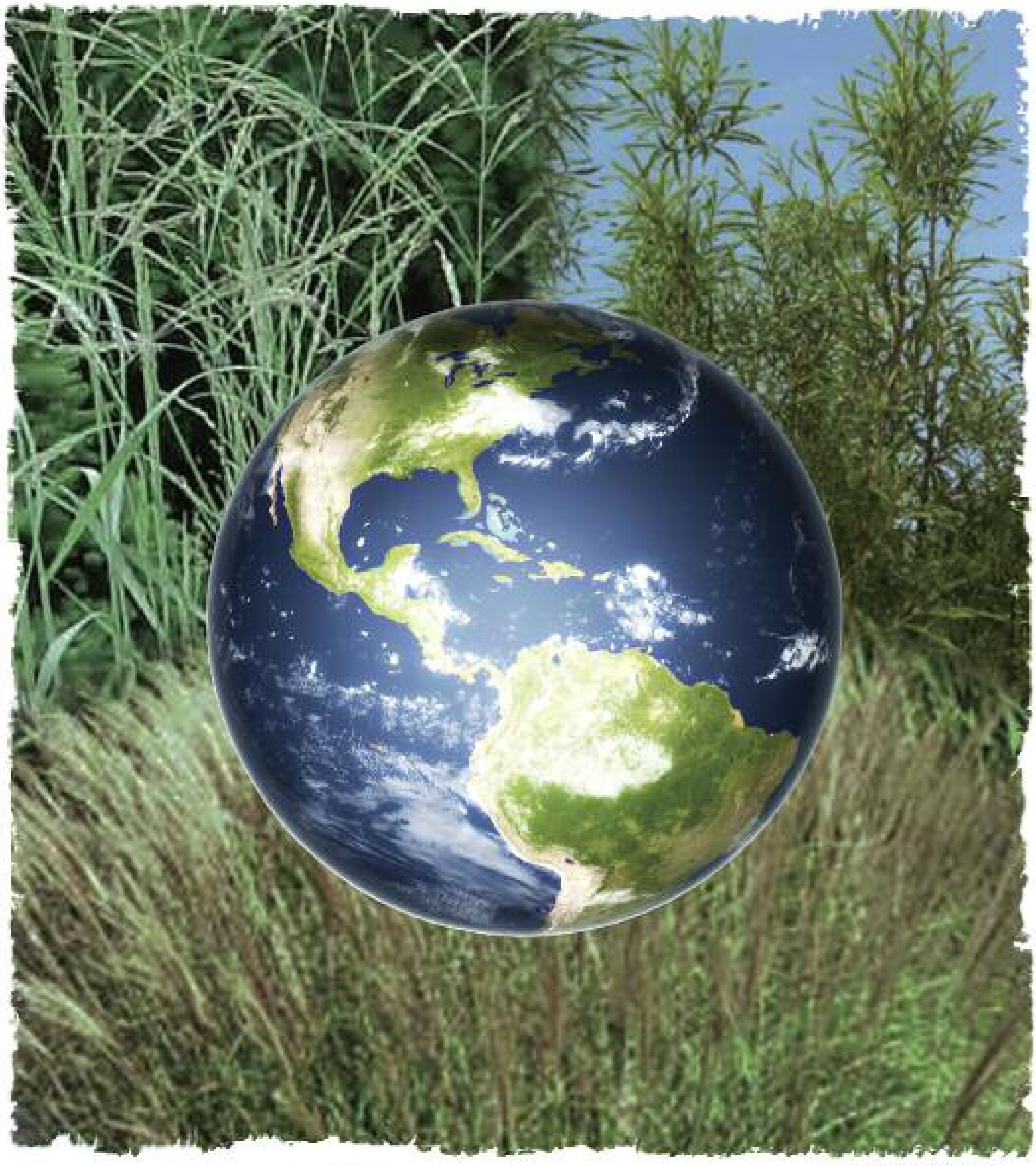
REPORT ON ENERGY CROP OPTIONS FOR ONTARIO POWER GENERATION



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Sincerely,

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Acknowledgements

Contents

Executive Summary

This report examines the feasibility of developing a sustainable energy crop industry in Ontario. The strengths and weaknesses of various energy crops are evaluated along with their potential for industrial-scale cultivation in Ontario. The economics surrounding the use of each crop for combustion, the environmental impacts anticipated and socio-political issues are also key considerations addressed in this research. The report provides conclusions and recommendations for OPG to consider in developing any future plans for a biomass fuel program.

In considering the food versus fuel debate, findings of this study are indicative of the fact that Ontario's agricultural sector can sustainably produce both food and fuel. Through improved agricultural practices and genetically modified crops, farmers in Ontario have been able to double their production yields every 30 years. This trend is expected to continue and accelerate in the coming years due to the rapid development of various technologies related to agricultural production. The fuel-mix proposed in this study includes biomass produced through the tall grass prairies program. This would facilitate expansion of an ecologically beneficial program that could increase bee populations, resulting in enhanced food production.

Ontario has the capacity to sustainably produce 8.75 million t/yr of energy crops. This estimated production level can be achieved through the establishment of a combination of miscanthus, switchgrass (including tall grass prairies) and willow on 783,000 ha of less productive farmlands. Currently almost all arable lands in Ontario are being used for food crops or tame hays. Therefore, this report bases its land availability and biomass production capacity on the conversion of about 32% of hay lands and 15% of low-yielding crop lands. There is also the potential for some prime land conversion to high-yielding energy crops, most likely miscanthus. Conversion of 37,000 ha of prime land, through the use of miscanthus as a rotational crop, could result in the production of an additional 1.25 million t/yr. Crop residues are also a contributing source of biomass in the proposed fuel-mix, and their inclusion would significantly increase the total sustainable supply of biomass in the province.

The proposed supply chain for the biomass industry is centred on a number of processing facilities located across Ontario, consisting of 150K t/yr pellet mills. The mills would source biomass from a mix of about 60-80% energy crops and the remainder from a combination of various agricultural residues and native grasses. A mixed energy crop provides greater biodiversity, minimizes fluctuations in biomass supply and spreads out harvests more evenly during a given year. Furthermore, the advantage of a pelletized mix of biomass fuel compared to coal is that OPG would have the flexibility to specify and change fuel quality through adjustment of the pellet blend. Use of a diverse mix in the pellet, which could include municipal sources of biomass in addition to the above mentioned agricultural sources, would help to diversify participation across large segments of Ontario's population. Therefore, economic benefits would not be limited to only rural and agricultural communities. In regards to transportation logistics, there are no major issues at the macro level. Marine shipping of biomass would be the preferred mode of transportation, considering the existing fuel-handling facilities at OPG stations, local traffic congestion and the marine infrastructure in Ontario.

Pelletized biomass fuel is estimated to cost between \$6.75/GJ to \$8.50/GJ at the OPG gate based on pellets composed of 100% energy crops. Total cost of biomass was obtained by combining the costs associated with growing, harvesting, storage, processing and transportation. Reduction in the cost of energy crop biomass would likely accrue from expected economies of scale and increases in crop yields as the industry advances. The price of pellets could decline to \$5.60/GJ to \$6.80/GJ. Inclusion of agricultural residues in the pellet mix could also contribute to further price reductions.

Miscanthus, switchgrass and willow SRC are perennial crops that are the most widely studied and grown energy crops in the world. They offer soil improvement through their massive permanent root systems and no serious diseases have been reported to date. Based on extensive experience with these crops in Europe and the U.S., dating as far back as the mid 1970s in Europe, the forms of pests and diseases that have been seen are easily mitigated and do not appear to have significant affect on the yield of the biomass.

Perennial energy crops would also have a positive impact on the environment. They reduce greenhouse gases through carbon sequestration and provide soil improvement by increasing organic matter. Since they require much less herbicide application than do annual crops, groundwater contamination would be reduced. The extensive root system also helps to prevent soil erosion and improves soil quality through increased water infiltration and nutrient-holding capacity. Energy crops would also provide over-wintering sites for birds, small mammals and invertebrates.

Currently there is a marginal quantity of energy crops planted in Ontario. The substantial economic benefits of energy crop adoption would be the most significant driving factor in the growth of this industry. With proper planning, contract development, dissemination of information and collaboration between various stakeholders, the energy crop industry has the potential to develop to meet OPG demands by 2015. However, for all of these energy crops to reach mature yields, a minimum of three years would be required from initial establishment. Furthermore, large-scale planting would be required in 2010 to achieve the adequate propagation feedstock to plant hundreds of thousands of hectares of these crops by 2015.

In conclusion, speedy adoption of energy crops would require a concrete and clear government energy policy, attractive biomass pricing and payment schemes, guaranteed market, effective information dissemination, demonstration farms and pellet mills. Emission of particles from biomass combustion would need to be addressed in replacing coal with biomass at OPG generating stations. The advantage of large-scale combustion facilities operated by OPG is that they can economically implement mitigation options such as electrostatic precipitator technology. It is recommended that the emission characteristics of the proposed pelletized biomass fuel mix be further investigated. A full life-cycle analysis of electricity generation at OPG generating stations using biomass from energy crops should also be performed. Such a study, in comparison with traditional fossil fuels, should provide a comprehensive social, economic and environmental feasibility assessment of biomass-fired power generation.

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Chapter 1

Description and Characteristics of Energy Crops

Energy crops are plants purposely grown to produce some form of energy. Ideal attributes of an energy crop are low cost, low maintenance, high yield, low moisture content, greater energy content, good fuel characteristics and no environmental risks. Energy crops generally fall into two categories: herbaceous and woody. Herbaceous energy crops are mostly perennial grasses such as miscanthus, switchgrass, Sudangrass and reed canary grass. These grasses are usually harvested on a yearly basis. They regrow from their roots and do not require replanting for 15 years or more. The woody energy crops are typically short rotation coppices (SRC) such as poplar and willow, which are harvested on a 2-5 year cycle. The SRC regrows by producing new shoots from the rootstock remaining in the ground after harvesting. Replanting of SRC is not necessary for 25 years or more.

Miscanthus, switchgrass, Sudangrass, willow and hybrid poplar are presented in this section as potential energy crops to power the currently fossil-fuelled generation stations of Ontario Power Generation (OPG). The brief description, fuel characteristics, recent research findings and environmental impact of each energy crop are given. An attempt to compare and identify the potential of energy crops in Ontario context and total biomass fuel requirement perspective is also made at the end of the section.

1.1 Miscanthus

1.1.1 Description

Miscanthus is a large perennial grass that produces cane-like stems, which can be used as a biomass fuel for electricity/heat generation. Possessing the efficient C4 photosynthetic pathway, with relatively low nutrient requirement and good water use efficiency, miscanthus grass can grow up to heights of more than 3.5 m in one growth season. Miscanthus is planted in the spring, and once planted can remain in the ground and be productive for at least 15-20 years. First-year growth is insufficient to be economically worth harvesting. The crop can be harvested from the second year onward. However, the crop normally takes three years to reach a mature yield. On marginal lands, this initial yield-building phase could take up to five years (DEFRA, 2007). New shoots emerge in early spring and grow rapidly in summer to produce bamboo-like canes. Miscanthus leaves fall off in the winter, providing nutrients for the soil. Freestanding, almost leafless canes can be harvested in winter or early spring. This growth pattern is repeated every year for the lifetime of the crop and the annual harvest provides income to the farmer. Miscanthus grass in spring, fall and winter are shown in Figure 1.1.

Fig 1.1 Miscanthus Plants from Spring to Winter

Miscanthus is a genus of about 15 species of perennial grasses native to subtropical and tropical regions of Africa and southern Asia, with one species *(M. sinensis)* extending north into temperate eastern Asia. *Miscanthus x giganteus,* the sterile hybrid between *M. sinensis* and *M. sacchariflorus,* has been at the centre of the research and field trials, extensively in Europe and recently in North America, due to the fact that *M. sacchariflorus* types are well adapted for warmer climates, and *M. sinensis* can provide genetic resources for cooler regions. Field trials, with 18 sites participating from 10 European countries since 1993, proved that *miscanthus x giganteus* was the most productive of all the genotypes tested (Scurlock, 1998; Clifton-Brown et al., 2001). There have been reports of losing plants of this hybrid in winter, during the first year after planting, in some European climates (Clifton-Brown and Lewandowski, 2000). Once it is successfully established, miscanthus seems to be tolerant of cold climate. The *miscanthus x giganteus* stands at the University of Illinois survived winters with periods below -23° C without loss (Pyter et al., 2007). *Miscanthus x giganteus* is likely the right variety for southwestern Ontario, since it is being successfully grown with good yields in Illinois. However, selection of different varieties or development of new genotypes may be necessary for northern Ontario. Pyarmid Farms Ltd. has recently planted trial plots for various genotypes of miscanthus in southwestern Ontario in collaboration with the University of Guelph and Mendel Biotechnology. Useful information on growing miscanthus in Ontario is expected from these trial plots within a couple of years.

As a rhizomatous grass, miscanthus is established by planting pieces of the root called rhizomes, which are usually collected from "nursery fields" where miscanthus has already been established. The rhizomes can be broken up, collected and planted using conventional farm machinery such as potato harvesters and planters. Rhizomatous grasses retain a large proportion of the nutrients in the rhizomes, retaining little in the biomass, so nitrogen and nutrient requirements are very low. High establishment cost associated with miscanthus planting is a drawback in comparison with other herbaceous grasses, such as switchgrass, which can be established from seeds. However, if the miscanthus can produce significantly higher yields than other types of grasses in the region considered, higher establishment cost would be financially justified. Figure 1.2 shows a *miscanthus x giganteus* rhizome.

Annual rainfall and soil water retention will strongly influence the yield of miscanthus at any site, although it can be grown in the regions with total annual rainfall ranging from 100-1500 mm (Prince et al., 2003). Water requirement for miscanthus should not be an issue for Ontario, where an annual rainfall is 750-1000 mm. Miscanthus possesses good water use efficiency when considered on the basis of the amount of water required per unit of biomass, and miscanthus roots can penetrate and extract water to a depth of around 2 m. However, to achieve high yields, miscanthus may need more water than the crops that it may replace. In addition, a dense canopy means that 20-30% of rainfall is intercepted by, and evaporates off, the leaves and never reaches to infiltrate the soil. Limited soil water availability during a growing season will prevent the crop from reaching full potential yield in that year. In times of severe drought, the foliage of miscanthus will first show leaf rolling and then die back from the leaf tip. This will reduce yield in the year of drought but in all cases experienced in the UK (DEFRA, 2007) the crop will survive and regrow the following year.

Figure 1.2. Miscanthus x giganteus Rhizome

1.1.2 Fuel Characteristics

If miscanthus is harvested in the late winter or early spring, as recommended by a number of studies, the mineral concentrations are reported to be low: e.g. 0.09-0.34% N; 0.37-1.12% K; 0.03-0.21% Cl (Lewandowski and Kicherer, 1997). The mineral content is low compared to wheat straw, and comparable with that of willow/poplar coppice. Like other biomass fuels, reactivity/ignition stability is high compared to coal. Overall, the CO_2 balance shows a 90% reduction in emissions compared to coal combustion (Lewandowski et al., 1995). At harvesting, moisture content may be 30-50%, However, following conditioning and drying in the field, this may be reduced to 20-25% (DEFRA, 2007).

The composition of miscanthus ash reportedly includes approximately 30-40% SiO_2, 20-25% K_2O, 5% P_2O_5, 5% CaO, and 5% MgO — a range of values from different studies (e.g., Moilanen et al., 1996; Hallgren and Oskarsson, 1998). Ash behavior (sintering) is no worse than many other biomass ashes, with potassium content a significant factor. Miscanthus ash showed clear sintering tendencies at temperatures as low as 600°C, compared with reed canary grass and willow (the latter of which was inert up to 900° C). This may be due to the combination of relatively high silica content in miscanthus, together with potassium and fluxing agents such as iron (Hallgren and Oskarsson, 1998). Table 1.1 shows typical fuel characteristics of *miscanthus x giganteus* from the different sources, mainly from the Energy Research Centre of the Netherlands, which maintains a comprehensive database of the physical/chemical properties of biomass fuels.

Miscanthus has been successfully burned on a commercial scale in Denmark, using a 78 MW circulating fluidized bed combustor (50% co-firing with coal) and a 160 MW powdered fuel combustor (20% co-firing). The plants were already adapted for co-firing with straw: 17t of miscanthus bales with 12% moisture were burned without major problems in the fluidized bed combustor, and 100t in the powdered fuel combustor (Visser, 1996). In a study in the UK (DTI, 2003), 50t of miscanthus was burned at the full 100% firing at the 36 MW cereal straw-powered electricity generation station owned by the Energy Power Resources Ltd. The performance of miscanthus was very similar to straw in the combustion trial in terms of the key indicators: steam flow temperature, combustion efficiency, cycle efficiency and plant electrical input. British energy company Drax has been co-firing miscanthus and willow with coal, and has a goal of 10% co-firing at its six 660 MW units by the end of 2009[1].

1.1.3 Impact on Environment

Positive: Miscanthus plantations provide over-wintering sites for birds, small mammals and invertebrates, suggesting immediate benefits to biodiversity (DEFRA, 2007). Nitrous oxide emissions are low compared with other annually harvested crops because of its high nutrient-use efficiency (Kaltschmitt et al., 1996; Lambert et al., 1996). Apart from herbicides in the establishment years, miscanthus requires very few agrochemical inputs after they have been established. Herbicide application in the establishment years is usually restricted to a single application per year. Once a good crop cover is attained in the second or third year, weed interference is suppressed and there is no need for herbicide application. Thus, the risk of ground water contamination by agrochemicals is very low. Some soil erosion benefits are claimed, but details are not available (Walsh and McCarthy, 1998). Miscanthus also offers the great benefit of carbon sequestration in comparison with field crops or other energy crops (Borzêcka-Walker et al., 2008).

Negative: Miscanthus has a long lifespan of over 15 years and can grow up to 3.5 m in height. This may create a significant visual impact on the landscape. There have been some

Table 1.1 Typical Fuel Characteristics of Miscanthus x Giganteus

Proximate Analysis		Ultimate Analysis		Water Soluble Alkalis		Elemental Composition		Other	
	(wt. %)		(wt. %)		(wt. %)		(wt. % ash)	Alkali, Lb/MMBTU	
Fixed Carbon		Carbon	48.4	Na_2O		SiO_2	39	Ash Fusion Temp. (°C)	1090
Volatile Matter	82.1	Hydrogen	6.3	K_2O		Al_2O_5	1.6		
Ash	1.5	Oxygen	43.3	CaO		TiO_2			
Moisture	30 - 50[a]	Nitrogen	0.3			Fe_2O_3	1.1		
		Sulfur	0.1			CaO	8.6		
		Ash				MgO	5.9		
		Moisture				Na_2O	2.2		
		HHV (MJ/kg)	19.58			K_2O	27		
		Chlorine	0.13			SO_3	4.9		
						P_2O_5	6.3		
						CO_2	0.5		
						Cl	3.5		

Sources: Phyllis database (http://www.ecn.nl/phyllis/) Energy Research Centre of the Netherlands (ECN)

- a. At harvest, can be reduced to 20% - 25% by natural drying in the field (DEFRA, 2007)

[1]http://www.fey.org.uk/site/WIPBiomass/CaseStudies/DraxCasestudy/tabid/179/language/en-GB/Default.aspx

concerns as to whether miscanthus, as an introduced species, might be an invasive plant. A number of researchers (Lewandowski et al. 2000; DEFRA, 2007; Pyter et al., 2007) suggested that this should not be a problem because most varieties used for biomass are sterile hybrids, which do not produce seed. To date, there are no reports of plant diseases significantly limiting production, but the crop is known to be susceptible to *Fusarium* blight and Barley Yellow Dwarf Luteovirus (Walsh and McCarthy, 1998). There are no insect pests that have significantly affected miscanthus production. However, two key pests, the common rustic moth and the ghost moth larvae, have been seen feeding on miscanthus and might cause future problems (DEFRA, 2007).

1.2 Switchgrass

1.2.1 Description

Switchgrass, *Panicum virgatum*, is a perennial warm season grass native to North America. Unlike many traditional crops, switchgrass is a perennial so it doesn't need to be planted each year. Once established, it can be harvested on an annual basis and will remain productive for an indefinite period (Samson, 2007). Switchgrass generally reaches full yield capacity after three years, but the crop can be harvested starting from the second year. The normal height of switchgrass is 1.5 - 2.5 m, depending on the region. Its permanent root system can extend over 3 m into the ground and, coupled with its large temporary root system, it can improve soil quality through increased water infiltration and nutrient-holding capacity. Like miscanthus, it processes the efficient C4 photosynthetic pathway, offering low nutrient requirement and efficient water use. Switchgrass was chosen as a model herbaceous energy crop species in the early 1990s by the U.S. Department of Energy as it had a number of promising features. These included its moderate to high productivity, adaptation to marginal farmlands, drought resistance, stand longevity, low N requirements and resistance to pests and diseases (Samson and Omielan, 1994; Parrish and Fike, 2005). Figure 1.3 illustrates switchgrass and its harvesting.

Figure 1.3. Switchgrass and Harvesting

Switchgrass varieties are classified into two broad categories: lowland and upland. Lowland ecotypes historically developed under floodplain conditions, while upland ecotypes developed under drier upland sites. Higher yields have been achieved with some lowland varieties in research trials in the southern U.S. Unfortunately, lowland varieties are more susceptible to winterkill. In most areas of Ontario, upland varieties will provide Ontario farmers with the best productivity and stand longevity. *Cave-in-Rock* is the most widely planted variety for northeastern North America, and produced the greatest yield among the switchgrass varieties tested in Quebec, as shown in Figure 1.4 (Samson, 2007). In southwestern Ontario, some northern lowland ecotypes may prove to be adequately hardy and included in mixed warm-season grass seedings in the future. Over a four-year period, a study in southern Illinois, (Jacobson et al., 1986) found that *Cave-in-Rock* had no appreciable winter injury in comparison with other varieties.

The prominent advantage of switchgrass over miscanthus is that it can be easily established from seeds. Christian et al., 2003 reported that the establishment cost of switchgrass could be as low as 10% of the cost of planting miscanthus. However, weed control is critical to achieving a successful establishment, as switchgrass is fairly slow to form a canopy. In the fall preceding establishment, fields may be sprayed with a broad spectrum herbicide to eliminate problem perennial weeds, such as quackgrass, from invading the establishing stand. Summer or fall tillage is recommended for forage and pasture fields in order to break sod clumps. Use of spring-applied formulations of

“Round-up ultra or max” should be avoided as growers have reported phytoxic effects on switchgrass establishment (Samson, 2007).

In a study (Turhollow et al., 1990) of screening herbaceous energy crops at several locations in the U.S., switchgrass and sorghums showed superiority under drought conditions. Switchgrass is well adapted to more marginal soils and crop yields would remain high (Girouard et al. 1999a,b). However, as a warm season grass, yield of switchgrass largely depends on the climate conditions. Eastern, central and southern Ontario regions are probably good-yielding sites. However, switchgrass is likely to be less productive in regions with fewer than 2500 corn heat units (CHU), such as northwestern Ontario, because switchgrass is not well adapted to cooler climatic regions (Jannasch, et. al, 2001). In more northerly areas of Ontario (i.e. less than 2500 corn heat units or CHU), a few early maturing varieties such as forestburg, sunburst, and shelter may prove more reliable in terms of winter hardiness and productivity (Samson, 2007). More field trials and research and development of new switchgrass varieties are needed for the cooler regions of Ontario.

Clinton area farmer Don Nott is Ontario's leading developer of switchgrass as an energy crop. Nott farms seeded 132 hectares to switchgrass in May 2006. This is the largest commercial plantation of switchgrass in Canada to date. Mr. Nott is also in the business of producing agro-pellets from crop milling residues. Nott Farms operates an oat processing facility that provides it with a by-product of oat hulls. In 2006, Mr. Nott began using this material along with purchased wheat bran to produce crop milling residue fuel pellets for heating applications. He now has a fleet of delivery trucks and a 10,000 tonne storage bin to hold this winter heating fuel. Nott Farms supplies approximately 20 greenhouses in Ontario with their winter heating fuel. The switchgrass yield at the first harvest from the Nott Farms was in line with the previous Ontario experience. Learnings and yield data from a commercial scale of this size in the coming years would provide invaluable information on the development of switchgrass energy crops in Ontario.

Table 1.2 Effects of Delayed Harvest on Elemental Composition of Switchgrass (Bailey-Stamler et al., 2006)

Month of Harvest	N (%)	Ca (%)	K (%)	Cl (%)	S (%)
July	1.35	0.49	1.33	0.26	0.11
August	0.78	0.50	0.98	0.22	0.08
November	0.45	0.59	0.30	0.10	0.06
December	0.46	0.59	0.20	0.06	0.08
February	0.53	0.65	0.10	0.02	0.08

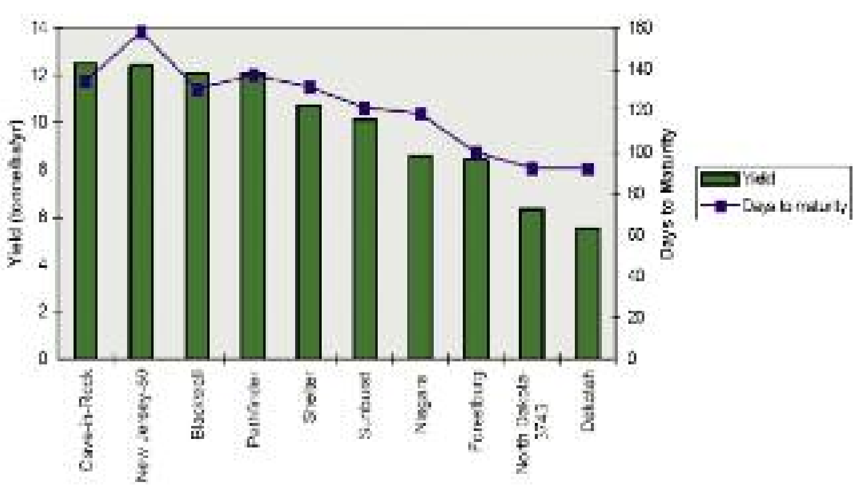


Figure 1.4. Yield of Switchgrass Varieties at Ste. Anne de Bellevue, Quebec (1993-1996) (Samson, 2007)

1.2.2 Fuel Characteristics

Harvest timing of grasses plays an important role in nutrient management and fuel characteristics of energy crops. Summer harvested switchgrass may have high chlorine, potassium, sulphur and nitrogen contents as shown in Table 1.2. As months pass and the crop over-winters, these nutrients are trans-located into the root systems or leached by rainfall, achieving their lowest concentrations during the spring. Over-wintering material is extremely effective in reducing nutrient contents of biomass with 95% of the potassium leached out of the switchgrass fiber over winter (Goel et al., 2000). Since reduction of potassium and chlorine contents in the biomass would be desirable for the combustion systems, over-wintering is a recommended practice for direct combustion uses.

The production of switchgrass on clay soils has also been found to lead to much higher, a factor of three to four, ash contents due to the higher uptake of silica in these soils (Samson and Mehdi, 1998; Elbersen et al., 2002). Sandy soils, which have less monosilicic acid, produce feedstocks lower in ash content. In eastern Canada, the ash content of switchgrass grown on sandy loam soils was 15% below that of clay loam soils (Samson et al., 1999). However, delayed harvesting of the grass (over-wintering the grass and harvesting the following spring) had an even bigger influence than soil type by reducing ash content by 39% (Bailey-Stamler et al., 2006). Typical fuel characteristics of switchgrass are given in Table 1.3.

1.2.3 Impact on Environment

Positive: Apart from a renewable energy source, switchgrass is a valuable soil stabilization plant on strip-mine spoils, sand dunes, dikes and other critical areas. Switchgrass provides excellent nesting of fall and winter cover for pheasants, quail and rabbits. The seeds provide food for pheasants, quail, turkeys, doves and songbirds (USDA, 2001). Because it is native, switchgrass is resistant to many pests and plant diseases as well as being very tolerant of poor soils, flooding and drought. Its permanent root system can extend over 3 m into the ground and, coupled with its large temporary root system, it can improve soil quality through increased water infiltration and "nutrient-holding capacity" (Bransby, 1999). An extensive root system can help to prevent soil erosion. Switchgrass can also reduce greenhouse gas emissions by increasing the carbon stored in landscapes through increased carbon storage in roots and soil organic matter. It has been found that land conversion to switchgrass on Conservation Reserve Program (CRP) plantings in the U.S. has led to 40 t/ha of CO_2 being stored, compared to conventional land use (Samson, 2007).

Negative: Switchgrass is generally planted as a monoculture, which is thought to be problematic by many farmers and advocates of a more sustainable agriculture. Switchgrass is susceptible to leaf diseases, and grasshoppers and leafhoppers can be major pests in new seedings. Ontario farmers should preferentially choose varieties originating from the eastern United States as

Table 1.3 Typical Fuel Characteristics of Switchgrass

Proximate Analysis		Ultimate Analysis		Water Soluble Alkalis		Elemental Composition		Other	
	(wt. %)		(wt. %)		(wt. %)		(wt. % ash)		
Fixed Carbon		Carbon	47.5	Na_2O		SiO_2	61.6	Alkali, Lb/MMBTU	
Volatile Matter	82.9	Hydrogen	5.8	K_2O		Al_2O_5	13	Ash Fusion Temp. (°C)	1016
Ash	3-5[a]	Oxygen	43.6	CaO		TiO_2	0.2		
Moisture	12-14[b]	Nitrogen	0.36			Fe_2O_3	1.1		
		Sulfur	0.05			CaO	11.1		
		Ash				MgO	4.9		
		Moisture				Na_2O	0.6		
		HHV (MJ/kg)	18.6			K_2O	8.2		
		Chlorine				SO_3	0.8		
						P_2O_5	3.1		
						CO_2			
						Cl			

Sources: Phyllis database (http://www.ecn.nl/phyllis/) Energy Research Center of the Netherlands (ECN)

- a. Samson, 2007
- b. At harvest, reduced to 6% - 8% by natural drying in the field (Samson, 2007; Bailey-Stamler et al., 2006)

these tend to be more disease resistant. Some western originating switchgrass varieties have developed leaf diseases in Ontario (Samson, 2007). Since it is native, switchgrass is not considered as an invasive species in regions in North America, although it could be invasive in non-native regions due to its propagation from the seeds. However, some researchers (Raghu et al., 2006) warned of potential invasiveness of the new genotypes being developed in search of higher yields, enhanced drought tolerance and greater adaptability to specific climate. Even within the native range of the species, it is suggested that modified cultivars be treated as non-native genotypes.

1.3. Sudangrass

1.3.1 Description

Sudangrass and sorghum-Sudangrass hybrids are warm-season, frost-sensitive, erect annual grasses. They are traditionally used as warm-season cover crops, forage and silage due to their fibrous roots and organic matter contributions in improving soil structure and their rapid, dense growth in suppressing weeds. Sudangrass and sorgum-Sudangrass hybrids can typically grow from 2-3 m tall and produce large amounts of dry matter if planted in the summer, well before the first frost. Sorghum-Sudangrass hybrids, which are a cross between the forage sorghum and the Sudangrass, are advantageous over either parent in producing larger quantities of biomass. This study will, therefore, focus on the sorghum-Sudangrass, since it is the most popular and performs best in Ontario climate (OMAFRA, 1998). As a tropical grass with the same C4 photosynthetic pathway as miscanthus, sorghum-Sudangrass hybrids efficiently utilize sunlight and soil moisture to quickly accumulate large amounts of biomass. Although maximum growth of sorghum-Sudangrass occurs with ample moisture, they are known for being drought resistant (Sattell et al., 1998). They are more efficient in water absorption because they have a massive root system and have less leaf area for evaporation. They have the ability to become dormant during extended drought periods. Growth will begin when the rains come.

Sorghum-Sudangrass should be planted after the threat of frost in spring, which generally means delaying planting until the end of May or the first of June to allow for maximum growth. Unlike miscanthus and switchgrass, sorghum-Sudangrass can be harvested 2-3 times before the first frost comes to maximize the yields. The first cut will be ready for harvest about 60 days after planting. The plants should be over 65 cm in height, and just before head emergence when cut (usually early August). For a faster recovery of aftermath growth, at least 10–18 cm of stubble is usually left when harvesting. Optimum growth of these plants occurs under hot, moist conditions. A second cut should be ready 30-35 days later. Figure 1.5 shows sorghum-Sudangrass planted in Iowa.

Figure 1.5. Sorghum-Sudangrass in Iowa

The advantage of sorghum-Sudangrass over miscanthus and switchgrass is no weed control requirement, since sorghum and Sudangrass have traditionally been called “smother crops” because of their ability to suppress weed growth (Rice, 1984). However, sorghum-Sudangrass is a low-yield energy crop, in comparison with miscanthus and switchgrass, with high moisture content. A number of sorghum-Sudangrass hybrid cultivars are available. Commonly recommended varieties by the USDA Natural Resources Conservation Service include ‘DeKalb SX-17+’ and ‘DeKalb ST-6E'. However, the selection of a sorghum-Sudangrass variety should be region and site specific. Since the optimum temperature for Sorghum-Sudangrass is 24-32° C (Sattell et al., 1998), this grass is not likely to be productive in northern Ontario. Although sorghum-Sudangrass has not been studied extensively as an energy crop, its rapid growing nature makes sorghum-Sudangrass a promising potential energy crop, especially at the humid continental climate of Southwestern Ontario.

1.3.2 Fuel Characteristics

As mentioned in the previous section, use of sorghum-Sudangrass for energy is not as extensive as the use of miscanthus or switchgrass. Therefore, little information is available on the fuel and combustion characteristics of sorghum-Sudangrass. Table 1.4 details typical fuel characteristics of sorghum-Sudangrass.

1.3.3 Impact on Environment

Positive: As an excellent smother and cover crop, sorghum-Sudangrass suppresses weeds with its rapid growth, adds organic matter to the soil and protects against soil erosion. Its extensive root system is effective in finding nitrogen in the ground, helping to prevent leaching. The nitrogen incorporated into the cover crop can then become available to subsequent crops as residues decompose. Mowing can be used to increase the extensive root system of sorghum-Sudangrass. Repeated mowing also causes the root system to penetrate deeper, helping to loosen compacted soil. Sorghum-Sudangrass is generally not considered as an invasive species, as the grass dies at the first frost and decomposes on the soil in the winter.

Negative: Sudangrass and sorghum-Sudangrass hybrids can produce toxic levels of hydrogen cyanide and nitrate while young or just after a frost (McGuire, 2003). Therefore cattle should be kept away from the field at these times. Chinch bug, sorghum midge, corn leaf aphid, corn earworm, greenbug, sorghum webworm, and armyworm may attack sorghum-Sudangrass hybrids. Sorghum-Sudangrass can harbor high populations of root lesion nematode, especially in Canada (McGuire, 2003), and sting nematode (Valenzuela and Smith, 2002).

1.4. Willow

1.4.1 Description

Willow is a short rotation coppice (SRC), which is a widely used energy crop in Europe along with poplar, especially for heating applications. Willow is usually densely planted and harvested on a 2-5 year cycle, although more commonly every three years. This SRC is a woody, perennial crop, the rootstock or stools remaining in the ground after harvest with new shoots emerging the following spring. Willow SRC can grow up to 6 m with 5-6 cm diameter stems before it is harvested. A plantation could be viable for up to 30 years before replanting becomes

Table 1.4 Typical Fuel Characteristics of Sorghum-Sudangrass

Proximate Analysis		Ultimate Analysis		Water Soluble Alkalis		Elemental Composition		Other	
	(wt. %)		(wt. %)		(wt. %)		(wt. % ash)		
Fixed Carbon	18.6	Carbon	44.58	Na_2O		SiO_2		Alkali, Lb/MMBTU	
Volatile Matter	72.75	Hydrogen	5.35	K_2O		Al_2O_5		Ash Fusion Temp. (°C)	
Ash	8.65	Oxygen	39.18	CaO		TiO_2			
Moisture	70-75[a]	Nitrogen	1.21			Fe_2O_3			
		Sulfur	0.08			CaO			
		Ash				MgO			
		Moisture				Na_2O			
		HHV (MJ/kg)	16.31 – 17.39			K_2O			
		Chlorine	0.13			SO_3			
						P_2O_5			
						CO_2			
						Cl			

Sources: Purdue University
(http://www.hort.purdue.edu/newcrop/duke_energy/Sorghum_sudanense.html)

- At harvest (OMAFRA, 1998)

necessary. Willow SRC requires minimal inputs, such as fertilizers, and grows well on marginal lands. Sweden, where over 15,000 ha of willow are currently grown for biomass production (Rosenqvist and Dawson, 2005), is the world leader in research and application of SRC techniques, with over 30 years of experience (Christersson and Senneby-Forsse, 1994). Willow plantation has been in North America for decades. However, extensive research in North America on willow as an energy crop was started after the "Salix Consortium" was formed in 1994. The State University of New York College of Environmental Science and Forestry (SUNY-ESF) is a leading institution in research and development and commercialization of willow SRC. The Montreal Botanical Garden (Quebec) — Institut de recherche en biologie végétale (IRBV) Jardin botanique - is a member of the Salix Consortium.

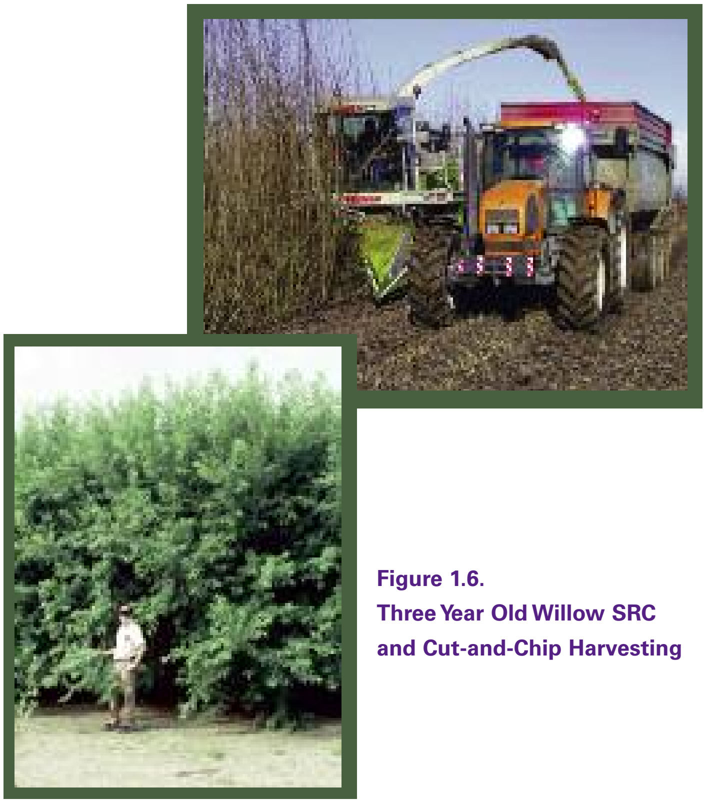


Figure 1.6.
Three Year Old Willow SRC and Cut-and-Chip Harvesting

The osier, a shrub willow, is parental stock to the majority of willow varieties planted as an energy crop. Selection of willow varieties is region and site-specific, since willow varieties developed in Sweden and the UK were tested in the New York area and quickly found to be susceptible to damage by potato leafhopper (Smart, 2008). There are over 120 species of shrub willow worldwide (Keoleian and Volk, 2005), and there has been rapid improvement and development of willow varieties in recent years in search for higher yields and greater pest and disease resistance. Several willow varieties suitable for North America are available from the research institutions and commercial nurseries. Two willow clones which showed good performance in the regions close to Ontario are *Salix dasyclados*, studied by (Kopp and Abrahamson, 2001) in New York, and *Salix viminalis*, investigated by (Labreque and Teodorescu, 2003) in Quebec. Mixed varieties, usually 4-5, are planted in a field to enhance structural and functional diversity, reduce the impact of pests and diseases and lower the potential for widespread crop failures (McCracken and Dawson, 2001).

The establishment of SRC plantations has more in common with agricultural or horticultural crops than forestry. Ground preparation is carried out using conventional agricultural machinery and methods. Generally, willow is planted by simply pushing cuttings, approximately 20 cm long and 1 cm in diameter, into the soil, usually 15,000 cuttings /ha at commercial sites (DEFRA, 2002). Planting materials are produced by specialist breeders, and equipment is specifically designed for the purpose. Shoots and roots quickly develop from these cuttings. Typically two or three shoots sprout from each cutting and grow between 2-4 m in the first growing season. During the winter after planting, the stems are usually cut back to ground level to encourage the growth of multiple stems i.e. coppiced. Generally, three years after cutback and again during the winter, the crop is harvested. The equipment used for harvesting will have been specifically developed for the purpose and depends on the fuel specification of the customer. Most operations other than planting or harvesting can be completed using conventional farm machinery. Figure 1.6 illustrates three-year-old shrub willow and cut-and-chip harvesting.

The major disadvantage of willow SRC, in comparison with herbaceous grasses, is the higher establishment cost due to requirement of planting from the cuttings, which need to be stored at -2 to -4° C (DEFRA, 2002), and utilization of specialized equipment. Weed control is very critical during the first year of establishment and is often a significant portion of total establishment cost (LandSaga Biogeographical — personal communication). Willow, in comparison with poplar, has a broader genetic base, offering more selection of varieties to suit different climate and soil conditions. Willow has no limitation of latitude and needs annual rainfall of 600-1,000 mm for excellent yields, so it can be grown anywhere in Ontario. LandSaga Biogeographical, located near Guelph, Ontario, is the largest supplier of hybrid willow species for North America, and maintains 12 hybrid willow clones, and 9 native species selections for use in constructed wetlands, phytoremediation, nutrient uptake in riparian areas, agricultural nutrient management, landfill cover, landfill leachate treatment and erosion control on rivers and streams. Native willow species are available for conservation, riparian plantings, wildlife habitat, and ecological restoration. Applications include places where willows can be used for water or soil treatment and also periodically harvested as a bioenergy crop.

1.4.2 Fuel Characteristics

Willow SRC biomass offers lower silica and potassium and higher calcium ashes and ash fusion temperature in comparison with herbaceous grasses. Its ash content is also lower. Co-firing and direct combustion of willow SRC, which has similar characteristics to those of other forest wood, is a well-established commercial technology and widely used in Europe for decades for both heating applications and electricity generations. Table 1.5 lists the typical fuel properties of Willow SRC.

Moisture content of willow can be as high as 60% at harvest. However, end-users may want the moisture content below 30%. Different types of harvesting machines can be used to meet the diverse end-user requirements. The *cut-and-bundle* harvester cuts the willow stems and collects them into bundles 2.5 m long. The bundles can be stacked on headlands or on the farm and can dry down to approximately 30% moisture content in 3-4 months. The *cut-and-chip* harvester cuts, collects and comminutes the crop, delivering the chip at the field edge. Although direct-chip harvesting is currently more efficient than rod harvesting, storage and drying of the fresh wood chip does cause problems. Stored, fresh wood chip can heat up to 60°C within 24 hours and start to decompose. During decomposition, calorific value, i.e. the energy value of the fuel, is lost. If the fuel is needed all year, storage, drying and prevention of decomposition must be considered to ensure the fuel quality of the willow (DEFRA, 2002).

1.4.3 Impact on Environment

Positive: The perennial nature and extensive fine-root system of willow crops reduces soil erosion and non-point source pollution, promotes stable nutrient cycling and enhances soil carbon storage in roots and the soil (Ranney and Mann, 1994; Aronsson et al., 2000; Ulzen-Appiah, 2002). Willow crops do not displace species and have high levels of biodiversity. Willow plantations

Table 1.5 Typical Fuel Characteristics of Willow SRC

Proximate Analysis		Ultimate Analysis		Water Soluble Alkalis		Elemental Composition		Other	
	(wt. %)		(wt. %)		(wt. %)		(wt. % ash)		
Fixed Carbon		Carbon	47.9	Na_2O		SiO_2	16.8	Alkali, Lb/MMBTU	
Volatile Matter	84.9	Hydrogen	5.84	K_2O		Al_2O_3	3	Ash Fusion Temp. (°C)	1380 – 1500[b]
Ash	1.1	Oxygen	44.4	CaO		TiO_2	0.1		
Moisture	45-60[a]	Nitrogen	0.63			Fe_2O_3	0.9		
		Sulfur	0.06			CaO	34.9		
		Ash				MgO	2.5		
		Moisture				Na_2O	3		
		HHV (MJ/kg)	19.34			K_2O	12.2		
		Chlorine	0.01			SO_3	1.7		
						P_2O_5	10.4		
						CO_2	17.6		
						Cl			

Sources: Phyllis database (http://www.ecn.nl/phyllis/) Energy Research Center of the Netherlands (ECN)

- a. At harvest, can be reduced to 30% by natural drying in the field (DEFRA, 2002)
- b. Marsh et al., 2008

provide habitat for a large varieties of birds, small mammals, and butterflies (DEFRA, 2002). Below ground, free living mites (Acari) have been used as an indicator of soil biodiversity because of their high population density, species richness, sensitivity to soil conditions and available well-developed sampling methodologies. Three years after planting, the density and diversity of these mites was similar to undisturbed old-fields, indicating that perennial willow biomass crops support a diverse soil biota (Minor et al., 2004). The shrub willow SRC are not invasive, largely due to the fact that they are planted from the cuttings. The shrub will not reproduce on its own (LandSage Biogeographical — personal communication).

Negative: Willow crops are very tall and can have a significant visual impact on the landscape. Willow roots, which are fibrous in nature, will penetrate down to field drains and it is recommended that SRC be planted at least 30 m from any drains that are considered important (DEFRA, 2007). To date, all the Swedish-bred varieties tested in the U.S., which have *S. viminalis* in their background, have been severely damaged by potato leafhopper. However, initial results indicate that resistance to this insect can be bred by crossing *S. viminalis* with varieties from Asia (Kopp et al., 2001). Rust is the most important disease of SRC, caused by a number of fungi called *Melampsora*. Rusts can infect both the leaves and stems of willow and, as they can adapt rapidly to changing circumstances, can successfully infect a whole crop if appropriate measures are not taken. Chrysomelids (willow beetles) are the most important insect pest of willow SRC.

