global BIO-HEAT Industry. Critical Review in Plant Science 24:461-495.

Sanderson, M. A., R. L. Reed, S. B. McLaughlin, S. D. Wullschleger, B. V. Conger and D. J. Parrish. 1996. Switchgrass as a sustainable bioenergy crop. Bioresource Technology, 56:83-93.

Savoie, Phillippe. 2006. Mechanization of harvesting. Discussion paper presented at the Northern Forest Research Centre, February, 7

Schuman, G. E., H. H. Janzen and J. E. Herrick. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environmental Pollution, 116: 391-396.

Sokhansanj, S., S. Mani, M. Stumborg and R. Samson. 2005. Cereal straw availability for industrial use on the Canadian Prairies. Submitted to Canadian Biosystems Engineering.

Sommer, R., M. Denich and P. G. L. Vlek. 2001. Carbon storage and root penetration in deep soils under small-farmer land-use systems in the eastern Amazon region. Plant Soil 219:231-241.

Tufekcioglu, A., J. W. Raich, T. M. Isenhart and R. C. Schultz. 2003. Biomass carbon, and nitrogen dynamics of multi-species riparian buffers within an agricultural watershed in Iowa, USA, Agro-forestry Systems, SI: 187-198.

Turhollow, A. The economics of energy crop production. Biomass and Bioenergy, 6:229-241.

Updegraff, K., M. J. Baughman and S. J. Taff. 2004. Environmental benefits of cropland conversion to hybrid poplar: economic and policy considerations. Biomass and Bioenergy, 27(5): 411-428.

Walsh, M. E., D. Becker and R. L. Graham. 1996. The conservation reserve program as a means to subsidize bioenergy crop prices. In: Proceedings of Bioenergy '96: The Seventh National Bioenergy Conference: Partnerships to Develop and Apply Biomass Technologies, pp. 6. Nashville, Tennessee.

Wojick, D. E. 1999. Carbon Storage in Soil: The Ultimate No-Regrets Policy. A report to Greening Earth Society. Online: http://www.greeningearthsociety.org/Articles/1999/carbon I.html.

Wood, S. M. and D.B. Layzell. 2003. A Canadian biomass inventory: feedstock for a biobased economy. Final report prepared for Industry Canada Contract #5006125, June 27, 2003. Kingston, ON: Biocap Canada Foundation, Queen's University.Customs

Woodward, K. R. and G. M. Prine. 1993. Dry matter accumulation of elephantgrass, energycane and elephant millet in a subtropical climate. Crop Science, 33:818-824.

Yang, W. and Y. P. Hsieh. 2002. Uncertainties and novel prospects in the study of soil carbon dynamics. Chemosphere, 49: 791-804.

Yemshanov, D, D. W. McKenney, T. Hatton and G. Fox. 2005. Investment attractiveness of afforestation in Canada inclusive of carbon sequestration benefits. Canadian Journal of Agricultural Economics. 53:4:307-324.

Zan, C. S., J. M. Fyles, P. Girourard, and R. A. Samson. 2001. Carbon sequestration in perennial bioenergy, annual corn, and uncultivated systems in southern Quebec. Agriculture, Ecosystems and Environment, 86:135-144.

Zan, C., J. M. Fyles, P. Girourard, R. Samson and M. Doan. 1997. Carbon storage in switchgrass and short-rotation willow plantations. In: Making a business from biomass in energy, environment, chemicals, fibers, and materials. Proceedings of the Third Biomass Conference of the Americas: Energy, Environment. Agriculture and Industry. August 24-29, Montreal. Quebec, Canada, Overend, R. P. and Chornet. E. (Eds.), pp.155-361, New York, NY: Pergamon.

Energy cost from different fuel sources

Base case: Produce 1GJ of energy from combustion process

	mc (%, wb)	heating value (GJ/ dry t)	GJ/t as received	Fuel cost $/t,or $/GJ	Combustion efficiency, %	Amount of fuel reqt, kg/GJ	**Cost $/GJ energy**	**Greenhouse gas emissions, kgCO2/GJ**
Natural gas	0	52	52	10	90	21	**11.11**	**68.50**
Coal	25	24	18	50	75	74	**3.70**	**208.15**
Wet biomass (wood chip)	50	18	9	40	60	185	**7.41**	**17.70**
Dry biomass (switchgrass)	15	18	15	50	70	93	**4.67**	**8.52**
wood pellet	8	18	17	100	80	75	**7.55**	**2.80**