Their numbers can build up rapidly in spring and, as both adults and larvae feed on the leaves, they can cause considerable damage to the crop. For example, removal of 90% of the leaves in summer can reduce the yield by as much as 40%. Adult willow beetles over-winter in rotting wood, under the bark of trees and in similar habitats short distances from the coppice. As temperatures start to rise in the spring, the adults move into the edge of the coppice, start feeding, mate and then gradually move further into the crop. Planting a mix of willow varieties can have a beneficial effect as the beetles tend to feed preferentially on some varieties before moving on to others and this slows their spread through the coppice.

Figure 1.7 Hybrid Poplar Trees and Harvesting

A localized application or over-spraying the entire plantation with appropriate insecticide, depending on the beetle populations, is critical in pest management (DEFRA, 2002). There have been no reports of serious pest problems to date with the willow SRC varieties developed by the State University of New York.

1.5. Poplar

1.5.1 Description

Hybrid poplars (*Populus spp.*) are among the fastest-growing trees in North America and are well suited for the production of bioenergy, fiber and other bio-based products. Willow and poplar species make up the family of the *Salicaceae*. Besides their rapid initial growth, an important aspect that willow and poplar species have in common is the ability to coppice from a cut stump. Like willow, poplar grown as an SRC plantation constitutes densely planted high-yielding varieties harvested on a 2-5 year cycle following coppice of the first establishment year's growth. The productivity of the stool that remains after coppice determines the lifespan of the crop, but plantations are commonly viable for at least 30 years. Poplar grows to the tree form, whereas willow grows with multiple stems of equal size. Italy is the leading European country in hybrid poplar SRC cultivation. This poplar plantation has had a rapid increase in the last few years because of the availability of regional subsidies for the establishment of SRC (Zenone et al., 2004). About 1,000-1,500 ha per year have been planted in northern Italy to a total extent of about 6,000 ha of poplar SRC grown mostly for bioenergy (Facciotto, 2005). Because of the local lack of raw material, pulp and wood panel industries have also drawn their attention to this new crop. In order to achieve higher quality standards required in these sectors, SRC with longer harvest cycles of five years, and wider spacing have been established to harvest logs with diameters exceeding 15 cm (Spinelli et al., 2005). Figure 1.7 shows hybrid poplar planted in rows and harvesting.

There are a large number of hybrid poplar species commercially available, and scientists continue to crossbreed hybrids to create trees that will grow faster and are more drought tolerant and insect resistant. Common hybrid poplar are crosses developed from *P. deltoids, P. trichocarpa, P. balsamifera,* and *P. nigra.* As with the willow, selection of hybrid poplar varieties are site-specific and mixed types are usually used in a field to make the SRC more rust and disease tolerant. Poplar, however, has a smaller genetic base in comparison with Willow.

Establishment of hybrid poplar is similar to that of willow. The density of planting has generally been lower than that for willow at 10-12,000 cuttings/ha. The cuttings should be stored at -2 to -4° C (DEFRA, 2002), The cuttings are 20-25 cm long and must have an apical bud within 1 cm of the top of the cutting. This means that poplar cannot be planted using step planters, as the cuttings have to be manually processed to ensure the presence of the apical bud. During establishment, poplars are intolerant to weed competition. The crop is generally cut back at the end of the establishment year to encourage the formation of a multi-stemmed plant in the following years. Poplar, having a stronger apical dominance than willow, generally produces fewer shoots per stool. Therefore canopy closure and shade suppression of weeds may not be as rapid, requiring additional herbicide treatments.

Higher establishment cost hybrid poplar, likely more costly than willow due to extra care requirements mentioned above, is a major drawback, in comparison with the herbaceous grasses, to be grown as an energy corp. The removal of poplar SRC at the end of its life is more problematic than willow. The rooting system of poplar includes a large taproot that grows down into the soil. Removal of the stools will generally require a large excavator. Hybrid poplar could be more attractive if it is planted for multiple uses, energy and fibre for wood industry, as in Italy. The harvest cycle in this case is usually over five years. This is due to the fact that lower crop density is associated with a longer crop cycle, resulting in bigger stem diameter required by the wood industry. Poplar will grow in most soils. Deep fertile, medium textured, and well-aerated soils offer maximum yield, and water-logged, very dry, or gravelly quick draining soils are best avoided. Annual rainfall exceeding 600 mm is required for good yield. Poplars have an optimal growing temperature of between 15° C to 25° C (TESC-BioSys, www.tsec-biosys.ac.uk).

Table 1.6 Typical Fuel Characteristics of Hybrid Poplar SRC

Proximate Analysis		Ultimate Analysis		Water Soluble Alkalis		Elemental Composition		Other	
	(wt. %)		(wt. %)		(wt. %)		(wt. % ash)		
Fixed Carbon		Carbon	50.2	Na_2O		SiO_2	5.9	Alkali, Lb/MMBTU	
Volatile Matter	84.8	Hydrogen	6.06	K_2O		Al_2O_3	0.8	Ash Fusion Temp. (°C)	1350
Ash	2.5	Oxygen	40.4	CaO		TiO_2	0.3		
Moisture	~50[a]	Nitrogen	0.6			Fe_2O_3	1.4		
		Sulfur	0.02			CaO	49.9		
		Ash				MgO	18.4		
		Moisture				Na_2O	0.1		
		HHV (MJ/kg)	19.02			K_2O	9.6		
		Chlorine	0.01			SO_3	2		
						P_2O_5	1.3		
						CO_2	8.2		
						Cl			

Sources: Phyllis database (http://www.ecn.nl/phyllis/) Energy Research Center of the Netherlands (ECN)

- a. At harvest, can be reduced to 30% by natural drying in the field (TESC-BioSys, www.tsec-biosys.ac.uk)

Research and field trials may be needed to determine the suitability of hybrid poplar for different regions of Ontario.

Willow is considered the preferable biomass species over poplar when produced in a coppice system (van Oosten, 2008). Feasibility of hybrid poplar energy crop, to be competitive with willow, will depend on research and development of new genotypes for lower establishment cost, cost-effective weed control and management system, higher yield and greater rust and disease resistance. The State University of New York (SUNY), which has been active in research and development of SRC in the U.S., has stopped pursuing the hybrid poplar as a biomass crop due to the occurrence and persistence of *Septoria* stem cankers (*Septoria musiva*) (van Oostern, 2008 — Oostern's personal communication with Tim Volk from SUNY).

1.5.2 Fuel Characteristics

Hybrid poplar and willow have similar fuel characteristics. The ash contents of hybrid poplar and willow are higher than that of the forest timber, but lower than that of herbaceous grasses. Typical fuel characteristics of poplar biomass are given in Table 1.6. Higher moisture of hybrid poplar at harvest creates similar drying and handling issues with willow. Calorific value of hybrid poplar would be reduced with the most cost effective *cut-and-chip* harvesting, when the chips are stored long before being burnt at the energy conversion facility. As with willow, *cut-and-bundle* harvesting of hybrid poplar would be the better option, if the fuel is needed all year. This would allow the natural drying of poplar bundles in the field to 30% moisture content before being used for the energy.

1.5.3 Impact on Environment

Positive: Hybrid poplar and willow offer similar environmental benefits. Despite the fact that it is essential to eradicate weeds during the establishment of SRC, once the crop is mature the growth of a ground flora is beneficial. Ground cover encourages the presence of invertebrates, which in turn leads to an increase in the number of small mammals and birds found. Chemical and fertilizer applications are considerably lower, lessening the potential for chemical runoff and leaching. Hybrid poplars, as buffer strips, also intercept runoff of nutrients from fields near streams, rivers and wetlands. As perennial cover, wind and water erosion over the life of the rotation is less than that with annual crops. Hybrid poplars also provide increased year-round habitat for birds and small mammals compared to annual row crops. Hybrid poplars, due to the similar planting and other characteristic to those of willow, are not considered invasive.

Negative: As in many tree species and traditional agricultural crops, poplars suffer from a variety of diseases. The most serious diseases are those caused by fungi and include stem cankers, leaf rusts, leaf blights and leaf spots. Of these, the most important diseases are Septoria stem cankers, caused by *Septoria musiva* and leaf rust, caused by various *Melampsora* species (Schroeder and Inouye, 2006). The State University of New York (SUNY) has stopped pursuing the hybrid poplar as a biomass crop due to the occurrence and persistence of *Septoria* stem cankers, which often result in stem breakage leading to lower biomass yields (van Oostern, 2008 — Oostern's personal communication with Tim Volk from SUNY). Different poplar varieties have different susceptibilities to rust. As with willow, it is recommended that a mix of varieties be planted. Willow beetles are also an important pest of poplars, and could also be managed by mitigation methods presented in the willow SRC section.

1.6 Tall Grass Prairies

Tall grass prairies (TGP) programs are being implemented by a couple of organizations in Ontario with a number of primary objectives such as reduction of soil erosion, restoration of native grasses and related ecological systems, soil conservation through carbon sequestration by the grass roots, etc. The TGP attract high biological diversity including grassland songbirds, pollinating and predatory, parasitic natural beneficial insects. Since the worldwide bee population is declining at an alarming rate, the benefit of bee population growth by the TGP is extremely favorable for the agricultural sector. Ontario Ministry of Natural Resources is carrying out a TGP program, where mixed native grasses are being or will be planted on agricultural land along the drains and along highways for soil conservation and other ecological benefits. The agricultural lands are rented from the farmers, similar to the CRP program in the U.S., for the TGP program. Tallgrass Ontario (www.tallgrassontario.org) is a not-for-profit organization implementing a similar program of growing mixed native grasses on marginal land rented from the farmers.

The potential of bioenergy from the native tall grass prairies programs is promising, if the end-users, like OPG, purchase biomass from the native grasses. Currently the native grasses are burnt every 3-4 years due to lack of end-use. Although TGP programs currently produce limited amount of biomass, they can expand significantly, if the funding is available through the sale of biomass. The TGP programs are mutually beneficial for both the environmental organizations and OPG in conserving the ecological system and securing the biomass supply. Lower cost of biomass can also be expected since TGP programs are executed by not-for-profit organizations.

The establishment of a mixed prairie is more complex than establishing a monoculture crop. There is no set definition of what should be planted, and it could be area specific. Tilman et al. (2006) planted up to 16 species in a plot, and there could be over 40 species of native grasses available for Ontario (personal communication with Ron Ludolph, Ontario Ministry of Natural Resources). Usual practice is to plant 7-8 species of native grasses in a plot. In general, the establishment of a mixed prairie should be similar to the establishment of a switchgrass field. There may be tradeoffs between biomass production and ecological objectives, including plant diversity. For bioenergy, tall prairie grasses such as switchgrass, Indian grass, and Big bluestem may crowd out smaller forbs and grasses. Yields could vary with land classes of the TGP programs, but, should be comparable to that of switchgrass. Fuel properties, moisture and mineral contents of native grasses should be investigated through lab testing to determine their suitability for burning in OPG boilers.

1.7. Energy Crops in Ontario Context and Fuel Requirement Perspective

1.7.1 Mixed Energy Crops Scheme

The dedicated energy crops in previous sections were studied with an objective of identifying the energy crop with the greatest potential of commercial development as outlined in the requirements of the study provided by OPG. However, findings during the study, through literature, information gathered from government and research organizations and farm operators, suggest that development of energy crops in Ontario should include a mix of different energy crops for the following reasons:

(i) Infancy State of Energy Crops

Compared to forest wood-chip-derived biomass, the energy crop industry is in its infancy in Ontario, and even in the rest of North America. To meet the biomass demand of OPG stations, total land required would be over 500,000 ha, assuming average biomass yield of 10 DM t/ha/yr. The researchers with experimental plots or energy crop growers on small-scale would prefer to use higher yield numbers. However, this is the conservative yield assumption with consideration of the commercial scale plantation and yield fluctuations due to weather conditions. This large land use for energy crops would be unprecedented for a region the size of Ontario, and no particular energy crop has been grown on that scale anywhere in the world. Sweden, which has an area of about half of Ontario, is using 15,000 ha to grow willow SRC for biomass (Rosenqvist and Dawson, 2005), and is a leading country in Europe in the development of energy crops. Almost all energy crops have yet to be proven in large commercial scale for their production, pest and disease tolerance and drought resistance. Growing of hybrid poplars in Europe and North America experienced various pests and diseases, significantly reducing the yields, after a few years of initial development (van Oosten, 2008). Therefore, selecting a particular energy crop as the most promising one for a large-scale production at this infancy state would be not only somewhat speculative but also a risky approach.

(ii) Biodiversity

The dedicated land of over 500,000 ha for energy crops is equivalent to over 9% of total agricultural land in Ontario. Inclusion of different energy crops in the scheme would provide biodiversity for the province. All tree species and agricultural crops could develop pest and disease at certain weather conditions and environment. The mixed energy crops would better restrain the pest and disease outbreaks associated with a particular crop. This approach also accommodates the choice of individual farmers based on specific soil types, existing farming machineries, preferred landscape and crop rotation expectation. Since knowledge of commercial production of any energy crop is limited at present, the mixed energy crops scheme would offer learning opportunities and allow elimination of problematic energy crop(s) in a particular region in future.

(iii) Fuel Requirement and Capital Cost

OPG needs biomass fuels all year to power its electricity generation stations. The mix of different energy crops would offer a multi-annual cropping system and keep the overall capital cost down due to different harvesting, handling, storage and fuel characteristics. For instance, the harvesting window for miscanthus is relatively narrow, if it is harvested in early spring for better fuel quality. If weather conditions do not permit, i.e. a long winter and wet early spring, the harvesting window would be narrower. This would require a large number of harvesting machines for a short period, if all farmers grow miscanthus. The mixed energy crops scheme would also minimize the fluctuations of biomass supply. Reduction in biomass yield of a particular energy crop is possible due to outbreaks of pests and diseases, and unfavorable weather conditions. For instance, a long winter and wet early spring would delay baling of switchgrass cut in the fall the year before. Late harvesting would be problematic, because new shoots start coming out of the ground. This would affect the yield in the following year, since some of the new shoots are destroyed during the harvest.

1.7.2 Identification of Potential Energy Crops

There are no serious agronomic or technical barriers for production and use of energy crops, investigated for this study, in the energy system. The practice will eventually find the necessary solutions and adjustments for large-scale implementation. The prominent strengths and weaknesses of the energy crops are summarized in Table 1.7 without detailed economic analysis of each crop.

To meet OPG's biomass demand, it is likely necessary to convert some crop lands to energy crops in Ontario, where almost all agricultural lands are being used either for food crops or hay production. This situation is different from some states in the U.S., where a large area of idle crop lands, including CRP programs, are available for energy crops. Since allocating crop lands to energy crops means less land devoted to other products, energy crops should be developed as a part of an overall environmental program covering both agriculture and the energy sector. This is where the perennial crops, like miscanthus, switchgrass, willow and poplar, could play an important role, since these crops are claimed by initial studies (Borzêcka-Walker et al., 2008) for soil improvement, erosion prevention, accumulation of organic matters in the soil, carbon sequestration, etc, due to their massive root systems and perennial nature. More studies[2] are underway in Ontario to quantify the soil improvement by perennial crops. There is a potential that energy crops can be part of crop rotation, for instance 10 years of energy crops followed by 10 years of food crops, and might offer significant benefits to the subsequent food crops. The energy crops and food crops in the rotation system might prove to be a better agronomic practice with improved yields and better disease control for food crops, and potentially offer a solution to the food-versus-energy issue.

Considering the soil improvement by the perennial crops and benefits of developing the energy crops in the overall environmental scheme, the non-perennial sorghum-Sudangrass is not considered as a potential energy crop. This is partly due to the fact that perennial crops add more organic matter to the soil compared with annual crops through their permanent root systems (Mapfumo et al, 2002). Additionally, sorghum-Sudangrass has the moisture content of 70-75% at harvest and drying in the field is highly dependent on the weather conditions, and likely produces the lowest dry matter compared with other energy crops listed in Table 1.11. Hybrid poplar can also be removed from the potential energy crops for Ontario at present due to the serious *Septoria* stem cankers experienced in New York, U.S. (van Oostern, 2008 – Oostern's personal communication with Tim Volk from SUNY). Therefore, this study identifies miscanthus, switchgrass and willow as potential energy crops for commercial development in Ontario. These three energy crops are relatively extensively studied crops, in North America or at least in other regions of the world, in comparison with other energy

[2] http://www.omafra.gov.on.ca/english/crops/field/news/croptalk/2008/ct-1108a8.htm

crops, not limited to those listed in Table 1.7. Furthermore semi-commercial or commercial scale lands dedicated to miscanthus, switchgrass and willow SRC are already in production. The fuel mix should also include the native tall grasses, which not only provide bioenergy but also could improve the yields of food crops due to increase in bee populations.

Table 1.7 Prominent Strengths and Weaknesses of Energy Crops

Energy Crop	Strengths	Weaknesses
Miscanthus	- Moderate to high yield - Low to moderate moisture content - Non-invasive - Soil improvement potential	- Moderate to high establishment cost - Winter survival during the first year of establishment is critical
Switchgrass	- Low establishment cost - Native crop - Moderate yield - Low moisture content - Better adaptability to marginal soils - Excellent drought resistance - Soil improvement potential	- Moderate to high ash content - Little knowledge on performance in cooler regions of Ontario
Sorghum-Sudangrass	- Low planting cost - Multiple harvests in one season - Non-invasive	- Annual crop - High moisture content - High ash content - Low dry matter yield
Willow	- Moderate yield - No latitude limitation - Low ash content - Non-invasive - Soil improvement potential	- Moderate to high establishment cost - Weed control during the fist year of establishment is critical - Moderate to high moisture content - Susceptible to pests and diseases
Hybrid Poplar	- Moderate yield - Flexible crop cycle (harvesting frequency) - Low ash content - Non-invasive - Soil improvement potential	- High establishment cost - High weed control cost - Moderate to high moisture content - Highly susceptible to pests and diseases

Chapter 2

Land Classification, Land Availability and Potential Biomass Supply

2.1 Canada Land Inventory System and Capability Classification

The Canada Land Inventory (CLI) for agriculture is an interpretative system for assessing the effects of climate and soil characteristics on the limitations of land for growing common field crops. Common field crops in Ontario include corn, soybeans, small grains and perennial forages, e.g. tame hay crops such as alfalfa and timothy. This system does not classify land for horticultural or other specialty type crops.

The system classifies mineral soils into seven groups according to their potentials and limitations. The first three classes are considered capable of sustained production of cultivated field crops and are considered prime agricultural land resources. The fourth class is marginal for cultivated field crops. The fifth is capable of hay production and permanent pasture use. The sixth is capable of sustaining unimproved pasture only and the seventh class has no agricultural capability. The system emphasizes the potential capability of soils. Therefore, the present land use and management of a given land area may or may not reflect its potential soil capability. For example, a forested area may rate highly under the CLI even though it has not been cleared and developed for agricultural use.

CLI classification uses certain assumptions. These are:

- CLI classification depends on combinations of climate and soil characteristics which affect limitations to soil use and productive capacity for common field crops. The need for land improvement by the removal of shrubs, trees and stumps is not considered a limitation to agricultural capability unless it is considered unfeasible to remove them.
- Contemporary best management practices for soil management and field crop production are in place.
- The various soils within a given capability class are considered similar in degree of limitation, notwithstanding the various kinds of limitations which may be present.
- The soil capability class represents the potential capability of land in its improved state. Land requiring improvements, such as stone removal or tile drainage, that are feasible and can be done by the individual farmer or landowner, is classified according to what its ongoing limitations would be with the needed improvements in place. It is recognized that in some local or site-specific situations certain improvements may not be feasible, even though such improvements are generally feasible on similar soils elsewhere.
- The capability classification of the soils in an area may be changed when major reclamation works are installed which permanently reduce or eliminate the present limitations.
- Distance to market, kinds of roads, location, size of farms, characteristics of land ownership and cultural patterns and the skill or resources of individual operators are not criteria for CLI classification.
- Capability groupings may be subject to change as new information about the behaviour and responses of soils becomes available.

In the CLI system there are seven capability classes. Soils descend in quality from Class 1, which is highest, to Class 7 soils which have no agricultural capability for common field crops. Class 1 soils have no significant limitations. Class 2 through 7 soils have one or more significant limitations and each of these are denoted by a capability subclass. Definition of capability classes in the CLI system and explanations are given in Table 2.1.

Each CLI land class may have 13 capability subclasses, which indicate the kinds of limitations present for agricultural use. For instance, subclass M is assigned to soils with moisture deficiency, indicating soils in this subclass have lower moisture holding capacities and are more prone to droughtiness. Details of the subclasses are not presented in this report since they are not quite relevant to the study.

2.2 Agricultural Land Use in Ontario and Gross Margins

Ontario farmers, based on personal communications with personnel from Ontario Ministry of Agriculture Food and Rural Affairs and farmers, grow vegetables and fruits on their best land, which is Class 1 soil. Food crops such as wheat, soybeans,

Table 2.1 Definition of Capability Classes and Explanations Class Description[1]

Class	Description
1	Soils in this class have no significant limitations in use for crops.
	Soils in Class 1 are level to nearly level, deep, well to imperfectly drained and have good nutrient and water holding capacity. They can be managed and cropped without difficulty. Under good management they are moderately high to high in productivity for the full range of common field crops.
2	Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
	These soils are deep and may not hold moisture and nutrients as well as Class 1 soils. The limitations are moderate and the soils can be managed and cropped with little difficulty. Under good management they are moderately high to high in productivity for a wide range of common field crops.
3	Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
	The limitations are more severe than for Class 2 soils. They affect one or more of the following practices: timing and ease of tillage; planting and harvesting; choice of crops; and methods of conservation. Under good management these soils are fair to moderately high in productivity for a wide range of common field crops.
4	Soils in this class have severe limitations that restrict the range of crops or require special conservation practices.
	The severe limitations seriously affect one or more of the following practices: timing and ease of tillage; planting and harvesting; choice of crops; and methods of conservation. These soils are low to medium in productivity for a narrow to wide range of common field crops, but may have higher productivity for a specially adapted crop.
5	Soils in this class have very severe limitations that restrict their capability in producing perennial forage crops, and improvement practices are feasible.
	The limitations are so severe that the soils are not capable of use for sustained production of annual field crops. The soils are capable of producing native or tame species of perennial forage plants and may be improved through the use of farm machinery. Feasible improvement practices may include clearing of bush, cultivation, seeding, fertilizing or water control.
6	Soils in this class are capable only of producing perennial forage crops, and improvement practices are not feasible.
	These soils may provide some sustained grazing for farm animals but the limitations are so severe that improvement through the use of farm machinery is impractical. The terrain may be unsuitable for the use of farm machinery, or the soils may not respond to improvement, or the grazing season may be very short.
7	Soils in this class have no capacity for arable culture or permanent pasture.
	This class includes marsh, rockland and soil on very steep slopes.

[1]http://www.omafra.gov.on.ca/english/landuse/classify.htm

corns, etc., are grown on productive lands, which are Class 1–3 soils as explained in Table 2.1. The less productive lands, which are Class 3–4 soils, are used to grow some food crops and tame hays. Note that tame hays such as alfalfa and timothy are included in field crops. The Class 5 and 6 soils are used for tame or seeded pasture and natural pasture, respectively. Farmland areas by use of land and by census region in Ontario appear in Table 2.2, and lists of counties/divisions/districts/municipalities in each agricultural census region are provided in Table 2.3 and Figure 2.1.

The agricultural land in southern and western Ontario census regions, shown in Inset A in Figure 2.1, accounts for 60% of

Table 2.2 Ontario Farmland Area (ha) by Land Use and by Ontario Region in 2006

Region	In crops	Summer fallow	Tame or seeded pasture	Natural land for pasture	Christmas tree area, woodlands and wetlands	All other land	Total
Southern	1,354,213	3,712	32,278	30,055	118,382	54,382	1,593,023
Western	1,178,977	3,053	114,222	90,089	183,575	58,771	1,628,687
Central	428,666	2,398	58,372	111,520	142,581	35,732	779,269
Eastern	546,726	1,862	59,754	128,860	193,353	43,429	973,984
Northern	153,921	876	38,904	89,949	112,784	17,355	413,789
Province	3,662,503	11,900	303,530	450,473	750,675	209,670	5,388,751

Source: http://www.omafra.gov.on.ca/english/stats/census/cty32.htm

Table 2.3 Counties/Division/District/Municipality in Agricultural Census Regions

	Southern Ontario	Western Ontario	Central Ontario	Eastern Ontario	Northern Ontario
County/Division/District /Municipality	Brant (29)	Bruce (41)	Durham (18)	Frontenac (10)	Algoma (57)
	Chatham-Kent (36)	Dufferin (22)	Haliburton (46)	Lanark (9)	Cochrane (56)
	Elgin (34)	Grey (42)	Hastings (12)	Leeds & Grenville (7)	Greater Sudbury (53)
	Essex (37)	Halton (24)	Kawartha Lakes (16)	Lennox & Addington (11)	Kenora (60)
	Haldimand-Norfolk (28)	Huron (40)	Muskoka (44)	Ottawa (6)	Manitoulin (51)
	Hamilton (25)	Peel (21)	Northumberland (14)	Prescott & Russell (2)	Nipissing (48)
	Lambton (38)	Perth (31)	Parry Sound (49)	Renfrew (47)	Rainy River (59)
	Middlesex (39)	Simcoe (43)	Peterborough (15)	Stormont, Dundas & Glengarry (1)	Sudbury (52)
	Niagara (26)	Waterloo (30)	Prince Edward (13)		Thunder Bay (58)
	Oxford (32)	Wellington (23)	York (19)		Timiskaming (54)

Note: Number in the bracket next to county/division/district/municipality refers to the region in the map (Figure 2.1)

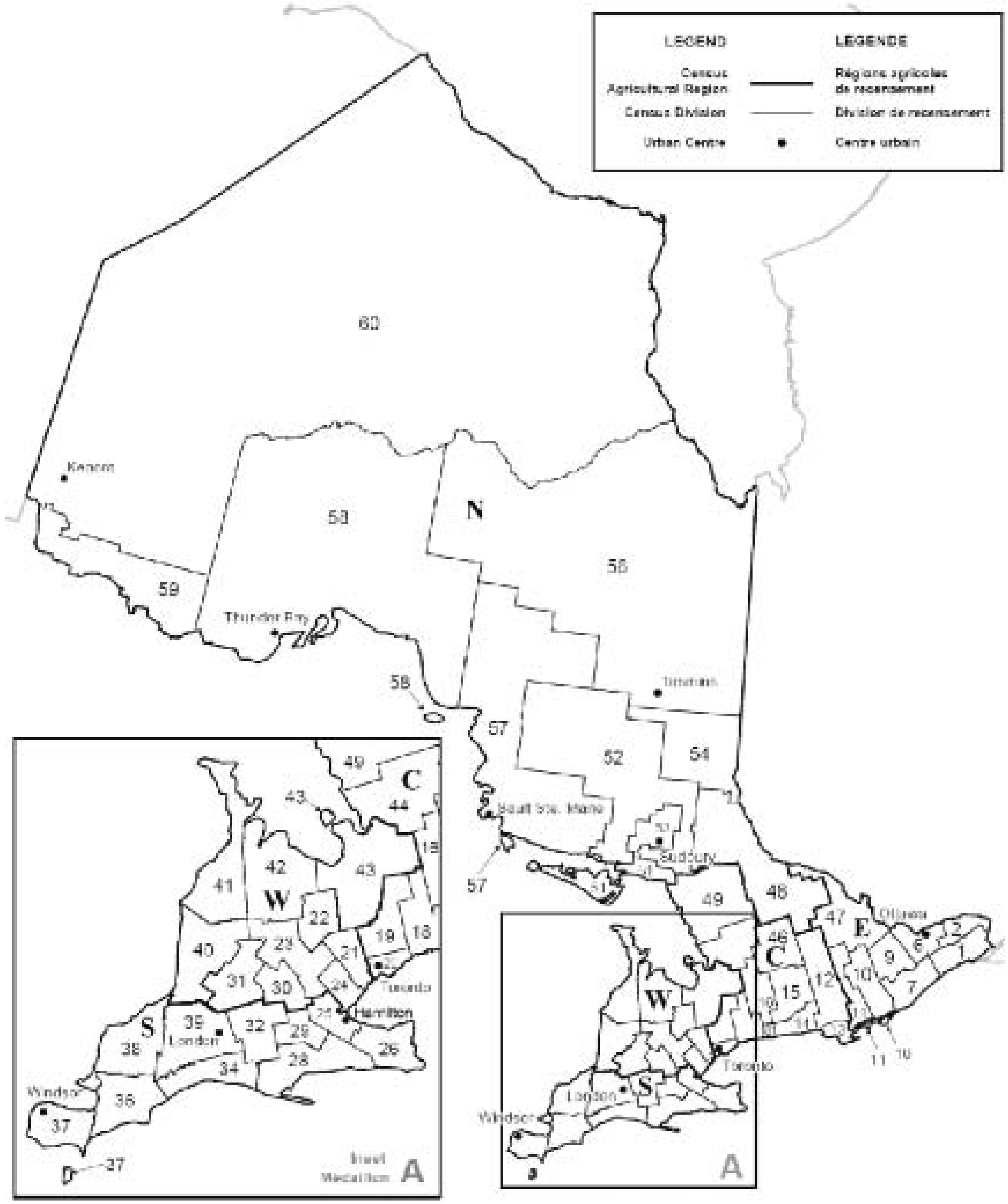


Figure 2.1 Agricultural Census Regions in Ontario

total farmland in Ontario. Gross margin expectations of farmers, based on personal communications during the study, for growing fruits and vegetables, i.e. the best of Class 1 soil, are \$1,480–\$1,730 /ha. Food crops on productive land, i.e. Class 1-3 soils, provide a gross margin of \$245–\$490 /ha. Food crops on less productive land, i.e. Class 3–4, give a gross margin of around \$245/ha. Tame hays on less productive land, i.e. Class 4, generate a gross margin of around \$100/ha. The expected minimum gross margins of selected field crops with their probabilities for year 2008 in Ontario estimated by OMAFRA[2] are given in Figure 2.2.

2.3 Land Availability for Energy Crops in Ontario

The ideal case is that the energy crops are grown on the land not currently used to supply the food chain. This would be possible in some states in the U.S. where a large area of idled crop land, such as land on the Conservation Reserve

[2] http://www.omafra.gov.on.ca/english/crops/index.html#field

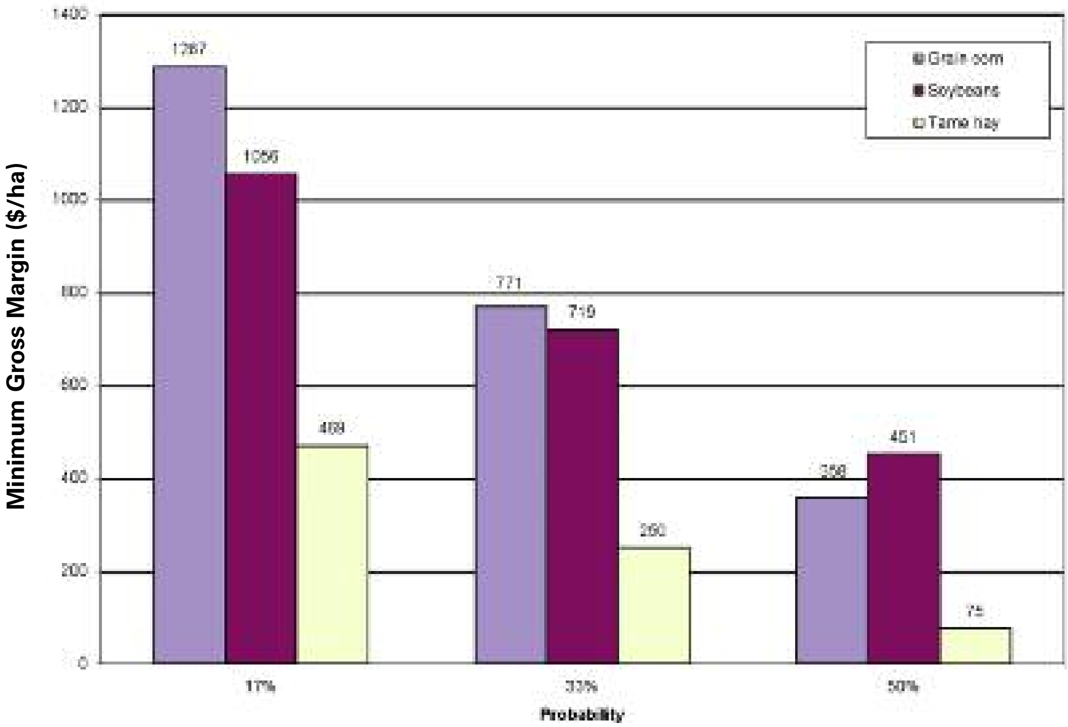


Figure 2.2 Expected Minimum Gross Margins and Probabilities for Selected Field Crops

Program (CRP), exists. However, almost all arable lands in Ontario are being used for food crops or tame hays. Conversion of some of the crop land is necessary to meet OPG's biomass demand, since total land required for the energy crops would be over 500,000 ha assuming the average yield of 10 DM t/ha/yr. Ontario has total farmland area of 5.39 million ha according to the 2006 census data. Therefore, total land area required for the energy crops would represent a significant portion of the total farmland, over 9% of agricultural land in Ontario.

It would be convenient if the breakdown of total agricultural land by the capability classes is obtainable to estimate the land available for energy crops. However, such a data set is not readily available at present. Overlaying the soil map and municipal map for each county in the province seems to be the only way to obtain such data. Most soil maps were created before 1975, and illustrate areas by land capability classes, covering the whole county including forested and residential areas. The municipal maps provide the current agricultural land, and together with the soil maps, total area of marginal land, mainly Class 4–5 and some Class 3 soils, could be estimated using geographical software. This approach would give an accurate calculation of the marginal land in Ontario. However, time constraint of this study does not allow for determination of the marginal land available on a county basis.

The estimate of total marginal land is, nevertheless, possible given the definition of land capability classification and the breakdown of land use by food and hay crops. A study[3] funded by OMAFRA reported that up to 560,000 ha of Ontario land could be converted to grow energy crops. In a separate study, the Resource Efficient Agriculture Production (REAP-Canada), which is a research organization with over 16 years of studying switchgrass as an energy crop, assumed that 20% of food crop land and 40% of forage land (tame hay plus tame or seeded pasture) are marginal land suitable for conversion to energy crops. With some reservations, the OMAFRA personnel and the farmers contacted, regard those estimates as the reasonable provincial averages. The reservations include the practicality of converting tame hay area in some regions and economic attractiveness of energy crops. The resulting total available land in Ontario for energy crops is 955,281 ha, the combined area of 450,847 ha from food crop land and 504,434 ha from forage land (Stephanie Bailey-Stamler et al., 2006). Also note that a few of the studies conducted by REAP–Canada were

[3]http://www.omafra.gov.on.ca/english/research/new_directions/projects/2001/sr9074.htm

partly funded by OMAFRA. A similar approach is used in this study to estimate the land available with different percentage rates of conversion applied to different census regions, considering the farm income per ha and ratio of tame hay area to total field crop land. Total farm area in crops, tame hay area, total farm income and farm income per ha in Ontario regions are given in Table 2.4.

The data in Table 2.4 is used as a basis to estimate the percentages to convert the crop land, hay land and tamed or seeded pasture land to energy crops. Note that tame hay land, in column 3, is part of total land in field crops, in column 2. The southern Ontario region has the smallest percentage of total crop land used for tame hay. Personal communication with Ron Van Damme, a local farmer in St. Clair township, revealed that tame hay in southern Ontario is just self-sufficient for the cattle and livestock in the region. Therefore, conversion of the tame hay land to the energy crops in southern Ontario is not likely. However, Don Nott, switchgrass grower in Clinton, in western Ontario region, stated that some hays from the region were sold to the U.S. The percentage of total crop land used for tame hay in western Ontario (27.6%) is comparable to that of the provincial average of 28.3%. Therefore, conversion of some of the tame hay land, as suggested by REAP-Canada, is possible. Similar considerations are given to other census regions to estimate the percentages of tame hay land to convert to the energy crops.

Net farm incomes per ha of crop land in the regions in Table 2.4 indicate that crop lands in southern, western and eastern Ontario regions are more economically productive than central and northern Ontario regions. Conversion of crop land in more productive regions to the energy crops needs more economic incentives compared to less productive regions. Therefore, differential percentages of food crop land should be considered to convert to the energy crops. Table 2.5 gives the land in major field crops, tame hay, and tame or seeded pasture for each census region with the potential conversion to the energy crops. The conversion percentages are estimated based on the specific conditions of the region, and the conversion percentages suggested by REAP–Canada are used as maximum values for each region.

Total land available for energy crops in Ontario is, therefore, 783,254 ha, the combined area of 353,907 ha from conversion of major field crop land and 429,347 ha from conversion of forage land. Total land available in southern, western and central Ontario regions, which are relatively close to OPG Lambton and Nanticoke generating stations, for potential conversion to the energy crops is 547,680 ha, which could produce approximately 6 million tons of biomass per year.

2.4 Yields of Energy Crops

2.4.1 Miscanthus Yield

Yield of miscanthus, like the yield of any plant, depends on sunshine, temperature, rainfall, soil types and nutrients used. Research in UK in 1993–2002 showed that no significant yield

Table 2.4 Field Crop land, Tame Hay Land and Net Farm Income in Ontario Regions in 2006

Region	Total Land in Field Crops (ha)	Tame Hay Land (ha)	Tame Hay Land/Total Land in Field Crops (%)	Total Net Farm Income ($ '000)	Net Farm Income/ha ($/ha)
Southern	1,354,213	125,133	9.24	229,408	169.40
Western	1,178,977	325,030	27.57	187,389	158.94
Central	428,666	198,597	46.33	19,910	46.45
Eastern	546,726	275,310	50.36	95,762	175.16
Northern	153,921	112,992	73.41	10,205	66.30
Province	3,662,503	1,037,062	28.32	543,234	148.32

Source: http://www.omafra.gov.on.ca/english/stats/county/index.html benefits were obtained by applying nitrogen (Christian, et al., 2003). However, other studies (Himken et al., 1997; Lewandowski et al., 2003) suggested that nitrogen requirement is site-specific. Comprehensive correlation between quality of soil and the yields is not available. However, difference in miscanthus yields between the "good soil" and "poor soil" as defined by the German researchers (Hotz et al., 1996) could be in the factor of two to three. Low rainfall, approximately 30% below normal, in Illinois in 2005, reduced the miscanthus yields by 31% in comparison with the yields in 2004 (Pyter et al., 2007).

Miscanthus has been evaluated in Europe over the past 10 years as a new bioenergy crop and considerable yield potential has been revealed. This is particularly relevant under conditions from central Germany to southern Italy, where the yields of 25 dry matter (DM) t/ha have been obtained. In northern and southern areas, achieved yields are about 15 DM t/ha, requiring irrigation in the southern parts of Europe (Scurlock, 1998). The yields from research plots, however, are usually higher than that under commercial conditions. For instance, the expected yield in the Netherlands and Germany for commercial–scale production is 10–12 DM t/ha, and mean yields in Denmark from the commercial sites have been 7–9 DM t/ha (Venendaal et al., 1997; Scurlock, 1998).

Researchers from the University of Illinois (Pyter et al., 2007) reported that yields have varied, depending on the crop age and the weather during the growing season. At three Illinois sites in replicated studies, the end-of-season biomass yields of unfertilized giant miscanthus planted in 2002 averaged over the 2004, 2005, and 2006 growing seasons were 23.7 DM t/ha in northern Illinois, 37.5 DM t/ha in central Illinois, and 44.0 DM t/ha in southern Illinois. Miscanthus produced more than twice the

Table 2.5 Estimation of Total Land Available (ha) for Energy Crops in Ontario Regions

Agriculture Product/land	Southern Ontario	Western Ontario	Central Ontario	Eastern Ontario	Northern Ontario	Province
Major field crops						
All wheat	228,393	146,499	35,228	4,298	1,792	416,210
Oats	10,286	12,729	12,234	10,122	8,029	53,400
Barley	4,717	46,814	12,327	15,339	10,250	89,447
Mixed grains	4,218	44,185	12,098	6,954	2,739	70,194
Corn (grain)	291,337	203,916	57,670	84,842	773	638,538
Corn (fodder)	28,185	58,755	14,695	26,545	1,627	129,807
Soybean	495,165	232,927	57,765	84,824	1,775	872,456
Summer fallow	3,712	3,053	2,398	1,862	876	11,901
Total crop land	1,066,013	748,878	204,415	234,786	27,861	2,281,953
Land converted to energy crops (%)	15	15	20	15	20	15.51
Land available for energy crops	159,902	112,332	40,883	35,218	5,572	353,907
Forage						
Tame hay	125,133	325,030	198,597	275,310	112,992	1,037,062
Tame or seeded pasture	32,278	114,222	58,372	59,754	38,904	303,530
Total forage	157,411	439,252	256,969	335,064	151,896	1,340,592
Land converted to energy crops (%)	0	30	40	40	40	32.03
Land available for energy crops	0	131,776	102,788	134,026	60,758	429,347
Total land available for energy crops	159,902	244,107	143,671	169,244	66,331	783,254

biomass of switchgrass at all sample locations in all years. The average yield results are very impressive in Illinois, which, like Southwestern Ontario, has a humid continental climate by the Koppen climate classification. However, these productive yields have yet to be proved on commercial–scale sites.

Research and field trials of growing miscanthus in Canada have been very limited to date. Small-scale Canadian trials of *Miscanthus x giganteus* began in 1997–1998 outside Montreal, with initial annual yields at spring harvest of 10–11 DM t/ha (Scurlock, 1998), which seems to be the first harvest of the plot. Pyramid Farms Ltd. is currently projecting 25–30 DM t/ha of miscanthus from its initial field trials in Southwestern Ontario. If the recent yield results in Illinois can be replicated in Southwestern Ontario due to similar climates, miscanthus would be the promising energy crop with great yield potential. The yield results from Europe and North America are summarized in Table 2.6.

Miscanthus yield data on different land capability classes in Ontario is not readily available at present. However, miscanthus yields for different land classes are estimated considering the ratio of the commercial to research sites, agronomic and genetic improvement over years, yield data in nearby regions and projections by the commercial growers. Table 2.6 summarizes the miscanthus yield estimates to be used in this study. The yield at the research plot in Illinois is regarded as a baseline for prime land or Class 2 soils. The ratio between commercial yield and research yield experienced in Europe is used to estimate the yield on the marginal land, some Class 3 soils and Class 4 soils. Based on the experiences in Germany, a factor of two is assumed between the yield on the marginal soils, Class 4, and the yield on the poor soils, Class 5. Willow breeding in Sweden resulted in yield increases of 10–20% per generation (van Oosten, 2008). Yield improvement of 20% is, therefore, assumed per generation by agronomic and genetic research and development, which are progressing rapidly at present.

2.4.2 Switchgrass Yield

Switchgrass, unlike miscanthus, has been extensively studied in Canada. Resources Efficient Agricultural Production (REAP–Canada) located in Quebec is a research organization, which has been actively working on energy crops, especially switchgrass, for over 15 years. Yield data for switchgrass has been collected in southern Ontario and Quebec since 1992 as part of project partnerships between REAP–Canada, McGill University and Alfred College of Guelph University. The switchgrass variety *Cave in Rock* has proven to be one of the more adapted and productive varieties for this region, with

Table 2.6 Miscanthus x Giganteus Yields (DM t/ha) in Different Regions

Region	Research Sites	Commercial-Scale
Warmer Europe (Germany, Italy, UK)	17 – 32	10 – 13
Colder Europe (Denmark)	15 – 25	7 – 9
Illinois, USA	24 – 44	na
Montreal, Canada	10 – 11	na
Southwestern Ontario, Canada	25 – 30[a]	na

Sources: Scurlock, 1998; Venendaal et al., 1997; Pyter et al., 2007; DEFRA, 2007

a. Projection by Pyramid Farms Ltd.

Table 2.7 Miscanthus Yield (DM t/ha) Estimates for Different Land Capability Classes

	Class 2 (DM t/ha)	Class 3 – 4 (DM t/ha)	Class 5 (DM t/ha)
Baseline	34	16	8
Improved–1	41	19	10
Improved–2	49	23	12

yield data collected from various locations including Guelph and Alfred in Ontario and Ste Anne de Bellevue in Quebec. Field yield assessments have also been made from commercial fields in eastern Ontario and southwestern Quebec. A summary of the fall harvested yield data from the variety *Cave in Rock* from these Canadian trials can be found in Table 2.8.

In comparison, the U.S. Department of Energy estimates average regional switchgrass crop yields to be 10.9 oven-dry-tons (odt)/ha/yr (7.9–12.4) for the Northeast, 10.8 (7.9–13.5) for the Lake States and 13.4 (11.1–15.1) for the Corn Belt (Walsh et al., 2003). Seasonal time of switchgrass harvest affects the yields and biofuel quality. Spring harvest is more desirable than fall harvest

Table 2.8 Summary of Switchgrass, Cave in Rock, Yields (Oven–dry–Tons) in Canada (Bailey–Stamler et al., 2006)

Location	Average Yield (odt/ha)		Comments
	First Year Production Crop	Fully Established Crop	
Small plot yields			
Alfred Ontario[1]	7.2	10.0	Established crop 2 yr. average, sandy soil
Alfred Ontario[1]	4.5	12.8	Established crop 2 yr. average, clay soil
Ste Anne de Bellevue, Québec[4]	10.9	13.3	Established crop 2 yr. average, sandy loam
Semi–commercial fields (>2 ha)			
Guelph Ontario[3]	8.1	–	First year crop data only available
Ste Anne de Bellevue, Québec[1]	8.8	11.9	Established crop 6 yr. average, sandy loam
Commercials fields (>5 ha)			
Valleyfield, Quebec[2]	9.0	10.5	Established crop 2 yr. average, clay loam
Berwick, Ontario[2]	6.1	10.8	Established crop 2 yr. average, clay loam
Production Average	7.8	11.6	
Overall Average	9.4		Assuming a weighted average of the first production year and 5 years established crop together with no harvest the year of seeding.

1.Jannasch et al., 2001a; 2.Samson et al., 1999; 3.Samson et al., 1995; 4.Madakadze et al., 1998

Table 2.9 Switchgrass Yield (DM t/ha) Estimates for Different Land Capability Classes

	Class 2 (DM t/ha)	Class 3 – 4 (DM t/ha)	Class 5 (DM t/ha)
Baseline	13	10	8
Improved–1	16	12	10
Improved–2	19	14	12

from the fuel quality perspective. However, switchgrass yield can be reduced by as much as 40% in winters with above average snowfall when the harvest was delayed over winter until spring (Adler et al., 2006). A study conducted in Ontario (Samson, 2008) to develop an optimum switchgrass harvest strategy identified that a late fall mowing of the grass prior to the onset of winter followed by spring baling increased field recovered yields by 23% compared to spring mowing and baling, also reducing the moisture content of the bales from 7.8% to 6.0%.

Yield estimates for switchgrass are given in Table 2.9 for this study considering current yields from research and commercial sites in Canada and insensitivity of switchgrass to soil types. Yield data from the sandy loam soil research plot is taken as baseline for Class 2 soils. Commercial yields and expected yields from the current switchgrass farms are assumed as baseline for Class 3–4 soils, and 20% yield improvement per generation is incorporated, as with miscanthus.

2.4.3 Sorghum–Sudangrass Yield

Yield data for sorghum–Sudangrass as an energy crop is very limited, since the grass is mainly used as forage. The yield of a warm-season fast growing grass, like sorghum–Sudangrass, varies with season, moisture and warmth and are higher in hot summers than in cool ones. Table 2.10 gives the yield data from different sources, and note that yields in the table are not the dry matter. The moisture content of sorghum–Sudangrass could be 70–75% at the time of harvest (OMAFRA, 1998), suggesting that the dry matter yields for energy use could be much lower than the yield data shown in Table 1.6. The data in the table highlights the wide range of yields, depending on the climate and the region.

There are a few studies which reported the dry matter yields of sorghum–Sudangrass. One of the studies (Beyaert and Roy, 2005) investigated the influence of nitrogen fertilization on the multi–cut forage sorghum–Sudangrass yields in Delhi, Ontario. The grass was harvested three times in a warm growth season, and the three-year average dry matter yields were 3.54 DM t/ha and 5.95 DM t/ha for without and with nitrogen fertilization, respectively. It was reported (Spitaleri et al., 2001) that total sorghum–Sudangrass yield of two cuts in year 2001 in Kentucky, U.S., was 9.14 DM t/ha. Nitrogen was applied to the small plots of sorghum–Sudangrass planted in Kentucky. In a study at the Texas A&M University Research and Extension Centre at Stephenville (Sanderson et al., 1991), 12 sorghum–Sudangrass varieties were evaluated for their dry matter yields and other performances. The average dry matter yield of the sorghum–Sudangrass varieties was reported 11.76 DM t/ha from the fertilized test plots.

Table 2.11 gives the estimates of sorghum–Sudangrass yields on different land capability classes. The baseline

Table 2.10 Sorghum–Sudangrass Yields (t/ha)

Region/Location	Yield	Source
Ontario	5.0 – 7.5	OMAFRA, 1998
Columbia Basin, Washington, U.S.	9.0 – 11.2	McGuire, 2003
Hawaii, U.S.	33.3 – 64.8	Valenzuela and Smith, 2002
U.S. average	23.3	USDA–NASS, 2004

Table 2.11 Sorghum–Sudangrass Yield (DM t/ha) Estimates for Different Land Capability Classes

	Class 2 (DM t/ha)	Class 3 – 4 (DM t/ha)	Class 5 (DM t/ha)
Baseline	16	7	4
Improved–1	19	8	5
Improved–2	23	10	6

yield for prime land is based on communication with local farmer Ron Van Damme, who has been growing sorghum–Sudangrass for seeds and forage on his productive land. Greater sensitivity to soil types, compared to switchgrass, yields data from the experimental sites. Genetic improvements in recent years are considered to estimate the yields on marginal and poor soils. Yield improvement of 20% is also assumed per generation in breeding of new genotypes.

2.4.4 Willow Yield

Willow SRC yields will vary according to the location of the site. Soil type, water availability, general husbandry and pest and weed control will also affect yield. In comparison with herbaceous grasses, the SRC, both willow and poplar, are less drought resistant (Möller–EPOBIO, *www.epobio.net*), likely with more pronounced effect on yields. Experimental yields of short–rotation willow as high as 24 to 30 odt/ha/yr have been measured in Sweden and North America (Adegbidi *et al.*, 2001; Christersson, 1986). Typical yields are more often in the range of 10 to 12 odt/ha/yr with second rotation yields of the best producing willow clones increasing by 20–90% depending on the site, variety and management practices (Labrecque and Teodorescu, 2003; Volk et al., 2001). Commercial yields have been considerably lower, and shown in Table 2.12 for different regions.

Difficulties with site preparation and tending, resulting in poor establishment, ineffective weed control and improper nutrient management, along with the use of unimproved clones, all contributed to these low yields (Keoleian and Volk, 2005). It was predicted (Larsson et al., 1998) that future commercial yields in Sweden should be above 7.5 odt/ha/yr if these issues are addressed according to current management recommendations. A similar increase in yield is anticipated for large–scale operations in North America with improved management and genetic material. However, a recent study (Mola–Yudego and Aronsson, 2008) developed a yield model based on the recorded production of willow SRC from over 2,000 commercial plantations in Sweden during the period 1989–2005. Their model predicts the yield of 4.5 odt/ha/yr, which is still much lower than the yields from the experimental plots, at third cutting cycle.

Experimental plots in Canada also produced impressive yields. Using a less intensive technique (20,000 plants/ha three years harvest cycle with irrigation), (Labreque and Teodorescu, 2003) obtained on sandy soil in Quebec an average annual yield of 15.7 odt/ha with *Salix viminalis* fully irrigated during the first three years after the establishment. The same clone without irrigation produced 9.6 odt/ha, which is still a good performance when considering that during the establishment years, trees must develop the root system, concentrating part of the biomass production in the above ground structures. LandSaga Biogeographical, the commercial supplier of willow species,

Table 2.12 Commercial–Scale Willow SRC Yields at Different Regions

Region	Yield (odt/ha/yr)	Source
Sweden	4	Larsson et al., 1998
UK	5 – 9	DEFRA, 2002
U.S.	6	Keoleian and Volk, 2005

Table 2.13 Willow Yield (DM t/ha) Estimates for Different Land Capability Classes

	Class 2 (DM t/ha)	Class 3 – 4 (DM t/ha)	Class 5 (DM t/ha)
Baseline	16	9	7
Improved–1	19	11	8
Improved–2	23	13	10

expects average annual yields of 10.7–13.8 odt/ha/yr (i.e. 7–9 t/acre/yr at 38% moisture content) in Ontario, if the appropriate clone and growing techniques are used.

The estimates of willow yields on different land classes and potential improvements are given in Table 2.13. Considerations for baseline yield on Class 3–4 soils include commercial productions in New York state, typical yields observed by previous studies (Labrecque and Teodorescu, 2003; Volk et al., 2001), and experiences with LandSaga Biogeographical. Yield estimate on prime agricultural land, Class 2 soils, is based on yield data of research plots, and lower sensitivity of willow to different marginal soils is incorporated for yield on Class 5 soils. Yield increase of 20% per generation in breeding of willow as experienced in Sweden is projected for future improvements.

2.4.5 Poplar Yield

Yield of hybrid poplar is associated with the density, i.e. number of cuttings planted, and crop cycle, i.e. how often the poplar is harvested. Earlier research focused on the effect of density and crop cycle on the yields. In a study performed in Oregon (DeBell et al., 1993), annual harvest yields of poplar planted at 111,000 and 308,000 cuttings/ha were compared to those of three wider spacing at 2,500, 10,000 and 40,000 cuttings/ha grown at a 5–year crop cycle. Mean yields of the densest spacing were 6.4–7.0 odt/ha/yr; for the wider spacing of the best hybrid poplar clone, the yield was 15.7–18.8 odt/ha/yr. The yield in the fifth year of this good clone at wider spacing exceeded 30 odt/ha, and the study found that hybrid poplar at these wider spacings would reach its mature yield in five years.

Table 2.14 Poplar Yield (DM t/ha) Estimates for Different Land Capability Classes

	Class 2 (DM t/ha)	Class 3 – 4 (DM t/ha)	Class 5 (DM t/ha)
Baseline	16	9	7
Improved–1	19	11	8
Improved–2	23	13	10

Table 2.15 Average Energy Crops Yield (DM t/ha) Estimates for Land Capability Classes

	Class 2 (DM t/ha)	Class 3 – 4 (DM t/ha)	Class 5 (DM t/ha)
Baseline – miscanthus	34	16	8
Baseline – switchgrass	13	10	8
Baseline – willow	16	9	7
Baseline – Average	21.0	11.7	7.7
Improved–1 – miscanthus	41	19	10
Improved–1 – switchgrass	16	12	10
Improved–1 – willow	19	11	8
Improved–1 – Average	25.3	14.0	9.3
Improved–2 – miscanthus	49	23	12
Improved–2 – switchgrass	19	14	12
Improved–2 – willow	23	13	10
Improved–2 – Average	30.3	16.7	11.3

In trials in England (Armstrong et al., 1999), two hybrid poplar clones were planted at 10,000 and 2,500 cuttings/ha at several different sites and on two different crop cycles, a 2–year crop cycles vs. a 4–year crop cycle (after the first year cutback to promote coppicing). The range of yield was 6.4–13.6 odt/ha/yr at denser spacing; at wider spacing the yield dropped to 4.3–9.7 odt/ha/yr. In all situations the 4–year crop cycle outperformed the two 2–year crop cycles in terms of yield, regardless of clone or crop density. The study concluded that one 4–year crop cycle not only produced better yields than the two 2–year crop cycles, but also could save money through a lower harvest frequency.

Yields of hybrid poplars in different regions of the world are reported in a wide range of 5–20 odt/ha/yr (Dickman, 2006). The experimental plots produced the yields as high as 35 odt/ha/yr in Washington, U.S. (Scarascia-Mugnozza et al., 1997) and 24 odt/ha/yr in UK (Rae et al., 2007). (Karacic et al., 2003) reported that hybrid poplar yield was comparable to willow yield at 7–9 odt/ha/yr at commercial sites in southern Sweden. Commercially grown UK plots generally yield an average maximum of 8–10 odt/ha/yr (TESC-BioSys, www.tsec–biosys.ac.uk).

The estimates of poplar yields on different land classes are shown in Table 2.14. The commercial yields of willow and poplar are comparable in southern Sweden, where the willow yield is similar to that in the northeastern U.S. Therefore, the yields of poplar and willow are assumed to be equal for this study.

2.5 Potential Biomass Supply from Energy Crops in Ontario

2.5.1 Estimation of Biomass Supply

Miscanthus, switcthgrass and willow SRC are identified as promising energy crops for Ontario due to their perennial nature, potential soil improvement, being the most extensively studied crops among energy crops, greater resistance to pests and diseases and the good yields. The yield estimates of these three energy crops are averaged for each yield scenarios, i.e. baseline, improved–1, and improved–2, assuming all three crops would have equal share of total land area dedicated for energy crops in Ontario. Table 2.15 gives the average yields of energy crops on different land classes for three yield scenarios.

Table 2.16 Potential Biomass Productions from Energy Crops in Ontario Regions

	Southern Ontario	Western Ontario	Central Ontario	Eastern Ontario	Northern Ontario	Province
Land Available (ha)						
Land by converting major field crops (Class 3–4)	159,902	112,332	40,883	35,218	5,572	353,907
Land by converting tame hay land (Class 4)	0	97,509	79,439	110,124	45,197	332,269
Land by converting tame or seeded pasture (Class 5)	0	34,267	23,349	23,902	15,562	97,079
Biomass productions (DM t/ha/yr)						
Baseline	1,865,523	2,710,856	1,582,762	1,878,902	711,608	8,749,659
Improved–1	2,238,628	3,257,596	1,902,427	2,257,870	856,005	10,512,535
Improved–2	2,665,033	3,885,705	2,269,983	2,693,251	1,022,511	12,536,495

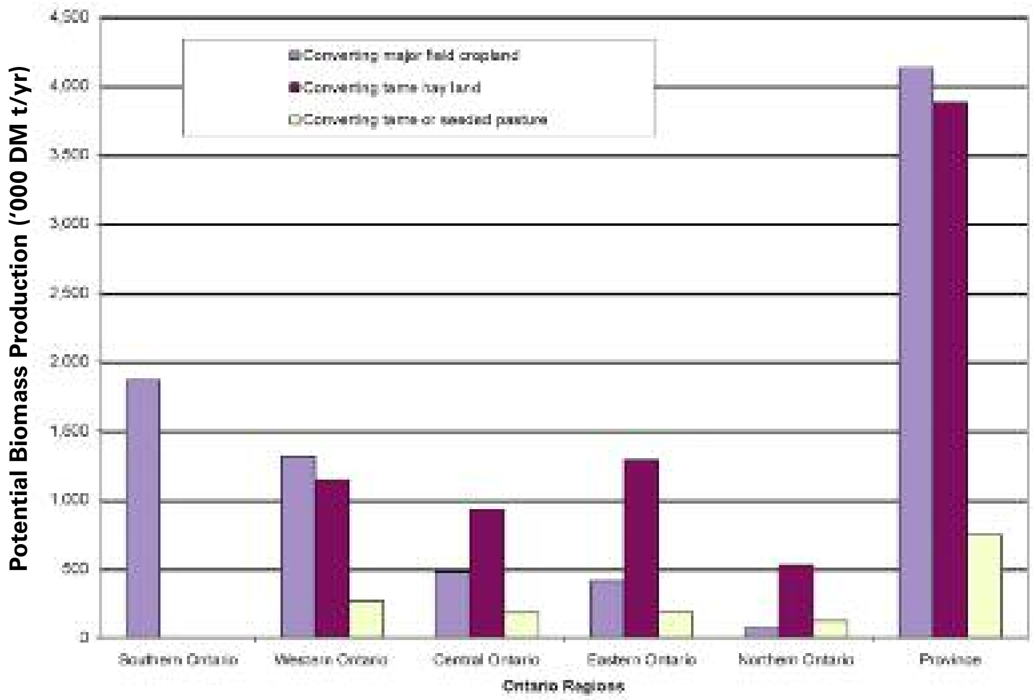


Figure 2.3 Potential Biomass (Baseline Yields) from Energy Crops in Ontario Regions

The potential biomass production from the energy crops is estimated using the land available given in Table 2.5. Lands converted from major field crop land are assumed some Class 3 and Class 4 soils, from tame hay land are Class 4 soils, and from tame or seeded pasture are Class 5 soils. Quality of lands potentially converted for energy crops could be better than land classes assumed in this study. However, these assumptions should provide a conservative estimate of potential biomass production. Applying the average yields of Class 3-4 soils and Class 5 soils shown in Table 2.15, potential biomass productions for each census region in Ontario are estimated and given in Table 2.16. Average yield data for Class 2 soils are not used for estimation in Table 2.16.

Total potential biomass production from the southern, western and central Ontario regions, which are closer to the Lambton and Nanticoke generating stations, are 6,159,141 DM t/yr for the baseline scenario. Figure 2.3 shows the potential biomass production from the different sources of agricultural lands in the Ontario census regions for baseline yield scenario. The European experiences (DTI, 2003) suggest that biomass productions from energy crops could fluctuate 10–15% due to normal changes in weather conditions. Reduction of yield by 15% would bring the total biomass production in the southern, western and central Ontario regions to 5,235,270 DM t/yr for the baseline scenario. Greater fluctuations can be expected with abnormal weather changes. For instance, the drought, with approximately 30% below normal rainfall in Illinois, in 2005 reduced the miscanthus yields by 31% in comparison with the yields in 2004 (Pyter et al., 2007).

2.5.2 Sensitivity Analysis of Potential Biomass Production

As mentioned in earlier sections, this study estimated that total biomass of 8.75 million DM t/yr could be potentially produced by growing energy crops on 783,000 ha of agricultural land in Ontario. Major assumptions for the estimate included yields of the energy crops, conversion rates of crops/hay land to energy crop land and mix of the energy crops. Sensitivity analysis is performed in this section to determine the effect of those assumptions on the total biomass production.

Yields of energy crops, like other agricultural crops, can vary +/- 30% due to more than normal changes in weather conditions. Therefore, high and low yield scenarios for the sensitivity analysis are +/- 30% of base case yield assumptions. Conversion rates of 15-20% were assumed for different Ontario regions for switching from regular crops to energy crops. Those conversion rates vary +/- 5% for high and low conversion rate scenarios. The conversion rates of 0-40% were applied to hay land to estimate the potential land available for energy crops. Those rates vary +/- 10% for the sensitivity analysis. Three energy crops (switchgrass, miscanthus and willow) should ideally occupy equal shares, i.e. one-third each, of land area to minimize the yield, pests/diseases and other risks. That was the base case assumption in estimating the potential biomass production. However, switchgrass will likely represent a greater share of energy crops due to its lower establishment cost. Possible mix of energy crops is 60% switchgrass, 20% miscanthus and 20% willow. This mix would give lower biomass production from the same area of total land and is considered as the low-mix scenario for the sensitivity analysis. A higher ratio of miscanthus in the mix would lead to greater production of biomass and, therefore, the mix of 20% switchgrass, 60% miscanthus and 20% willow is considered as the high mix scenario for the sensitivity analysis. The variations of parameters for the sensitivity analysis are summarized in Table 2.17.

Potential biomass production from energy crops are calculated for the possible combination of scenarios, including base cases, shown in Table 2.17. The results of the sensitivity analysis are given in Table 2.18. The worst scenario of low yield, low land conversion and low crop mix would reduce the potential biomass production to 4.09 millions tons/yr. However, the likelihood of that worst case is believed to be low. Based on discussion with farm operators in Ontario, the land conversion estimates of this study are considered reasonable; the base case of the land conversion is, therefore, the most likely scenario. The crop mix would depend on the level of financial tools that the governments and OPG would want to use. If there is zero or minimal establishment grants, or other similar financial tools, the most likely scenario for the crop mix is the low-mix scenario, i.e. 60% switchgrass, 20% miscanthus and 20% willow. With the base

Table 2.17 Variations of Parameters for Sensitivity Analysis of Biomass Production

Parameter	Scenario	Description
Yield	Low yield	- 30% to base case
	High yield	+ 30% to base case
Land conversion	Low conversion	- 5% to base case (crop land) - 10% to base case (hay land) Note: This scenario would result in 551,000 ha of total land available for energy crops.
	High conversion	+ 5% to base case (crop land) + 10% to base case (hay land) Note: This scenario would result in 1,031,000 ha of total land available for energy crops.
Energy crops mix	Low mix	60% switchgrass, 20% miscanthus, 20% willow
	High mix	20% switchgrass, 60% miscanthus, 20% willow

Table 2.18 Sensitivity Analysis of Total Biomass Production from Energy Crops

Yield	Land Conversion	Crops Mix	Biomass Production (M t/yr)
L	L	L	4.09
L	L	B	4.3
L	L	H	4.9
L	*B*	*L*	*5.81*
L	H	L	7.56
B	L	L	5.84
H	L	L	7.59
B	*B*	*L*	*8.31*
B	H	L	10.8
H	H	H	16.82

L – Low, H – High, B – Base case

case land conversion and low crop mix scenarios, the potential biomass production could range from 5.81 million tons to 8.31 million tons per year for low and base case yields, as highlighted with blue italic fonts in Table 2.18.

2.5.3 Effects on Hay Production and Market

The majority of potential land available for energy crops estimated in this study would be converted from land currently used for hay production. As shown in Table 2.5, forage land of 429,000 ha, which is about 32% total hay land in Ontario, could be used for growing crops. This includes 332,000 ha of hay crop land and 97,000 ha of seeded pasture. Ontario has about 1,037,000 ha of land currently used to grow hay crops such as alfalfa and timothy (OMAFRA statistics). It is, therefore, necessary to investigate the effect of energy crop development on the hay market and production in Ontario.

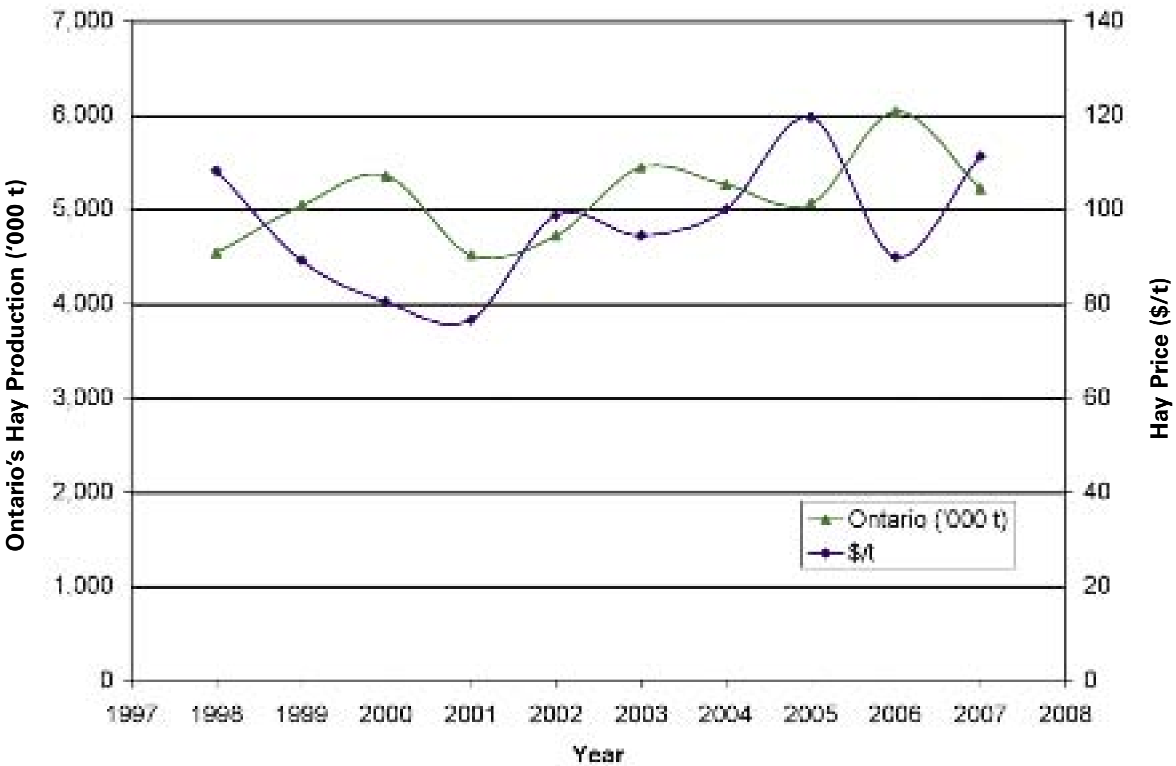
Table 2.19 gives the tame hay production in Ontario and Canada with export quantity. Ontario produces more than 5 million tons of hay annually, whereas total hay production in Canada is about 25 million tons per year. If hay production is reduced by 32% because

Table 2.19 Ontario and Canada's Hay Production and Export

Year	Ontario ('000 t)	Canada ('000 t)	Export ('000 t)	Export (%)
1998	4,536	21,825	526	2.4
1999	5,035	25,033	590	2.4
2000	5,352	23,922	678	2.8
2001	4,513	20,374	811	4
2002	4,717	18,141	533	2.9
2003	5,443	22,336	450	2
2004	5,262	25,615	679	2.7
2005	5,058	26,629	616	2.3
2006	6,033	27,617	677	2.5
2007	5,216	30,245	746	2.5
Average	5,117	24,174	631	2.6
Standard deviation	460	3,611	109	0.5
Standard deviation as % of Average	9	14.9	17.3	20.4

Sources: OMAFRA and Statistics Canada

Figure 2.4 Hay Price and Ontario's Hay Production (source: OMAFRA)

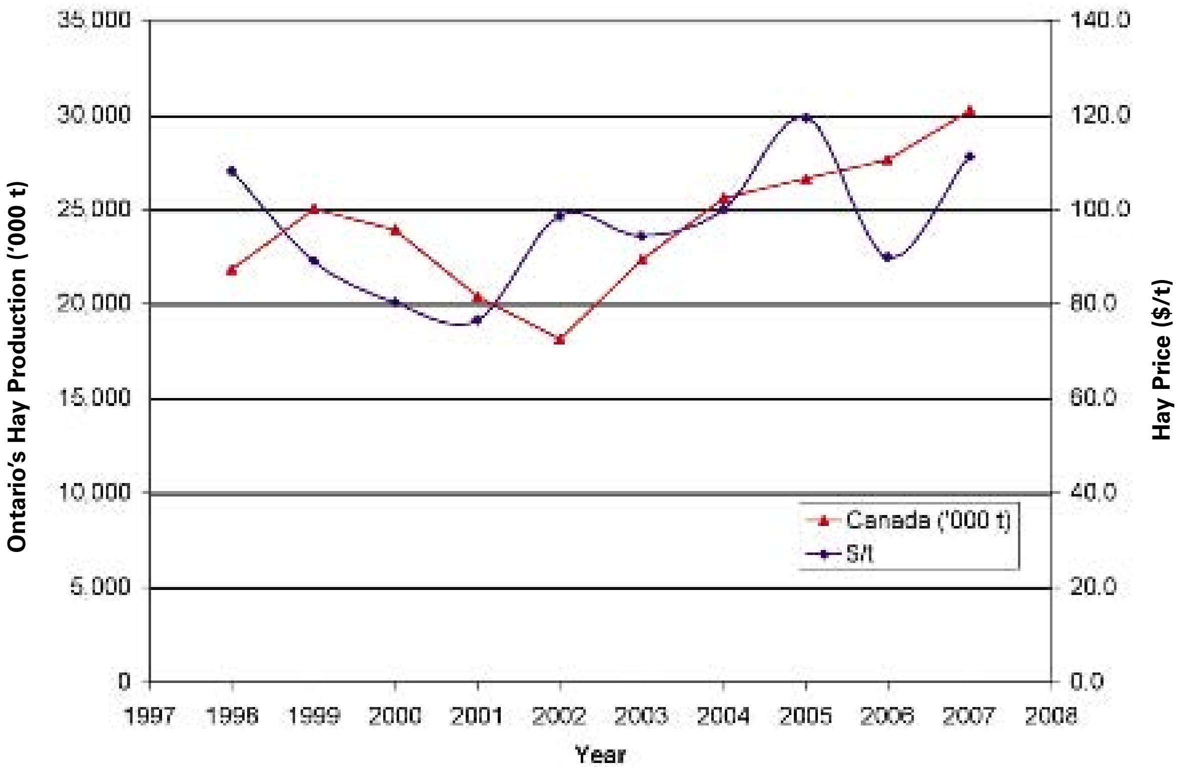


of switching to energy crops, Ontario will produce about 1.6 million tons less of hay annually. That amount would represent about 3.6 times the standard deviation for Ontario but would account for half of the standard deviation for Canada, as seen in Table 2.19. Therefore, the effect of energy crop development on Canada's hay production can be considered minimal.

Potential impact on hay price due to energy crop development is also examined in this study. Figure 2.4 shows the hay price and production in Ontario from 1998 to 2007. The correlation between the hay price and Ontario's hay production was –0.087, which is statistically very weak. Figure 2.5 illustrates the hay price and Canada's hay production for the same period. The correlation between the hay price and Canada's hay production is 0.375, which is also a statistically weak number. Therefore, it can be concluded that reduction in total hay production by 1.6 million tons per year should not significantly impact the hay market in Ontario and Canada. Reasons for the weak correlation between the hay price and Canada's total hay production could be that the U.S. produces up to 130 million tons of hay per year (USDA NASS, 2007). Lower hay yield in Canada in a particular year does not necessarily mean lower hay production in North America in the same year.

Alfalfa and timothy are the most widely grown tame hay crops in Ontario. Tame hay can be categorized into two groups, legume and grass. Alfalfa is a legume and provides protein to the animals. Alfalfa is grown on about 65% of tame hay land in Ontario. Timothy is a grass, which is the main source of fibres with some protein for animal feed. Alfalfa and timothy mix are the most popular hay for cattle and horses due to superior palatability. Other hay products such as sorghum, orchard grass and switchgrass are mixed in smaller portions for animal feeds. It is unlikely that switchgrass, which has a higher yield,

Figure 2.5 Hay Price and Canada's Hay Production (source: Statistics Canada)



could replace timothy as forage due to the difference in relative feed value (RFV). Timothy has a RFV of 103 whereas switchgrass's RFV is 88 (Angima and Kallenbach, 2006). More importantly, palatability of switchgrass is lower than that of timothy. Hays with higher RFV usually contain a higher level of nitrogen, minerals and protein, which are not the attributes of the grasses with higher fuel value.

As discussed above, it seems unlikely that high yielding grasses, which are good biofuels, would replace alfalfa and timothy. Ontario will experience about a 30% reduction in hay production if the energy crops are grown on some hay land. Currently, Ontario farmers are exporting about 10% of hay produced in the province. Therefore, the province may need to import about one million tons of hay annually to maintain its cattle and horse businesses at the current level. However, this is not likely, since the cattle industry in Ontario is declining. If the biomass from energy crops is attractively priced, Ontario farmers are interested in diversifying their products. Note that switchgrass can give about 10 DM t/ha whereas timothy yields about 5–6 DM t/ha.

Chapter 3
Energy Crops Supply Chain and Assessment of Potential Suppliers

3.1 Analysis of Major Supply Chain Components

The energy crop study identified production, storage, processing and transportation as major supply chain components to meet OPG's biomass demand. The market currently does not exist in Ontario to supply the biomass required by OPG due to the fact that there are insignificant plantations of energy crops in the province. The substantial volume of biomass required calls for well-planned efforts in developing components of the biomass supply chain. Although the scales of biomass energy are smaller, the experiences in Europe in promoting energy crops can be applied in Ontario to some extent. The wood pellet industry, which produced about 1.5 million tons of pellets in 2007 in Canada (Swaan, 2008), also offers valuable learning in managing the supply chain, especially in locating the storage and processing facilities to minimize the overall cost.

3.1.1 Production of Biomass

The supply chain of the biomass from energy crops starts with growing the crops. As mentioned earlier, to supply the biomass volume required by OPG, over 500,000 ha of dedicated land is required. At present, energy crop plantations provide a total commercial area of less than 1,000 ha of combined miscanthus, switchgrass and willow in Ontario. This is insignificant, in comparison with what is needed. A great deal of concerted effort is required to ensure the rapid adoption of energy crops by the farming industry in order to produce the biomass that would meet OPG demand.

Adoption of the energy crops by farm operators may pose a significant challenge since it is not a process completely reliant on economic cost and benefits. As with other innovations, there will be early adopters and wait-and-see latecomers. Rogers, who is an innovation specialist, commented in 1995: "The innovation decision is not passive; it is basically an information-seeking and information-processing activity in which the individual is motivated to reduce uncertainty about the advantages and disadvantages of an innovation." As an infant industry in North America, the energy crop business presents uncertainty in terms of yield, gross margins, pests and diseases etc. A study (Villamil, 2007) performed by the University of Illinois on potential adoption of miscanthus in Illinois is worth mentioning. A survey was sent out to farmers in the state of Illinois and about 21% of the recipients responded.

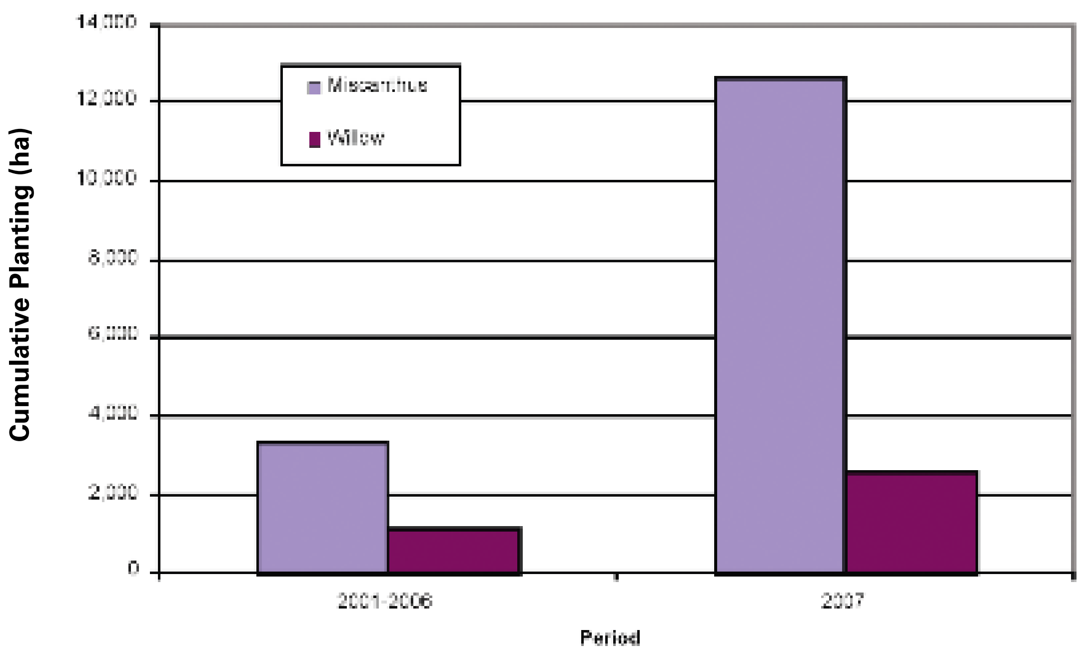


Figure 3.1 Cumulative Planting Areas of Selected Energy Crops in UK

About 30% of respondents were identified as potential miscanthus adopters, and the average farm size was 365 ha. The farmers stated that they would allocate about 12 ha of their land to miscanthus in the first year. If these trial plots perform well, miscanthus would be planted in up to 50 ha over the next five years.

Production of energy crops may therefore be in three phases: phase-1 production is from the trial plots of early adopters; phase-2 production is from the full participation of early adopters and the trial sites of the latecomers; and final phase production is from the full participation of all adopters. That phenomena was observed in the progress of energy crop development in the UK. In addition to comprehensive information on energy crops, such as planting guides and yield maps, the Department of Environment, Food and Rural Affairs (DEFRA) in the UK has been providing grants for energy crops with higher establishment costs such as miscanthus and willow SRC. The DEFRA grants are £920 and £1000 per ha for miscanthus and willow SRC, respectively, to establish the crops. BiCAL, a miscanthus developer in the UK, currently has a contract to supply up to 300,000 tons of biomass per annum to Drax Power Limited[1], which has been co-firing biomass with coal in its power station. With that guaranteed market, the growth of energy crops in the UK during the periods of 2001-6 and 2007[2] is shown in Figure 3.1.

Even with a number of financial, information and regulatory tools in place, development of energy crops might undergo initial slow adoption period as seen in Figure 3.1. Assessment of BiCAL on what caused the initial slow adoption of energy crops (personal communication with Dr. Carver from BiCAL) was lack of clear government energy policy and firm biomass pricing. The length of development to full production level would depend not only on the attractive pricing of biomass in the supply contracts, which could be incorporated with establishment grants, but also existence of demonstration sites on commercial scale. Providing necessary information on energy crops to farmers through efficient communication channels is also of paramount importance. This study does not consider the planting and harvesting machines required for the identified energy crops as major barriers in supply chain development, since most machines needed would be standard or well developed, at least in some part of the world. Acquisition of those machines, for which the lead time is usually less than one year (personal communication with Pyramid Farms and LandSaga Biogeographical), is not likely a part of the critical path in development of the energy crops supply chain.

3.1.2 Storage and Processing

Perennial energy crops are usually harvested in late fall or early spring to allow the new shoots to emerge in the spring and grow rapidly in the warm season. This limited harvest frequency for biomass and the year-round fuel requirement at OPG generating stations call for prudent management of biomass storage and processing. Biomass naturally deteriorates and loses dry matter during storage through a number of mechanisms, and this effect is more pronounced with higher moisture content. Switchgrass, which is a relatively dry biomass, can lose 13% of dry matter within six months of storage (Sanderson et al., 2007). Other biomass with higher moisture content could lose more than 40% of dry matter during storage (Northwest Research & Outreach Centre, 2007). The higher moisture content of biomass would potentially also lead to the formation of moulds, the spores of which can be dangerous if inhaled. The energy crops should, therefore, be dried after harvest to a certain moisture level for storage to accommodate the year-round usage from the energy content and public health perspectives.

Bulk nature of biomass and presumed limited storage area at OPG generating stations lead to processing, at least drying of biomass, and storage of biomass at a number of centralized facilities located near the farms. Experience with the wood pellet industry, which produced about 1.5 million tons of wood pellets in 2007 (Swaan, 2008) also suggests that locating the pellet mills closer to the source of feedstock reduces the overall transportation cost. This is because the bulk density of wood pellets is about 650 kg/m3, which is 4-10 times denser than raw materials. Therefore, the biomass should not only be dried for better storage but also be densified, into the forms of briquette or pellets, to minimize the overall cost of the biomass at the gates of OPG generating stations. Details of the economics of the different forms of biomass are discussed in a separate section.

[1] http://www.farmersguardian.com/story.asp?sectioncode=19&storycode=20678
[2] http://www.tsec-biosys.ac.uk/index.php

Development of the central storage and processing facilities is essential to the creation of the biomass supply chain. This development could present a chicken-and-egg syndrome; investors will not build the central storage and processing facilities without a guaranteed supply of feedstock, but a few facilities should be in place before some commercial production of biomass from the energy crops during the initial adoption period. The experience with the wood pellet industry in British Columbia suggests that the optimum size of a pellet mill is about 75,000 t/yr to minimize the cost of pellet at the BC ports (Karwandy, 2007). The capital requirement of 75,000 t/yr wood pellet mill could be around $10 million (Urbanowski, 2005; Mani et al., 2006). Biomass pellet mills, however, can produce higher tonnage per year for the same milling power, and 150,000 t/yr of biomass pellets mill would cost about $10 million (personal communication with Steve Flick, Show Me Energy Cooperative, Missouri). It will require 35 mills across the province to supply 5 million tons of biomass per annum. Demonstration central storage and processing facilities or capital incentives might be necessary for initiation of the investments in those facilities. It takes about 13 months from the start of construction, i.e. after the permit obtained to build, to be ready for production stage.

The central storage and processing facilities could play the central role in the biomass supply chain. The mills could source biomass from a mix of about 60-80% energy crops and the remainder from a combination of various agricultural residues and native grasses. Furthermore, the advantage of a pelletized mix of biomass fuel compared to coal is that OPG would have the flexibility to specify and change fuel quality through adjustment of the pellet blend. Use of a diverse mix in the pellet, which could include municipal sources of biomass in addition to the above mentioned agricultural sources, would help to diversify participation across large segments of Ontario's population. Therefore, economic benefits would not be limited to only rural and agricultural communities.

3.1.3 Transportation

The fuel value of biomass is 18-19.5 MJ/kg, whereas that of coal could be as high as 30 MJ/kg. This means the volume of solid fuel to be handled at end could be more than that associated with coal for the same electricity output. However, the transportation segment of the biomass supply chain should not be an issue at the macro level in Ontario, where the agricultural sector produces more than 50 million tons of grains and other products every year (compiled from the statistics of the field crops OMAFRA web site). These agricultural products are transported to other parts of Canada and the U.S. by truck, rail and marine vessels. Therefore, handling of biomass from energy crops would unlikely impact the capacity of the agricultural transportation system, especially if the biomass is to be produced from the converted land. Additionally, agricultural yields can easily vary +/- 10 - 15% due to weather influence; the biomass volume required by OPG from energy crops is well within the range of yield fluctuations of the total agricultural products in Ontario.

Transportation of biomass from energy crops to the OPG station, however, could be an issue from the perspective of local traffic congestion and existing rail infrastructure. If the biomass is transported in bales, about 225 trucks per day year round will be unloaded at the OPG station to generate one TWh of electricity/yr (which requires about 1.25 million tons of biomass). This number would be reduced to 90 trucks per day, if the biomass is pelletized at the central storage and processing facilities. Existing rail infrastructure at OPG generating stations are not designed for freights coming from eastern, central, western and southern Ontario regions. Since OPG generating stations are currently receiving the coal through marine shipping, construction of a rail handling system would be required for the rail transport of biomass. If biomass from energy crops can be transported by marine vessels to OPG generating stations, the existing coal handling system could be continued in service with minimal facility conversion. Furthermore, marine shipping offers the lowest cost of transportation in most cases, and is the most environmentally sound mode in comparison with truck or rail transportation.

It is worth mentioning how biomass is and will be transported to the Drax power plants in the UK[3], since the current and future biomass requirements at the Drax are comparable to that of the Lambton and Nanticoke generating stations. Drax is co-firing biomass at <5% rate at its 4,000 MW power plant. Energy crops are grown within an 80 km. radius of the power plant, and

[3]http://www.draxgroup.plc.uk/

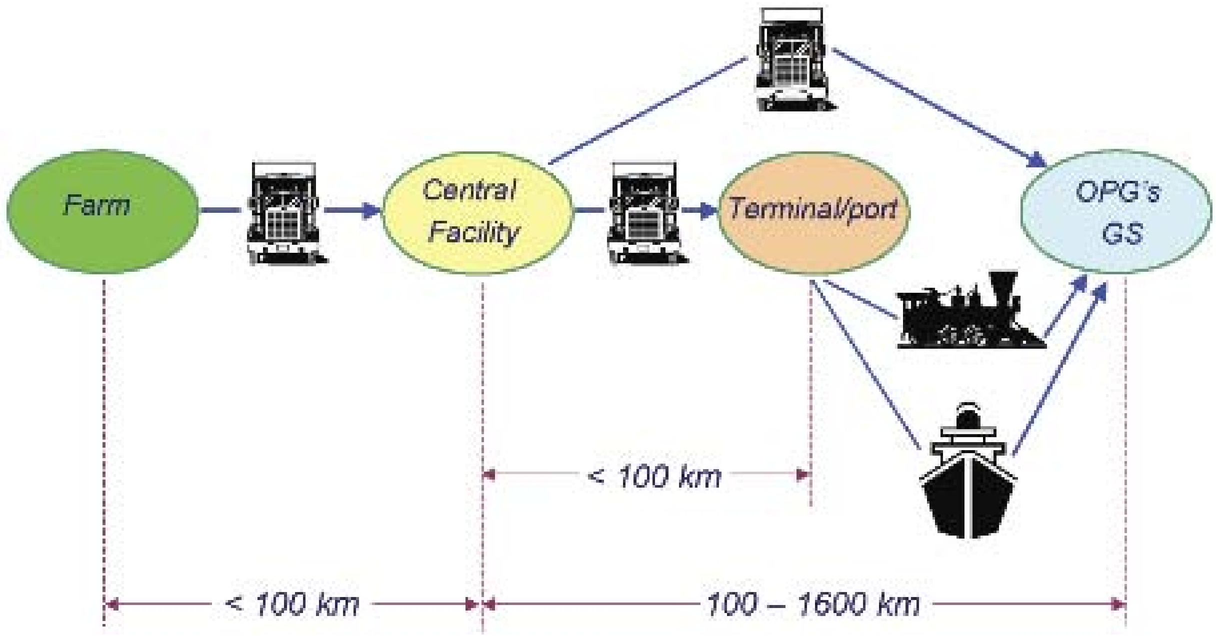


Figure 3.2 Modes of Transportation of Biomass from Energy Crops

Estimated biomass production from energy crops: 8.75 Mt/yr

Region	% Biomass Production	Distance (km)
Southern	21.3	< 300
Western	31.0	< 300
Central	18.1	< 600
Eastern	21.5	< 800
Northern	8.1	< 1600

Figure 3.3 Potential Biomass from Energy Crops in Ontario Regions and Distances

the biomass system can handle 5,000 tons of biomass per week or 20 trucks per day. The biomass from energy crops is transported to Drax by trucks. Drax is planning to ramp up the co-firing rate to >10% in 2010, and rail will be the mode of transporting biomass. Alstom Power Limited is building a rail-handling system to handle 1.5 million tons of biomass per year at the Drax 4,000 MW power plant. Drax is going to build three new biomass-fired power plants of 300 MW each in 2010 and the biomass requirements for those new plants are estimated at over 2.5 million tons per year. Marine shipping will be the mode of biomass transportation for the new power plants.

Experience with Canada's wood pellet industry suggests that locating pellet mills close to the biomass source reduces the overall transportation cost due to the bulk nature of raw biomass. Additionally, widely spread farmlands across the province call for the transportation model shown in Figure 3.2. The central storage and processing facilities can be located close to the farms, < 100 km, in order to reduce the transportation cost of bulky raw biomass. Truck transport of biomass from the farms to the central facility is expected. The processed biomass, for example pellets, can be transported from the central facility to the OPG power station by trucks if the distance is less than

Figure 3.4 Rail Transportation Infrastructures in Ontario Regions

200 km. Otherwise, the processed biomass can be trucked to the rail terminal or marine port for rail transport or marine shipping to the OPG station. Most of the biomass from energy crops is located within 600 km radius of the Lambton and Nanticoke generating stations as shown in Figure 3.3.

Existing rail and marine transportation infrastructures are examined in this study. Figure 3.4 and Figure 3.5 give the rail lines and marine ports, respectively, in Ontario. The thick green lines in the map divide the Ontario agricultural census regions. The rail lines are in red in Figure 3.4, and the potential cargo ports are shown in blue squares with a small red circle inside in Figure 3.5. It can be seen from Figure 3.4 and Figure 3.5 that it is possible in most cases to locate central storage and processing facilities within 100 km of farms and within 100 km of rail terminals or marine ports. Vessel shipping of biomass from western, central and eastern Ontario regions could be an attractive option, since the marine ports are more evenly located across the regions compared with rail terminals.