Assume C in coal is 75%

Emission factors for different fuel sources

	GHG factor	NG		kg/kg of NG	lb/ton of coal	kg/kg of coal	wet biomass kg/MJ	kg/kg of wet fuel	dry biomass kg/MJ	kg/kg of dry fuel	wood pellet, kg/t	wood pellet, kg/kg
CO2	1	1920000	3200000	3.2	5445	2.25225	8.39E-02	0.00E+00	8.39E-02	0.00E+00	0	0
CO	1	1347	2245	0.002245	0.5	0.000206818	2.58E-04	2.32E-03	2.58E-04	3.95E-03	0.6356	0.0006356
CH4	21	36.8	61.33333333	6.13333E-05	0.01	4.13636E-06	9.03E-06	8.13E-05	9.03E-06	1.38E-04	0	0
N2O	310		0	0	0.09	3.72273E-05	5.59E-06	5.03E-05	5.59E-06	8.55E-05	0	0
NOX	40	35.2	58.66666667	5.86667E-05	33	0.01365	2.11E-04	1.90E-03	9.46E-05	1.45E-03	0.91	0.00091

Environmental emissions during production of different crop types

Crop types	Crop yield, t/ac	Fertilizer, lb/ac	Nitrogen in the fertilizer, kg	Diesel use, l/ac	Greenhouse gas emissions, kg/ac
Timothy, dry	2.3	90	16.4121	32	146.57
Wheat, dry	1.74	145	10.3512	20	241.65
Barley, dry	1.73	105	17.1612	20	282.26
Timothy, irri	3.5	190	27.5578	32	214.44
Barley, irri	2.18	120	18.7048	20	329.22

Greenhouse gas emissions contributes emissions from the following
1. Emission from fertilizer use
2.Emission from machinery operations or diesel use
3. Emission from crop residues on the land
Note: Emission from timothy crop is assumed zero as all the grasses are removed from the crop land unlike cereals

Diesel fuel emissions

Emissions	Emission factors	diesel emission, kg/l
CO2	1	0.6992
CO	1	0.00406144
Nox	40	0.018848
N20	310	0

Fertilizer emissions

From fertilizer applications, only N2O will be emitted from N fertilizers.
Emission factors for fertilizers = 0.019642857 kg of N20/kg of N

It was assumed that all the biomass from timothy crop land is removed.
However, crops such as barley and wheat crop residues are left on the field which emit N2O

N2O emission from crop residues

Emission factor	0.019642857
Crop factors for cereals	0.0165
Prop_Biomass for wheat	0.855
Barley	0.85

Cost Comparison, Alternate Fuel Systems

Assumptions:

equipment life =	10	y
interest rate =	6%	
run time =	7,200	hr/yr
run rate =	2	GJ/hr
	14,400	GJ/yr

Capital cost

	Equip cost, $	Installed cost, $	Cap. Rec. factor	Capital cost, $/A	Capital cost, $/GJ
Bio cubes	120,000	220,000	0.14	29,891	2.08
Coal	120,000	220,000	0.14	29,891	2.08
Sawdust, 40%	120,000	220,000	0.14	29,891	2.08
Natural gas	50,000	75,000	0.14	10,190	0.71

Operating cost

Fuel type	Fuel Heating value GJ/t*	Fuel burner efficiency	Fuel cost, $/t or $/GJ	Total fuel cost, $/yr	Op'n Cost $/yr	R & M cost, $/yr	Total opn cost $/GJ
Biofuel, raw**	15	0.70	50	68,571	8,000	12,000	6.15
Bio cubes ***	18	0.80	130	130,000	3,000	10,000	9.93
Coal	18	0.75	50	53,333	3,000	10,000	4.61
Sawdust, 40%	10	0.60	28	67,200	6,000	12,000	5.92
Natural gas		0.90	10	160,000	500	5,000	11.49

	Cap. Cost, $/GJ	**Op. cost, $/GJ**	**Total cost, $/GJ**
Natural gas	**0.71**	**11.49**	**12.20**
Bio cubes	**2.08**	**9.93**	**12.01**
Biofuel, raw	**2.08**	**6.15**	**8.23**
Sawdust	**2.08**	**5.92**	**7.99**
Coal	**2.08**	**4.61**	**6.68**

Sawdust cost =	0	$/t
Transport distance =	400	km
Truck capacity =	24	t
Trucking cost=	0.07	$/t/km
Transport cost =	28	$/t
Total sawdust cost =	28	$/t

* as received
** biomass, raw form
*** biomass, processed into pellets or cubes at $80/t

Annex C

Preprocessing Agricultural Products
- Options and Potential Benefits

Relevance of Preprocessing Considerations.