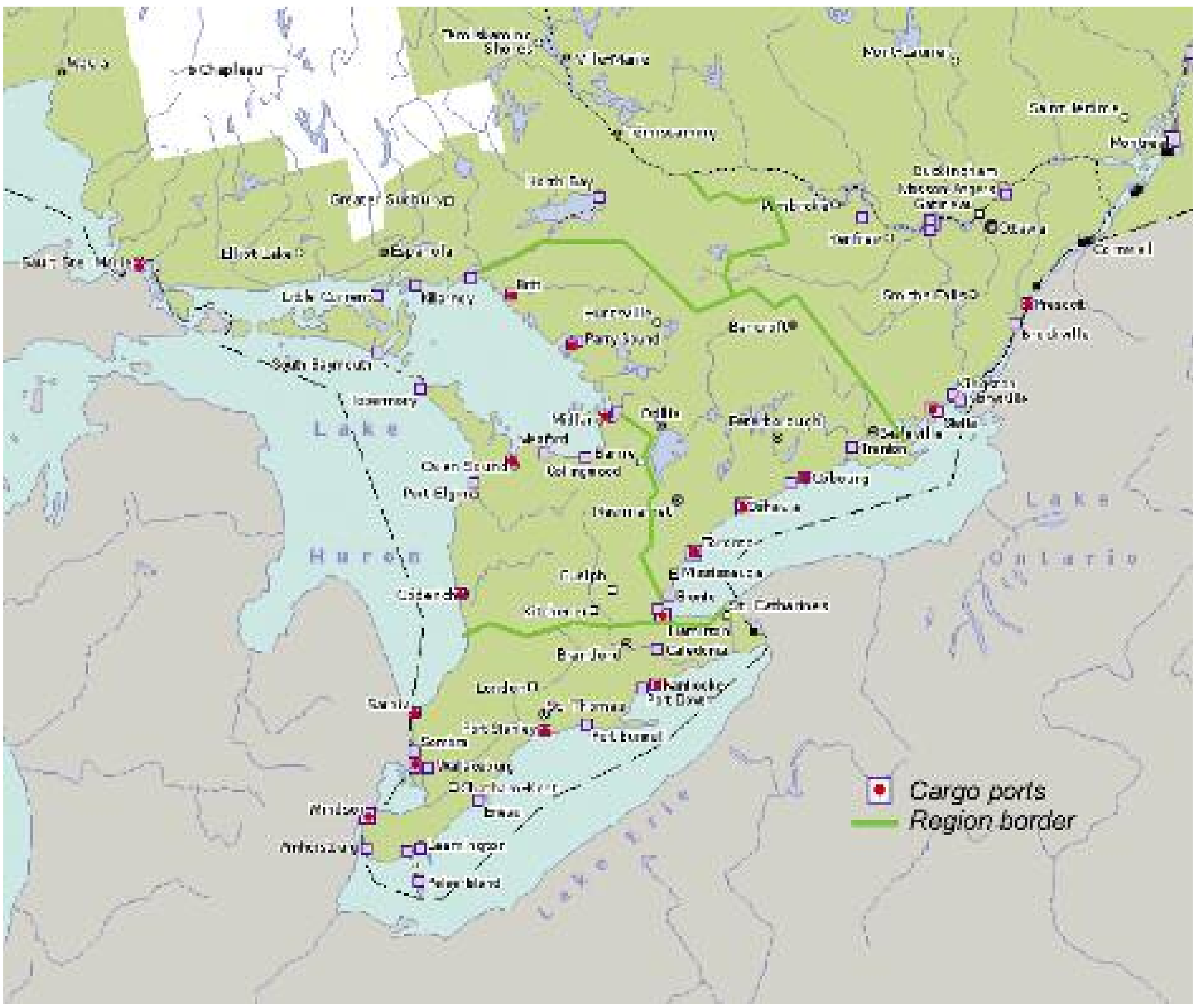


Figure 3.5 Marine Transportation Infrastructures in Ontario Regions

3.2 Timelines to Develop Biomass Supply Chain

Accurate estimation of time required to develop the energy crops supply chain to meet OPG's biomass demand is a formidable task. The adoption of energy crops by farm operators and investment in the central storage and central processing facilities could depend on a number of psychological factors in addition to the economic cost and benefits. The major concern raised by industry experts is the sustainability of the biomass energy program. Policy change could jeopardize the energy crop programs, since the biomass currently costs more than coal. This could be the major consideration for farmers in adopting energy crops to a substantial commercial scale and for investors to build the central storage and processing facilities. With several tools in place, such as comprehensive information (planting guides, yield maps) dissemination, guaranteed demands and establishment grants, the UK has approximately 20,000 ha of land dedicated to energy crops accumulated over the past 8-10 years and more rapidly in recent years. Note that the UK has total agricultural land of about 4.75 million ha (DEFRA statistics), whereas Ontario has about 5.39 million ha (OMAFRA statistics).

Figure 3.6 illustrates the entities and activities on a relative time scale in developing the biomass supply chain. Comprehensive information dissemination, development of contract with attractive pricing of biomass, and demonstration of commercial scale plantations might be necessary first steps to initiate the adoption of energy crops by the farm operators. Firm government energy policy and assurance of long-term biomass demand by OPG generating stations seem to be important factors influencing the speedy adoption of energy crops. Continued involvement of government and research and development organizations through all the production phases may help the smooth creation of the supply chain and application of new agronomic and genetic developments. Demonstration of central storage and processing facilities may be required to initiate private sector investment in those facilities. As mentioned earlier, prudent management and concerted efforts will be important in the development of the biomass energy system of unprecedented commercial scale being considered.

Time required to develop the energy crop supply chain may vary from crop to crop. Existence of commercial scale sites and capital requirement might play important roles in adoption of

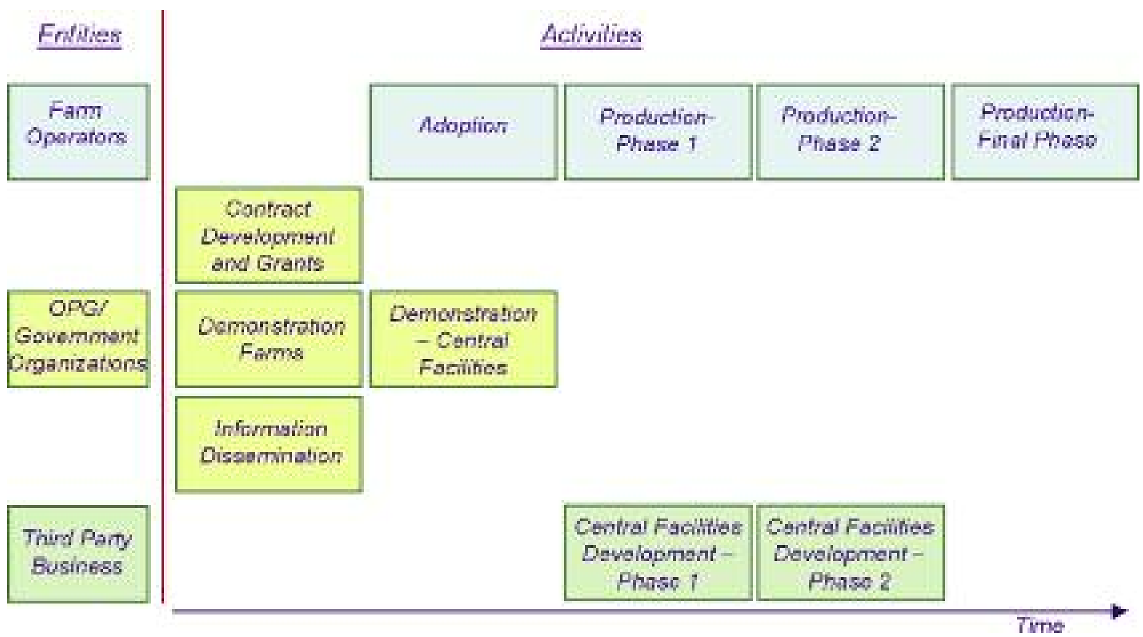


Figure 3.6 Entities and Activities in Development of Biomass Supply Chain

the energy crops. Switchgrass may offer the most rapid development in Ontario, since the over 130 ha of commercial plantation in place in Clinton, Ontario can act as a demonstration farm. Furthermore, switchgrass is relatively easier to propagate, and can be grown using existing farming machines used for hay production. Farm operators could see switchgrass as the least risk energy crop, since switchgrass can also be used as forage, and has minimum establishment cost. Therefore, using switchgrass as a launching crop to develop the energy crops scheme would likely be a beneficial strategy for Ontario.

The timeline to develop switchgrass energy crop could be 6–7 years, which includes about a six-month period of contract development and three phases of adoption/production. This timeline is to reach total switchgrass plantation of a third of over 500,000 ha of land dedicated to the energy crops.

As mentioned earlier, the mixed energy crops scheme is what should be developed to minimize the risk from the fuel requirement perspective. Development of other two crops, miscanthus and willow, is therefore also important, and expected to take longer in comparison with switchgrass. The major barriers in adoption of miscanthus and willow could be high establishment costs and delayed returns. Establishment grants for those energy crops may be required to initiate the adoption. Lack of demonstration farms at large commercial scales, comparable to that of switchgrass, in Ontario could also slow the adoption of those crops. The Pyramid Farms of Ontario is planning to establish more miscanthus, expected to reach ~ 120 ha in 2009-10 (personal communication with Dean Tiessen, Pyramid Farms). More cases of wait-and-see approach can be expected in the development of miscanthus and willow in Ontario. The timelines to reach the fully developed levels meeting OPG's demand could be 8–9 and 13–14 years for miscanthus and willow, respectively, if they follow the same development paths of European countries.

The timelines can, however, be reduced significantly, if the coordinated efforts are taken by OPG, different levels of governments, and farm organizations like Ontario Federation of Agriculture (OFA). As Dr. Carver from BiCAL, UK mentioned, farm operators who are well-convinced and informed on the concrete government energy policy would be a must to accelerate adoption of energy crops. The OFA personnel, through personal communication, indicated that Ontario farmers are interested in diversifying their farm products, given current price fluctuations for field crops and declining income from the cattle industry. Attractive pricing of biomass would play an important role in development of the energy crop industry in Ontario with substantial initial production. Establishment grants could also be incorporated, although not necessarily, into pricing of the biomass. Assessment of establishment grants during this study revealed the diverse views by farm operators. The guaranteed market, i.e. long-term contracts (5-10 years), would protect the interest of both energy crop growers and OPG. Inclusion of annual payments in the long-term contracts was also suggested by personnel interviewed, since energy crops such as willow have a long delayed return. Formation of an energy crop growers group would be instrumental in effective dissemination on information on energy crops and public relations activities on issues such as food verses fuel. OFA personnel expressed interest in formation of the energy growers group to facilitate the speedy adoption of energy crops and better coordination among farmers.

Like the adoption of energy crops, building central storage and processing facilities could represent as a critical path in development of the biomass supply chain. The capital cost of these central facilities could be 350 million dollars for 5 million tons of biomass supply annually. An important factor in development of this segment could be the assurance of long-term biomass demand by OPG generating stations. Financial tools, such as incentives for the capital investment, or business models such as OPG co-ownership of facilities, would help minimize risk perceived by the business sector in investing in the central facilities. This could help to shorten the timeline. The business model of farm cooperatives owning central storage and processing facilities is possible, if a guaranteed market and attractive pricing exist.

3.3 Biomass Supply Models

Although considerable research effort has been devoted to the agronomic and genetic aspects of biomass production, organizational development of the industry has received far less attention by researchers. However, in the biomass sector the organizational concerns are important because the energy crop supply chain is far less advanced than that of other feedstocks such as corn for ethanol. Hence, it is a very important component of the energy crop industry; yet, it is far from clear how the energy crop feedstock market will develop and which would be the most efficient biomass supply model. The end users of biomass for energy are currently employing different biomass supply models ranging from contracting with individual farmers and/or farm cooperatives to third-party fuel merchants. Those biomass supply models are examined to identify the strengths and weaknesses of each model. The study also investigated a number of contract scenarios for the procurement of biomass from energy crops.

3.3.1 Individual Farmer Supplier Model

In this supply model, the end users such as OPG utilizes a production contract signed with individual farmers. This model is currently used by Suncor Energy in acquiring corn from the farmers in southwestern Ontario to produce ethanol. Such a contract can include different sections such as supply and storage, price and payment, quality of biomass, change in terms, and termination etc. Contents of a typical supply contract with individual farmers are mentioned in Table 3.1 (adopted from Altman et al., 2008).

The strengths of this supply model include the accommodation of pricing and payment preference by individual farmers. However, this model is not likely suitable for OPG's need, since dealing with individual farmers to supply a total of five million tons annually would lead to the administrative burden of handling a large number of contracts. Quality control of biomass fuel would also require higher effort for this supply model. Furthermore, the overall cost of biomass could be higher, if the production, harvesting, processing and transportation of biomass are managed individually.

3.3.2 Farm Cooperative Model

In this supply model, a number of producers of energy crops collaborate on the supply of biomass. This can be an efficient model that allows specialized equipment such as a baler or delivery lorry to be shared between members of the co-operative, and collaboration on marketing and administration. It can also help to ensure that there is always biomass available to meet demand even if a particular member may be unable to supply at a particular time. The overall cost of biomass from energy crops would be lower due to the reduced costs by sharing equipment and the purchase of planting stock in bulk.

The major strength of the farm cooperative model is fewer supply contracts to handle and more detailed contracts could be developed. The supply contract between a farm cooperative and OPG could be comprehensive and include:

- Determining the annual quantity of biomass fuel to be delivered
- Establishing quality specifications
- Establishing a mechanism for determining the price for biomass fuel
- Establishing a way for the utility to subsidize the establishment of biomass plantations
- Establishing a method of financing plantations, and
- Providing an escape clause for both the utility and grower covering events or conditions beyond their control.

An energy crop cooperative could provide a consistent and uniform supply of biomass in comparison with an individual supplier model. Comprehensive quality specifications could be developed as shown in Table 3.2 as a sample (adapted from Stricker et al., 2000). Another advantage of the farm cooperative model is that the cooperatives likely have financial capability to own the biomass pellet mills. The Show Me Energy Cooperative (www.goshowmeenergy.com) in Centerview, Missouri, owns a biomass pellet mill with a capacity of 150,000 t/yr. At the cooperative, about 420 members supply different types of biomass, ranging from the agricultural residues to energy crops, to the plant. The plant was started in May 2007 and shipped its first pellets in July 2008. Customers of the Show Me Energy cooperative include homeowners, small businesses, a university and an electric utility for space heating and co-firing. This business model, with pellet plants owned by the farm cooperatives, would ensure greater involvement of farm operators in the supply chain and likely be the preferred model for OPG's need. The weakness of this supply model is the potential collapse of farm cooperatives, leaving supply contracts not honored.

Another interesting business model identified by a few farm cooperative representatives at OPG Biomass Information

Table 3.1 Contents of a Typical Individual Supply Contract

Sections	Key Points
Supply, Storage and Coordination	1. Defines the minimum annual tons 2. Grants buyer option to purchase biomass for life of the contract (5-10 years) 3. Farmer must supply storage for up to 6 months after harvest and meet standards for biomass quality, storage and access (for delivery) 4. Farmer must estimate crop hectares by March 15, provide a forecast of biomass production by June 15, and provide notice of all changes to hectares farmed, crop rotation, or any other pertinent information for biomass volume or yields 5. Buyer must exercise option to purchase biomass by April 15 and July 15 6. Farmer is responsible for selecting and working with custom operators 7. Biomass stocks must be accessible for loading and transport equipment 12 months a year, 24 hours per day, 7 days per week 8. Performance may be excused because of unforeseeable events, such as natural disasters 9. The risk of crop loss remains with the buyer until delivery
Pricing and Payment	1. Pricing option include three choices: a. Fixed price, e.g. 5 years at $90/ton b. Variable price based on crude oil prices c. A combination of (a.) and (b.) 2. Payments are made in three instalments a. One-third order value will be paid within 30 days of the buyer's receipt of the producer's farm service agency report verifying total hectares b. A second payment will occur after storage at an appropriate site and a buyer inspector has verified the estimated tonnage c. Final payment will be made on delivery and certified measurement of the tons delivered
Quality	1. Acceptable biomass quality to be harvested golden without rot or weathering, maximum of 18% moisture content, segregated as the type of energy crop as agreed, and free of any preventable toxins as identified by the buyer in advance of harvest
Change in Terms	1. Buyer has the right to develop and modify standards as it requires as long as changes apply to all producers 2. Producers can be compensated for this change in standards
Assignment, Termination, Transfer, and Extension	1. Buyer has the right to transfer the claims for the biomass and biomass procurement services to another processor 2. Procedure has the right to terminate the agreement if the commencement of construction of a facility has not occurred within 4 years of the date of this option 3. Buyer has the right to offer to extend the agreement 2-4 years, if the producer does not reject the extension within 60 days the extension will be deemed accepted 4. If the producer sells his land or does not renew leased land, the producer shall make their best effort to transfer the obligations under this agreement 5. Neither the producer not successor operators can sell biomass to competition firms without meeting the obligation of this agreement first

Workshop in January, 2009 was the development of biomass pellet mills combined with small-scale biomass power plants. This arrangement would allow for the utilization of waste heat from the power generation in drying the biomass to maximize the overall efficiency. The farm cooperatives would consider this model as a less risky investment, if the power generated is allowed to be exported to the grid.

3.3.3 Crop Developer Model

In this supply model, the energy crop developer produces and/or buys biomass fuel for sale to the customers such as OPG. This model is employed by Drax, which is the largest coal-fired power producer in the UK and has a contract with the miscanthus developer BiCAL to acquire up to 300,000 tons per annum. BiCAL, in turn, has supply contracts with a large number of miscanthus growers, and offers comprehensive establishment and other services associated with crop production to the farmers. BiCAL has vast capabilities in miscanthus agronomy, technical production, supply chain management and comprehensive advisory services. The prominent strength of this supply model is that the latest crop genetic developments are introduced in a timely manner as the industry advances. This leads to the higher biomass yields and lower costs over the long run. If the crop developer manages the complete supply chain, including the biomass pellet mills, this would also be an attractive supply model for OPG. A weakness of this supply model is that the supplier may have better bargaining power due to limited competition in the energy crop industry in Ontario at present.

The biomass can be priced in different ways in the supply contracts. Typical supply contract alternatives, those are not limited to this crop developer supply model, are mentioned below (adapted from Larson et al., 2008):

- Spot market type contract, where the buyer purchases the biomass based on the current energy price equivalent
- Standard marketing contract, where the buyer pays the supplier a guaranteed price on a proportion of the expected supply and spot price for the supply in excess of the guaranteed proportion
- Acreage contract, where the buyer pays a guaranteed price on the actual biomass produced in each year on the contracted biomass acreage
- Gross revenue contract, where the buyer provides a guaranteed annual gross revenue per hectare
- Above contracts with or without the establishment incentives

The standard marketing contract is the innovative option and worth exploring in consultation with farm operators. Due to the volatility of grain prices experienced in 2008-9, farmers are concerned that they would miss future grain price increases after crop lands are converted to the energy crops. A portion of energy crop supply to the spot prices of mixed field crops would reduce the risk perceived by the farmers in adoption of energy crops.

3.4 Assessment of Potential Suppliers

This section presents potential key organizations who can supply biomass from energy crops, processing technologies and other energy crop items of interest to OPG.

3.4.1 Ontario Federation of Agriculture (www.ofa.on.ca/site/home.asp)

As the largest voluntary general farm organization in the country, the Ontario Federation of Agriculture (OFA) has more than 38,000 members, as well as 32 organizational members and affiliates representing most agricultural commodity groups. The OFA represents 90% of farmers in Ontario, and expressed interest in formation of an energy crop growers group to effectively disseminate energy crop related information and handle public relation issues, such as food versus fuel debates. A number of farm cooperatives in Ontario could supply the majority of the biomass required by OPG. The OFA could take the role of facilitator for its member cooperatives in producing and supplying biomass. The OFA has a strong influence on local, provincial and federal governments in the area of agricultural and rural affairs.

The OFA advocates the establishment of a "right to connect" to the grid for the renewable energy projects.[4] Building combined small-scale, biomass-fired power plants and pellet mills might be of OFA interest to minimize investment risk by diversifying the end uses of biomass from energy crops. Ag

[4] www.ofa.on.ca

Table 3.2 Example of Quality Specifications for Biomass Fuel

	Test number	Sample test results
Dry Basis		
Ash	ASTM D 5142	1.93% by Wt.
Heat of combustion	ASTM D 5865	18.5 MJ/kg
Carbon	ASTM D 5373	51.32% by Wt.
Hydrogen	ASTM D 5373	5.62% by Wt.
Nitrogen	ASTM D 5373	0.23% by Wt.
Chlorine	ASTM D 3761	500 ppm
Sulfur	ASTM D 4239	0.08% by Wt.
As Received		
Moisture, total	ASTM D 2013	51.50% by Wt.
Ash	ASTM D 5142	0.94% by Wt.
Heat of combustion	ASTM D 5865	13.5 MJ/kg
Carbon	ASTM D 5373	24.90% by Wt.
Hydrogen	ASTM D 5373	2.73% by Wt.
Nitrogen	ASTM D 5373	0.11% by Wt.
Chlorine	ASTM D 3761	242 ppm
Sulfur	ASTM D 4239	0.04% by Wt.
General		
Heat of combustion, Moisture and ash free	ASTM D 5865	19.5 MJ/kg
Sulfur-kg/GJ	ASTM D 3180	0.042 kg

Energy Cooperative[5], which provides energy products and services to its members, would potentially be working with the OFA in assessing the feasibility of investing in such plants.

3.4.2 Show Me Energy Cooperative, Missouri (www.goshowmeenergy.com)

Show Me Energy Cooperative is a non-profit, producer-owned cooperative founded to support the development of renewable biomass energy sources in west central Missouri, U.S. At the co-operative, 400 producers have each invested a minimum of $2,500 to build a biomass pelletization plant. Approximately $8 million was capitalized to build the plant with the capacity to process 75,000 tons per year, which was expanded to 150,000 t/yr, of biomass into pellets. The plant was started in May 2007 and shipped its first pellets in July 2008. The payback period of less than three years was estimated for the pellet plant.

Two qualities of pellets are produced at the plant. The pellets for the homeowner market are bagged in 40 lb (18 kg) plastic bags. A more industrial pellet product is shipped in bulk or in large totes. Customers include homeowners and small businesses that have installed pellet stoves, furnaces or boilers alone or in tandem with their current heating system, to reduce their heating costs. Larger customers include a university that has installed large biomass burners for its campus heating system. An electrical utility is also purchasing pellets to co-fire with coal to produce electricity. The co-op only accepts biomass from its members. Members can deliver any biomass source, but are obligated to tell the plant what the biomass is and deliver it to the plant as required. Any biomass shortfalls are made up by outsourcing. Typical feedstock includes poor quality round bale hay, grain, soybean straw, corn stover and seed cleanings. The members are getting $70 per ton plus delivery.

The biochemistry of the feedstocks has been studied to enable recipes to be made from the different feedstocks available that will produce the pellet quality they are targeting. Three large coverall sheds are filled with different types of biomass. Each has a large hopper at the end that is kept full by a front end loader. The hay is processed through a grinder and blower system. The control room can meter the volumes of various feedstock sources to the mixer. This ensures that the right volumes of the various materials come together to give the consistency of feedstock into the pelletizers in order to form the best pellets possible. Two big Swedish pelletizers, each driven by two 200 hp electric motors, extrude the pellets (McDonald, 2008).

The Show Me Energy Cooperative claims that it has developed the pelletizing technology for the agricultural biomass, both energy crops and residues, and the extraction of silicon from the biomass (personal communication with Steve Flick). The cooperative would provide the turnkey pellet plants with the plant cost plus a licensing cost of U.S. $750,000 at the time of this study. Further evaluation of the technology is required, since the pellet plant has been in operation for less than a year. The cooperative would be the potential supplier of the agro biomass pelletizing technology, if OPG decides to share the ownership of the pellet mills during the initial development of the energy crop industry.

3.4.3 BiCAN (Pyramid Farm)

BiCAN/BiUS is a joint venture between Pyramid Farms in Leamington, Ontario and BiCAL (www.bical.net) of the UK, BiCAN an Ontario company working in Canada and BiUS in the USA. The management and parent companies of BiCAN have over 15 years of experience in commercial development of miscanthus. BiCAN is positioned in the middle of the value chain, aligned with the experience and capability of BiCAL, to provide two services. The first is to establish crops of miscanthus for customers (farmers, end users, etc), providing annual income. The second is to provide managed feedstock service on BiCAN crops, providing multi-annual income (10-20 years) to manage feedstock production and trading. This provides a balance of short and long-term income streams. The strategy of BiCAN is to become the leading developer and provider of commercial services for miscanthus in North America. In Canada, BiCAN uses the latest genetics available in the marketplace from Cantus Bio Power (www.cantusbiopower.com), a joint venture between Tinplant of Germany and Pyramid Farms of Leamington. Cantus proprietary genetics can grow miscanthus in all farming areas of Canada. Cantus has research plots throughout the country with public and private institutions, and has a combined 22 years of breeding and propagation experience.

[5] www.agenergy.coop

BiCAN is the potential crop developer supplier for OPG, offering valuable experience gained by BiCAL in managing the complete miscanthus supply chain in the UK. The required piece in the total supply chain for OPG is the pellet plants, which could be realized by BiCAN partnering with a pellet technology supplier such as the Show Me Energy Cooperative or its affiliate. However, BiCAN is currently not positioned to handle the complete supply chain. If the farm cooperative supplier model is chosen by OPG, BiCAN could still be the supplier of planting materials and crop services to the farmers. BiCAN is also a potential candidate for OPG to collaborate with in developing the miscanthus fuel specifications.

3.4.4 Ecostrat Inc. (www.ecostrat.com/biofuel-company.php)

Ecostrat and its biofuel affiliate General Biofuel, purchase, manufacture and distribute wood byproducts, renewable fuels and biomass. Ecostrat has over 17 years of wood fuel supply experience. The integrated logistics and supply network (truck, rail and ocean vessel) of Ecostrat is capable of delivering biomass anywhere in North America and the world. Ecostrat has been supplying wood pellets to Europe since 2003.

Ecostrat is interested in supplying miscanthus pellets to OPG, and willing to manage the complete supply chain, including ownership and operation of the pellet plants. Pyramid Farms is an affiliate of Ecostrat in providing miscanthus establishment and crop production services to farm operators. The consulting division of Ecostrat also performs the following kinds of studies:

- Biofuel supply assessments to determine availability and cost of wood fuel in any woodshed across North America.
- Biomass power and co-generation evaluations to determine capital expenditure, operating cost, cash flow and return on investment for clean power projects and conversions.
- Carbon credit evaluations to determine whether a project qualifies for GHG offsets or other carbon credits and the most effective direction to monetize credits.

Ecostrat is the potential biomass pellets supplier to OPG with proven experience in the biomass business, integrated supply network and financial capability. Escostrat also mentioned its willingness to fill the gap in the supply chain, if the farm cooperatives are reluctant to own and operate the pellet plants.

3.4.5 Nott Farms

Clinton area farmer Don Nott is Ontario's leading developer of switchgrass as an energy crop. Nott farms seeded 132 hectares to switchgrass in May 2006. This is the largest commercial plantation of switchgrass in Canada to date. Mr. Nott is also in the business of agro-pellets from crop milling residues. Nott Farms operates an oat-processing facility that provides it with a byproduct of oat hulls. In 2006, Don Nott began using this material along with switchgrass and purchased wheat bran to produce biomass fuel pellets for heating applications. He now has a fleet of delivery trucks and a 10,000 t storage bin to hold this winter heating fuel. Nott Farms supplies approximately 20 greenhouses in Ontario with their winter heating fuel. Nott Farms works closely with agricultural organizations such as OMAFRA and REAP-Canada on energy crops, especially switchgrass. Mr. Nott has plans to expand the switchgrass acreage and pelletizing capacity, and is a potential supplier of switchgrass pellets to OPG.

3.4.6 Tall Grass Prairies Programs

As mentioned in Chapter 1, tall grass prairies (TGP) programs are being implemented by a couple of organizations in Ontario with the primary objective of ecological benefits. Ontario Ministry of Natural Resources is carrying out a TGP program, where mixed native grasses are being or will be planted on agricultural lands along the drains and along highways for soil conservation and other ecological benefits. Tallgrass Ontario (www.tallgrassontario.org) is a not-for-profit organization implementing similar program of growing mixed native grasses on marginal land rented from farmers.

The potential of bioenergy from the native tall grass prairies programs is promising, if end-users like OPG purchase biomass from native grasses. Currently native grasses are burned every 3-4 years due to lack of end-use. Although TGP programs currently produce a limited amount of biomass, they can expand significantly, if funding is available through the sale of biomass. The TGP programs are mutually beneficial for both the environmental organizations and OPG in conserving the ecological system and securing the biomass supply. Lower cost of biomass can also be expected since TGP programs are executed by not-for-profit organizations.

3.4.7 Major Energy Crops Breeding Companies

This section briefly describes companies, although they are not likely direct suppliers to OPG, that are looking at ways of improving the quality of energy crops, either through conventional breeding or genetic engineering.

(i) Ceres Corporation (www.ceres.net)

Ceres is a privately owned company, based in Thousand Oaks, California, that is focusing on developing superior breeds of switchgrass. Working with its partner, the Samuel Roberts Noble Foundation, the company is marking genes to increase the effectiveness of conventional breeding. Ceres is currently testing new breeds that yield about 20 t/ha, compared with 12 t/ha conventional switchgrass in the U.S.

The company has also analyzed 12,000 switchgrass genes and characterized the genetic variation associated with each one in order to create a trait database. This has been done in order to perfect cloning strategies that turn on/off specific genes that regulate traits such as yield, chemical composition, and drought tolerance and facilitate easier hydrolysis in the biorefinery. Ceres has recently started breeding miscanthus and hybrid poplar energy crops.

(ii) Mendel Biotechnology (www.mendelbio.com)

Founded in 1997 in Hayward, California, Mendel Biotechnology Inc. is a closely-held private company. It has been a pioneer in the application of functional genomics to the study of plant genes. Mendel has identified and patented the use of genes that control many aspects of plant growth and development, and is using such inventions to develop or co-develop new plant varieties with improved productivity and quality. Mendel has relationships with leading agricultural, forestry and horticultural companies for the commercialization of improved seed and plant products. Mendel Biotechnology is co-owned by Monsanto. British Petroleum (BP) is also a shareholder of Mendel in developing miscanthus varieties.

In 2007, Mendel acquired the entire miscanthus breeding program from Tinplant Biotechnik und Pflanzenvermehrung GmbH, a German breeding and plant science company. The Tinplant team has spent about 15 years in research and breeding of more than 1,000 different Miscanthus varieties in order to improve the properties of the high biomass yield plant. Tinplant and Pyramid Farms of Leamington, Ontario had formed a joint venture, Cantus Bio Power (www.cantusbiopower.com), which owns propriety genetics of miscanthus, claimed to be suitable for Ontario.

(iii) Monsanto (www.monsanto.com)

Monsanto is the major producer of genetically modified seeds in the world. It has a biofuel department which is currently focusing on conventional breeding for corn varieties. Monsanto is a player in the development of miscanthus through Mendel Biotechnology. Monsanto is also interested in the fuel potential of switchgrass, and currently collaborates with Ceres Corporation to research its possibilities.

(iv) Performance Plants Inc. (www.performanceplants.com)

The Performance Plants Inc. was established in 1995, and is in the business of agricultural and biofuel technology development. The company patented the weatherproof technologies that boost crop yields and drought tolerance for food and biofuel crops. The company has licensed its breakthrough yield protection technology to some of the world's leading seed companies such as Syngenta, Stine, RiceTec and Scotts Miracle Gro. Headquartered in Kingston, Ontario, the privately-held company has research and development facilities in Kingston, Saskatoon, and Waterloo, New York. This Canadian-based firm is actively growing non-food biofuel crops to replace coal at Lafarge Canada Inc.'s cement plant in Bath, Ontario. New varieties of energy crops, especially miscanthus, can be expected in the near future from the Performance Plants.

(v) State University of New York College of Environmental Science and Forestry (www.esf.edu)

The State University of New York College of Environmental Science and Forestry (SUNY-ESF) initiated the willow SRC breeding program in the mid-1990s, and is the current leading breeder in North America. Since 1994, a diverse collection of more than 700 willow accessions, representing over 20 species and hybrids, has been assembled through collection of naturally established plants in the wild or disturbed environments, contributions of naturally collected or bred germplasm from the United States and overseas collaborators, and from the purchase of varieties available from commercial nurseries. Techniques for the collection of pollen and for mechanical pollination were developed and adapted for the species in the breeding program. Since 1998, researchers at SUNY-ESF have produced approximately 200 families from more than 575 attempted controlled pollinations. *Salix miyabeana* ‘SX64’ is one of the best performing willow SRC variety the SUNY-ESF. The SUNY-ESF and the Research Foundation of SUNY have licensed shrub-willow varieties developed through research at the college to Double A Willow (www.DoubleAWillow.com) for production and commercial sale of willow planting stock (whips, stakes and cuttings). Double A Willow has installed storage freezers capable of holding approximately 10 million cutting equivalents. They have also established nursery beds with over 100,000 plants representing 16 biomass varieties.

Chapter 4
Economics of Energy Crops

Total cost for the production and delivery of the biomass from energy crops to OPG's generation station includes establishment and management, land rental, reasonable gross margin, harvesting, storage, processing and transportation. Generalized estimates of those items and underlying assumptions are presented in this section. Actual costs may vary for specific farm operations and locations. Sensitivity analysis was also performed on influential parameters, and the economies of scale of the energy crops were also estimated.

4.1 Cost of Growing and Harvesting Energy Crops

4.1.1 Miscanthus

Miscanthus varieties grown for energy are usually propagated though rhizomes, which are typically planted at a density of 10,000-20,000 per hectare. The cost of rhizomes represents the major portion of total establishment. At present, rhizomes are available at 30-40 cents per plant. Note that miscanthus in Ontario and North America is just at the beginning of commercialization. The price of rhizomes can decrease materially as the industry advances, as seen in the UK. In this analysis, we assume the planting density of 15,000 per hectare and the rhizome cost of 10 cents per plant, i.e. farm cooperative purchase of planting materials is considered for the volume required by OPG.

The growing and harvesting costs for miscanthus used in this study are based on personal communication with Dean Tiessen of Pyramid Farms and a number of previous studies in the U.S. Site preparation such as herbicide spray in the fall before the spring planting and sub-soiling to remove the compacting, if necessary, are also part of the establishment cost and estimated at $100/ha. Planting can be carried out using potato planters or specialized planters. Weed control is critical during the establishment year, and assumed at $200/ha. Once established, miscanthus can last for 15-20 years, and the crop life of 15 years is used in this economic analysis. No fertilizer is required during the establishment. However, about 75 kg of nitrogen per hectare annually during the production years is sufficient to sustain the biomass yield. There is also a removal cost, which involves herbicide spraying and sub-soiling at the end of the crop life. The establishment cost and the removal cost are annualized at the assumed interest rate over 14 years, i.e. the crop life minus one, since there is no harvest in the first year after the establishment. The yield of miscanthus at first harvest, i.e. at the second year, could be lower than the mature yields at the second harvest onwards. To simplify this financial analysis, the average yield is assumed for all harvests during the crop life.

The parameters in estimating the growing and harvesting costs of miscanthus and the results are shown in Table 4.1. The marginal land rental cost of $247/ha and gross margin of $247/ha are assumed for all energy crops. The net present value of the establishment and end-of-life removal costs of miscanthus is $2,564/ha (Note that it could be $5,564/ha at the rhizome cost of 30 cents/plant for small-scale plantation by individual farmers). The annualized cost, over 14 years, of the establishment and removal cost is $276/ha. Total costs of biomass/ha at each harvest year include land rental, fertilizer, harvesting, annualized establishment and removal cost and the gross margin. As seen in Table 4.1, the cost of biomass at the farm gate for miscanthus is $76/DM t or $3.89/GJ.

4.1.2 Switchgrass

Switchgrass offers the lowest establishment cost among the energy crops considered, since it can be planted from seeds. The establishment and other growing and harvesting cost figures are based on personal communication with Don Nott, who has been growing switchgrass in Clinton, Ontario and the studies conducted by the REAP-Canada. The site-preparation cost for switchgrass is similar to that of hay crops at $40/ha. The seeding rate of 9 kg pure live seeds per hectare is assumed at $15/kg. Frost seeding can be used to establish switchgrass. This requires a tandem disk, harrow, airflow planter and self-propelled sprayer. In addition to the planting cost, weed control is also a part of the establishment cost. Once established, switchgrass can be productive for 15-20 years, and the crop life of 15 years is used in this economic analysis. No fertilizer is required during the establishment. However, it is assumed that there are about 50 kg of nitrogen per hectare annually during the production years. The establishment cost and removal cost are annualized at the assumed interest rate over 14 years, similar to the economic analysis of miscanthus. The average yield is assumed over the production year to simplify the analysis.

Table 4.1 Growing and Harvesting Costs of Miscanthus

Parameter	Value
General Input Parameters	
Average biomass yield (DM t/ha)	16
Fuel value (GJ/DM t)	19.6
Life of crop (yrs)	15
Interest rate (%)	6
Establishment/Removal Cost Items	
Site preparation ($/ha)	100
Seeds ($/ha)	1500
Planting ($/ha)	350
Weed/pest control ($/ha)	200
Land rental ($/ha/yr)	247
Removal cost after final harvest ($/ha)	400
Present value of establishment and removal costs ($/ha)	2563.91
Annualized establishment and removal cost ($/ha)	275.84
Total Cost of Biomass at Farm Gate	
Land rental ($/ha/yr)	247
Fertilizer ($/ha)	100
Harvesting ($/ha)	350
Annualized establishment and removal cost ($/ha)	275.84
Gross margin ($/ha)	247
Total cost at farm gate ($/ha)	1219.84
Cost of biomass at farm gate ($/DM t)	76.24
Cost of biomass at farm gate ($/GJ)	3.89

Table 4.2 Growing and Harvesting Costs of Switchgrass

Parameter	Value
General Input Parameters	
Average biomass yield (DM t/ha)	10
Fuel value (GJ/DM t)	18.6
Life of crop (yrs)	15
Interest rate (%)	6
Establishment/Removal Cost Items	
Site preparation ($/ha)	40
Seeds ($/ha)	135
Planting ($/ha)	105
Weed/pest control ($/ha)	200
Land rental ($/ha/yr)	247
Removal cost after final harvest ($/ha)	300
Present value of establishment and removal costs ($/ha)	852.18
Annualized establishment and removal cost ($/ha)	91.68
Total Cost of Biomass at Farm Gate	
Land rental ($/ha/yr)	247
Fertilizer ($/ha)	66
Harvesting ($/ha)	235
Annualized establishment and removal cost ($/ha)	91.68
Gross margin ($/ha)	247
Total cost at farm gate ($/ha)	886.68
Cost of biomass at farm gate ($/DM t)	88.67
Cost of biomass at farm gate ($/GJ)	4.77

Table 4.3 Growing and Harvesting Costs of Willow

Parameter	Value
General Input Parameters	
Average biomass yield (DM t/ha)	9
Fuel value (GJ/DM t)	19.3
Life of crop (yrs)	25
Interest rate (%)	6
Establishment/Removal Cost Items	
Site preparation ($/ha)	150
Seeds ($/ha)	1500
Planting ($/ha)	500
Weed/pest control ($/ha)	300
Land rental ($/ha/yr)	247
Removal cost after final harvest ($/ha)	500
Present value of establishment and removal costs ($/ha)	2813.5
Annualized establishment and removal cost ($/ha)	224.18
Total Cost of Biomass at Farm Gate (harvested every 3 yrs)	
Land rental ($/ha)	741
Fertilizer ($/ha)	0
Harvesting ($/ha)	600
Annualized establishment and removal cost ($/ha)	672.53
Gross margin ($/ha)	741
Total cost at farm gate ($/ha)	2754.53
Cost of biomass at farm gate ($/DM t)	102.02
Cost of biomass at farm gate ($/GJ)	5.29

The results of the growing and harvesting costs of switchgrass are given in Table 4.2 with the parameters assumed. The net present value of the establishment and end-of-life removal costs of switchgrass is $852/ha. Those costs can be annualized over 14 years, and result in $92/ha. Total costs of biomass/ha at each harvest year include land rental, fertilizer, harvesting, annualized establishment and removal cost and the gross margin. As seen in Table 4.2, the cost of biomass at the farm gate for switchgrass is $89/DM t or $4.77/GJ.

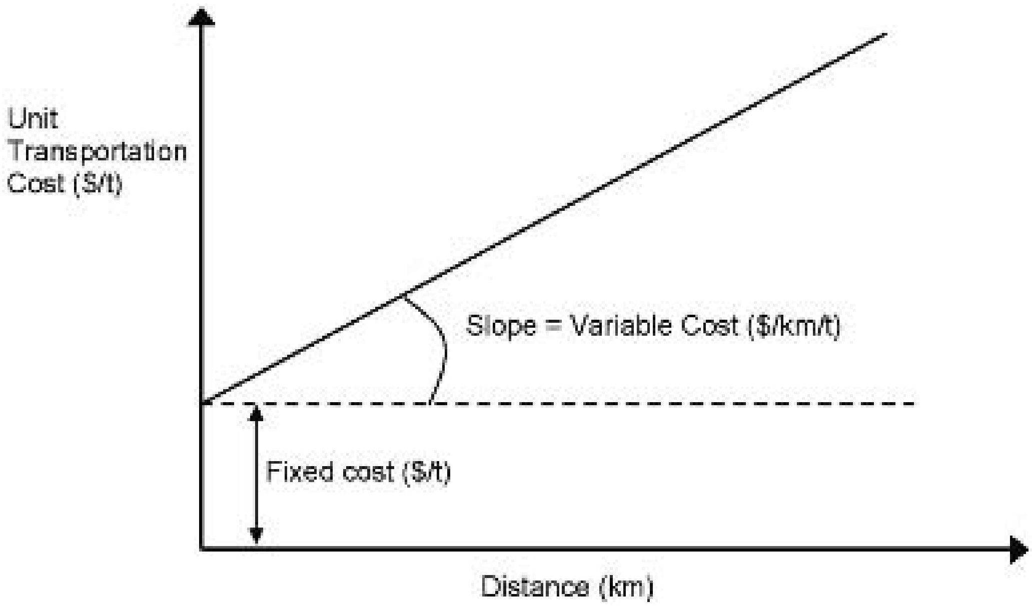
4.1.3 Willow

Willow SRC for energy use is usually planted in spring using the planting materials or cuttings produced by specialist breeders and equipment specially designed for the purpose. The cost of willow cuttings, similar to the miscanthus rhizomes, is the major component of total establishment. At the time of this study, the cost of willow cuttings was 30 cents/cutting and could be as high as $1/cutting. This cost could come down significantly when the industry reaches commercial-scale production. Based on the high volume biomass required by OPG, the purchase of willow cuttings by the farm cooperatives at bulk volume is considered in this study, and the cost is estimated at 10 cents/cutting. The density of plantation is assumed at 15,000 plants/ha.

The parameters used in estimating the growing and harvesting costs of willow SRC in this study are based on personal communication with the LandSaga Biogeographical and Dr. Naresh Thevathasan, a willow researcher from the University of Guelph and studies performed by the researchers at the State University of New York. Land preparation is important for the establishment of willow and subsequent harvests. Complete eradication of invasive perennial weeds and appropriate sub-soiling prior to the planting are parts of land preparation and estimated at $150/ha.

Planting of willow SRC can be accomplished by specialized equipment, such as a step planter or energy planter. Weed control, which is of paramount importance for successful establishment, is estimated at $300/ha. Removal cost of willow at the end of the crop life involves more work, in comparison with that for miscanthus or switchgrass, and could cost $500/ha. The crop life of 25 years is assumed for willow SRC,

Figure 4.1 Fixed Cost and Variable Cost of Transportation



and the establishment and removal costs are annualized for 24 years. As with other energy crops, average yield is used for the financial analysis for all the harvests.

The growing and harvesting costs estimated for willow SRC are presented in Table 4.3 with all parameters used for the analysis. The willow SRC has the highest establishment and removal cost at the net present value of $2,814/ha in comparison with the energy crops considered. That cost could be as high as $5,824/ha for small-scale planting by individual farmers at the cost of 30 cents/cutting. It is assumed that no fertilizer is required for willow SRC. Therefore, total costs of biomass/ha at each harvest year include land rental, harvesting, annualized establishment and removal cost and the gross margin. Harvesting frequency of every three years is employed in this study. As seen in Table 4.2, the cost of biomass at the farm gate for willow SRC is $102/DM t or $5.29/GJ.

4.2 Transportation Models and Costs

Transportation cost of biomass is a function of not only the distance but also the density of the biomass and mode of transportation. Transportation cost usually represents a substantial share in total cost of the biomass fuel, and sometimes the limiting factor in the financial feasibility of the biomass energy project. For all transportation modes, i.e. truck, rail and marine, biomass transportation cost has a fixed cost component and a variable cost component. The fixed cost includes loading and unloading, capital cost of railcars, marine port, etc. The variable cost component can be expressed in $/km, and includes fuel and operating costs. Figure 4.1 illustrates the fixed cost and variable cost of the biomass transportation in general.

Density of biomass plays an important role in estimating the transportation cost. For instance, a conventional switchgrass bale has a bulk density of about 150 kg/m3, and a truck with 100 m3 can load approximately 12.5 tons of bales, whereas the switchgrass pellets with a bulk density of 580 kg/m3 would allow a loading of 40 tons/truck or higher as allowed by the road load regulations. It is obviously more costly to ship the bulky biomass than the densified biomass. The transportation cost models used in this study for the biomass bulk density of 120 kg/m3 are mentioned in Table 4.4 and are adapted from a number of studies (Flynn, 2007; Samson, 2008; Sokhansanj and Fenton, 2006; Sorensen, 2005). Transportation cost of biomass for a given mode is calculated as:

Transportation cost (\$/ DM t) = $C_1 + C_2 \times L$

Where:

C_1 = Fixed cost constant (\$/DM t)

C_2 = Variable cost constant (\$/DM t/km)

L = Distance in km

Table 4.4 Transportation Models of Different Modes for Bulk Biomass Density of 120 kg/m3

Mode	C1	C2
Truck	5.7	0.1369
Rail	17.1	0.0277
Marine	19.6	0.0113

Adapted from Flynn, 2007; Samson, 2008; Sokhansanj and Fenton, 2006; Sorensen, 2005

As presented in the supply chain section (Figure 3.2), the transportation model considered for the biomass from energy crops includes all modes of transportation. Total costs of transportation for the biomass pellets are shown in Figure 4.2 for different modes of transportation at varied distances between the farm and OPG's generating station (GS). If the raw biomass is transported from the farm to the central storage and processing facility with trucks, and the biomass pellet is trucked from the central facility to OPG's GS, i.e. T+T, the total transportation cost would be the least up to the farm to OPG distance of about 350 km. However, this "T+T" transportation would cost significantly more than others, as seen in Figure 4.2, for the longer farm to OPG distances. The "T+T+R" transportation includes trucking of raw biomass from farm to the central facility, trucking of biomass pellets from central facility to rail terminal and rail transportation of biomass pellets from the rail terminal to the generating station. The "T+T+M" is similar to the "T+T+R" except with marine shipping instead of rail transportation.

Figure 4.3 presents the sample breakdown of total transportation costs for all combination of the transportation modes considered. The assumptions are the farm to OPG distance of 500 km, the farm to the central facility distance of 100 km and the central facility to rail terminal or marine port distance of 100 km. The density of raw biomass and pellets is estimated at 120 kg/m3 and 580 kg/m3, respectively. It can be seen in Figure 4.3 that, for instance with "T+T+M" transportation modes, cost of transporting bulky biomass from farm to the central facility, i.e. T1, is about \$20/DM t, whereas, transporting biomass pellets by truck, i.e. T2, costs about \$ 6/DM t. Note that distance of T1 and T2 are the same at 100 km. This is due to the substantial change in biomass density and suggests that central storage and processing facilities should be located as close as possible to the farms to minimize the total biomass transportation cost.

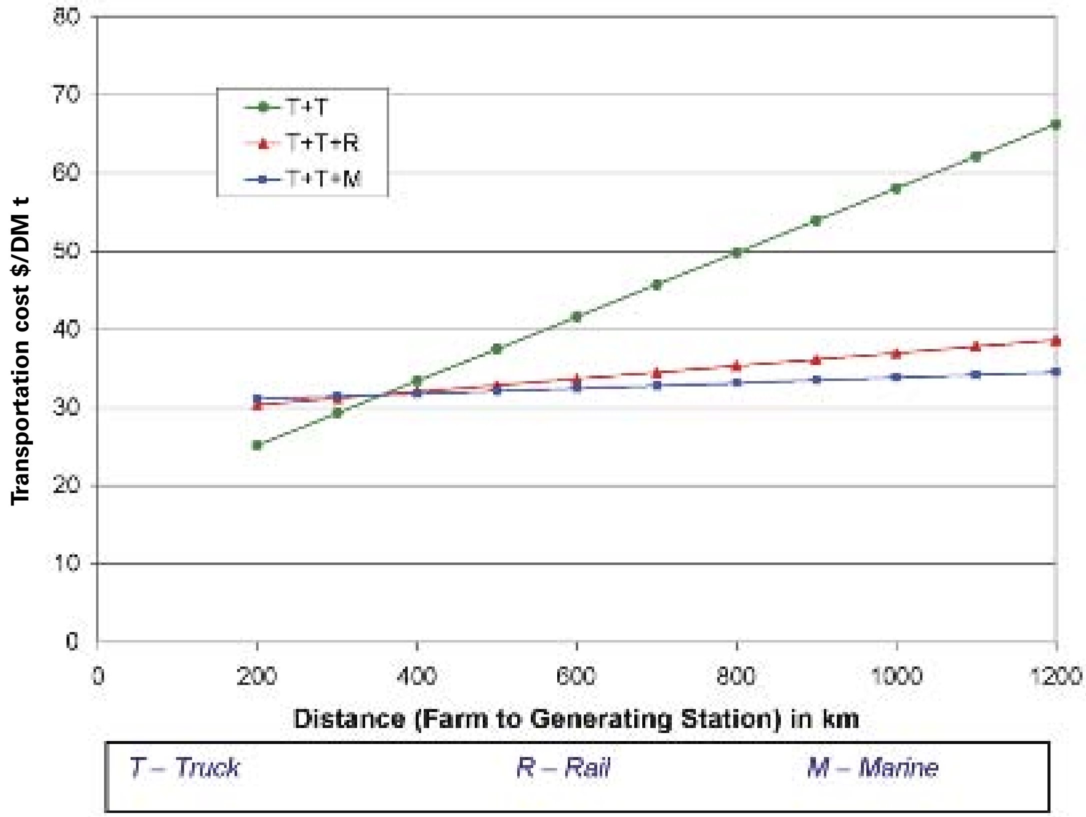
4.3 Storage and Processing Costs

As discussed in the supply chain section, biomass from energy crops needs at least to be dried, if not densified subsequently, for year-round storage to minimize the dry matter lost. A number of studies reported a wide range of storage cost for biomass. Durffy and Nanhou (2002) reported U.S. \$2.92/t storage cost for switchgrass, whereas Samson (2008) estimated the cost of \$5/DM t for storing 3,600 t of switchgrass at the Nott farm in Clinton, Ontario. For a pellet mill with greater capacity, 150,000 t/yr considered in this study, would offer economies of scale in comparison with the storage costs experienced by the Nott farm.

Drying of biomass sometimes represents the major portion of the biomass densification process. Mani (2006) estimated that cost associated with drying the wood residues with 45% moisture is about 30% or US\$10.3/t of total pelletizing cost. Energy used for drying wood residues also represents 22% of wood pellet energy and 70% of total energy consumed in the pelletizing process (Karwandy, 2007). Biomass with relatively lower moisture content, such as switchgrass, offers lower drying costs. The cost of drying biomass has an approximately linear relation to the moisture content of the biomass. It is assumed in this study that the incoming biomass is dried to 8% moisture content for subsequent densification process or storage.

Grinding, also known as milling, is a sub-process in biomass densification. Biomass materials should be grounded after drying to a size no bigger than the diameter of the pellets. Raw

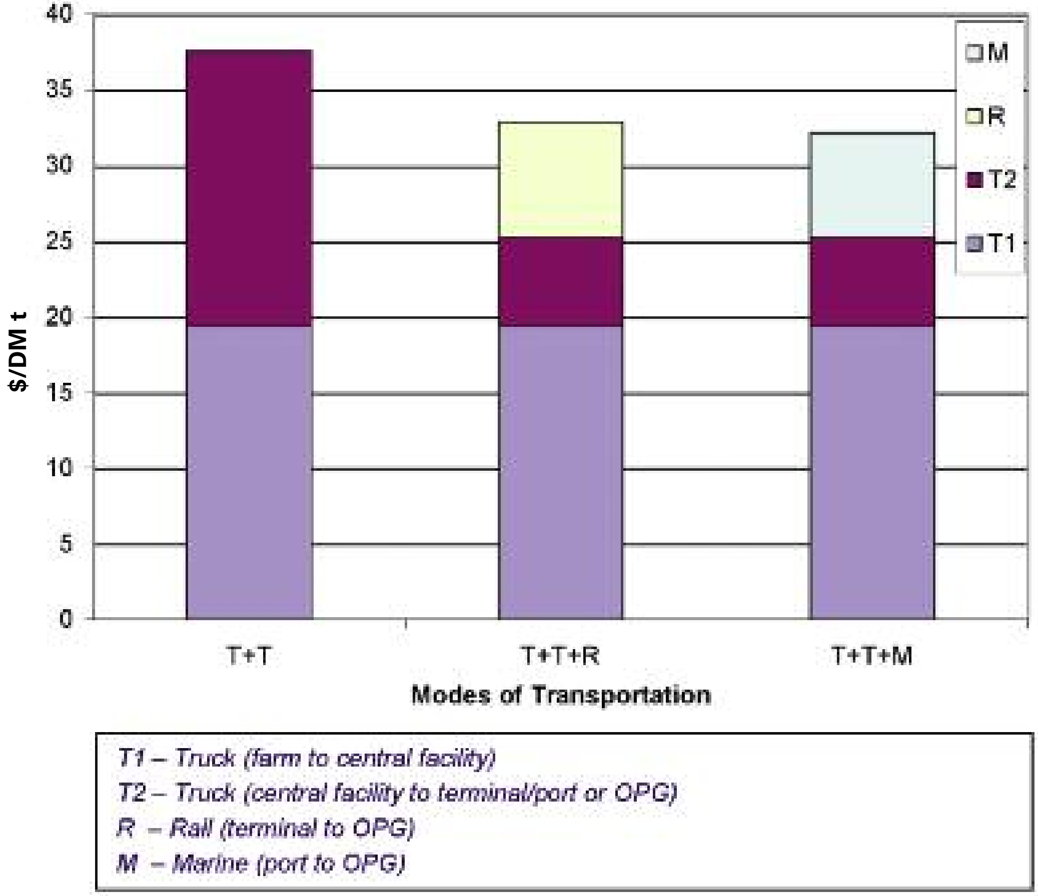
Figure 4.2 Transportation Cost of Biomass Pellets from Farm to Generating Station



materials are usually filtered before grinding to remove foreign objects such as stone and metal. Mani (2006) estimated the grinding cost of US$0.95/t for wood residues. Biomass from energy crops could have higher grinding costs due to greater filtering work before grinding, since agricultural biomass is more prone to foreign materials such as soil and stone than is forest wood.

Pelletizing machines, also known as extruders, are available in a range of sizes. Generally, every 100 hp provides a capacity of approximately one ton of wood pellets per hour. Higher pellet output of 2-4 t/hr can be expected for the agricultural biomass. Many pelletizing machines come with a built-in steam conditioning chamber. Super-heated steam, at temperatures above 100°C, is used to soften the biomass before it is densified. Steam conditioning is not necessary but does make the raw material less abrasive to the pelletizing equipment. This helps reduce the maintenance cost. There are two types of die used in pelletizing: flat die, where raw material is pressed though the top of a horizontally mounted die, and rotary die, where two or more rotary presses push raw material from inside a ring die to the outside where it can be cut into the desired length. In both cases, a pellet is created by using a great deal of pressure to force the raw material through holes in the die. As pressure and friction increases so does the temperature of the biomass. This allows the lignin of the biomass to soften and the fibre to be reshaped into the pellet form. Pelletizing cost of agricultural biomass could be relatively higher than that of forest wood due to high silica content, which leads to greater wear and tear in the pelletizing equipment.

Figure 4.3 Sample Breakdown of Biomass Transportation Cost



Samson (2008) estimated total pelletizing cost, including drying and grinding, of switchgrass at $40/t for a 50,000 t/yr (6.7 t/hr) pellet plant. Since a pellet plant with a capacity of 150,000 t/yr (20 t/hr) is considered for this study, lower pelletizing cost due to economies of scale is expected. The economy of scale of a wood pellet mill is shown in Figure 4.4 (Mani, 2006). It can be seen that there is no significant gain in economy of scale beyond the mill capacity of 75,000 t/yr (10 t/hr). Making biomass briquettes is similar to pelletizing. However, briquette machines require less capital and operating cost. Cost of making biomass briquette could be 50% that of producing pellets (Samson, 2008).

Based on the discussions above and the studies mentioned, cost estimates for storage and processing of biomass from energy crops are given in Table 4.5. Switchgrass offers the lowest storage and processing cost at $31.30/ DM t (of pellets) due to its lower moisture content. Total storage and processing costs of miscanthus and willow pellets are $35.54/ DM t and $42.05/ DM t, respectively. Considering the fuel values of the energy crops (see Table 4.1-4.3), the storage and processing costs of biomass pellets are $1.81/ GJ for miscanthus, $1.68/ GJ for switchgrass, and $2.18/ GJ for willow.

4.4 Financial Model and Total Cost of Biomass at OPG Gate

A financial model was developed to estimate the cost of different forms, i.e. grounded, briquette, and pellet, of biomass from energy crops. The inputs to the spreadsheet model are

Figure 4.4 Wood Pelletizing Cost Versus Plant Size (Mani, 2006)

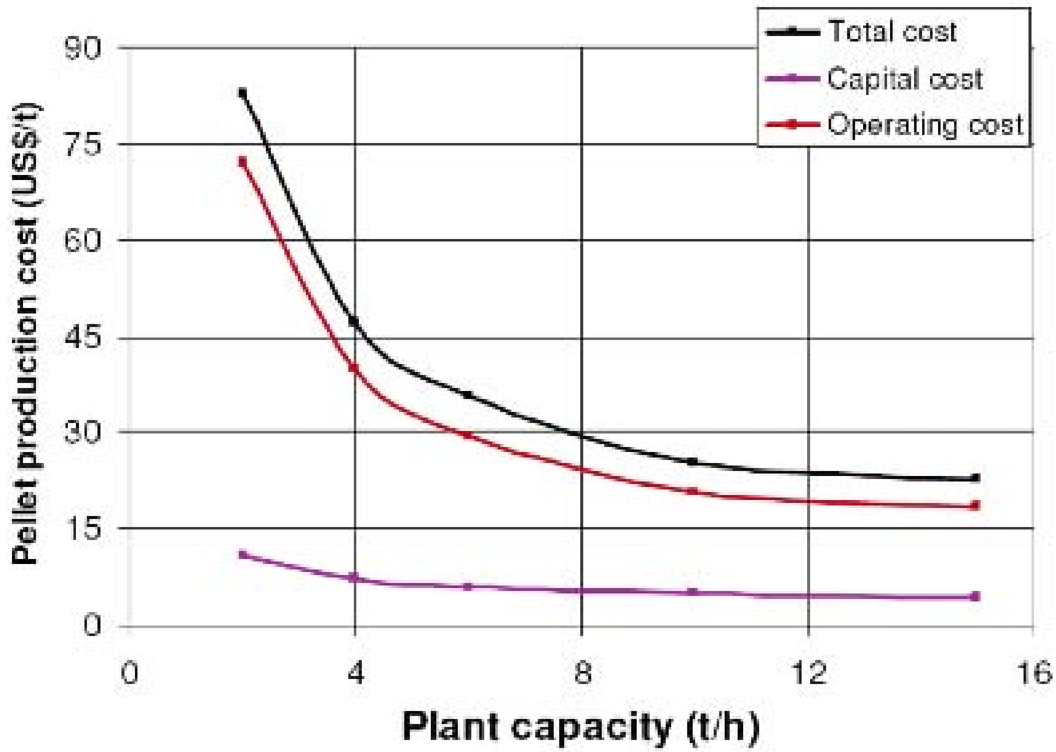


Table 4.5 Storage and Process Costs of Energy Crop Biomass

	Miscanthus	Switchgrass	Willow
Processing cost items			
Storing and administration expenses ($/ DM t)	4.5	4.5	4.5
Drying to 8% moisture content ($/DM t)	5.54	1.3	12.05
Grinding ($/DM t)	2.5	2.5	2.5
Briquetting ($/DM t)	14	14	14
Pelletizing ($/DM t)	23	23	23
Total storage and processing costs ($/ DM t)			
Grind	12.54	8.3	19.05
Briquette	26.54	22.3	33.05
Pellet	35.54	31.3	42.05
Total storage and processing costs ($/ GJ)			
Grind	0.64	0.45	0.99
Briquette	1.35	1.2	1.71
Pellet	1.81	1.68	2.18

Table 4.6 Total Cost of Biomass ($/GJ) at OPG Gate

		Grind	Briquette	Pellet
Miscanthus	Growing	2.77	2.77	2.77
	Harvesting	1.12	1.12	1.12
	Processing	0.64	1.35	1.81
	Transportation	2.37	1.67	1.58
	Total	**6.9**	**6.91**	**7.28**
Switchgrass	Growing	3.5	3.5	3.5
	Harvesting	1.26	1.26	1.26
	Processing	0.45	1.2	1.68
	Transportation	2.56	1.82	1.72
	Total	**7.77**	**7.79**	**8.17**
Willow	Growing	4.13	4.13	4.13
	Harvesting	1.15	1.15	1.15
	Processing	0.99	1.71	2.18
	Transportation	2.34	1.63	1.53
	Total	**8.61**	**8.63**	**9.00**

the parameters and underlying assumptions discussed in above sections (Section 4.1-4.3). The spreadsheet models for the energy crops considered are presented in Figure 4.5, Figure 4.6 and Figure 4.7 with detailed economics of each crop. Total costs of biomass at OPG's gate are summarized in Table 4.6. For the biomass pellet, which is the form most preferred by OPG, miscanthus offers the lowest cost at $7.28/ GJ due to its high biomass yield. The costs of switchgrass and willow pellets are $8.17/ GJ and $9.00/ GJ respectively.

4.5 Sensitivity Analysis

Yields of energy crops, like those of other agricultural products, can vary up to +/- 15% due to normal fluctuations in weather conditions. Cost of biomass at the farm gate, with changes in yields, are estimated using the financial model and presented in Figure 4.8. This is an important factor to be considered in development of supply contracts, The cost of miscanthus at the farm gate would vary from $ 66-90/ DM t for the +/-15% changes in yields from the base case assumption. For switchgrass and willow, the ranges are $ 77-104/ DM t and $ 89-120/ DM t respectively.

The energy crop industry is still in its early development, especially in North America. A great deal of research and development in breeding and agronomic practices is underway, and a substantial gain in biomass yields can be expected as the industry expands. The sensitivity of the analysis of the cost of biomass pellets at OPG's gate with yield improvements is recognized. The results are presented in Figure 4.9 for yield improvements of 10-30%. Miscanthus pellets with a current cost of $7.28/GJ could be reduced to $6.38/ GJ if the yield improves by 30% due to genetic and agronomic advances. For switchgrass and willow, a 30% improvement in yield would reduce the cost of biomass pellets to $7.07/ GJ and $7.78/ GJ respectively.

The cost of biomass is calculated assuming a gross margin of $247/ ha ($100/ acre) for marginal or less productive agricultural lands. Sensitivity analysis of increasing the gross margin to $370/ ha ($150/ acre) and $494/ ha ($200/ acre) was performed

Figure 4.5 Financial Model for Miscanthus

Financial Model - Miscanthus

General Input Parameters	Value
Average biomass yield (DM t/ha)	16
Fuel value (GJ/DM t)	19.6
Moisture content at farm gate (%)	25
Life of crop (yrs)	15
Land rental ($/ha/yr)	247
Gross margin expectation ($/ha)	247
Average distance - farm to central facility (km)	100
Average distance - central facility - marine port (km)	100
Average distance - marine port to OPG (km)	300
Interest rate (%)	6

Establishment/Removal Cost Items	Value
Site preparation ($/ha)	100.00
Rhizomes ($/ha)	1500.00
Planting ($/ha)	350.00
Weed/pest control ($/ha)	200.00
Land rental ($/ha/yr)	247.00
Removal cost after final harvest ($/ha)	400.00
Present value of establishment and removal costs ($/ha)	2563.91
Annualized establishment and removal cost ($/ha)	275.84

Total Cost of Biomass at Farm Gate	Value
Land rental ($/ha/yr)	247.00
Fertilizer ($/ha)	100.00
Harvesting ($/ha)	350.00
Annualized establishment and removal cost ($/ha)	275.84
Gross margin ($/ha)	247.00
Total cost at farm gate ($/ha)	1219.84
Cost of biomass at farm gate ($/DM t)	76.24
Cost biomass at farm gate ($/GJ)	3.89

Transportation Costs	Value
Transportation - farm to central facility ($/DM t)	18.23
Transportation - grind - central facility to marine port ($/DM t)	12.91
Transportation - briquette - central facility to marine port ($/DM t)	6.64
Transportation - pellet - central facility to marine port ($/DM t)	5.81
Transportation - grind - marine port to OPG ($/DM t)	15.33
Transportation - briquette - marine port to OPG ($/DM t)	7.98
Transportation - pellet - marine port to OPG ($/DM t)	6.90

Processing Cost Items	Value
Storing and administration expenses ($/DM t)	4.50
Drying to 8% moisture content ($/DM t)	5.54
Grinding ($/DM t)	2.50
Briquetting ($/DM t)	14.00
Pelletizing ($/DM t)	23.00

Cost ($/GJ) of Different Forms of Biomass at OPG gate

	Grind	Briquette	Pellet
Growing	2.77	2.77	2.77
Harvesting	1.12	1.12	1.12
Processing	0.64	1.35	1.81
Transporting	2.37	1.67	1.58
Total	6.90	6.91	7.28

Figure 4.6 Financial Model for Switchgrass

Financial Model - Switchgrass

General Input Parameters	Value
Average biomass yield (DM t/ha)	10
Fuel value (GJ/DM t)	18.6
Moisture content at farm gate (%)	12
Life of crop (yrs)	15
Land rental ($/ha/yr)	247
Gross margin expectation ($/ha)	247
Average distance - farm to central facility (km)	100
Average distance - central facility - marine port (km)	100
Average distance - marine port to OPG (km)	300
Interest rate (%)	6

Establishment/Removal Cost Items	Value
Site preparation ($/ha)	40.00
Seeds ($/ha)	135.00
Planting ($/ha)	106.00
Weed/pest control ($/ha)	200.00
Land rental ($/ha/yr)	247.00
Removal cost after final harvest ($/ha)	300.00
Present value of establishment and removal costs ($/ha)	852.18
Annualized establishment and removal cost ($/ha)	91.68

Total Cost of Biomass at Farm Gate	Value
Land rental ($/ha/yr)	247.00
Fertilizer ($/ha)	66.00
Harvesting ($/ha)	235.00
Annualized establishment and removal cost ($/ha)	91.68
Gross margin ($/ha)	247.00
Total cost at farm gate ($/ha)	886.68
Cost of biomass at farm gate ($/DM t)	98.67
Cost biomass at farm gate ($/GJ)	4.77

Transportation Costs	Value
Transportation - farm to central facility ($/DM t)	10.37
Transportation - grind - central facility to marine port ($/DM t)	12.91
Transportation - briquette - central facility to marine port ($/DM t)	6.84
Transportation - pellet - central facility to marine port ($/DM t)	5.51
Transportation - grind - marine port to OPG ($/DM t)	15.33
Transportation - briquette - marine port to OPG ($/DM t)	7.98
Transportation - pellet - marine port to OPG ($/DM t)	6.90

Processing Cost Items	Value
Storing and administration expenses ($/DM t)	4.50
Drying to 8% moisture content ($/DM t)	1.30
Grinding ($/DM t)	2.50
Briquetting ($/DM t)	14.00
Pelletizing ($/DM t)	23.00

Cost ($/GJ) of Different Forms of Biomass at OPG gate

	Grind	Briquette	Pellet
Growing	3.50	3.50	3.50
Harvesting	1.26	1.26	1.26
Processing	0.45	1.20	1.68
Transporting	2.56	1.82	1.72
Total	7.77	7.78	8.17

Figure 4.7 Financial Model for Willow

Financial Model - Willow

General Input Parameters	Value
Average biomass yield (DM t/ha/yr)	9
Fuel value (GJ/DM t)	19.3
Moisture content at farm gate (%)	45
Life of crop (yrs)	25
Land rental ($/ha/yr)	247
Gross margin expectation ($/ha)	247
Average distance - farm to central facility (km)	100
Average distance - central facility - marine port (km)	100
Average distance - marine port to OPG (km)	300
Interest rate (%)	6

Establishment/Removal Cost Items	Value
Site preparation ($/ha)	150.00
Cuttings ($/ha)	1500.00
Planting and cutback ($/ha)	500.00
Weed/pest control ($/ha)	300.00
Land rental ($/ha/yr)	247.00
Removal cost after final harvest ($/ha)	500.00
Present value of establishment and removal costs ($/ha)	2813.50
Annualized establishment and removal cost ($/ha)	224.18

Total Cost of Biomass at Farm Gate	Value
Land rental ($/ha/3yrs)	741.00
Fertilizer ($/ha/3yrs)	0.00
Harvesting ($/ha/3yrs)	600.00
Establishment and removal cost ($/ha/3yrs)	672.53
Gross margin ($/ha/3yrs)	741.00
Total cost at farm gate ($/ha/3yrs)	2754.53
Cost of biomass at farm gate ($/DM t)	102.02
Cost biomass at farm gate ($/GJ)	5.29

Transportation Costs	Value
Transportation - farm to central facility ($/DM t)	18.90
Transportation - grind - central facility to marine port ($/DM t)	12.91
Transportation - briquette - central facility to marine port ($/DM t)	8.64
Transportation - pellet - central facility to marine port ($/DM t)	5.81
Transportation - grind - marine port to OPG ($/DM t)	15.33
Transportation - briquette - marine port to OPG ($/DM t)	7.88
Transportation - pellet - marine port to OPG ($/DM t)	6.90

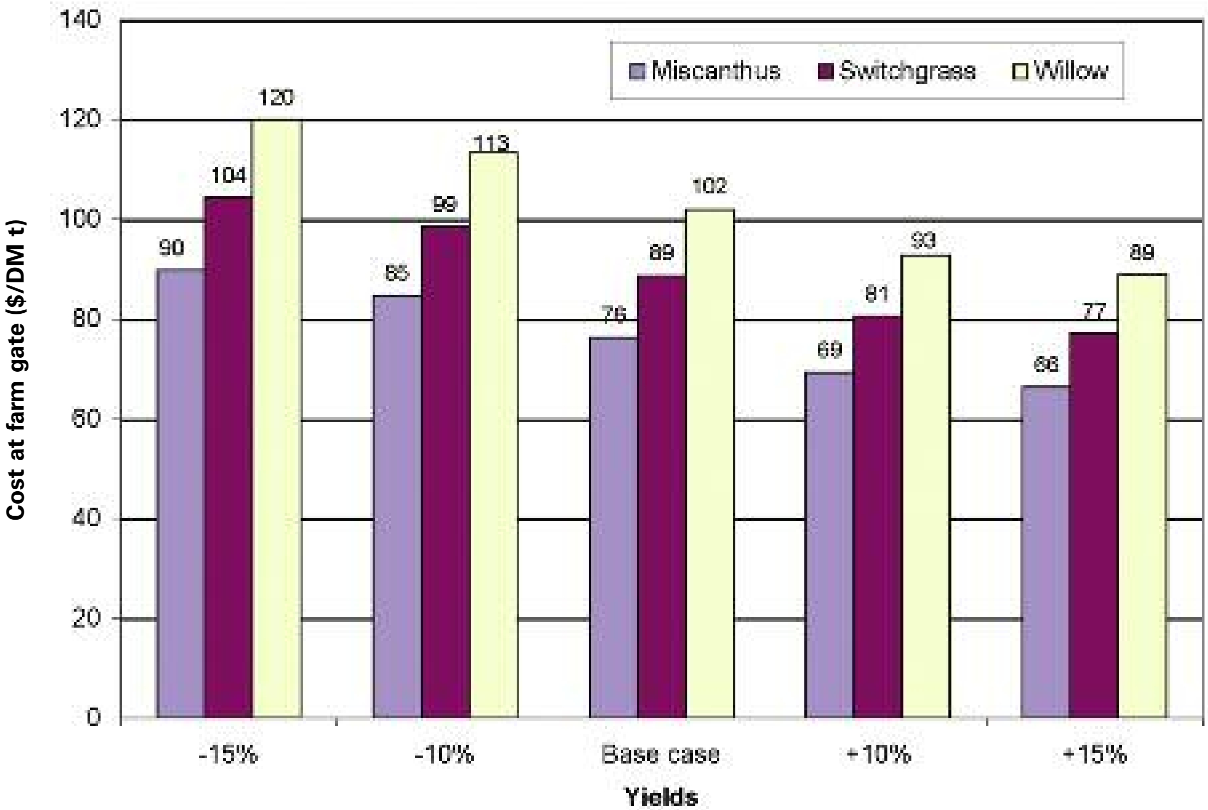
Processing Cost Items	Value
Storing and administration expenses ($/DM t)	4.50
Drying to 8% moisture content ($/DM t)	12.05
Grinding ($/DM t)	2.50
Briquetting ($/DM t)	14.00
Pelletizing ($/DM t)	23.00

Cost ($/GJ) of Different Forms of Biomass at OPG gate

	Grind	Briquette	Pellet
Growing	4.13	4.13	4.13
Harvesting	1.15	1.15	1.15
Processing	0.99	1.71	2.18
Transporting	2.34	1.63	1.53
Total	8.61	8.63	9.00

Economics of Energy Crops

Figure 4.8 Cost of Biomass at Farm Gate with Varied Yields



and results are shown in Figure 4.10. The cost of miscanthus pellets would increase from $7.28/ GJ to $8.07/ GJ if the gross margin of the farm is raised from $247/ ha to $494/ ha. At the farm gross margin of $494/ ha, the cost of switchgrass and willow pellets would be $9.50/ GJ and $10.42/ GJ, respectively at OPG's gate.

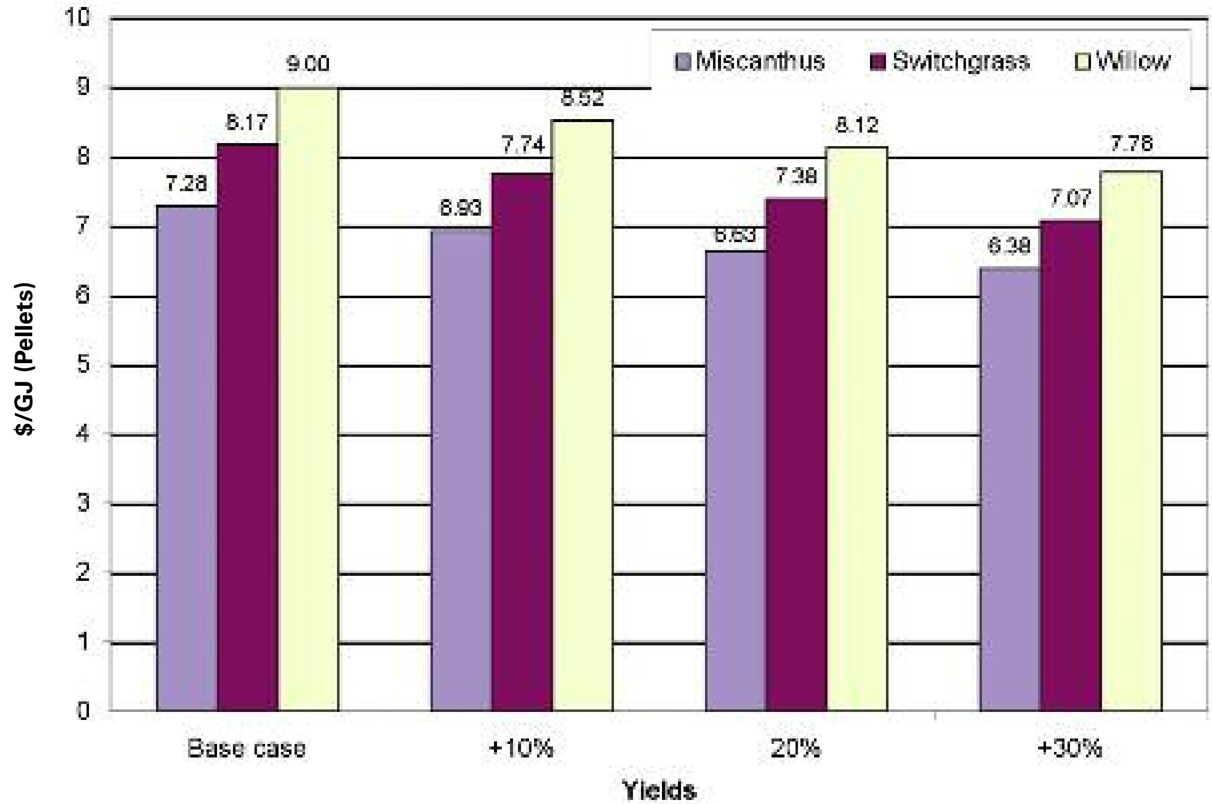
4.6 Cost of Biomass with Economies of Scale

All the cost estimates presented so far in this economic section are based on the assumption that plantation area of each energy crop is about 20,000 ha or total biomass production of about 700,000 DM t/yr. As with any other commodity/industry, there will be economies of scale associated with an increase in biomass production in all components of the supply chain, i.e. growing, harvesting, processing and transportation. An attempt was made to estimate the reduction in biomass cost due to the economies of scale.

Growing and harvesting components of the supply chain likely offer the least gain in economies of scale, especially for switchgrass. About one million hectares of agricultural land is being used to grow hay crops in Ontario, and switchgrass can be grown and harvested with existing equipment. However, economies of scale for miscanthus and willow could be greater than for switchgrass due to their establishment characteristics and requirement of specialized equipment. Depending on the crop, about a 5% reduction in unit cost of growing and harvesting could be expected for an increase in biomass volume of the energy crop industry by approximately 10 times.

Storage and processing components of the supply chain may offer greater economies of scale than growing and harvesting as the industry expands. As presented in Figure 4.4, no substantial gain is expected in increasing the size of central storage and processing facility beyond 150,000 t/yr capacity. In

Figure 4.9 Costs of Biomass Pellets at OPG Gate with Improved Yields



fact, further increase in processing capacity would likely result in higher overall cost of biomass due to increase in transportation cost from farms to the central facilities. Therefore, the gain in economies of scale with the storage and processing component are likely due to improvement in processing technology. This would include better management of silicon contents of the biomass and reduction in administration and management expenses. About a 10% reduction in unit cost of storage and processing can be expected when total volume of biomass from energy crops reaches 5 million DM t/yr.

Transportation is the supply chain component which may offer the greatest economies of scale. The gain could be mainly due to volume discounts that the transportation companies can provide. The economic consulting firm Global Insight reported that the gross margins of transportation companies could be as high as 30%. Therefore, about a 15% reduction in unit transportation cost can be expected, if total 5 million DM t/yr of biomass is shipped from the farms to the central stations to OPG's station.

In order to estimate the economies of scale of the energy crops, the following typical mathematical model is used in this study:

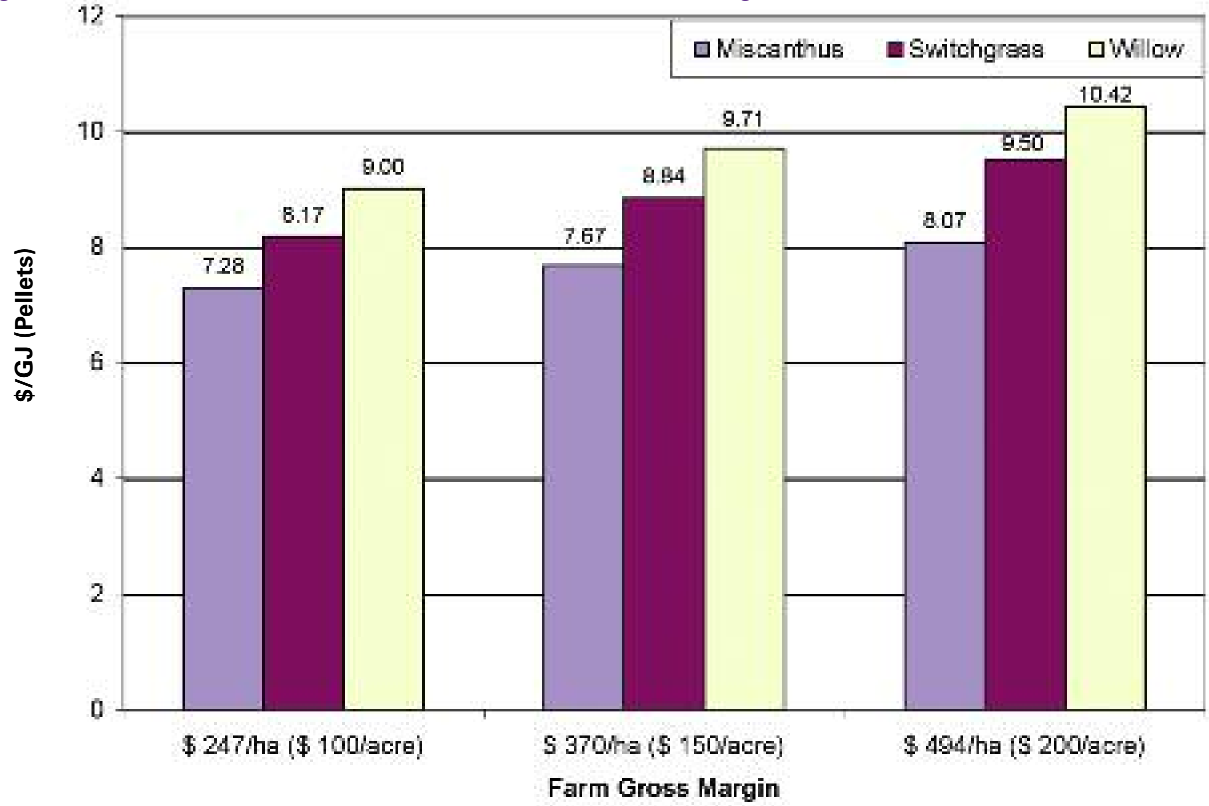
$$\mathbf{Y = K\ (X)^F}$$

where:

Y	= Total cost of production ($)
K	= Constant
X	= Biomass production (Mt/yr)
F	= Scale Factor

Typical range of scale factor F is 0.65-0.99, depending on the degree of economies of scale and the type of industry. Note that the lower the scale factor, the greater are the economies of scale, and the unit scale factor, i.e. F=1, means there are no

Figure 4.10 Costs of Biomass Pellets at OPG Gate with Varied Gross Margins



economies of scale. Based on the discussions above of the different supply chain components, the scale factors estimated for each energy crop are given in Table 4.7. Results of the economies of scale for the energy crops, by applying those scale factors, are presented in Figure 4.11 for miscanthus, in Figure 4.12 for switchgrass and in Figure 4.13 for willow.

The cost of biomass pellets with the economies of scale can be estimated for a given volume of biomass for each energy crop. As discussed in the supply chain chapter, the energy crop industry is expected to develop with a gradual adoption of energy crops by the farm operators. It will take time to reach the required volume of biomass, depending on the level of concerted efforts by all the key players of the industry. Considering the medium-term future, 1.25 DM t/yr of each energy crop is assumed to estimate the cost of biomass pellets with the applied economies of scale. Results for different yields are summarized in Table 4.8.

Table 4.7 Scale Factor (F) Estimates of Energy Crops

	Growing	Harvesting	Processing	Transportation
Miscanthus	0.97	0.98	0.95	0.93
Switchgrass	0.99	0.99	0.95	0.93
Willow	0.97	0.97	0.95	0.93

The costs of biomass pellets with applied economies of scale are also estimated for growing energy crops on more productive lands, classes 1-2. The objective was to determine the economics of energy crops on higher yielding lands, which also have higher land rental costs and gross margins. The results are given in Table 4.9 for all energy crops considered at different yields. It would cost more to grow switchgrass on more productive lands. Cost of willow pellets would be approximately the same for the biomass grown on marginal and productive lands. However, growing miscanthus on class 1-2 lands is more economic than growing on class 3-4 lands due to its significantly higher yield on productive lands. This means that there is potential for growing miscanthus on productive farmlands, even if the biomass is priced to be slightly more financially attractive than growing hay crops. About 37,000 ha of class 1-2 land is required to produce 1.25 millions DM t/yr of miscanthus. The positive aspect of using less land for miscanthus is that it helps maintain the biodiversity.

4.7 Renewable Energy Incentives

Different forms of renewable energy have attracted widespread interest from policy-makers, and incentives play an important role in financial feasibility of renewable energy projects. The incentives are granted by the governments as a measure to address the issues of energy security, climate change and rural economic development. A study conducted by REAP-Canada (Samson et al., 2008) for the BIOCAP Canada Foundation reported the incentives currently received by liquid transportation fuel producers are given in Table 4.10.

REAP-Canada suggested a renewable incentive of $4/GJ for biomass pellets to make the solid biomass fuel cost-competitive compared to other energy sources. As shown in Table 4.11, biomass targeted at replacing coal offers a significant advantage for reducing greenhouse gas emissions. Potential government incentives for biomass pellets can, therefore, considerably improve the economics of energy crops.

Table 4.8 Cost ($/GJ) of Biomass Pellets at OPG Gate for Class 3-4 Land

	Switchgrass			Miscanthus			Willow		
Yield (DM t/ha)	Base (10)	Imp. 1 (12)	Imp. 2 (14)	Base (16)	Imp. 1 (19)	Imp. 2 (23)	Base (9)	Imp. 1 (11)	Imp. 2 (13)
Growing	3.44	2.87	2.46	2.63	2.21	1.83	3.91	3.2	2.71
Harvesting	1.24	1.03	0.89	1.08	0.91	0.75	1.09	0.89	0.75
Processing	1.54	1.54	1.54	1.65	1.65	1.65	1.99	1.99	1.99
Transportation	1.52	1.52	1.52	1.39	1.39	1.39	1.35	1.35	1.35
Total	7.73	6.95	6.4	6.74	6.16	5.62	8.34	7.43	6.8

Assumptions: 1.25 million DM t/yr for each crop; Land rent: $ 247/ha, Gross Margin: $ 247/ha

Table 4.9 Cost ($/GJ) of Biomass Pellets at OPG Gate for Class 1-2 Land

	Switchgrass			Miscanthus			Willow		
Yield (DM t/ha)	Base (13)	Imp. 1 (16)	Imp. 2 (19)	Base (34)	Imp. 1 (41)	Imp. 2 (49)	Base (16)	Imp. 1 (19)	Imp. 2 (23)
Growing	5.26	4.27	3.6	2.15	1.78	1.49	4.14	3.49	2.88
Harvesting	0.95	0.78	0.65	0.51	0.42	0.35	0.61	0.52	0.43
Processing	1.54	1.54	1.54	1.65	1.65	1.65	1.99	1.99	1.99
Transportation	1.52	1.52	1.52	1.39	1.39	1.39	1.35	1.35	1.35
Total	9.27	8.1	7.31	5.7	5.25	4.89	8.1	7.34	6.65

Assumptions: 1.25 million DM t/yr for each crop; Land rent: $ 600/ha, Gross Margin: $ 500/ha

Figure 4.11 Expected Economies of Scale for Miscanthus Pellets

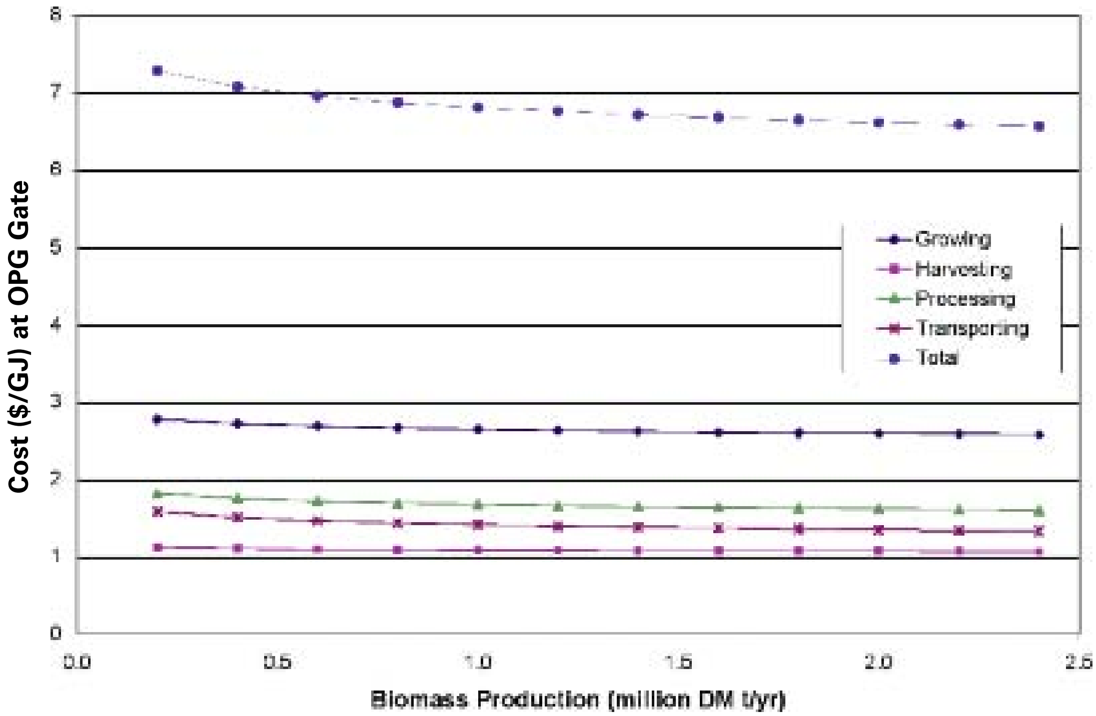
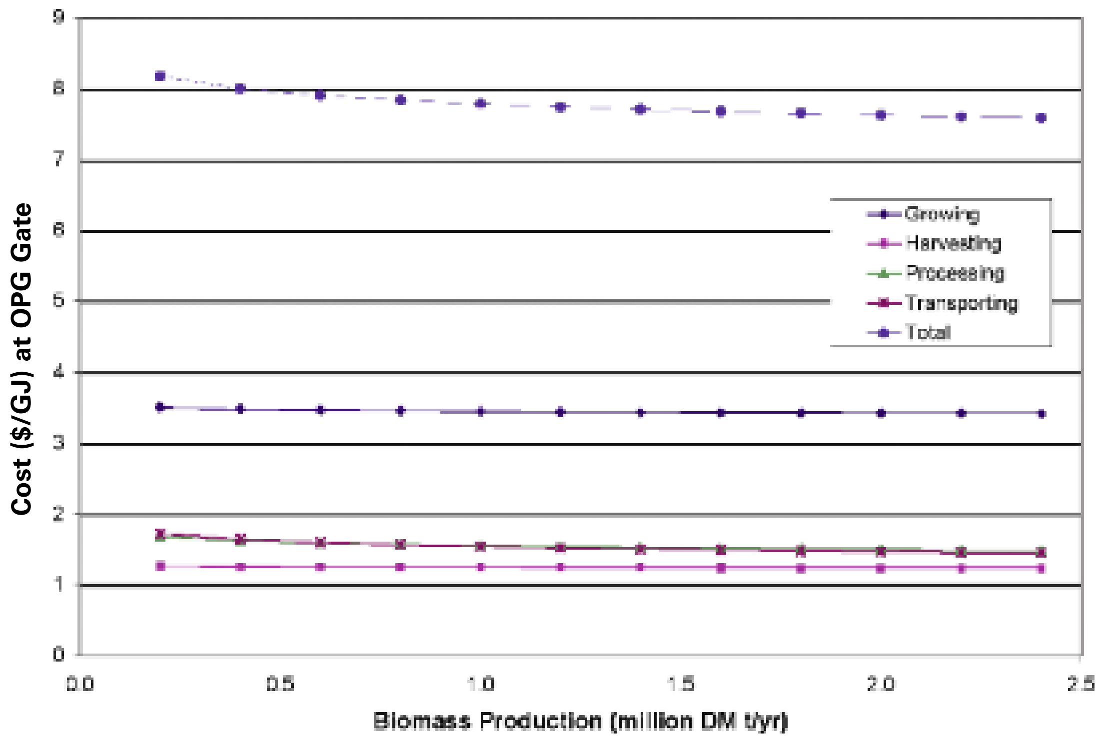


Figure 4.12 Expected Economies of Scale for Switchgrass Pellets



Economics of Energy Crops

Figure 4.13 Expected Economies of Scale for Willow Pellets

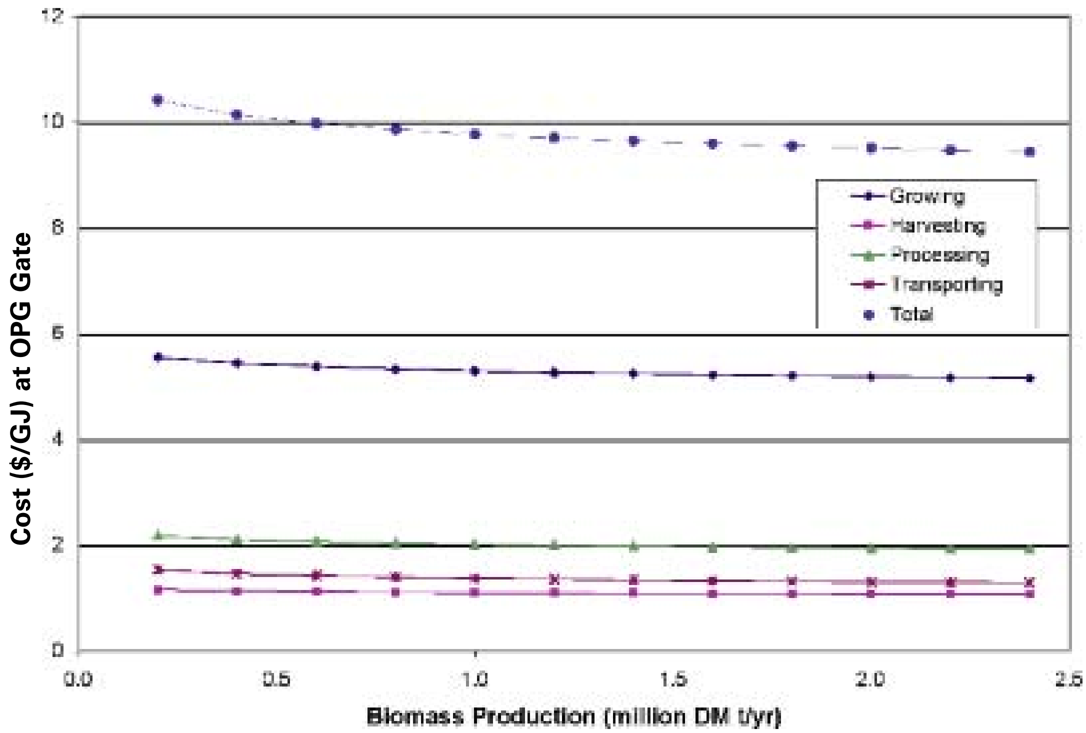


Table 4.10 Existing Incentives for Liquid Transportation Fuels

Renewable Energy	Incentives		Traditional Fossil Fuel Replaced	Net Offset (kgCo2e/GJth)	Cost of offset ($/t Co2e)
	$/L	$/GJth			
Canola biodiesel	0.2	5.61	Diesel	57.09	98.21
Corn ethanol	0.168	8	Gasoline	21.23	378.53

Source: Samson et al., 2008

Table 4.11 Incentive for Biomass Fuel Proposed by REAP-Canada

Renewable Energy	Proposed Incentive ($/GJ)	Traditional Fossil Fuel Replaced	Net Offset (kgCo2e/GJth	Cost of offset ($/t Co2e)
Biomass pellets	4.00	Coal	82.94	48.26
		Oil	77.73	51.5
		LNG	61.79	64.8
		Natural gas	47.40	84.56

Chapter 5

Potential Issues in Agriculture and Politics

5.1 Food Versus Fuel Debate

Food versus fuel is an issue related to the use of food crops for biofuel production and its impact on global food supply. The food versus fuel debate could easily extend to the use of agricultural land for energy crops. There was an intense international debate in 2008 when a significant jump in food prices coincided with increased use of corn for ethanol, especially in the US. There are valid arguments from both sides of the debate. This study examines those arguments and supporting data to determine an appropriate approach for OPG to take on the issue.