Preprocessing agricultural products implies adding value to the products as they are moved to the final user. These activities presumably should be done at the most efficient location and by the most efficient processes and players. However, there is also a more insidious force that needs to be considered in the development of new crops and products. The support of producers and rural communities is normally essential to the success of such ventures, and their support can often be related to their participation in the value-added activities. Simply selling the agricultural products in raw form is often of little interest, and will garner little enthusiasm or supply. A case in point relates to a potential mega project in Western Canada targeted on using straw as feedstock. The potential producers were not pre-occupied with whether the value of the raw straw was $10 or $15/t. They were focused on the $40/t or $50/t, or more, that they could earn in the harvesting, transportation, and storage operations, as well as the potential for off-earnings that might result. While these services provided by producers may or may not be the most efficient, they may be required to make the sourcing of straw possible; i.e., in some cases, it may be necessary to trade-off certain efficiencies in order to realize the larger potentials. This section examines some of the areas of opportunity for producers and rural communities to add value to the products.

Post-production versus Post-harvest.

Traditional terminology distinguishes between the processes[1] harvest and post-harvest. With changes in technology, products, and markets, and with the trends to vertical integration of supply chains, the distinction between harvest and post-harvest operations is becoming blurred. A traditional harvest operation would have started with a crop standing in the field, and ended with the grain in a bin and the straw scattered in the field. Typical post-harvest operations involved grain cleaning, grain drying, storage, and transport, ending up with the grain delivered to the end-user (grain or feed company, miller, industrial user). The new emerging concept is whole crop utilization, and the various operations are being orchestrated to maximize the value of the whole crop. For example, in one system the entire crop is cut and transported to a central processing facility where it is fractionated into its components of grain and biomass fractions.[2] This may involve the application of traditional post-harvest operations (such as drying) to pre-threshed products. In another case, the threshing and separation of grain and chaff from straw occurs in the field, and the separation of grain from chaff takes place in a central facility.[3] When one process in the system is adjusted, or changed in sequence, all other processes are impacted and must be adjusted accordingly. The total system becomes very fluid, and very non-traditional. Because of this, we adopt the term post-production instead of post-harvest. We start with the crop when it is physiologically ready to be harvested, and then examine all processes that follow.

---

[1] An example being the "Whole Crop Utilization Workshop" convened in Saskatoon, March 9, 2006, hosted by PAMI.

[2] For example, see PAMI, " Modeling and comparing whole crop harvest systems". Publication No. 739 – 1998. This approach is also being extensively investigated by US researchers at Iowa State University and elsewhere.

[3] One such example is the McLeod Harvester.

As such, we use the term **post-production** to include all activities and operations taking place following the point at which the crop is ready for harvest. The stage of harvest, the processes applied, the order of processes, and where the processes occur will be determined by the various economic, environmental and social forces and objectives as related to the whole crop. The economic forces are important (such as maximizing total profits), but so are the environmental forces (such as soil conservation), and the social forces (such as work scheduling). It is a whole crop-whole system approach.

Examples of questions that need to be addressed when considering the whole crop include:

- In what form and by what method should the crop be harvested, as in the case of finding the most economical way to realize on biomass as a residual product?
- Should the crop be treated with chemicals or biological agents during harvest, as in the case of preserving the biomass component for an uncertain market?
- Should higher straw to grain varieties be grown?
- Is it feasible to grow a biomass crop with grain or seed as the by-product?
- Should the crop be harvested before it is mature, to provide greater control over the quantity and quality of the crop fractions?

In each of the above cases, we have a crop standing in the field, and we are making decisions about how and when the whole crop should be harvested and prepared for the market(s). This may involve several crop fractions and various processes. The decisions are driven not by the traditional harvest component, but by the sum of the components. And, the non-traditional components can become significant drivers.[4]

Consistent with the above, we start with the product to be delivered to the end-user, and then look for the most effective, efficient, and acceptable methods of providing this product, without the constraint of conventional processes and thinking. This is not to imply an abandonment of conventional knowledge and experience. Rather, it is a recognition of new products in a traditional system, and looking for the best ways to adjust the system to accommodate these new products; e.g., increasing the amount of biomass for use as on-farm energy without a significant decrease in revenues.

Preprocessing.