A strong argument by the food and fuel proponents is that the agricultural sector can provide both food and fuel because of increasing crop yields due to improvements in agricultural knowledge, farming techniques and genetic engineering. Figure 5.1 shows the yield growth of corn over time with a remarkable increase recently. It seems that farmers have been able to double their yields every 30 years, and similar increases could be expected for all major field crops. Yield data for corn in Ontario is presented in Figure 5.2 with the nominal and inflation-adjusted prices. Due to significant improvement in crop yield, the price of corn in inflation-adjusted terms is decreasing over time. Crop yields are expected to increase further in future, and the decreasing price of grains could negatively affect the viability of the Ontario agricultural sector, which is a major industry from economic and food self-sufficiency perspectives.

If about 15% of agricultural land in Ontario is converted to energy crops, grain prices should not increase significantly,

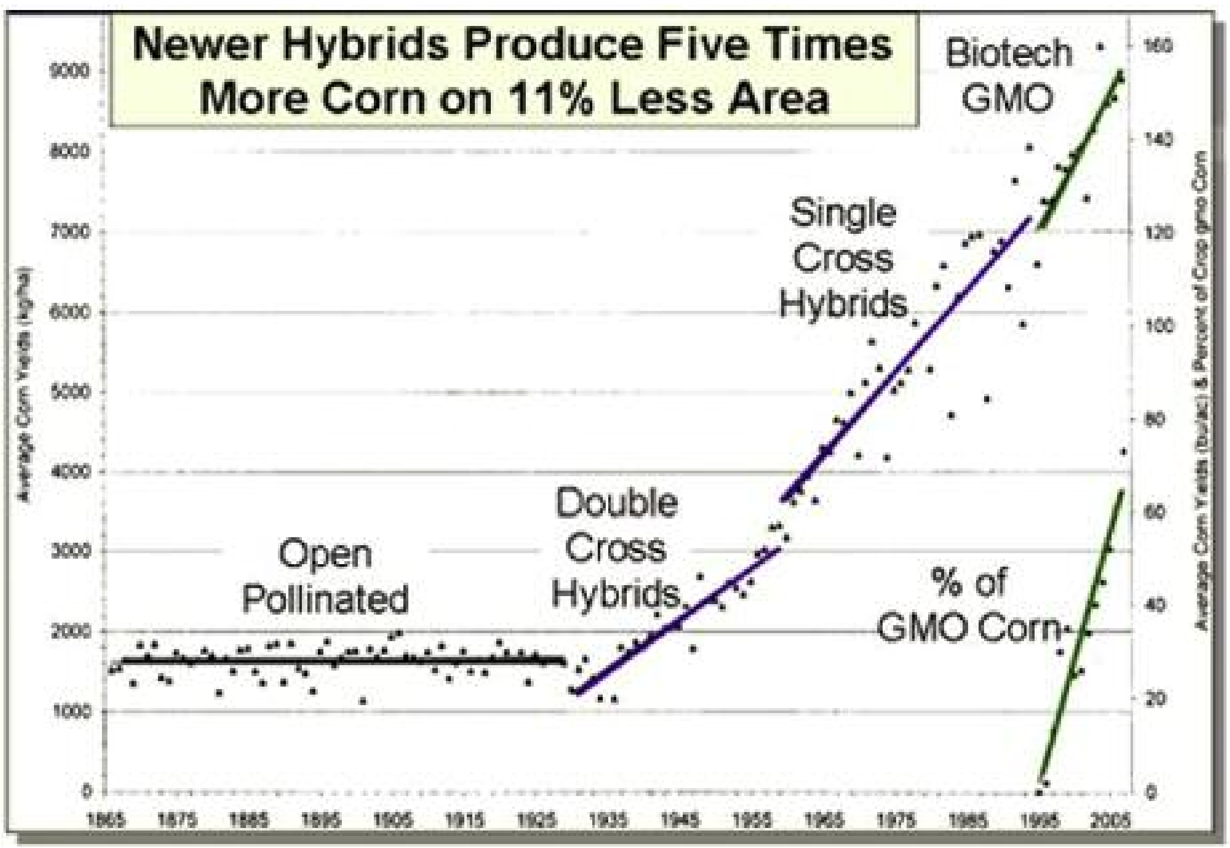
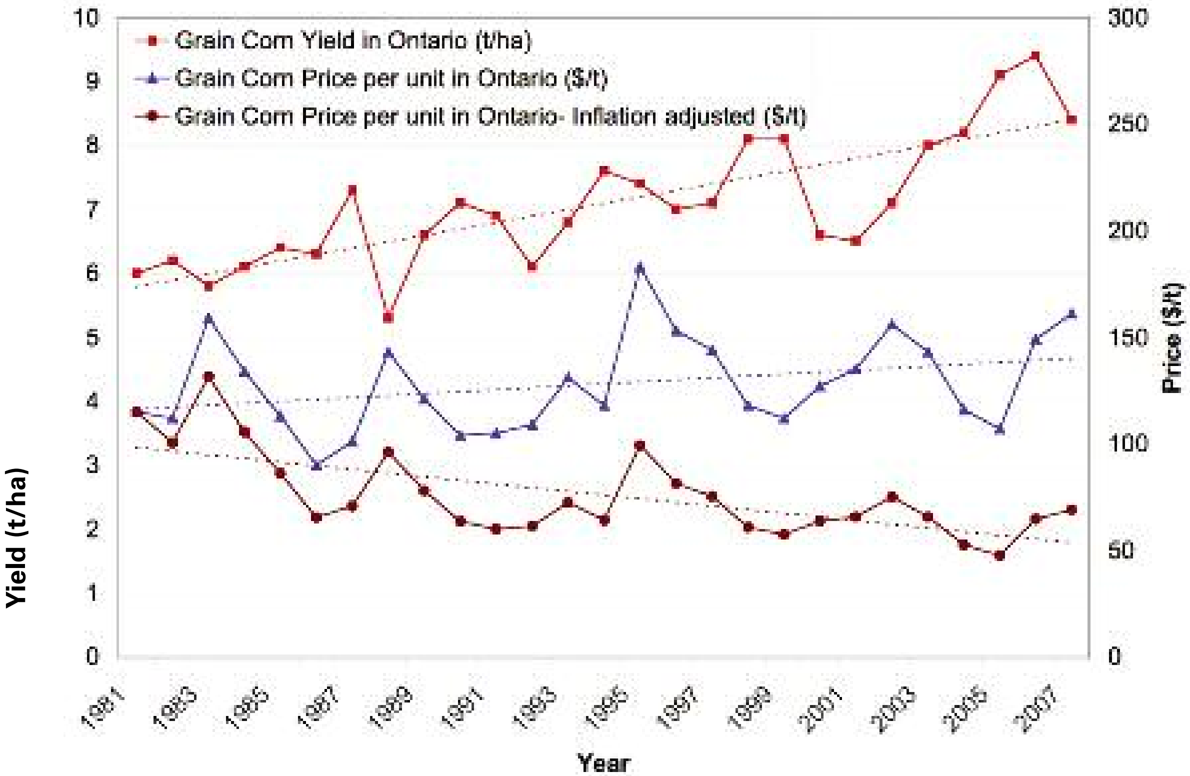


Figure 5.1 Yield Growth of Corn (Source: Ontario Federation of Agriculture)

Figure 5.2 Grain Corn Yield, Nominal and Inflation Adjusted Corn Prices



(Source: OMAFRA and Statistics Canada)

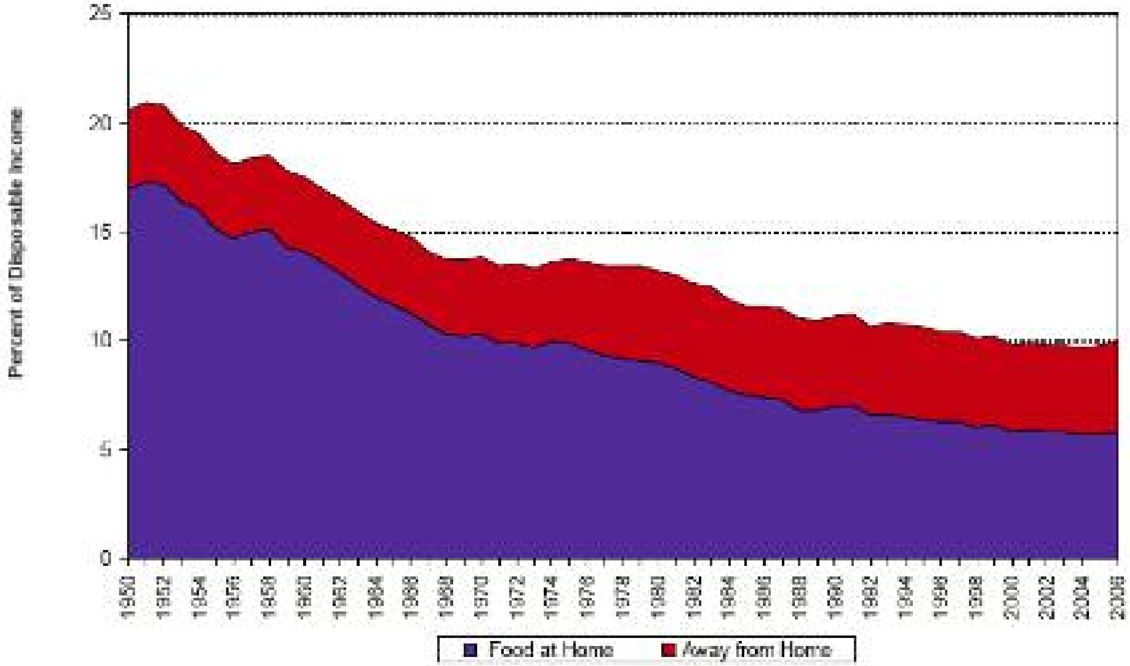
given expected improvements in crop yields. The share of commodity raw materials, or farm value, is only 19% of total food costs are the farm value at present, compared to about 37% in 1973 (source: USDA, Economic Research Service). The marking bills, which include labor, packaging, transportation, energy, advertising, profit, depreciation, business tax, etc., represent over 80% of the total food costs. A similar proportion of farm value and marking bills can be expected in Canada. For instance, a loaf of bread in Canada currently costs about $2.50. The amount of money that farmers receive for wheat to make a loaf of bread is only 5-6 cents (McDonald and Stewart, 2008). If the price of wheat increases by 50%, the farm value will increase from 5-6 cents to 7-9 cents. This should not impact the price of bread considerably.

Any increase in food prices due to utilization of some of the agricultural land for energy crops should also have a minimal social impact in North America. Figure 5.3 illustrates the decreasing portion of disposable income spent on food, with 21% in 1950 compared to 10% in 2007. This percentage of expenditure on food is also applicable to Canada. The Ontario Federation of Agriculture stated that February 12 is food freedom day, i.e. average Canadians have earned enough money on that day to pay for food bills for the year.

Based on the discussions and data presented above, this study concluded that Ontario's agricultural sector can supply both food and fuel in a sustainable manner with minimal, if any, negative social and economic impacts. Energy crop development in Ontario, in fact, would improve the rural economy and ensure the viability of the agricultural sector. A declining cattle industry, as shown in Table 5.1, also makes lands being used for hay production available for energy crops, thereby providing business diversification to farmers. Another side of food versus fuel debate, however, argues from the global perspectives of growing populations and hunger in many parts of the world, which could be due to many global factors including food and wealth distribution. Therefore, food versus fuel activists call using food for fuel "unethical", and the United Nations and Food and Agricultural Organization (FAO) have accused the U.S. and the European Union of having taken a "criminal path" in using food in ethanol production[1].

Assessment of this study is that the food versus fuel debate will continue, although not as intensely as in 2008, when food prices reached their peaks. Less productive agricultural lands are not expected to come under the same political scrutiny. The establishment grants for energy crops provided by the government of the UK are only for set-aside lands, which are not in the

Figure 5.3 Consumer Food Expenditure as Percentage of Disposable Income



(Source: USDA, Economic Research Service)

food chain. The cost of biomass from the less productive farmland should be, in general, more competitive for OPG. In the meantime, OPG should engage organizations like OMAFRA and the OFA for educating the general public on benefits of acquiring both food and fuel from the agricultural sector.

5.2 Management of Intellectual Property in Energy Crop Industry

Plant breeding is a sophisticated and high investment business and recent scientific and genetic technological development has allowed a greater rate of improvement. The constant aim of plant breeding in the energy crop industry is to increase biomass yields, to improve drought and pest resistance and to enhance the fuel quality. Plant breeding involves long-term research and development with major investment in people, technology and facilities and no guarantee of success. Plant breeders are awarded a form of intellectual property (IP) on each successful new variety through an internationally agreed system of plant breeder's right. Licensing the use of breeder's IP, through seed or planting materials production, allows the royalties to be collected on seed or planting material sold. There are two alternative ways of collecting the IP fees:

- The royalty fee is included in the sale of seeds or planting materials and additional fees are collected for new planting of farm-saved seeds or planting materials. The royalty fee in this alternative is a one-time fee for all new plantations.
- The royalty fee is collected as a percentage of total revenue for every harvest.

Most switchgrass varieties currently grown in North America are native species with no IP owners. However, new genetically modified varieties with high yield claims are expected to come to the market in the near future. In contrast, most varieties of miscanthus and willow SRC are genetically modified and owned by breeding companies. BiCAN, the miscanthus crop developer in Ontario, stated that only a one-time royalty fee would be charged to farm operators for the strains BiCAN has the right to propagate in Canada. SUNY-ESF, the willow breeder in the US, charges the royalty fee of 4% of total revenue at every harvest for the willow varieties it developed[3].

When growing energy crops, farm operators are required to comply with national laws related to IP rights. Non-compliance of the farm operators, who are supplying biomass to OPG, could have a legal impact, although remote, on OPG. As a due diligence measure, OPG should consider a similar practice of Wal-Mart stores, which buy flowers and plants from the nurseries for resale to the general public. The following statements are included in standard Wal-Mart supplier agreements[4]:

"All Vendor Partners shall comply with the legal requirements and standards of their industry under the national laws of the countries in which the Vendor Partners are doing business."

"Vendor Partners shall warrant to Wal-Mart that no merchandise sold to Wal-Mart infringes the patents, trademarks or copyrights of others and shall provide to Wal-Mart all necessary licenses for selling merchandise sold to Wal-Mart which is under license from a third party to protect intellectual property rights in the United States or elsewhere."

Wal-Mart reserves the right of inspection to assure the compliance of suppliers with the standards, and performs regular inspections. For energy crop development, a due-diligence statement on compliance of the farm operators with energy crop IP regulations should be included in biomass supply contracts. Suppliers should be required to produce supporting documents on a regular basis. Those measures should be sufficient for OPG in managing the energy crop IP.

5.3 Management of Latest Energy Crop Varieties

Tinplant, the German company, has spent about 15 years in research and breeding of over 1,000 miscanthus varieties. There are about 20 switchgrass native varieties, and new genetically modified species are being developed. Over 200 varieties of willow SRC are available globally for bioenergy use. More and more energy crop varieties will be developed in the search for higher yields, greater drought and disease resistance and better fuel quality. Keeping abreast of the latest energy crop varieties would be a formidable task for an end-user like OPG. Common practices of managing the new crop varieties are examined in this study with the aim of identifying a suitable approach.

In the UK, the forestry commission, a government organization, maintains a list of recommended willow SRC varieties, which have been through field trials to ensure high yields, erect growth habits and resistance to, or tolerance of, diseases. The list is updated as the information on new varieties becomes available and provides useful sources of information when selecting the willow planting materials (DEFRA, 2002). Similar service is provided for miscanthus by the DEFRA's Plant Health Division (DEFRA, 2007). The practice in Canada for managing new varieties of grains, e.g. corn, soybeans, etc, is that the Canada Grain Commission controls the licensing of new varieties of grains[5].

Therefore, a government organization, such as OMAFRA, should manage the latest energy crop varieties to ensure no negative impacts on agricultural lands and the environment. OPG should work closely with the farm organizations and the agricultural entities so that the best energy crop varieties, in terms of fuel quality and disease resistance, are deployed as the industry advances. The latest development in energy crop plantations is that mixed varieties, instead of one strain, are planted in a given plot for biodiversity benefits and better disease control. At the time of this study, following are the

Table 5.1 Numbers of Cattle (Millions) on January 1st of the Year

Year	Canada	Ontario
2003	13.47	2.09
2004	14.56	2.13
2005	14.93	2.05
2006	14.66	1.98
2007	14.16	1.9
2008	13.9	1.88
2009	13.18	1.7
% Decrease (2003 – 2009)	**2.1**	**18.4**

(Source: Statistics Canada)

[1]http://www.globe.ca/communications_globe_net.cfm

varieties planted in Ontario and nearby regions by the research organizations and the commercial growers:

- Miscanthus
  - *Miscanthus x giganteus* varieties from University of Illinois and Europe
  - *Miscanthus Sinensis*: Amorui and Nagara
- Switchgrass
  - Cave-in-rock
  - Tecumseh
- Willow SRC
  - SX series from State University of New York (SUNY-ESF)
  - Other varieties, such as Sherburne, Otisco, Viminalis, Alpha, Hotel, Accute, etc, planted together with SX series

5.4 Timelines for Energy Crop Plantations

If the biomass from energy crops is chosen by OPG to replace coal at OPG's generation stations for electricity generation, the biomass fuel should be available in early 2015 to comply with the current Ontario government's requirement. It takes 3-4 years for energy crops to reach mature yields after the establishment and no biomass is expected in the first year for miscanthus and switchgrass. For willow SRC, the first harvest is four years after planting. This study examined the availability of seeds and planting materials in Ontario and the nearby regions and farming capability to determine the timelines for the energy crop development so that biomass required by OPG will be delivered in 2015 and beyond. Based on personal communications with Nott Farms, Pyramid Farms, LandSaga Biogeographical and researchers at the University of Guelph, cumulative plantation areas of energy crops and available biomass are presented in Table 5.2. These estimates are derived from the currently available seeds and planting materials, and do not consider the potential slow adoption rates of the farmers at the beginning of the energy crop development.

As seen in Table 5.2, the plantations should start in 2010 in order to produce biomass required by OPG in 2015 and beyond. This would require concerted efforts by OPG, farm cooperatives, pellet mill operators and agricultural organizations in contract development, preparation of seeds and planting materials, acquisition of farm equipment, building the pellet mills, etc. Information dissemination in the agricultural community on energy crop development is also extremely important to accelerate the initial adoption. The assessment of this study is that the timely development, i.e. to meet the deadline of replacing coal with energy crop biomass in 2015, of energy crops in Ontario would be an ambitious task. However, it could be possible with the collaboration of all the stake-holders. Agricultural residues represent an interim opportunity to fill the gap where energy crop development may fall short. This opportunity requires further investigation.

Table 5.2 Timelines for Energy Crop Plantations

		2010	2011	2012	2013	2014	2015	2016
	Cumulative plantation ('000 ha)	2	40	100				
	Biomass (Mt)				0.4	1.1	1.4	1.6
Switchgrass	Cumulative plantation ('000 ha)	3	40	160				
	Biomass (Mt)				0.3	1	1.4	1.6
Willow	Cumulative plantation ('000 ha)	2	60	120	180			
	Biomass (Mt)						1.6	1.6

Assumptions:

- Plantations in 2010 are for propagation in the following year
- Miscanthus and switchgrass produce 60% of mature yield at the first harvest
- Miscanthus and switchgrass produce 80% of mature yield at the second harvest
- Mature yields (DM t/ha/yr): 16 (miscanthus), 10 (switchgrass), 9 (willow)

[3]http://www.doubleawillow.com/
[4]http://walmartstores.com/Suppliers

Chapter 6

Summary, Conclusions and Recommendations

This report examines the feasibility of developing a sustainable energy crop industry in Ontario to supply biomass and replace coal at OPG's generating stations. A number of energy crops were investigated to evaluate their suitability for commercial development and large-scale biomass-fired power generation at OPG. The current state of Ontario's agricultural sector was examined in terms of land availability, the gross margins of different land classes and potential adoption of energy crops. Components of the energy crop supply chain were assessed and potential suppliers were evaluated. Costs of biomass ($/GJ) from energy crops were estimated with a detailed breakdown of the costs associated with growing, harvesting, processing and transportation. Expected economies of scale for each energy crop were also determined. Potential agricultural and political issues related to development of the energy crop industry were also explored. The energy crop study answers 11 questions outlined by OPG for this study. The summary findings, conclusions and recommendations specific to these questions are included. General recommendations are also provided at the end of this section.

6.1 Summary of Findings, Conclusions and Recommendations

i. Description and Identification of Energy Crops

This study investigated miscanthus, switchgrass, native perennial grasses, sudangrass, sudan-sorghum, poplar and willow as potential energy crops for cultivation in Ontario. Miscanthus, switchgrass and willow SRC were identified as energy crops with the greatest potential for commercial development for combustion purposes. These perennial crops are the most widely studied and grown energy crops in the world and offer soil improvement through their massive permanent root systems. No serious diseases associated with the identified energy crops have been reported to date.

The most promising miscanthus varieties potentially grown in Ontario in the coming 1-2 years are *giganteus* clones from Illinois and Europe and *sinensis* clones Amorui and Nagara. For switchgrass, the native Cave-In-Rock and Tecumseh are likely suitable varieties and a few new varieties are expected to be introduced in the near future. For willow SRC, the SX series from the State University of New York are the high yield varieties and are expected to grow well in Ontario. The SX series is usually grown with other varieties such as Sherburne, Otisco, Viminalis, Alpha, Hotel, Accute et cetera.

The ideal strategy for large-scale commercialization of energy crops in Ontario should include a mix of different energy crops. Miscanthus, switchgrass and willow are preferred as the most significant portion of the energy crop fuel mix in terms of quantity. Native perennial grasses and agricultural residue would also contribute to the mix. This would reduce the risk of disease or pest outbreak associated with a particular energy crop. The mixed energy crops also provide greater biodiversity, minimize the fluctuations in biomass supply and spread out harvests more evenly in a given year.

ii. Chemical Characteristics of Energy Crops

Willow SRC offers the best quality fuel in comparison with herbaceous grasses, miscanthus and switchgrass. As a woody biomass, willow has lower ash content (1.1%) and associated minerals and a higher ash fusion temperature (1380-1500° C). Miscanthus and switchgrass have a higher sintering potential in boilers since their ash fusion temperature is 1000-1100° C. Miscanthus and switchgrass contain 1.5-5% ash but offer lower moisture content (8-20%) in comparison with willow, which has a moisture content of about 50% at harvest.

Mineral content of miscanthus and switchgrass can be significantly lowered by harvesting in spring or mowing in fall and baling in spring. These practices not only return the nutrients to the soil but also leach minerals from the biomass, improving the fuel quality. Comprehensive fuel performance testing of energy crop biomass would be required to determine the technical feasibility of 100% conversion from coal to biomass at OPG's generating stations.

iii. Impact on the Environment

All perennial energy crops reduce greenhouse gases through carbon sequestration and provide soil improvement by increasing organic matter. They require much less use of herbicides in comparison with annual crops, reducing the risk of ground water contamination with agro-chemicals. The extensive root system also helps to prevent soil erosion and improves soil quality through increased water infiltration and nutrient-holding capacity. Rotating the perennial energy crops with other field crops is expected to increase yields of subsequent field crops due to the improved soil. Energy crops provide over-wintering sites for birds, small-mammals and invertebrates as well as biodiversity benefits. The tall grass prairies programs, which establish a mix of dozens of native perennial grasses on ecologically significant lands, also provide environmental benefits in terms of biodiversity, natural habitats and potential increased bee populations.

Miscanthus, switchgrass and willow SRC are not considered invasive species based on the commercial experiences in the U.S. and Europe. All energy crops could develop pests and diseases at certain weather and environmental conditions. However, based on extensive experience dating as far back as the mid 1970s in Europe, the forms of pests and diseases that have been seen are easily mitigated and do not appear to have significant affect on the yield of the biomass. Miscanthus and willow SRC can create significant visual impact due to their heights.

iv. Land Classes and Gross Margin Expectations

The Canada Land Inventory System classifies agricultural soils into seven groups, according to their potential and limitations in growing common field crops. The first three classes are considered capable of sustained production of cultivated field crops and are considered prime agricultural land resources. The fourth class is marginal for cultivated field crops. The fifth is capable of hay production and permanent pasture use. The sixth is capable of sustaining unimproved pasture only and the seventh class has no agricultural capability.

For growing fruits and vegetables, i.e. the best of class 1 soil, farmers in Ontario have gross margin expectations of \$1,480–\$1,730/ha. Food crops on productive land, i.e. class 1-3 soils, provide a gross margin of \$245–\$490/ha. Food crops grown on less productive lands provide a gross margin of about \$245/ha. Tame hays grown on less productive lands generate a gross margin of about \$100/ha.

v. Yield Estimates of Energy Crops

Due to the infancy state of the energy crop industry in Ontario, the yield data of energy crops is very limited, especially for different land classes. Yield data from research plots is normally significantly higher than from the commercial plantations. This is because of greater care provided to the small research plots and the better soils on which agricultural research institutions are usually located.

Yields of energy crops were estimated considering the yield data available in Ontario and nearby regions, the yield ratio between the research and commercial plots, the yield ratio between the good and poor soils and projections by commercial growers in Ontario. Miscanthus is the highest yielding energy crop with 34 DM t/ha on class 2 soil, 16 DM t/ha on class 3-4 soil, and 8 DM t/ha on class 5 soil. Yield estimates of switchgrass are 13 DM t/ha on class 2 soil, 10 DM t/ha on class 3-4 soil, and 8 DM t/ha on class 5 soil. Willow SRC is expected to yield 16 DM t/ha on class 2 soil, 9 DM t/ha on class 3-4 soil, and 5 DM t/ha on class 5 soil. Genetic advances in energy crops are likely to improve the yields by 20% per generation.

vi. Land Availability and Potential Biomass Production

Ontario has a total of 5.4 million ha of agricultural land. Hay crops are grown on over one million ha. Currently almost all arable lands in Ontario are being used for food crops or tame hays. Based on the gross margin of hay crops, it is assumed that lands used for hay production are less productive lands. On provincial average, conversion of about 32% of hay land to energy crops is considered. About 15%, on provincial average, of field crop land is also considered less productive land and is suitable for conversion to energy crops. The conversion rates are actually estimated individually for each Ontario census region in this study considering the land use and farm economics of the specific region. Total land available for energy crops is estimated at 783,000 ha, which is about 15% of agricultural land in Ontario.

Converting this land to energy crops would sustainably produce 8.75 million t/yr of energy crops, based on conservative yield estimates. To estimate the biomass production capacity, yields of energy crops on class 3 and class 4 soil were used. It was also assumed that equal shares of each of the three energy crops (miscanthus, switchgrass, and willow) would be established. There is also the potential for some prime land conversion to high-yielding energy crops, most likely miscanthus. Conversion of 37,000 ha of prime land, through the use of miscanthus as a rotational crop, could result in the production of an additional 1.25 million t/yr. Crop residues are also a significant contributing source of biomass in the proposed fuel-mix, and their inclusion would increase substantially the total sustainable supply of biomass in the province. The impact of converting 32% of Ontario hay land to energy crops on the hay price would be minimal, since Ontario produces about 5 million tons of hay annually, whereas total hay production in North America is about 160 million tons per year.

vii. Assessment of Supply Chain

The energy crop study examined production, storage, processing and transportation as major supply chain components. However, the most important component of this chain is a number of processing facilities located across Ontario, consisting of 150K t/yr pellet mills. It takes about 13 months from the start of construction, i.e. after the permit obtained to build, for the central processing facility to reach the production stage. Year-round fuel requirement by OPG calls for drying of biomass to about 8% moisture content to minimize the dry matter losses during storage. The biomass also needs to be densified in order to reduce the overall transportation cost. The central processing facility will also act as an aggregator, contracting the biomass from several hundreds of small-producers increasing the long-term security of biomass supply to OPG. It provides OPG with quality control assurances and compliance with IP rights.

The mills would source biomass from a mix of about 60-80% energy crops and the remainder from a combination of various agricultural residues and native grasses. The advantage of a pelletized mix of biomass fuel compared to coal is that OPG would have the flexibility to specify and change fuel quality through adjustment of the pellet blend. Use of a diverse mix in the pellet, which could include municipal sources of biomass in addition to the above-mentioned agricultural sources, would help to diversify participation across large segments of Ontario's population. Therefore, economic benefits would not be limited to only rural and agricultural communities.

Another critical component of the supply chain is the development of biomass feedstock. Ontario farmers are interested in growing energy crops to diversify their agricultural production. However, adoption of energy crops could be challenging. Currently there is a minimal quantity of energy crops planted in Ontario. The substantial economic benefits of energy crop adoption would be the most significant driving factor in the growth of this industry. With proper planning, contract development, dissemination of information and collaboration between various stakeholders, the energy crop industry has the potential to develop to meet OPG demands by 2015. However, for all of these energy crops to reach mature yields, a minimum of three years would be required from initial establishment. Furthermore, large-scale planting would be required in 2010 to achieve the adequate propagation feedstock to plant hundreds of thousands of hectares of these crops by 2015.

In regards to transportation logistics, there are no major issues at the macro level, since Ontario produces more than 50 million tons of agricultural products every year and exports to the U.S. and other parts of Canada. Marine shipping of biomass would be the preferred mode of transportation, considering the existing fuel handling facilities at OPG stations, local traffic congestion and the marine infrastructure in Ontario.

viii. Assessment of Potential Suppliers

A number of farm organizations and private firms in Ontario are interested in supplying biomass to OPG. A request for expression of interest produced by OPG has also attracted significant biomass supply proposals. The farm cooperative supplier model, in which a number of producers of energy crops collaborate on the supply of biomass, was identified as a suitable model for the required biomass volume. Another suitable model is the crop developer supplier model, in which the energy crop developer produces and/or buys biomass fuel for sale to the customers such as OPG. Advantages of these two supplier models include fewer supply contracts to handle, the possibility to develop a comprehensive quality control system, reduction in overall cost of biomass and timely deployment of the latest energy crop varieties.

The standard marketing contract is the innovative option and worth exploring in consultation with farm operators. Due to the volatility of the grain prices experienced in recent years, farmers are concerned that they would miss future grain price increases after crop lands are converted to the energy crops. Linking a portion of energy crop supply to the spot prices of mixed field crops would reduce the risk perceived by the farmers in adoption of energy crops.

Major energy crop breeding companies, which are not likely direct suppliers to OPG, are important players in the biomass supply chain. Ceres, Mendel Biotechnology, Monsanto, Performance Plants Inc., and the State University of New York have been identified as potential suppliers of energy crop varieties. A number of farm cooperatives in Ontario are expected to supply the majority of the biomass required by OPG. The OFA could take the role of facilitator for its member cooperatives in producing and supplying biomass. The OFA has a strong influence on local, provincial and federal governments regarding agricultural and rural affairs. It has expressed interest in formation of an energy crop growers group to effectively disseminate the energy crop related information and handle public relations issues. Other potential suppliers identified in this study are: Show Me Energy Cooperative, BiCAN, Ecostrat Inc., Nott Farms and tall grass prairies programs.

ix. Economics of Energy Crops

Total cost of biomass was estimated by combining the costs associated with growing, harvesting, storage, processing and transportation. Miscanthus pellets offer the most competitive cost at $7.28/GJ at OPG's gate. Switchgrass pellets and willow pellets costs are $8.17/GJ and $9.00/GJ, respectively, at OPG's gate. These cost estimates are based on the farm cooperative purchase of seeds and planting materials in bulk.

The reduction in cost of energy crop biomass was also estimated, based on the expected economies of scale as the industry advances. The cost of miscanthus pellets could be reduced to $6.74/GJ at OPG's gate. The cost of switchgrass pellets and willow pellets with expected economies of scale is $7.73/GJ and $8.34/GJ, respectively, at OPG's gate. The supply volume of 1.25 million tons from each crop was assumed for these cost estimates. Inclusion of agricultural residues in the pellet mix could also contribute to further price reductions.

All cost estimates of the biomass from energy crops are based on the assumption of utilizing the less productive farmlands, which have a land rent cost of $247/ha and gross margin of $247/ha. The yields of energy crops on class 3-4 soil are used in calculating the cost of growing energy crops. Growing miscanthus on class 1-2 soil is more cost competitive due to its substantially higher yields on good soils. Therefore, there is a potential that some class 1-2 soil would be converted to miscanthus. About 37,000 ha of class 1-2 land would be required to supply 1.25 million tons of miscanthus pellets to OPG. For switchgrass and willow, effective biomass pricing could limit these energy crops to less productive lands only.

x. Identification of Potential Issues in Agriculture, Politics and Other Areas

In considering the food versus fuel debate, findings of this study are indicative of the fact that Ontario's agricultural sector can sustainably produce both food and fuel. Through improved agricultural practices and genetically modified crops, farmers in Ontario have been able to double their production yields every 30 years. This trend is expected to continue and accelerate in the coming years due to the rapid development of various technologies related to agricultural production. The fuel-mix proposed in this study includes biomass produced through the tall-grass prairies program. This would facilitate expansion of an ecologically beneficial program that could increase bee populations, resulting in enhanced food production. The food versus fuel debate will likely continue from a global perspective, although not as intensely as in 2008 when food prices peaked.

As a due-diligence measure in managing the intellectual property issue in the development of energy crops, a compliance statement from farm operators with energy crop IP regulations should be included in biomass supply contract. Suppliers should also be required to produce the supporting documents on a regular basis. To ensure the timely deployment of the latest energy crop varieties, OPG should engage organizations such as OMAFRA for testing and recommending the new varieties suitable for Ontario as they become available. The timelines for planting energy crops are relatively tight to supply the biomass required by OPG in 2015. Planting should start in 2010 in order to achieve the required supply volume. This would require concerted efforts by OPG, farm cooperatives, pellet mill operators and agricultural organizations in contract development, information dissemination, preparation of seeds and planting materials, acquisition of farm equipment and building of pellet mills.

xi. Feasibility of Development of Energy Crops

It is feasible to develop the energy crop industry in Ontario to supply the biomass fuel required by OPG. The development of the energy crop industry would improve the rural economy and ensure the long-term viability of the agricultural sector in Ontario. Reduction in greenhouse gases would be substantial due to the renewable nature of biomass from energy crops. Ontario farmers are interested in growing energy crops to diversify their agricultural production. The declining cattle industry in Ontario also makes some hay lands available for energy crops. The storage and processing facilities can be developed in a reasonable time. The required transportation infrastructure exists in Ontario.

The costs of biomass pellets from energy crops seem competitive to the long-term average costs of traditional fossil fuels other than coal. The proposed feed-in tariff for electricity from renewable energy sources could also make the biomass more attractive than the fossil fuels. Collaboration between OPG and farm cooperatives, agricultural organizations, energy crop developers, pellet mill operators and government organizations would be extremely important in timely development of the energy crop industry.

6.2 General Recommendations

In order to obtain the required biomass volume in 2015, OPG should initiate biomass contract development with potential suppliers in the near future so that plantations can start in 2010. Total biomass demand should be met by mixed energy crops, mainly by miscanthus, switchgrass and willow SRC, native perennial grasses and agricultural residues.

OPG should engage agricultural organizations such as OFA and OMAFRA and other stakeholders for information dissemination, commercial demonstrations of energy crop farms and processing facilities, and other public relations issues such as environmental impacts of biomass combustion and food versus fuel debate.

Due to a tight timeline to develop the energy crop industry in Ontario to meet the biomass demand by OPG in 2015, utilization of agricultural residues as supplement biomass fuels should be explored. The study should investigate available biomass volume without affecting the soil quality, fuel characteristic of residues, economics of residues and environmental impact.

Emission of fine particles from biomass combustion would be an environmental concern in replacing coal with biomass at OPG generating stations. The advantage of large-scale combustion facilities operated by OPG is that they can economically implement mitigation options. Emission characteristics of energy crop biomass should be studied, and mitigation options such as electrostatic precipitator technology should be investigated.

A full life-cycle analysis of electricity generation at OPG generating stations using biomass from energy crops should also be undertaken. Such a study, in comparison with traditional fossil fuels, should provide a comprehensive social, economic and environmental feasibility assessment of biomass-fired power generation.

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Appendices

Energy Crop Study

A feasibility study is required to evaluate the suitability of various energy crops for biomass fuel at Ontario Power Generation's fossil fuel generating facilities. The study should evaluate the ability to supply each type of biomass in a variety of forms (eg. Pelletized, ground), in volumes of 1–5 million tons/year. The successful organization is encouraged to utilize their expertise in identifying opportunities and weaknesses of various energy crop options beyond the identified requirements of the study. Below are the requirements of the study.

1) The study should include the following forms of biomass:

   A) Miscanthus
   B) Switchgrass
   C) Sudangrass
   D) Poplar
   E) Willow
   F) Other alternatives, with the goal of identifying the energy crop with the greatest potential for commercial development.

A summary description of each form of biomass should be provided, along with an identification of the preferred strains to be used for energy crop development.

2) A breakdown of the chemical characteristics and BTU heating value should be provided for each fuel and its associated ash. Appendix A outlines the requirements.

3) An assessment on whether the crop represents a potential invasive species to the environment should be completed.

4) A description of how classes of land differ should be provided. The gross margin range that a farmer could expect per acre should be provided for each class.

5) Current expected yield ranges and future potential yields of the crop should be provided for various land classes/grades. Of particular interest are the yields on marginal land which is not currently used to supply the food chain (class 3 & 4 or worse).

6) An assessment of land availability, for various classes of land on which the crop can grow should be completed. A description of the land and locations should be provided (a map may be of value).

7) An evaluation of whether there is sufficient maturity in the industry to deliver the required volumes should be completed. This includes a description of each component in the supply chain, and an evaluation of the current and expected future capability for each element. Expected timelines to develop an operation capable of supplying required volumes should be explored.

8) An assessment of potential suppliers is to be completed. Potential suppliers are to be interviewed and their input noted in the report. The assessment of potential suppliers should include the following:

   A) An evaluation of their experience in energy crop development
   B) Ability to secure required financial resources
   C) Experience in planning and logistics of a large scale supply operation
   D) An identification of their current customer base
   E) Whether they hold proprietary information/genetics of plant material
   F) Other strengths and weaknesses of the potential supplier

9) An economic evaluation of the delivered biomass product should be completed. This would include the following:

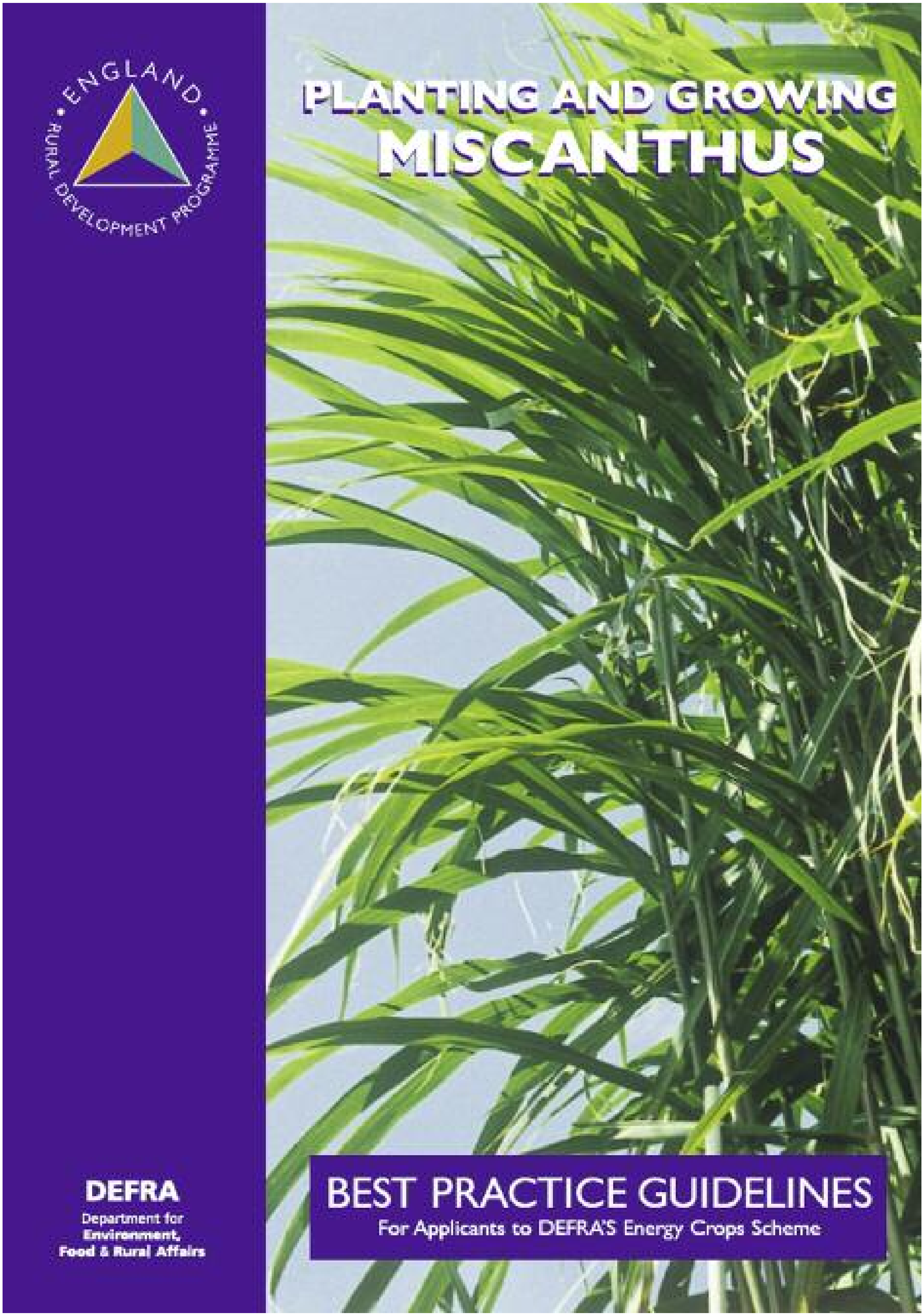
   A) An evaluation of expected delivered costs at various volumes based on expected economies of scale.
   B) A breakdown of cost estimates associated with growing, harvesting, processing and delivering the fuel.
   C) An evaluation of current and future biomass product costs based on expectations of changes in yields.
   D) A comparability review of the cost of fuel per Gj for the various types of biomass.

10) An identification of potential issues in the agricultural community and politics.

11) A final conclusion on the feasibility of the various biomass options.

Appendix A – Fuel Breakdown Requirements

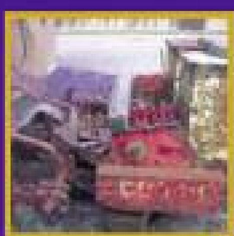
Proximate Analysis	Ultimate Analysis	Water Soluble Alkalis%	Elemental Composition	Other
Fixed Carbon	Carbon	Na_2O	SiO_2	
Volatile Matter	Hydrogen	K_2O	Al_2O_3	Alkali, Lb / MM
Ash	Oxygen	CaO	TiO_2	
Moisture	Nitrogen		Fe_2O_3	Ash Fusion Temp
	Sulfur		CaO	
	Ash		MgO	
	Moisture		Na_2O	
			K_2O	
	HHV, Btu / lb		SO_3	
	Chlorine %		P_2O_5	
			CO_2	
			Undetermined	

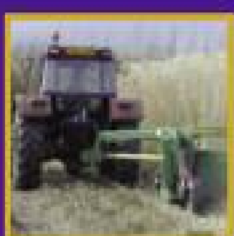

ENGLAND
RURAL DEVELOPMENT PROGRAMME
PLANTING AND GROWING
MISCANTHUS
DEFRA
Department for
Environment,
Food & Rural Affairs
BEST PRACTICE GUIDELINES
For Applicants to DEFRA'S Energy Crops Scheme

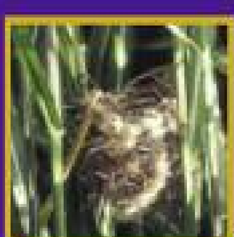
Appendix B

Appendix B

Contents







Introduction

This booklet has been produced to introduce farmers to a new crop. It gives guidance on the most appropriate location, land preparation, planting techniques and crop management required to grow miscanthus as an energy crop. The booklet summarises current research, which is ongoing, and these guidelines may be modified as further experience is gained. Please check that you have the latest version of the booklet with the DEFRA office at Crewe.

This booklet should be read in association with the Energy Crops Scheme explanatory booklet, 'Establishment grants for short rotation coppice and miscanthus.'

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Why grow energy crops?

Why grow energy crops?

The market for energy crops – crops which are grown specifically to be harvested and burnt in power stations or heating systems – is now developing in response to the need for atmospheric carbon dioxide (CO_2) abatement. The UK Government identifies biomass-derived energy as one of the ways that it can achieve its obligations to the Kyoto Climate Change Protocol of reducing greenhouse gas emissions by 12.5%. It has a target to generate 10% of the nation's electricity from renewables by 2010, and aims to reduce CO_2 output by 20% relative to 1990 levels. These targets could mean the generation of 500 - 1000 MWe from biomass by the year 2010, an undertaking that would require as much as 125,000 hectares of energy cropping.

One energy crop is miscanthus. Grants to establish this crop can be obtained from DEFRA under the England Rural Development Programme (Energy Crops Scheme). For details of the grant scheme, ask for a booklet from the DEFRA office at Crewe (see page 18), or see the DEFRA ERDP website **www.defra.gov.uk/erdp/default.htm**

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What is miscanthus?

Miscanthus species are woody, perennial, rhizomatous grasses, originating from Asia which have the potential for very high rates of growth. Miscanthus may be familiar to many as a flowering garden ornamental, but it is the non-flowering forms that are of interest agriculturally.

Miscanthus is planted in spring and canes produced during the summer are harvested in winter. This growth pattern is repeated every year for the lifetime of the crop, which will be at least 15 years. Miscanthus differs from short rotation coppice willow (an alternative energy crop) in that it gives an annual harvest and thus an annual income to the farmer. Miscanthus spreads naturally by means of underground storage organs (rhizomes). However, their spread is slow and there will not be any uncontrolled invasion of hedges or fields. These rhizomes can be split and the pieces re-planted to produce new plants. All propagation, maintenance and harvest operations can be done with conventional farm machinery. In the UK, long-term average harvestable yields from a mature crop have exceeded 13 dry tonnes per hectare per year (t/ha/yr) at the most productive experimental sites. These high yields suggest that the crop has the potential to make an important contribution to the UK's commitments to energy generation from renewable sources.

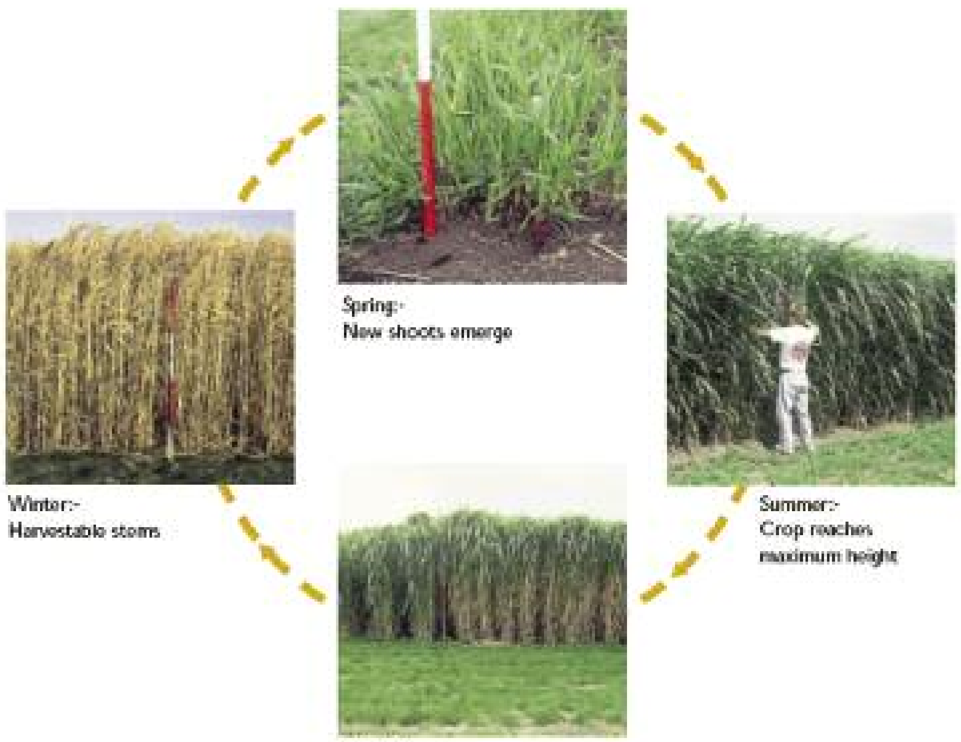
Miscanthus in a semi-natural habitat in Japan

Annual growing cycle

Annual growing cycle

The growth pattern of the crop is simple. It produces new shoots annually and these usually emerge from the soil during April. These shoots develop into erect, robust stems, which reach 1 - 2 m in height by late August of the year of planting, with a diameter of 10 mm. The stems, which have an appearance similar to bamboo canes, are usually unbranched and contain a solid pith.

From late July the lower leaves start to dry. Crop drying accelerates during autumn, as nutrients move back to the rhizome. Leaves then fall and a deep leaf litter develops. Any remaining foliage dies following the first air frost, and the stems dry to a relatively low moisture content (30-50%) during winter. By February, free standing, almost leafless canes remain and it is these which are harvested mechanically. This growth cycle is repeated once spring-time temperatures increase again. From the second season onwards the crop can be expected to achieve a maximum height of 2.5 - 3.5 m.



Annual growing cycle

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Appendix B

Where will miscanthus grow well?

More experience is needed of yields under a wide range of soil conditions, but current information suggests that most lowland agricultural sites in England should be suitable for miscanthus cropping, with the highest yields coming from deep, moisture retentive soils.

Key determinants of yield are sunshine, temperature and rainfall. The old 'maize growing zone'; south of a line drawn between the Bristol Channel and the Wash, will satisfy the environmental requirements for high yield, but many lowland sites north of this line will also be suitable. Within these areas, annual rainfall levels will effect yield.

Soils

Miscanthus has been reported growing, and producing high or reasonable yields on a wide range of soils - from sands to high organic matter soils. It is also tolerant of a wide range of pH, but the optimum is between pH 5.5 and 7.5. Miscanthus is harvested in the winter or early spring and therefore it is essential that the site does not get excessively waterlogged during this period, as this may cause problems with the harvesting machinery.

Temperature

The potential cropping zones for miscanthus are quite widespread. Photosynthesis, and therefore plant growth, is not achieved at very low temperatures. However, the threshold for miscanthus photosynthesis (6°C) is considerably lower than for maize and, therefore, the potential growing season is longer. The major constraint to long season growth is late spring frosts which destroy early spring foliage and effectively reduce the duration of the growing season.

Yield as plants mature

The yield from the first season's growth, 1-2 t/ha, is not worth harvesting. The stems do not need to be cut and so the stems may be left in the field until the following season. From the second year onwards the crop is harvested annually. The second year harvestable yields may range from 4-10 t/ha (occasionally up to 13 t/ha), and those in the third year would be between 10 - 13 t/ha or more. Peak harvestable yields of 20 t/ha/yr have been recorded at a number of sites. The reason for the variation depends on planting density, soil type and climate. At sites where moisture supply or exposure limit yield, there may be a longer 'yield-building' phase.

Long term yield

The long-term average results from a multi-site study in England show that harvestable yields from good sites, including clay, clay loam and peaty soils, exceed 13 t/ha/yr. Yields from sites at 300 m altitude in the Yorkshire Wolds (ADAS High Mowthorpe) and on free-draining sandy soils (ADAS Gleadthorpe) have been much lower at 9 t/ha/yr or even less.

Site selection and planning

As with any crop that is likely to be in the ground for a number years, it is important that a number of issues (such as landscape, wildlife value, archaeology and public access) are considered in the selection of a site. Miscanthus, once established can grow to 3.5 m in height, it is therefore important to consider the visual impact this might have on the local landscape, especially if the site is close to a footpath or a favourite local view.

Miscanthus has the potential to encourage a greater diversity of wildlife than some agricultural crops. This potential is most likely to be realised if it is grown as one component of a mixed cropping pattern and if it is located in an area of low conservation value or as a link between existing habitats. Care must be taken to prevent this new habitat from adversely affecting existing habitats, especially those within existing conservation areas.

Details of land which is eligible, the environmental standards you must observe and the assessment of your application which will take place can be found in the Energy Crops Explanatory Booklet. If you are unsure about any of these requirements you should seek advice from DEFRA's office at Crewe.

Pre-planting requirements

Thorough site preparation is essential for good establishment, ease of subsequent crop management and high yields. As the crop has the potential to be in the ground for at least 15 years, it is important that it is established correctly to avoid future problems.

The first step, in the autumn before planting, is to spray the site with an appropriate broad spectrum herbicide (e.g. glyphosate) for controlling perennial weeds. The site should be sub-soiled if necessary to remove compaction, then ploughed and left to over-winter. On light soils it may be more appropriate to spring plough. This will allow frost activity to break down the soil further. This may also help prevent 'ley' pests attacking the newly established plants, as any larvae or eggs already in the soil from the previous crop will have insufficient food over the winter to survive. In the following spring the site should be rotovated immediately prior to planting. This will not only improve establishment by aiding good root development but will also improve the effectiveness of any residual herbicides applied after planting.

Micro-propagated miscanthus

Miscanthus rhizomes

Planting material

Two methods of propagation are currently used in the UK - rhizome division and micro-propagation. Rhizome division is favoured because it is less expensive and generally produces more vigorous plants. To produce new planting material, two or three-year-old plants are split whilst dormant, using a rotary cultivator, and the rhizome pieces collected for re-planting. A 30-40 fold increase in plants can be achieved this way over a period of 2-3 years, depending on soil conditions.

Rhizome pieces must have at least 2-3 'buds' and must be kept moist before re-planting. This is best achieved by keeping rhizomes under cold-storage conditions, (<4°C) (possibly for up to a year) but they will remain viable in the field for a short period of time, if stored in a heap and covered with moist soil. The optimal planting density for either propagation system is 20,000 plants/ha, but this may vary slightly from site to site. Rhizomes need to be planted to allow for some expansion of the plant during the life of the crop and at a soil depth of 5-10 cm. The optimal planting date for rhizomes is March-April. Early planting takes advantage of spring-time soil moisture and allows an extended first season of growth. This is important because it enables larger rhizome systems to develop. These are more robust in future years, and allows the crop to tolerate drought and frost better.

Note: *the import of miscanthus rhizomes from third countries, other than European and Mediterranean countries is prohibited. The European Commission may consider derogations to the ban. For further advice contact DEFRA's Plant Health Division (see address on page 18).*

Planting equipment

Planting can be carried out using semi-automatic potato planters, manure spreaders or bespoke planters. There is still some uncertainty as to which is the best planting method, because local site conditions can dramatically affect performance. However, use of the potato planter or bespoke planter are recommended, as the results below indicate.

Potato planter

For rhizomes destined for use in the potato planter, grading is required to remove rhizomes which will not fall down the planting tube or have less than 2-3 'buds'. Once graded, the operator of the potato planter places rhizomes into a cup or drops them down a planting tube. The distance between plants is governed by the speed of a land wheel. As the rhizomes enter a furrow opened by a share, the soil is ridged over the rhizomes. The potato planter should be followed by a heavy roller to aid soil consolidation. The work rate achieved is low (0.3 ha/hr). This technique ensures accurate placement and good depth control, both of which are important for good establishment success.

Results - In a four-site study, this method achieved a work rate of 0.3ha/hr and an establishment rate of 95%.

Semi-automated potato planter

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Manure spreader

This is the least favoured option. A manure spreader can be used simply by filling the hopper with rhizomes or a rhizome/soil mixture, and then spreading the material at a pre-determined rate to attain the desired plant density. Following broadcasting, the rhizomes are then cultivated into the soil, to a target depth of 10-15 cm and the soil rolled, for good rhizome-soil contact. This must be done as quickly as possible, to reduce moisture loss in the exposed rhizomes on the soil surface. This method produces a faster work rate (3 ha/hr), but it is an imprecise method due to the lack of control of plant spacing and depth. Perhaps most importantly, the rhizomes are not planted into a fine tilth, so even following rolling, contact with the soil may be very poor and the rhizomes prone to drying out.

Results - In the same four-site study, a work rate of 3ha/hr, but only 22% establishment was achieved with this method.

Manure spreader

Bespoke planter

A machine has been designed specifically for planting miscanthus by Hvidsted Energy in Denmark. This machine works by planting two rows of rhizomes into a shallow furrow opened by shares. Once planted, the soil is moved back to cover the rhizomes and then rolled. The machine can be calibrated, to plant different densities, if required.

Results - a work rate of 1.25ha/hr and an average establishment rate of 92%, in the four-site study.

Hvidsted planter

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Fertiliser requirements

The annual fertiliser demands of the crop are low. This is due to good nutrient use efficiency and the plant's capability to re-cycle large amounts of nutrients into the rhizomes during the latter part of the growing season. As a consequence, nutrient off-take at harvest is low, as shown in Table 1. Since the leaves predominately remain in the field it is only necessary to account for the amount of nutrients removed in the stems. The nutrient requirements during the following seasons are met by leaf litter decomposition, natural soil nutrient reserves, rhizome reserves and atmospheric depositions. Mature rhizomes tend to store more nutrients than the crop needs, so after the first 2 years, only a small quantity of additional micro-nutrients may be required. For good miscanthus yields a minimum phosphorus and potassium soil index of 1 should be aimed for and soil nitrogen supply should exceed 150 kg/ha in each of the first 2 seasons. When nutrients are needed in the first 2 seasons, this could come from farm-yard manure or sewage sludge.

Codes of Good Fertiliser Practice should always be followed.

	Stem	Leaf litter
N	88	47
P	11	2
K	95	14

Table I. Nutrient 'off-take' (kg/ha) for an 'average crop' consisting of 13.5 t/ha of stems and 4.5 t/ha leaf litter

Weed control

Weeds compete with the crop for light, water and nutrients and can reduce yields. Weed control in the establishment phase of the crop is essential because poor control can severely check the development of the crop. **It is vital that proposed sites should be cleared of perennial weeds before any planting takes place.** DEFRA's Pesticides Safety Directorate has given off-label approval for herbicides used for cereals,grass and maize to be used on miscanthus. Write to PSD (see page 18) or see **www.pesticides.gov.uk/solaweb/solaweb.htm**

Herbicide application must not be made on miscanthus crops greater than 1 metre in height and the crop cannot subsequently be used for food or feed. A wide range of herbicides have been used effectively with no visible damage to the crop in Denmark and the UK. Following the establishment year, an annual spring application of a broad-spectrum herbicide may be needed to control grass weeds such as common couch and annual meadow-grass and broad-leaved weeds with early season vigour. Glyphosate and paraquat have been used in this dormant period between harvest and initiation of spring growth but they will cause severe damage to any new shoots which might have emerged. **Once the crop is mature (i.e. from the summer of the second year), weed interference is effectively suppressed.** This is initially due to the leaf litter layer on the soil surface and subsequently due to the closure of the crop canopy, which reduces the light penetrating into the under-storey. Weeds that do survive offer little competition to the crop. Since there are no labelled recommendations, all products used are at the users own choosing and the commercial risk is entirely theirs.

Active Ingredient(s)	Data Source	Notes
atrazine	A	Gesaprim @ 2.5 l/ha
bromoxynil/ioxynil	A	Briotril @ 2.5 l/ha
bromoxynil/fluroxypyr/ioxynil	A	Advance @ 2 l/ha
clopyralid	A, B	Dow Shield @2.4 l/ha
dichlorprop	B	(667g/l of active ingredient) @ 5 l/ha
diflufenican/isoproturon	B	(100:500g/l of active ingredient)@3 l/ha
fluroxypyr	A, B	Starane 2 @ 2 l/ha
glyphosate[2]	A, B	Roundup @ 3 l/ha
isoproturon	B	Tolkan @ 4 l/ha
metsulfuron-methyl	A, B	Ally @ 30g/ha
metsulfuron-methyl + bromoxynil / ioxynil[3]	A	Ally @ 30g/ha + Deloxil @ 1 l/ha
metsulfuron-methyl+ fluroxypyr[3]	A	Ally @ 20g/ha + Starane 2 @ 0.5 l/ha
MCPA	B	(750g/l of active ingredient) @ 5 l/ha
MCPA + MCPB	A	Trifolex-Tra @ 7.7 l/ha
mecoprop-P	B	Duplosan @ 6 l/ha
paraquat2	A	Gramoxone @ 4 l/ha

[1] *(A) ADAS, (B) Georg Noyé Institute of Weed control 'Rakkebjerg', Denmark.*
[2] *Herbicides for use before miscanthus emergence.*
[3] *Tank mixtures.*

Table 2 Herbicides which have been used successfully to control weeds in miscanthus

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Appendix B

Pests and diseases

Miscanthus species are susceptible to pests and diseases in the areas to which they are native (Asia) but, as yet, none of these has been reported in the UK. Commonplace cereal diseases known to occur in miscanthus include barley yellow dwarf virus (BYDV), which may limit yield. Also, stem basal diseases may infect stems in the autumn or winter, reducing stem strength. There are no reported insect pests in Europe that have significantly affected the production of miscanthus. However, two 'ley pests', the common rustic moth and ghost moth larvae, have been reported feeding on miscanthus and may cause problems in the future.

Harvesting

The annual harvest of the stem material **can be carried out between January and March** using a number of different machines, depending on availability and requirement of the end market. For energy cropping, a baled product is the most desirable. However, this type of harvest involves two operations before the bale is produced and this can result in high biomass losses.

The crop is first cut with a mower conditioner. Conditioning breaks up the rigid stems allowing accelerated moisture loss, and provides a light, rectangular windrow. This not only makes baling easier, but also helps in the drying of the material, by increasing the surface area and increasing air circulation in the swath.

There are a number of different types of balers, each producing different bales, (e.g. rectangular, round and compact rolls), suitable for different scales of energy combustion. Large rectangular and round balers are capable of producing bales with a dry matter density of between 120 and 160 kg/m3 and weighing between 250 and

Miscanthus being cut and conditioned

THE RESEARCH PARK
LONDON | SARNIA-LAMBTON

Miscanthus being baled

600 kg. These balers generally have a capacity of 1 ha/hr.

A critical factor for an energy crop is the moisture content at harvest. The drier the crop, the higher the energy yield and bale value. Moisture contents as low as 15% have been reported in southern Europe - although the lowest moisture content achieved in the UK has been around 20%, with the average closer to 50%. This may be partly because, in the UK, plants are still in the vegetative phase when the first frost induces die back. By conditioning and allowing to dry in the field, the stem moisture content can be halved from 50% to 25%.

Miscanthus bale

Energy value

Miscanthus has a net calorific value, on a dry basis, of 17 MJ/kg, with a 2.7% ash content. The energy value of 20 t of dry miscanthus would be equivalent to that of 12 t of coal.

Elean Biomass power station

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Biodiversity

Biodiversity

Two studies, one at IACR-Rothamsted and another in Germany, comparing miscanthus with cereals, indicated that miscanthus seemed to provide a habitat which encourages a greater diversity of species than winter sown cereal crops. In these studies three times as many earthworms and spiders were found in the miscanthus crop, miscanthus also supported a greater diversity of spider species. One of the studies also showed that the miscanthus crop had 5 more mammal species and 4 more bird species than a crop of wheat. Miscanthus crops can also act as a nesting habitat for reed nesting birds, (e.g. reed warbler), later in the summer. Miscanthus might be a useful game cover crop and nursery for young pheasants and partridges.

Within the area for which establishment grant is applied, up to 10% can be left as open ground where this is used for management or environmental purposes. The wildlife value of this crop could be increased by the inclusion of rides and headlands to increase the number and species of flora and fauna. The use of grass headlands around the crop will protect edge habitats which are particularly important for wildlife by preventing shading to existing habitat. Headlands may also act as a sacrifice crop for rabbits or deer to feed on and thus reduce any damage they may cause to the newly established crop and they will also improve the access to the site, particularly at harvest.

Reed nesting bird

Useful contacts and references
Reports and publications

Useful contacts and references:

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Electra Way
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Plant Health Division
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York
YO1 7PX
Tel: 01904 641000

Reports and publications

Final Report for DEFRA projects are available from:

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Chief Scientist's Group
1A Page Street
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ENGLAND RURAL DEVELOPMENT PROGRAMME

Contacting DEFRA

If you have a query and are unsure about who to talk to in DEFRA, you can call the Helpline who will be pleased to help you to find the right person.

DEFRA Helpline: 08459 33 55 77 *(local call rate)*

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March 2001

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DEFRA
Department for
Environment,
Food & Rural Affairs

Switchgrass Production in Ontario: A Management Guide

Samson, R., 2007. Resource Efficient Agricultural Production (REAP) - Canada

Revised from: Girouard, P., B. Mehdi, R. Samson and P. Blais, 1999. Joint publication by Resource Efficient Agricultural Production (REAP) – Canada and the Research and Technology Transfer Section of the Collège d'Alfred of the University of Guelph

Introduction

New levels of concern about the need to reduce greenhouse gases and develop low cost renewable fuels are of increasing interest in biofuel production systems. Since the 1960's switchgrass, a native C4 or warm-season grass has been identified as a promising bioenergy feedstock through studies by the US department of Energy. It has been under investigation in Canada as a bioenergy crop since 1991. Several market opportunities involving switchgrass are now emerging for growers in Eastern Canada. This management guide intends to provide the basic knowledge on how to successfully grow switchgrass.

A long history of use

Switchgrass (*Panicum virgatum* L.) is a native, perennial warm-season grass. Along with big bluestem and indiangrass, it is one of the three dominant native grasses found in the North American tallgrass prairie prior to settlement. In Ontario, it can still be found in remnant oak savannah prairies. Switchgrass has been researched since the 1940's in the United States as a mid-summer forage crop. It is most commonly used for livestock forage in the south-central states. In the 1990's it was widely used in the Conservation Reserve Program (CRP) in the United States. To enhance its erosion control and biodiversity value, it is now recommended in the latest Conservation Reserve Enhancement Program (CREP) in the United States to be used in mixtures with other warm-season grasses.

Warm-season agricultural crops including corn, sorghum, millet and sugarcane are widely grown in the world. They are commonly grown in regions experiencing warm temperatures during the growing season. In Ontario, switchgrass produces most of its biomass in the warm summer months of June through August. The successful production of switchgrass requires different production techniques and harvest schedules than those used for cool-season grasses such as timothy and bromegrass. In particular, switchgrass can be relatively slow to establish. A switchgrass stand that appears poor in the seedling year often produces a high yielding stand in subsequent years. Adapted warm-season grasses have few pest and disease problems and are rather remarkable for their stand longevity and stable productivity year after year.

Varieties of Switchgrass

Switchgrass varieties are classified into two broad categories: lowland and upland. Lowland ecotypes historically developed under floodplain conditions, while upland ecotypes developed under drier upland sites. Yields of up to 25 tonnes per hectare (10 tonnes/acre) have been achieved with some lowland varieties in research trials in the southern United States. Unfortunately, lowland varieties are more susceptible to winterkill. In most areas of Ontario, upland varieties will provide Ontario farmers with the best productivity and stand longevity. In Southwestern Ontario, some northern lowland ecotypes may prove to be adequately hardy and included in mixed warm-season grass seedings in the future.

Cave-in-Rock is the most widely planted variety for northeastern North America. In more northerly areas of Ontario (i.e. less than 2500 corn heat units or CHU) other early maturing varieties such as forestburg, sunburst, and shelter may prove more reliable in terms of winter hardiness and productivity. Ontario farmers should preferentially choose varieties originating from the eastern United States as these tend to be more disease resistant. Some western originating switchgrass varieties have developed leaf diseases in Ontario. New switchgrass varieties with improved seedling vigor, disease resistance and yield are currently under development.

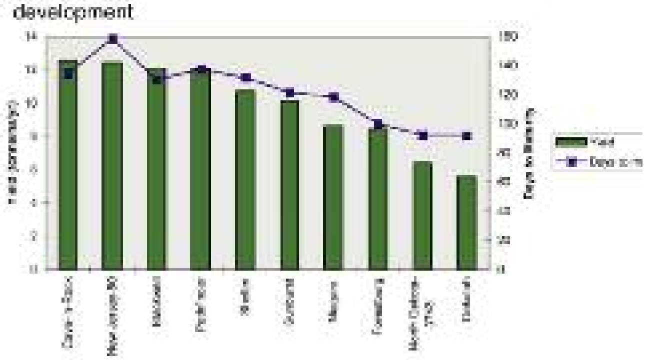

***Figure 1** – Yield (oven dry tonnes ha-1) of switchgrass cultivars at Ste. Anne de Bellevue, Quebec (1993-1996)*

Seed

Eight to 10 kilograms of Pure Live Seed (PLS) per hectare are recommended for a successful establishment. Switchgrass is usually sold based on its PLS content as the seed varies greatly in purity and germination. Seed lots with equal amounts of PLS may differ in their volume of bulk seed. This must be taken into consideration when calibrating seeding equipment.

Newly harvested switchgrass seed can have a high percent dormancy. High dormancy seedlots will require higher seeding rates (or storage to provide acceptable germination levels) for successful field establishment. For newly harvested seed, a dormancy rating of 10 percent or less is excellent. Seed cost currently varies between $7-$21/kg, depending on the desired variety and demand. In Ontario, big bluestem can be included in mixtures with switchgrass to enhance environmental benefits and to reduce potential for disease pressure on monoculture seedings of switchgrass. New releases of big bluestem appear to have similar productivity levels as switchgrass and as such an overall seeding rate of 8-10 kg /ha of PLS can be used for switchgrass and bigbluestem seedings. It is best to use a seeding rate of 4 kg/ha switchgrass and 6 kg/ha big bluestem if a mixed planting is desired. Big bluestem requires better field drainage than switchgrass. Big bluestem that has had the seed coat buffed during seed cleaning to remove fine hairs is highly preferred. The advantage of buffing is that the big bluestem seed can flow through the bromegrass seed box on forage seed drills. Switchgrass and big blustem seed is available from a number of Canadian and U.S. dealers.

Establishment

Experience in Ontario indicates that switchgrass is easier and faster to establish on loam and sandy soils than on clay soils. The roots and crowns of switchgrass spread more readily on these lighter soil types. This results in a maximum yield level being achieved in a shorter time period. Typically switchgrass produces about 30% of its biomass potential in the first year, 70% in the second year and 100% of maximum biomass production by year 3. Switchgrass seed is fairly small, therefore poor contact with the seedbed caused by clay clumps will result in poor or uneven germination. Clay soils are also usually slower to warm up in the spring. Packing fields before and after planting is highly recommended on all soil types, especially on clay soils. A good rule of thumb for seeding is that a footprint should barely be visible in the soil before seeding.

Switchgrass will establish best on well-drained soils (surface and/or tile drainage) that warm up early. On sandy loam soils in corn growing areas, switchgrass is highly competitive with invading perennial weeds. Increased competition from aggressive cool-season perennial grasses (such as quackgrass, bromegrass and reed canary grass) in establishing stands of switchgrass can be expected at more northerly sites, in heavier soils and fields formerly in cool-season grass production. Due to the extensive perennial root system and drought tolerance, switchgrass is relatively productive on medium to lower fertility soils compared to most annual field crops. Switchgrass is well suited to be grown in areas with less than 2600 CHU which are marginal for corn and soybean production. Soil pH should be above 6.0 for optimal yields.

As switchgrass is fairly slow to form a canopy, weed control is critical to achieving a successful establishment. In the fall preceding establishment, fields can be sprayed with a broad-spectrum herbicide to eliminate problem perennial weeds, such as quackgrass, from invading the establishing stand. Summer or fall tillage is recommended for forage and pasture fields in order to break sod clumps. Use of spring applied formulations of "Round-up ultra or max" should be avoided as growers have reported phytoxic effects on switchgrass establishment.

In the spring, seeding should be performed when soils are relatively warm, usually between May 15th and June 10th. Soil preparation should include one or two passes of harrow (or disk) and packing (cultipacking). Seeding in conventionally tilled fields is best performed with a Brillion seeder at a seeding depth of 0.5 -1.0 cm (1/4 to 1/2 inch). If use of a mixture is planned, buffed big bluestem seed can be seeded using the bromegrass seed box on Brillion seeders. If the field is not fine and firm after planting, it should be packed again immediately. No-till soybean seed drills are commonly used for no-till seeding of switchgrass in all areas of the United States. The alfalfa box on these drills is used for the switchgrass.

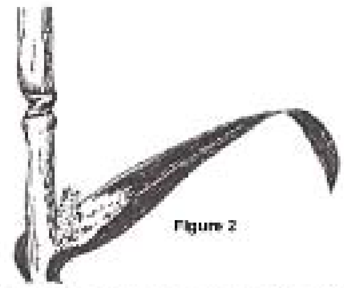

Figure 2

Switchgrass seedlings can be difficult to distinguish from annual grass weeds. A key feature of switchgrass plants is the white patch of straight hair at the point where the leaf (topside) attaches to the stem (Figure 2). Another means of identifying switchgrass during its first 6 weeks of growth is that the stems have a reddish-purplish tint and are round. Switchgrass may take weeks to emerge depending on the season. The switchgrass seedlings are frequently smaller than early emerging annual grass weeds. A stand is successfully established if 10-32 seedlings per m^2 (1-3 seedlings per ft^2) can be found at the end of the establishment year. Some winter heaving problems can be experienced in the seeding year. Heaving can arise especially on clay soils and on fields where plants are relatively small (less than 20cm) and weakly rooted into the soil going into the winter.

Establishment: Weed Control

Switchgrass establishes best on fields that have modest annual and perennial grass pressure. Spring cultivations at 7-10 day intervals prior to seeding can help reduce annual weed pressure in fields. No herbicides are registered for use on switchgrass in Canada. Weed control research has mainly been conducted on upland ecotypes of switchgrass. Studies are available from a number of institutions in the United States and from the University of Guelph in Ontario. It is the farmer's responsibility to read and comply with the label instructions of each product. Switchgrass seedlings and mature plants show tolerance to atrazine. Guidelines from the United States are to use Aatrex atrazine at 1.1-2.2 kg/ha of active ingredient (1-2 lbs./acre) at, or soon after, planting. Basagran® (bentazon) and Laddock® (blend of atrazine and bentazon) are effective against most post-emergent broadleaf weeds, with minimal crop damage. Switchgrass should not be sown as an underseeding in cereal crops as it is not shade tolerant.

Grass weeds such as barnyard grass, foxtail and crab grass are the most difficult to control in switchgrass stands. It is difficult to find herbicides that effectively remove grass weeds from switchgrass seedlings without causing injury to the switchgrass. Research is ongoing on this issue and guidelines should be available within the next few years. In the event of weed escapes, the field can be clipped just above the switchgrass canopy up to two times during the summer months. Cutting off the growing point of the switchgrass will significantly retard switchgrass development. Loss of stands or delayed establishment due to weed competition is more likely to occur with seedings on heavier soils. If big bluestem is used in mixed seedings with switchgrass, no more than 1.1 kg/ha of active ingredient of atrazine should be applied to the field. In the U.S., Plateau® (imazapic) herbicide is used on pure big bluestem seedings at a rate of 0.07a.i./ha to control annual grass weeds. Plateau® is not suitable for use on switchgrass and will cause significant injury during establishment. Organic farmers looking to grow switchgrass should use a combination of cultural weed control measures. They should also consider planting in sandy-loam fields that have low residual nitrogen fertility (example following a fall rye crop in the rotation) and that are known to be relatively free of perennial weeds.

Establishment: Fertilization

In almost all cases, nitrogen fertilization is not utilized in the establishment year. Switchgrass is an excellent nutrient scavenger in establishing fields. Applying nitrogen fertilizer commonly stimulates weed growth and this reduces the competitive ability of switchgrass. Potassium and phosphorus fertilizers are not applied during establishment, unless levels are low (less than 81 ppm for potassium, and less than 10 ppm for phosphorus, according to OMAFRA guidelines for forage crops). Switchgrass seldom responds to potassium and phosphorus fertilizer as it has a large root system and relies on mycorrhizae for phosphorus uptake. It is best to avoid manuring fields before planting to minimize weed competition.

Establishment: Harvest

Fall dormancy of the switchgrass is generally delayed in the seeding year and this increases risks of winter hardiness problems in the first winter. To ensure good winter hardiness and vigorous regrowth, it is recommended that switchgrass grown in the establishment year be overwintered prior to harvest.

Production Years

Research conducted in eastern Canada indicates that maximum production is first attained during the third growing season. Once established and properly maintained, a switchgrass stand will remain productive for an indefinite period. Experience has shown in Ontario that if switchgrass stands are subject to winter injury or heaving, they can commonly recover in the subsequent growing season. Switchgrass has large underground carbohydrate reserves which help regenerate regrowth.

Production Years: Harvesting

As a biomass crop, switchgrass is best grown as a one-cut per year crop, with the harvest performed any time after fall dormancy is well initiated (i.e. leaf yellowing). This ensures adequate nutrient and carbohydrate translocation to the root reserves to help encourage winter survival. The harvest period can include late fall, mid winter (in snow-free conditions) and early spring (anytime between mid-April and late-May). If fall cutting switchgrass, leaving at least a 10 cm stubble to improve winter survival and reduce winter heaving. The base of the stem of switchgrass is the slowest part of the plant to dry out in the fall. It may not be possible to fall-harvest switchgrass when wet fall harvest conditions occur. Early maturing varieties can be chosen to help create an earlier fall dry-down of the crop. As well, varieties that have minimal lodging and thin stems tend to dry down more effectively. Another common problem on heavier soils is that field conditions are too wet in the fall to enable baling and transport equipment for fall harvesting. Delaying the harvest to the following spring has the advantage of improving winter survival and weed control. It also reduces nutrient extraction resulting in reduced fertilizer requirements and improves combustion properties of the material. The ash content of switchgrass typically declines from 5% in the fall to 3% in spring. By spring the crop is typically harvested at 12-14% moisture as good drying condition are present. This can eliminate the need for drying the fibre prior to pelleting. Some drying can also be expected when bales are placed in covered storage. Commonly fall stored baled forage at 16-17% moisture will be at 12-14% moisture content by spring.

The main problem that has been identified with overwintering switchgrass in fields has been breakage of the seed heads and leaves by the winter winds and ice storms. Typically 20-30% of the total dry matter can be lost in fields. As well, cutting the material in the spring can lead to large harvest losses due to material shattering because of its dry and brittle state at harvest. Swathing standing switchgrass in the spring can substantially reduce harvest losses compared to harvesting with a mower conditioner. Another possible harvest option is to fall mow and spring harvest the material. This approach may reduce winter breakage and promote more rapid soil warming and field drying in the spring. This harvest system appears promising based on preliminary field trials. Well-drained sandy soils offer the greatest flexibility for farmers in accessing fields under wet weather conditions.

Production Years: Fertilization

In most cases, the only operation required following harvesting is the application of nitrogen fertilizer. For a late fall or spring harvest regime, 50-60 kg of actual nitrogen per hectare every year (45-53 lbs./acre) is sufficient to sustain production. Over-fertilization with nitrogen usually results in crop lodging, which ultimately results in yield reduction and harvesting difficulties.

By adopting a late winter or spring harvesting regime, phosphorus and potassium fertilization requirements are minimized. Usually no phosphorus or potassium is applied on medium to rich soils under switchgrass cultivation. Soil concentrations of these two nutrients should be monitored 2-3 years after establishment and fertilization performed if deemed necessary. Modest rates of solid and liquid manure and sewage sludge can be applied to established switchgrass stands when actively regrowing (typically in early June).

Biomass and Energy Yields

Once fully established in Ontario, switchgrass can typically produce 8-12 tonnes/ha of harvestable dry matter by fall. Leaving the crop in the field over winter will cause some reduction in harvestable yields. However, the resulting material will have an improved quality for combustion applications. Research is ongoing to optimize the yield and quality of switchgrass through both variety improvement and harvest management. Typically switchgrass and grain corn have similar energy contents on a dry matter basis of approximately 18.5 GJ/tonne. Assuming a harvested grain corn yield of 6.5 tonne/ha and switchgrass yield of 10 tonne/ha, switchgrass produces 185 GJ/ha of energy vs 120 GJ/ha for grain corn. If the fossil energy inputs used for crop production are subtracted from energy output, the net energy gain per ha is 73% higher for switchgrass than grain corn.

Costs of Production

Switchgrass represents the lowest cost means to capture and store solar radiation in a field crop in Ontario. The main factors contributing to making it a low cost energy producing system are: its perennial nature and stand longevity, its adaptation to marginal farmlands (i.e. low land rents), its low input requirements and its moderate to high productivity on marginal soils. Variable costs to grow and harvest switchgrass are approximately $40-$50/tonne.

The cost of harvesting and transporting the crop to a conversion plant is approximately $30-$35/tonne. Any efficiency gains made in these two areas will strongly influence returns to farmers. A major advantage of developing local conversion plants to produce fuel pellets are that they can help reduce hauling distances and enable bulk switchgrass harvesting and delivery to conversion facilities. Other costs include the annual fertilization charges (i.e. 130 kg/ha of 46-0-0 at $500/tonne) of approximately $75/ha, and the amortization, usually over 10 years, of the establishment costs incurred in the first year. Land rent can have a strong influence on overall switchgrass production costs. A land rent of $250/ha adds an additional $25/tonne to production costs, if a 10 tonne per ha yield is obtained.

Markets

Switchgrass can be used in a diversity of agricultural and energy markets. It can be used for livestock bedding, as part of a dry cow ration, as a mushroom compost substrate, as a horticultural or roadside mulch and in straw bale house construction. In Ontario, the main emerging bioenergy application is as a pelletized fuel for commercial heating. On-farm applications can include greenhouse heating, heating of livestock buildings, and corn drying. Switchgrass can also be used as a fresh or ensiled feedstock for biogas production. The main interest presently in Ontario is its use as a commercial fuel pellet. Preliminary combustion trials with switchgrass have been conducted in both residential pellet stoves and commercial boilers. Fall harvested switchgrass appears to have more difficulty in combustion applications when it is used as the only fuel. Overwintered switchgrass appears to have few limitations for use in combustion systems designed for higher ash fuels. Experience has also shown that overwintered switchgrass has superior pellet durability when compared with fall harvested switchgrass.

Pelleting switchgrass typically costs $35-$50/tonne. If the crop can be grown for $70/tonne and pelletized for $40/tonne it could be a highly competitive fuel source to compete with rising propane and natural gas costs. At a bulk retail price of $125/tonne, switchgrass pellets cost $7/GJ on an energy basis. Ethanol currently receives a federal incentive of 10 cents per litre or $4.48/GJ. If federal and provincial incentives are also applied to switchgrass it will become a highly competitive energy source in Ontario that will help revitalize the farm sector.

Switchgrass and Climate Change

Switchgrass and other warm-season grasses could provide a major solution in helping Canada achieve major emission reduction targets. Overall, switchgrass pellets can reduce greenhouse gas emissions by about 90% when compared with using an equivalent amount of energy in the form of fossil fuels.

Switchgrass can also reduce greenhouse gas emissions by increasing the carbon stored in landscapes through increased carbon storage in roots and soil organic matter. It has been found that land conversion to switchgrass on CRP plantings in the United States has led to 40 tonnes/ha of CO_2 being stored compared to conventional land use.

Additional Information

An electronic version of this switchgrass production guide and additional reports are available at www.reap-canada.com

Resource Efficient Agricultural Production (REAP) - Canada

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Acknowledgements

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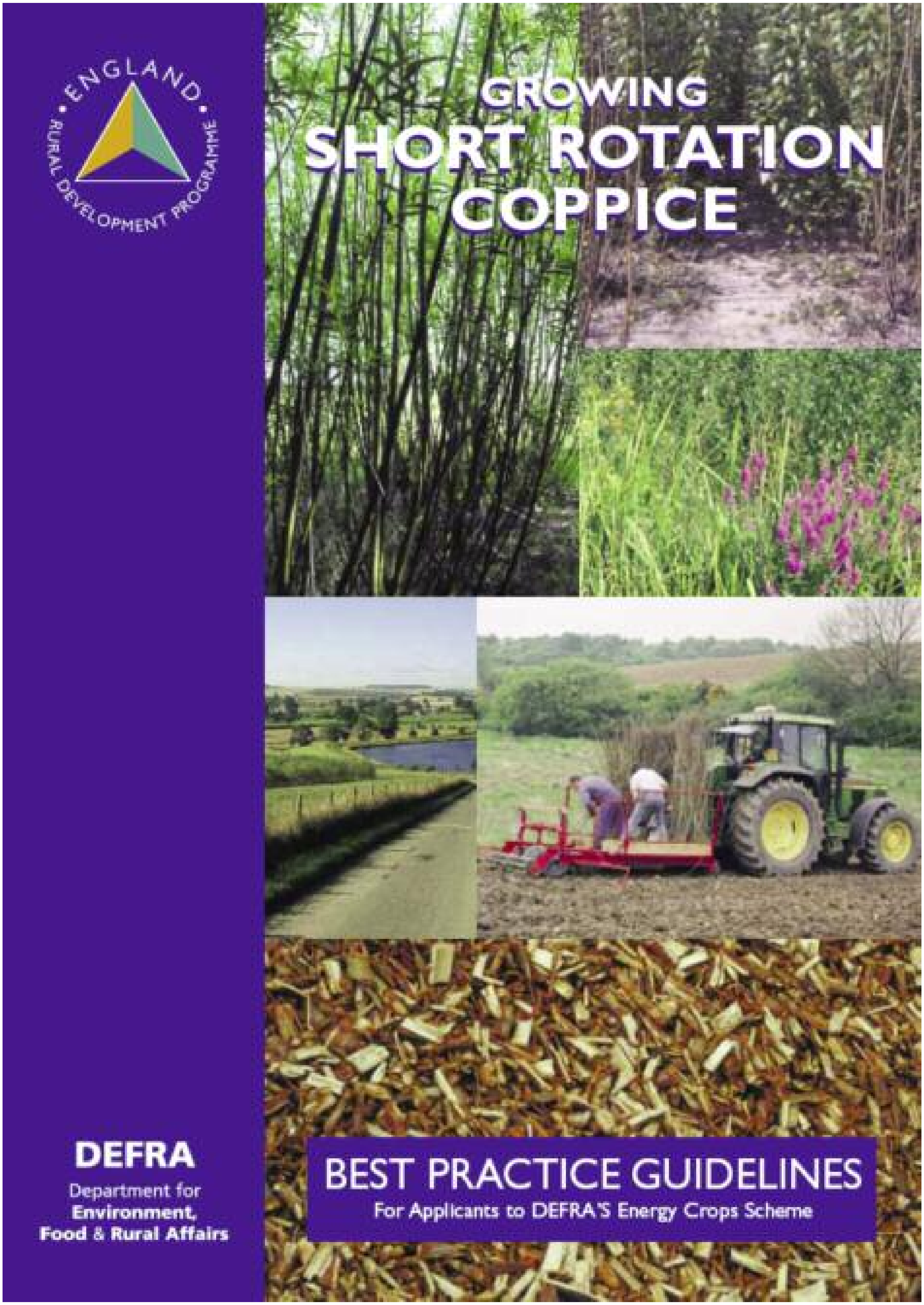
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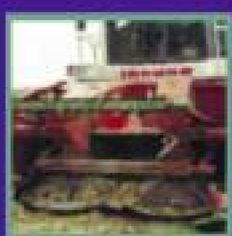
Appendix D



Contents

Introduction

This booklet has been produced by the Department of Environment, Food and Rural Affairs (DEFRA) to introduce farmers to a new crop. It provides guidance on the choice of site, planting techniques, crop management and harvesting methods required when growing short rotation willow or poplar coppice as an energy crop. The booklet summarises current agronomic techniques and, therefore, may need to be modified as further experience is gained. Please check that you have the latest copy of the booklet with the DEFRA office at Crewe.