We use the term **preprocessing** to include all post-production operations and activities used to prepare the product(s) for market. Typically all such activities would be "value-added" activities, implying both higher value of the product to the end-user and higher costs of providing the product. The end-user would generally be interested in those "value-added" (preprocessing) activities that can be purchased for less than the cost of doing them internally, but there may be over-riding considerations such as

[4] In economic terms, this assumes operating on the maximum efficiency frontier, that the products compete for resources as opposed to being supplementary, and the product price ratios support operating in the product competitive zone. Otherwise, the additional products will simply be treated as independents, and produced as long as added revenue exceeds added cost, with no impact on the primary product or its production methods. An example of the two situations is found in the rotary versus cylinder combines. Livestock producers placing a relatively high value on straw for their own needs will often opt for the cylinder type combine, knowing that this is coming at some loss of efficiency in grain production; i.e., the two products compete.

security of supply and proprietary protection. Nevertheless, the preprocessing options and opportunities need to be identified and quantified for these decisions to be made.

Preprocessing processes.

Biomass when harvested is characterized by its low density, varying and often high moisture content, and varying size, shape, and density of its different parts. The biomass may be contaminated with dirt and other undesirable foreign materials that adversely affect the bio-refining quality; e.g., rocks, metal objects, paper, rodent carcasses, plastics. Some preprocessing treatments are designed to improve the handling, transport, and storability of the biomass. Others are designed to make the biomass more readily usable in processing.

The following are potential preprocessing treatments:

- Cleaning
- Size reduction
- Separating and sorting
- Mixing / blending
- Controlling moisture
- Densifying
- Chemical or biochemical treatments.

Specifics of preprocessing operations.

In order to evaluate the merits of preprocessing agricultural products in any given case, it is useful to review the specifics of what is meant be each of the possible preprocessing activities.

Typically the **physical characterization** of the material is a first step in designing a preprocessing system; i.e., a knowledge of the physical properties of a biomass is the foundation of a successful preprocessing operation. These properties include: moisture relations, size and density, and mechanical properties such as shear and tensile stresses and strains. Optical and electrical properties may be used for on-line control of separation and mixing operations. Thermal properties are needed for designing drying and densification processes. Each of these characteristics affects how each of the following is approached, and this knowledge of the biomass is required.

> **Cleaning.** The objective is to remove dirt and other undesirable contaminants that have been mixed with biomass during harvest and subsequent handling operations. A cleaned biomass will have a more predictable conversion efficiency than a contaminated biomass, and fewer microorganisms that may cause spoilage.
>
> **Size reduction.** Plant material that is fibrous and leafy is difficult to handle in its original form. Baling is a way of postponing size reduction to latter stages of handling and processing. However, if bulk handling of biomass becomes a strategy for lowering costs, size reduction becomes a necessary component of this process. The bulk density of reduced biomass can be two or even three times that of unprocessed biomass, depending on the size of particles. A size-reduced biomass is uniform and ready for use in conversion processes.

Separating and sorting. Consists of operations that segregate components of plant material based on shape, size, or density. These operations commence during normal harvesting operations, but further separation can take place during later processes for producing a more uniform product. Separating and sorting usually leads to a higher and more specialized commodity commanding a higher price.

Mixing and blending. These operations involve bringing together two or more of the same or differing materials for purposes of preparing a mixture with improved product characteristics. Blending is a powerful means of dealing with variations in biomass production; e.g., low quality or high moisture biomass can be mixed with better quality and drier biomass to yield product with the desired moisture, and physical and chemical properties.

Drying. Drying may occur either in the field or at a central location, and is carried out to deal with both high moisture and unpredictable moisture. Drying operations reduce the moisture content of biomass to levels that are safe for long-term storage. Dried biomass is easier to handle, especially with respect to frictional forces. Over-dry biomass, however, is not desirable, as any moisture loss below the optimum storage moisture results in net weight loss that may mean direct monetary loss to the producer.

Densifying. These operations reduce the volume of a given mass of biomass. The increase in unit density results in smaller space requirements for storage and transportation, substantially reducing the cost of biomass supply. Densification processes may involves size reduction and pressing biomass into compact form. Double compacting bales is one form of densification that has been developed for forages. Another form of densifying is pelleting, which results in a flowable material that can be handled with the existing grain storage and handling system.

In general, preprocessing may consist of one or a combination of the above treatments. For example, reducing size to increase density and improve ease of handling may be desirable for preparing material as feedstock for a biorefinery. Chopped and cleaned biomass is storable in conventional steel bins or buildings, it flows by gravity, and is less prone to spoil or catch fire. Additionally, size reduction gives producers the ability to mix and blend feedstock from a variety of sources to meet the physical and chemical specifications for efficient and predictable conversions. Mixing and blending of biomass with small quantities of water/steam and binders are essential operations for pelleting. Partial chemical and biochemical treatments on the farm or at storage sites are often desirable to further improve the processability of the biomass. The appropriate types and levels of preprocessing vary with each situation.