This booklet should be read in association with the Energy Crops Scheme booklet, "Establishment grants for short rotation coppice and miscanthus" which outlines the requirements for claiming grant to establish the crop.

There is further information on short rotation coppice in the Forestry Commission Information Note "The establishment and management of short rotation coppice - a practitioner's guide" (Tubby and Armstrong, 2002).

Why grow energy crops?

Energy crops are used as fuel in power stations and heating systems. In substitution for fossil fuels, they have the potential to reduce emissions of the greenhouse gas carbon dioxide. Energy crops will need to contribute if the UK is to meet its:

- obligation under the Kyoto Protocol to reduce greenhouse gas emissions by 12.5 per cent below 1990 levels by 2012;
- domestic goal to generate 10% of the nation's electricity from renewable sources by 2010.

This provides a significant opportunity for the energy crop industry.

Currently the major energy crop grown in the UK is short rotation coppice (SRC), primarily willow, although poplar has been used occasionally and may be planted more commonly in the future following the production of varieties more suited to coppicing. This booklet concentrates on willow SRC, although a section relating specifically to poplar has been included.

DEFRA provides grants to assist with the establishment of SRC under the Energy Crops Scheme (ECS), part of the England Rural Development Programme (ERDP). Grants are also available for setting up SRC producer groups to facilitate harvesting and supply to the energy market. Full details can be found in the ECS booklets "Establishment grants for short rotation coppice and miscanthus" and "Grants for establishing producer groups".

For details of support available for energy crops, contact the DEFRA office at Crewe or visit the ERDP website:

www.defra.gov.uk/erdp/erdphome.htm

Woodchip boiler for heat

ARBRE power station fuelled by woodchip

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What is SRC?

SRC (short rotation coppice) consists of densely planted, high-yielding varieties of either willow or poplar, harvested on a 2 – 5 year cycle, although commonly every 3 years. The osier, a shrub willow, is parental stock to the majority of willow varieties planted for use as an energy crop. SRC is a woody, perennial crop, the rootstock or stools remaining in the ground after harvest with new shoots emerging the following spring. A plantation could be viable for up to 30 years before re-planting becomes necessary, although this depends on the productivity of the stools.

Willow SRC is planted in the spring using planting material produced by specialist breeders and equipment specifically designed for the purpose. The willow will grow rapidly in the first year reaching up to 4m in height. During the winter after planting the stems are cut back to ground level to encourage the growth of multiple stems i.e. coppiced. Generally three years after cutback and again during the winter, the crop is harvested. The equipment used for harvesting will have been specifically developed for the purpose and depends on the fuel specification of the customer/end-user. Most operations other than planting or harvesting can be completed using conventional farm machinery.

In the UK, yields from willow SRC at first harvest are expected to be in the range 7 – 12 oven dry tonnes per hectare per year (odt/ha/yr) depending on site and efficiency of establishment.

Willow SRC 3 months after planting

Mature willow SRC

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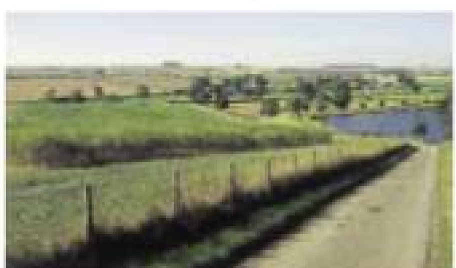
Where to grow SRC?

The key determinants of SRC yield are water availability, weed control, light and temperature.

Willow SRC will produce good growth where there is sufficient soil moisture available within 1 metre of the soil surface. It can withstand seasonal flooding but not permanent waterlogging. Where land is prone to flooding most years, the willow will survive but consideration must be given to operational requirements, particularly the need to harvest in winter. Annual rainfall of 600-1000mm is ideal.

SRC can be established on a wide range of soil types from heavy clay to sand including land reclaimed from gravel extraction and colliery spoil. Clay or sandy loams that retain moisture but are well aerated are ideal soils. Establishment may be slow on heavy clays as they tend to be cold in spring although, once established, SRC grown on these soils can be highly productive. Where compaction may prove to be a problem, sub-soiling to a depth of 40cm will be necessary to ensure maximum root development. Soil pH should be in the range 5.5 – 7.



SRC in the landscape

Site selection

A site must meet the requirements of the ECS, these can be found in the Establishment Grants booklet.

As a perennial crop, SRC is likely to be in the ground for up to 30 years and can reach 7-8 metres in height prior to harvest. Its impact on the local landscape, ecology, archaeology and public access must therefore be considered alongside the operational parameters.

Under the ECS, a proposed SRC site is assessed and consultation takes place to ensure there will be no significant adverse impact on the environment. This consultation takes up a significant part of the 3-month application process time. To speed the process potential growers may wish to contact organisations that may be affected by the planting of the crop in advance, e.g. local councils for bylaws relating to public rights of way or the county archaeologist to check the records for any important archaeological remains. Where a proposed site is adjacent to a river or on a floodplain, the Environment Agency should be consulted.

Another factor to consider is soil erosion. Compared to many crops, SRC has large areas of open ground within the crop during establishment. On light, sandy soils this can lead to wind erosion of the soils and also some damage to the newly emerged shoots due to abrasion. On sloping sites, soils can be eroded following heavy rain.

Willow roots, which are fibrous in nature, will penetrate down to field drains and it is recommended that SRC is planted at least 30 metres from any drains that are considered important. When choosing a site consider the life of the drainage system in relation to the expected life of the SRC plantation.

To be eligible for grant the proposed site must be at least 3ha in total, although this can be made up of smaller plots. However, to ensure economies of scale for all field operations larger plantations are better. The most appropriate field shapes are those that minimise the need for short row lengths or require no changes in direction during field operations. Choosing fields that can be harvested economically is of critical importance. For ease of operations the ideal site would be flat or with a slope of no more than 7%. It is strongly recommended that the slope of the field should not exceed 15%.

Appropriate access must be available for all machinery involved in establishing and harvesting the crop. Gate widths should be at least 4.5m but it is recommended that if new gates have to be installed they should be up to 7.2m in width. Bridge height or weight restrictions should also be considered where necessary. Ideally areas for transferring and storing the harvested crop should be adjacent to the coppice.

Plantation design

The plantation design should fit in with the surrounding landscape and advice relating to this can be obtained from Forestry Commission Guideline Note 2 (Bell & McIntosh, 2001). Operational requirements must also be taken into account. Headlands of at least 8 metres in width are necessary at both ends of the rows to allow for vehicle turning. Where only one trailer will be available at harvest or the harvester has an integral trailer, row lengths should be restricted to a maximum of 200 metres to avoid the need to reverse along the rows to off-load. Where two or more trailers will be available, row lengths can be longer. However, if liquid sludge is to be applied using an umbilical system, the maximum row length should be 400 metres. Rides of 4 metres should be left along the edges of the crop to allow machinery access for willow beetle control if required. A maximum of 20% open ground is allowed within a SRC plantation under the ECS.


Edge of SRC plantation

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Appendix D

Land preparation

The importance of efficient land preparation for SRC cannot be stressed too highly. As SRC is a long-term, perennial crop, ensuring ideal conditions at establishment will reap benefits at first and all subsequent harvests.

Weed control is a critical part of coppice establishment. Complete eradication of all invasive perennial weeds is essential prior to planting. One or two applications of a glyphosate-based herbicide, applied at the appropriate rate, should be carried out in the summer/autumn prior to spring planting. Ideally the first herbicide application should take place in mid-summer with a follow-up application in autumn to control any further flush of weeds. An additional application just before planting in spring may be necessary on some sites. Spring spraying alone is unlikely to be effective.

If required the site should be sub-soiled to a depth of 40cm to remove compaction. It should then be ploughed to a depth of at least 25cm and left to over-winter. On lighter land it may be more appropriate to spring plough. Power harrowing of the site should be carried out immediately before planting.

Sludge cake, well-rotted farmyard manure or other bulky organic manure with a low available nitrogen content can be incorporated into the soils prior to ploughing. This is particularly beneficial on light soils where it will increase moisture retention and help to condition the soil. The DEFRA Code of Good Agricultural Practice for the Protection of Water (1998) must be adhered to when applying organic manures.

Rabbits, if present, must be kept out of the crop at least during the first two years and ideally up to first harvest, to allow the crop to mature beyond its vulnerable stage. Rabbit fencing should be erected to British Standard, buried and turned out. DEFRA and the Department of Trade and Industry (DTI) have produced a leaflet on rabbit management techniques for SRC (McKillop & Dendy, 2000).

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Planting material

Access to the ECS is not restricted to specified varieties of willow. However, several willow varieties, bred specifically for use as SRC energy crops, are listed in the Forestry Commission Information Note "Poplar and willow varieties for short rotation coppice" (Tabbush, Parfitt and Tubby 2002). The recommended varieties have been through trials to ensure high yields, erect growth habit and resistance to, or tolerance of, disease. The list is updated as information on new varieties becomes available and provides a useful source of information when selecting planting material.

Melampsora rust is the most common fungal disease of willows. Ideally, a mix of willow varieties with diverse rust tolerance characteristics, referred to as "mix types", should be used. Details of these varietal characteristics are available in the Forestry Commission Information Note referred to above or from material providers. Recent research has also shown that mixed planting can lead to reduction in damage caused by willow beetles, the main pest species of willows.

Planting rods

European Plant Breeders' Rights protect the majority of varieties and crop harvested on the farm cannot be used as planting material. Further information can be obtained from the holders of Rights.

Planting material	
Planting rods	Cut and trimmed willow stems, generally 1.5 – 3m long
Cuttings	Cut fresh from rods and between 18 – 20cm in length

Willows are planted either as cuttings or rods. Only licensed producers should conduct willow propagation. Rods or cuttings are taken from one-year-old material that is harvested between December and March when the plants are dormant. They must be either planted immediately or stored at -2 to -4°C, where cuttings will remain viable for several weeks and rods up to 3 months. They should only be taken from cold store and

Planting material

delivered to the planting site on the morning of planting. If rods/cuttings are left in temperatures above 0°C a break in their dormancy will occur, adventitious roots will develop and the buds may burst. This will lead to a reduction in water and nutrient content and consequently reduced viability.

Willow cuttings colour-coded by variety

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Establishment

Planting

Willows are planted either as cuttings or rods, depending on the type of planting machinery used. Details of the latest machinery available to buy or hire can be obtained from British BioGen's Energy Crops Network (see 'Contacts' section).

At present, the most commonly used machines are 'step planters'. Willow rods of 1.5-2.5 metres length are fed into the planter by two or more operatives depending on the number of rows being planted. The machine cuts the rods into 18-20cm cuttings, inserts the cuttings vertically into the soil and firms the soil around each cutting. 15,000 cuttings per hectare is the current standard commercial planting density using this method. Lower density planting may lead to thicker stems and consequently larger chip size. Therefore, planting densities down to 12,000 cuttings/ha may be appropriate where quality of chip is of more importance than yield.

For small areas of planting, modified cabbage planters can be used for planting cuttings directly. These machines are not economic for planting large areas however.

A 'lay-flat planter' is being developed which lays whole rods horizontally into furrows opened by discs at 2-8cm depth. The rods are laid end to end with a slight overlap, the soil covers them and is consolidated to minimise moisture loss. Distance between

A 'step planter'

Establishment

rows can be controlled but as the shoots tend to grow randomly along the length of the rods there is no way to accurately control density.

Planting should ideally take place after the last frosts but as early as February if soil conditions allow. Planting can be successful as late as June but late planting is best avoided as the longer the first growing season the better in order to take the plants successfully into winter and cutback. Another factor is that late planting has to rely on planting material from cold store, i.e. harvested earlier in the year. This will restrict the material available, especially as cuttings start to lose viability after a few weeks in storage.

Willows should be planted in twin rows 0.75 metres apart and with 1.5 metres between each set of twin rows. This spacing allows standard agricultural machinery fitted with wide tyres to work across the crop. A spacing of 0.59 metres along the rows when planting cuttings will give a planting density of 15,000/ha, the commercial standard (see diagram opposite).

The site should be rolled immediately after planting to consolidate the soil for effective herbicide application. Pre-emergence residual herbicide should be applied within 3-5 days of planting.

If the site was previously grassland or long-term set-aside, leatherjacket control should be applied. For commercial reasons it is better to apply the insecticide at the same time as the pre-emergence residual herbicide but ensure that it is before root or shoot development.

A 'lay-flat planter'

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Establishment year management

From each cutting 1 – 3 shoots will arise and reach up to 4 metres in height by the end of the first growing season, depending on soil conditions. In the case of rods, shoots develop randomly along the length of the rod but the stem heights will be similar to those from cuttings.

No fertiliser should be applied during the establishment year.

The coppice should be monitored carefully for pests, weed growth and general health during the establishment year. If remedial weed control proves necessary, a hooded band sprayer, specifically designed for use on SRC, should be used.

Cutback

During the winter following planting the willow is usually cut back to within 10cm of ground level to encourage the development of the multi-stemmed coppice. The work

Growth shortly after planting

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Establishment

should be carried out as late as possible in the winter but before bud-break, generally late February. The most effective machines are modified mowers/reapers as these give a clean cut to the stems.

A contact herbicide should be applied after cutback to control those weeds that have grown during the establishment year. It is important that the herbicide is applied before coppice bud-break otherwise the crop will be damaged. Generally the use of systemic/translocated contact herbicides should be avoided due to the risk of crop damage although some, e.g. amitrole, have been shown to be safe when applied before bud-break.

Another option is to use a mix of amitrole and pendimethalin (residual herbicide) after cutback. The addition of the residual herbicide helps maintain weed-free

Plantation prior to cutback

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conditions until canopy closure. Again, if used, this mix must be applied before bud-break.

5 – 20 shoots will emerge from each cutback stool depending on the variety. Within 3 months of cutback, canopy closure will have occurred providing natural weed control due to reduced light at ground level.

SRC stool

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Calendar of activity

The following table provides an indication of the timing of major activities during the first two harvest cycles of a willow SRC plantation under a 3-year rotation.

Stage	Year	Period	Activity
Pre-planting	-1	Jan - Jun	• Consider site selection and liaise with neighbours, local authorities, archaeologists, etc. • Prepare evidence of market for SRC • Prepare and submit DEFRA Establishment Grant application
		Jun - Sep	• 1st application of glyphosate-based herbicide
		Oct - Dec	• 1st or 2nd application of glyphosate-based herbicide • Incorporate sludge cake if required • Sub-soiling • Ploughing • Ordering cuttings
Establishment	1	Jan - Mar	• Erect rabbit fencing where necessary
		Mar - May	• 2nd or 3rd application of a glyphosate-based herbicide • Power harrowing and planting • Rolling and application of pre-emergence residual herbicide (together with leatherjacket control if necessary) • Monitor for pests and check rabbit fencing
		Jun - Dec	• Monitor for pests, maintain rabbit fencing and check overall crop health • Remedial weed control if required

2	Jan - Feb	• **Cutback** and gap up as necessary
	Feb - Mar	• Application of contact herbicide
	Apr - Jun	• Apply liquid sludge/fertiliser as required • Monitor for pests and check rabbit fencing
	Jun - Dec	• Monitor for pests and diseases and maintain rabbit fencing
3	Mar - Aug	• Apply liquid sludge/fertiliser if required and practicable • Monitor for pests, particularly willow beetle
4	Mar - Aug	• Apply liquid sludge/fertiliser if required and practicable • Monitor for pests and diseases, treat as necessary
	Oct- Dec	• Agree harvesting dates and delivery schedule with end user • **Harvesting** and delivery to end user as fresh material • Harvesting, storage and drying
5	Jan - Feb	• Harvesting, storage and drying
	Feb - Mar	• Apply contact herbicide if necessary • Apply liquid sludge/fertiliser as required • Storage and drying of harvested material • Delivery of chip to end user
	Mar - Aug	• Monitor for pests, particularly willow beetle and spray as necessary • Storage and drying of harvested material • Delivery of chip to end user
6	Mar - Aug	• Apply liquid sludge/fertiliser if required and practicable • Monitor for pests and diseases, treat as necessary
7	Mar - Aug	• Apply liquid sludge/fertiliser if required and practicable • Monitor for pests and diseases, treat as necessary
	Oct - Dec	• **Harvesting**

Pre-planting

Establishment

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General management

Headlands and rides

Headlands and rides should be grassed and cut twice a year. This regime provides some support for vehicle movements at harvest whilst also encouraging the establishment of beneficial flora.

Fertilisation

Digested, i.e. treated, sewage sludge can be applied to SRC as a fertiliser if it is considered feasible by the local Water Company under UK sludge regulations and their own guidelines. Accurate nutrient requirements of the crop are still under research but where treated sewage sludge has been applied the subjective view of growers is that it is beneficial. Under the Code of Good Agricultural Practice for the Protection of Water (COGAP 1998), no more than 250kg organic nitrogen/ha/year can be applied to agricultural land. Willow SRC has a low demand for nitrogen (N) and the current UK recommendations for application are 40, 60 and 100kg N/ha/yr for the 1st (i.e. after cutback), 2nd and 3rd years of the harvest cycle respectively (Johnson P. 1999). Where the soil has high residual N levels from previous cropping or a high soil organic matter level, these rates should be reduced.

Liquid sludge application using dribble bar

No fertiliser should be applied during the establishment year, i.e. from planting until after the post-cutback herbicide application has had time to be effective.

Unfortunately, due to the growth form of SRC and the equipment currently available, fertiliser application can be difficult in year 2 of the harvest cycle and impossible in year 3. Opportunities to work over the crop usually have to be taken in year 1 after cutback and, where possible, in year 2. However, treated sewage sludge in liquid form can be applied using a dribble bar fed by an umbilical system. This allows the sludge to be applied directly to the ground surface through a series of pipes fed from the dribble bar with no contamination to the crop and it can be used on coppice up to 2.5 metres in height. Application should be at the rates given above.

The use of composted sewage sludge applied using standard agricultural spreaders is being investigated to assess the benefits of applying up to 3 times the annual limit of total N, i.e. 700-750kg N/ha, in 1 application. Currently sludge cake or composted organic wastes, which contain very little plant available N, may be applied at rates of 500kg N/ha in 1 application every 2 years, in areas not sensitive to nitrate leaching (COGAP 1998). The potential of composted sludge is that it could be applied after cutback and again after harvest when there are few practical difficulties with working over the crop, although the height of the stems must be less than 50cm. Only 5-10% of the nitrogen would be released per year, i.e. during the growing season when temperatures rise the composted sludge would provide up to 70kg N/ha/yr for each year of the 3-year harvest cycle. The remaining nitrogen is held within the organic component of the compost and is not leached out. DEFRA will issue more guidance on this as results from the investigations become available.

Nitrate Vulnerable Zones

A mature SRC plantation, i.e. after establishment, will have a dense, widespread root system and this, combined with a long growing season, enables the crop to efficiently utilise nutrients. Research, in the UK and areas of Scandinavia with similar growing conditions, has shown that the uptake of available nitrogen by SRC is very effective and, consequently, nitrate leaching is much lower than that from fertilised grassland or arable land. Also with SRC there is no soil disturbance to promote mineralisation.

Nitrate leaching has been recorded in the following situations:

- after green cover removal in the land preparation phase,
- during the establishment year where nitrogen has been applied as fertiliser, and
- after final removal of the crop.

It is therefore important that no fertiliser is applied during the establishment year, i.e. after planting and before cutback. The root system will not have fully developed and would not be able to utilise the additional nutrients.

Although from research to date SRC will prove to be a beneficial crop for planting within Nitrate Vulnerable Zones, it is essential that all DEFRA regulations relating to these zones are complied with.

Pests and diseases

Rust is the most important disease of SRC, caused by a number of fungi called *Melampsora*. Rusts can infect both the leaves and stems of willow and, as they can adapt rapidly to changing circumstances, can successfully infect a whole crop if appropriate measures are not taken.

General management

Melampsora rust on willow leaves

Monocultures of willow, i.e. block planting of single varieties, are highly susceptible to rust damage. The UK and European Plant Breeding Programmes, one of whose aims is to identify varieties that are resistant to rust, recommend that at least 5 different varieties be planted in a random mix at each site. The Forestry Commission Information Note by Tabbush, Parfitt and Tubby (2002) gives details of appropriate mixes. The use of fungicides is not recommended for economic, practical and environmental reasons.

Chrysomelids (willow beetles) are the most important insect pest of willow SRC. Their numbers can build up rapidly in spring and, as both adults and larvae feed on the leaves, they can cause considerable damage to the crop. For example, removal of 90% of the leaves in summer can reduce the yield by as much as 40%. Adult willow beetles over-winter in rotting wood, under the bark of trees and in similar habitats short distances from the coppice. As temperatures start to rise in the spring, the adults move into the edge of the coppice, start feeding, mate and then gradually move further into the crop.

If beetle numbers reach 100 adults or more shaken from the canopy per square


Willow beetle larvae

metre of ground surface, then either a local application of an appropriate insecticide directed specifically to where the beetles are congregating or a spray applied from the edges of the coppice if the beetles are more dispersed, will save the crop from further damage. Overspraying a mature plantation would prove costly, not only financially but also ecologically as the insecticides used are not specific to their targets and would therefore damage many non-target and beneficial insects. Beetle populations do tend to fluctuate between years so a large infestation one year does not necessarily mean that it will occur again. Planting a mix of willow varieties can have a beneficial effect as the beetles tend to feed preferentially on some varieties before moving onto others and this slows their spread through the coppice.

Browsing animals such as rabbits and deer can also cause damage to SRC but mainly during establishment.

The Game Conservancy Trust has produced a booklet describing integrated pest management techniques for SRC (Tucker & Sage, 1999) which includes sections on willow beetles and rust.


Adult willow beetles

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Harvesting

Harvesting generally takes place on a 3-year cycle, the first harvest being 3 years after cutback. The work is carried out during the winter, after leaf fall and before bud-break, usually mid-October to early March. SRC can be harvested as rods, chips and billets (see table below).

End-users will generally require the fuel in the form of wood chip, to a maximum size. They may also need the wood chip dried to a particular moisture content (MC). For example, willow is generally in the range 45-60% MC at harvest but end-users may want a MC below 30%.

The type of harvesting machinery used will depend on the end-user's requirements. Details of the latest machinery available to buy or hire can be obtained from British BioGen's Energy Crops Network (see 'Contacts' section).

Rod harvesting

A number of machines are available for rod harvesting most of them producing loose rods which need to be off-loaded into heaps on the headlands or on farm. There is some wastage with this method as rods are left in the field and after collection from headlands. However, loose rods do dry by natural convection and do not deteriorate with time. 'Bundler' harvesters cut whole stems, bind them and then cut them into bundles 2.5 metres long. The bundles can be stacked on headlands or on farm and can dry down to approximately 30% MC in 3-4 months.

Chipping of dried whole rods or bundles tends to result in shattering of the material rather than chipping; therefore, where chip size and quality are important, chipping fresh material is recommended.

Direct-chip harvesting

Specifically designed SRC headers for direct chipping of the crop have been fitted to forage harvesters: the stems are cut, chipped and then blown into an accompanying trailer. Although direct-chip harvesting is currently more efficient than rod harvesting, storage and drying of the fresh wood chip does cause problems. Stored, fresh wood chip can heat up to 60°C within 24 hours and start to decompose. During decomposition calorific value, i.e. the energy value of the fuel, is lost. Also the fungal and bacterial

Harvested material	
Rods	Harvested stems up to 8m in length
Billets	Cut material, 5 – 15cm long
Chips	Cut material, up to 5 x 5 x 5 cm in size

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spores produced during decomposition constitute a health hazard.

As the fuel will be needed all year, storage, drying and prevention of decomposition must be considered. The use of grain driers, ventilated-floor-driers and low-rate aeration using ducts are all being investigated, although it is currently considered uneconomic to dry wood chip by any method other than natural air-drying. It is important to ensure that the energy used in producing wood chip for fuel is kept to a minimum.

Billet harvesting

Intermediate between rod and direct chip harvesting is billet harvesting. The stems are cut whole, cut further into billets and blown into an accompanying trailer. Due to the spaces between the billets, natural ventilation occurs within storage piles preventing the difficulties associated with chip storage. However, depending on the fuel specification of the end-user, the billets may need to be chipped prior to use.


Direct-chip harvesting

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Yield

SRC yields will vary according to the location of the site. Soil type, water availability, general husbandry, and pest and weed control will also affect yield. Yield following the first harvest of a number of commercial sites was in the range 5-9 odt/ha/yr. However, planting densities at many of these sites were 12,000 cuttings/ha rather than the current standard of 15,000 cuttings/ha. Yields should also increase at second and third harvests. Average yields from experimental plots growing new varieties, some of which are now commercially available, have reached more than 18 odt/ha/yr. Breeding programmes continue to produce varieties that out-perform older varieties.

Harvested woodchip

Biodiversity

Despite the fact that it is essential to eradicate weeds during the establishment of SRC, once the crop is mature the growth of a ground flora is beneficial. Ground cover encourages the presence of invertebrates, which in turn leads to an increase in the number of small mammals and birds found. At least three times the number of plant-eating species spend part of their life cycle in the canopy of willow SRC compared to conventionally grown barley and wheat (Sage & Tucker, 1998).

High numbers of bird species are also found throughout the year and over the 3-year harvest cycle. For example, skylark, lapwing, yellow wagtail and snipe are often found in newly planted, cutback and harvested SRC. Species of high conservation value such as bullfinch, reed bunting and song thrush have been noted to regularly hold territories in SRC during the breeding season.

Headlands and rides provide further habitat opportunities for a wide range of plants and animals, for example, 14 species of butterfly have been recorded on SRC headlands.

Many of the species that use the habitats associated with SRC will predate pest species. For example, two of the birds commonly associated with SRC, the garden and willow warblers, are two of the most important consumers of defoliating invertebrates. Therefore, any management practice that enhances the conservation potential of the crop is likely to prove valuable for pest management.

Headland flora

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Removal of SRC

After the final winter harvest, the stools should be left and allowed to shoot the following spring. When shoots of more than 15cm in height have developed, the entire coppice should be over-sprayed with a glyphosate-based contact herbicide to kill the willow. Running either a sub-soiler or a large diameter disc along the rows close to the stools will sever the main structural roots, which run horizontally from the stools. When the shoots have died back, the stools themselves can be mulched by use of a bush-hogger (heavy-duty grass-topper or pulveriser) into the top 5-10cm of soil. The field can then be grassed for the first year following removal and (if appropriate) used for standard arable cropping the following year. Using this method, final harvest to re-seeding, will take 18-24 months.

To shorten the process, the final harvest can be taken in late summer/early autumn and the stools again allowed to shoot. When the shoots are 15cm or more in height, the herbicide should be applied, the structural roots cut and, following death of the shoots, the stools mulched. Depending on soil type, the stools can be ploughed in prior to winter. This will allow an early re-seeding the following spring.

Poplar SRC

Poplar has been used as a short rotation coppice crop on a small scale to date, often planted adjacent to willow SRC to provide visual diversity.

Site

Poplar grows best in deep fertile soils, although it will grow in most conditions. The main exceptions are shallow soils and sites that remain waterlogged. Soil pH should ideally fall in the range 5.5 - 7.5, although research suggests that there are varieties tolerant to soil pH outside this range.

Preparation of the site should be the same as that for willow SRC, taking care to ensure eradication of all weeds. The soil should be well cultivated to a depth of at least 25cm. Where compaction is present, sub-soiling should be carried out to a depth of 40cm.

Planting material

Most new poplar varieties have been bred for high yield but as a single stem crop. Also a number of varieties planted in the mid-1990's succumbed to rust as their resistance broke down. However, current breeding programmes aim to produce high yielding varieties that will coppice more readily and have long term resistance to rust. The current recommended and approved poplar varieties for SRC are listed in the Forestry Commission Information Note, "Poplar and willow varieties for short rotation coppice" (Tabbush, Parfitt and Tubby 2002).

Poplar varieties are controlled under the Forest Reproductive Material Regulations, which are in place to improve the quality of poplar varieties, increase production and ensure that the most suitable varieties are used. These Regulations also control the marketing of poplar varieties so that reproductive material is only available from registered sources.

Planting

Planting should take place as early as possible in the spring but avoiding frost. The density of planting has generally been lower than that for willow at 10-12,000 cuttings/ha. The cuttings are 20-25cm long and must have an apical bud within 1cm of the top of the cutting. This means that

Poplar SRC

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Poplar SRC

poplar cannot be planted using 'step planters', as the cuttings have to be manually processed to ensure the presence of the apical bud. Consequently, modified cabbage planters have to be used but due to the ridged nature of poplar stems, the cuttings occasionally block the planter mechanisms. The 'lay-flat planter' is currently being tested for planting poplar rods.

Management

Weed control is very important in the establishment year, so after planting and rolling a residual herbicide should be applied within 3-5 days. Cutback takes place late in the winter following planting. Due to its apical dominance, poplar will generally produce only 1-3 shoots after cutback.

Melampsora rust is also the most common disease of poplar, although different species of rust affect poplar and willow. Different poplar varieties have different susceptibilities to rust so it is important to read the latest version of the Forestry Commission's 'varieties' Information Note referred to above. As with willow, it is recommended that a mix of varieties be planted.

Willow beetles are also an important pest of poplars and should be treated either by spraying localised colonies or, if the population reaches 100 or more adult beetles per square metre of canopy, edge spraying the coppice in early spring. Overspraying the entire plantation would be ecologically and financially inadvisable.

Yields

Research has shown that poplar can often outperform willow in terms of yield but this appears to be site specific and highlights the fact that choosing the appropriate varieties for a site is essential. Unlike willow, poplar tends to produce better yields when allowed to grow for four years or more from cutback.

Harvesting

As poplar produces fewer, heavier stems, careful consideration must be given to the harvesting machinery used; it must be capable of dealing efficiently with large diameter, rigid stems. Details of the latest machinery available to buy or hire can be obtained from British Biogen's Energy Crops Network (see 'Contacts' section).

Removal

The removal of poplar SRC at the end of its life is more problematic than willow. The rooting system of poplar includes a large taproot that grows down into the soil. Removal of the stools (following final harvest and spraying off of the shoots) will generally require a large excavator.

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Notes

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ENGLAND RURAL DEVELOPMENT PROGRAMME

Contacting DEFRA

If you have a query and are unsure about who to talk to in DEFRA, you can call the DEFRA Helpline who will be pleased to help you to find the right person.

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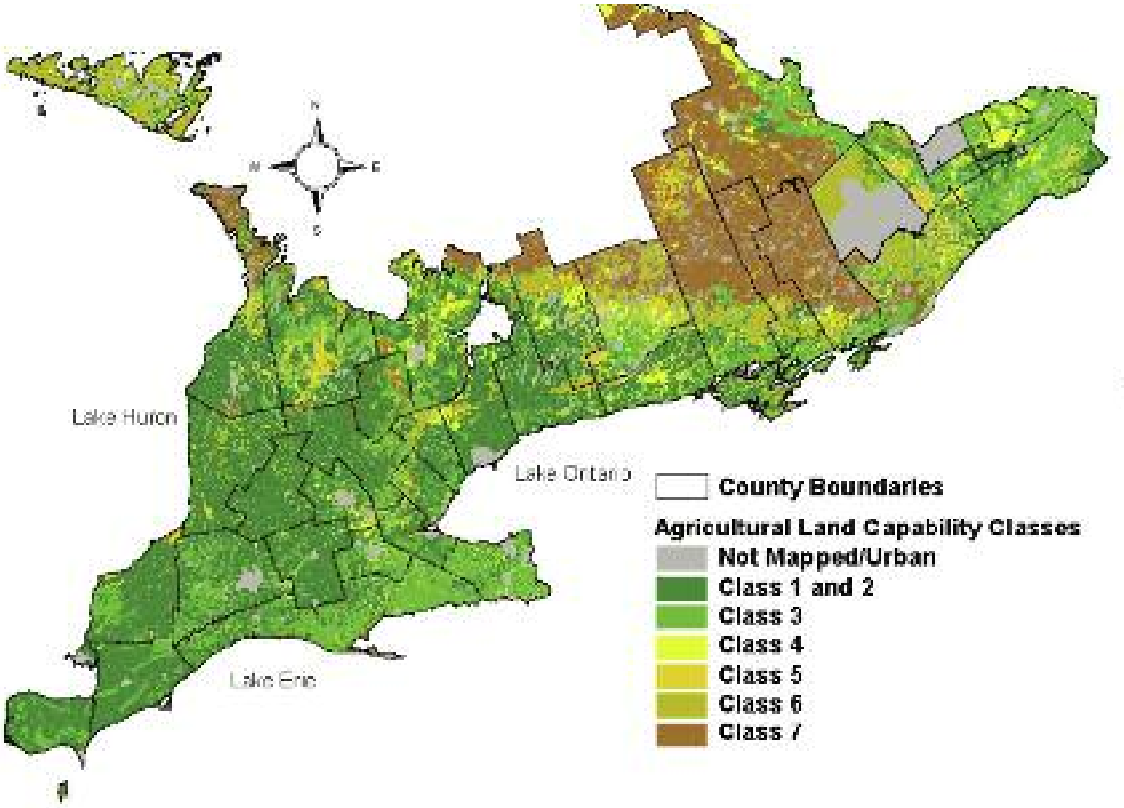

Figure. Ontario Agricultural Land Capability Classes (Source: OMAFRA)

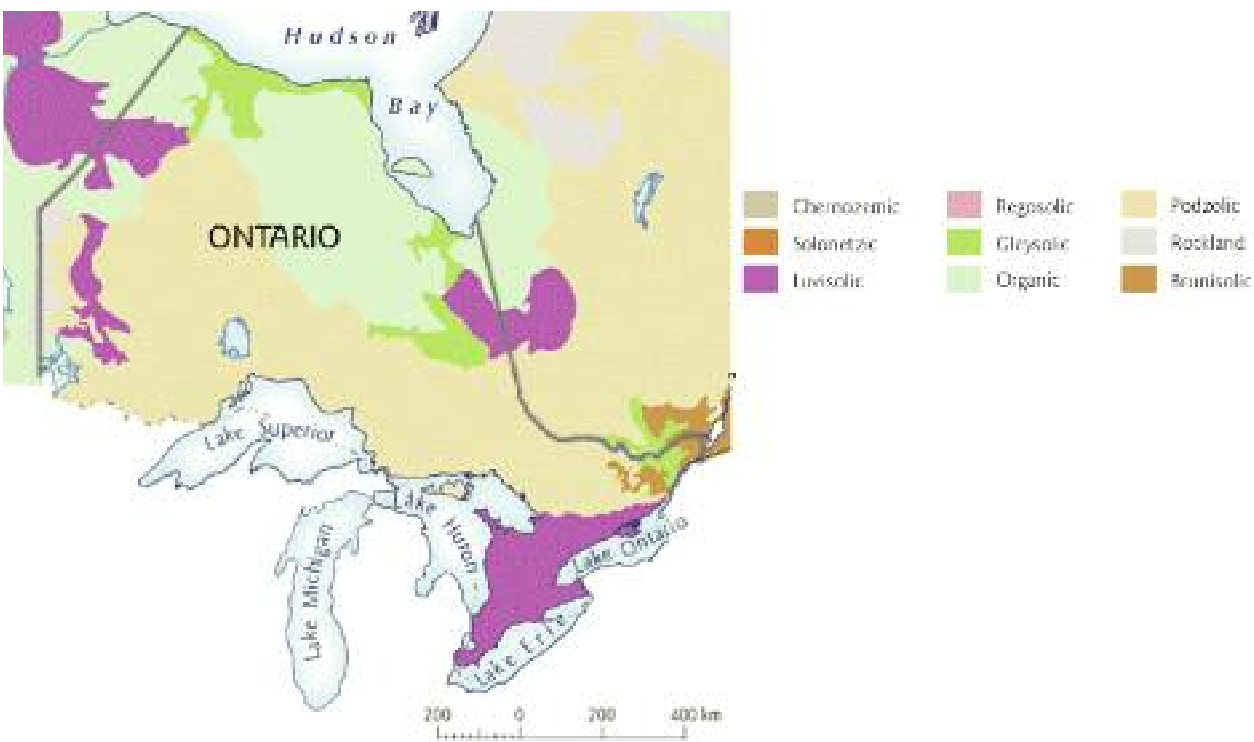

Figure. Ontario Soil Map (Source: Environmental Commissioner of Ontario, www.eco.on.ca)

Shipping in Canada – 2005 (Source: Statistics Canada)

Table 12-6

Domestic shipping – Number of movements, vessel capacity and tonnage transported by province or territory and port — Ontario

	Ballast			Cargo			Total tonnage handled
	Movements	Gross tonnage	Net tonnage	Movements	Gross tonnage	Net tonnage	
	number	'000 t		number	'000 t		
Ontario	2,566	31,764.1	19,865.4	2,148	27,628.9	17,581.9	30,901.6
Amherstburg	1	0.4	0.1	0	0.0	0.0	0.0
Bath	27	296.4	181.3	24	258.4	154.4	254.3
Britt	4	23.7	12.2	4	23.7	12.2	22.8
Cardinal	1	1.0	0.3	0	0.0	0.0	0.0
Clarkson	145	1,929.4	1,348.1	137	1,786.5	1,240.8	2,356.8
Colborne	110	1,425.8	1,015.0	110	1,425.8	1,015.0	1,942.1
Courtright	40	761.4	523.3	11	158.2	113.5	76.4
Goderich	114	1,893.1	1,247.6	72	1,303.0	858.3	1,520.9
Hamilton	335	4,873.2	2,850.2	279	4,496.5	2,852.9	5,564.5
Badgeley Island	24	255.3	144.9	25	265.9	148.4	401.5
Kingsville	50	204.6	90.4	35	24.3	13.1	17.1
Little Current	14	150.4	102.7	3	67.7	46.1	81.3
Midland	34	246.1	136.9	32	374.5	260.3	536.1
Morrisburg	2	42.3	27.6	8	125.3	86.6	153.8
Nanticoke	111	1,229.2	690.2	153	1,519.4	761.9	1,562.4
Oakville	23	173.7	84.1	25	151.4	90.7	213.6
Oshawa	24	81.1	43.1	7	52.7	42.2	30.8
Owen Sound	10	152.7	78.5	11	154.7	59.5	112.6
Parry Sound	9	121.0	86.8	9	128.5	88.2	112.9
Pelee Island	29	0.5	0.3	33	0.6	0.4	0.5
Picton	82	1,067.0	556.7	60	485.3	303.3	443.8
Port Colborne	42	480.9	236.1	8	117.2	91.7	100.5
Port Maitland	1	0.3	0.1	0	0.0	0.0	0.0
Port Stanley	6	4.3	2.3	3	10.1	10.1	8.1
Prescott	18	295.3	188.4	19	314.1	201.2	376.4
Sarnia	325	2,314.6	1,286.3	307	2,422.2	1,345.9	2,458.7
Sault-Ste-Marie	87	901.0	482.2	61	753.6	455.5	831.8
Sombra	21	342.3	251.0	1	16.3	11.3	15.8
Spragge	18	319.9	226.9	5	94.8	68.1	116.9
St.Catharines	13	288.8	169.5	0	0.0	0.0	0.0
Thorold	6	73.6	45.0	2	47.4	24.0	29.1
Thunder Bay	244	3,462.1	2,229.2	255	4,261.7	2,754.3	5,254.6
Toronto	114	1,128.9	708.1	114	1,218.0	772.3	1,395.0
Welland	1	16.4	13.5	0	0.0	0.0	0.0
Whitefish	153	2,420.0	1,650.9	49	815.7	553.2	541.0
Windsor Ontario	147	1,872.9	1,209.5	161	2,483.8	1,647.2	2,186.4
Bowmanville	18	371.3	243.4	11	220.6	152.6	264.7
Meldrum Bay	163	2,543.0	1,703.2	116	2,039.3	1,346.5	1,918.4
Canada	28,856	98,599.8	54,394.6	26,166	189,841.3	116,338.8	139,163.0

Appendix F

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Summary of Industry Experts' Opinions, Discussions and Comments

A number of industry experts were approached in this study through personal interviews, phone conservations, presentations, and e-mail communications for their opinions and comments on various aspects of the development of the energy crop industry in Ontario. The following table provides highlights of their opinions, discussions and comments.

Table. Summary of Industry Experts' Opinions, Discussions and Comments

Industry Experts	Highlights of Opinions/Discussions/Comments
Paul Carver **BiCAL, UK**	• Firm government energy and environmental policies, not establishment grants, play important roles in adoption of energy crops in the UK. Such policies include legally binding greenhouse gas reduction targets for power producers. Attractive biomass pricing is also essential in accelerating adoption of energy crops.
Rachelle Clinch **Canadian Forest Service** *Naresh Thevathasam* **University of Guelph**	• Willow and poplar may yield 3 odt/ha/yr on poor soils. • There could be 800,000 ha of marginal lands suitable for energy crops in Ontario. • Poplar could out-yield willow in early years, and should not be excluded from the potential energy crop list. The researchers are aware that the State University of New York discontinued the work on poplar due to septoria canker disease. • Current establishment cost of willow SRC could be as high as $10,000/ha. • Moisture content of willow SRC could be as high as 65–80% at harvest. • Farmers see willow SRC and poplar as trees, not crops. This could be a barrier in adoption. • Formation of an energy crops grower group would be helpful for information dissemination and public relations.
Ron Van Damme **St. Clair Township farmer**	• Sorghum-Sudangrass is not suitable for energy use due to its higher moisture content (~ 70% at harvest in Summer). • Miscanthus could be the major candidate for bioenergy use in Ontario. • Agricultural residues are promising biofuels in Ontario. • Price of wheat straw could be as low as $20/t. • Harvesting miscanthus and switchgrass in early spring could compact soil, negatively affecting the water withholding capability of soil. • Food crops can be grown in crop rotation with miscanthus/switchgrass. • Gross margin of growing vegetables: $600-700/acre. • Gross margin of growing field crops: $100-200/acre. • Biomass should be dried to < 15% moisture content to prevent from self-heating and dry matter losses. • Farm cooperative model is attractive for large volume biomass supply, but there is a risk of cooperatives collapsing. • Guaranteed market and attractive biomass pricing are important for energy crop development.
Phil Dick & Ian McDonald **OMAFRA**	• Utilization of some class 1–2 land may be required to meet OPG's biomass demand, since there are limited class 3–4 lands in Ontario. • Timeline to develop the energy crop industry in Ontario to meet OPG's biomass demand in 2015 is fairly tight. • About 15–20% of total agricultural land in Ontario could be converted to energy crops from the historical perspective. • Rotating energy crops with cash crops could be a beneficial strategy; research and field trials are underway. • OMAFRA is in early stage of research and field-testing of energy crops in Ontario. • Agricultural residues can play an important role in bioenergy.

Industry Experts	Highlights of Opinions/Discussions/Comments
Steve Flick **Show Me Energy Cooperative**	• Pelletizing technology for agricultural products is different from that for forest products. • Biomass requirement of a 150,000 t/yr pellet mill can be usually met by agricultural residues and energy crops available within the 50-mile radius. • About 30% of agricultural residues should be left in the field for nutrient replenishment. • The US government provides 50% investment tax credit for new investments in bioenergy in some cases.
Cheryl Hendrickson & Hauk Rask **LandSaga Biogeographical Inc.**	• Sustainability of 5 million tons/yr of biomass supply is questionable. It could lead to depletion of forests/woods. • Willow SRC is not invasive. • Willow SRC can be grown in all regions of Ontario. • Selection of willow varieties is site-specific. • Fertilizer application for willow SRC could be a zero sum game, i.e. economic gain due to yield increase is offset by cost associated with fertilizers. • Willow can be grown on reclaimed land for soil remediation, and land along the highways for natural snow fence and bioenergy use. • Establishment grants and annualized payments would help accelerate the adoption of willow SRC. • The willow plantations can be developed within 3 years in Ontario to meet OPG's demand. • Complete supply chain can be developed within 5 years, since technologies for willow SRC are in place.
David Lee **Soy 20/20**	• Demonstration of energy crops on commercial scale is important in accelerating the adoption. • Cattle industry in Ontario is declining. However, dairy farms are doing well. • Gross margin of energy crops on class 1-2 soils should be higher than that of soybeans for farmers to convert their productive land to energy crops. Soybean price can go back to the higher level seen in 2008 once the global economy is back on track.
Jake Lozon & Ron Ludolph **Ministry of Natural Resources (MNR)**	• Mixed native perennial grasses offer a number of environmental benefits such as soil improvement, erosion prevention, restoration of ecological system, increasing bee populations, biodiversity, etc. • Mixed tall grass prairie plantations do not require fertilizer applications. • Environmental impact of miscanthus should be studied since it is not a native crop.
Don McCabe **Ontario Federation of Agriculture**	• Ontario farmers are interested in growing energy crops as a diversification of their agricultural products. • Attractive biomass pricing and long-term contracts are important in adoption of energy crops. Slow adoption of willow SRC can be expected. • Ontario agricultural sector can supply both food and fuel as yields of major field crops have been significantly increasing due to genetic advances. • Gross margin of growing vegetables: $1,000/acre. • OFA will be working on formation of an energy crops grower group, which would educate the agricultural community and general public on energy crop development. • Energy crop industry in Ontario will improve rural economy. • Establishment grants might be helpful for adoption of energy crops. • Cattle industry of Ontario is declining due to lower demand and tough competition from western Canada.

Industry Experts	Highlights of Opinions/Discussions/Comments
Matt McLean **Southwestern Ontario Bioproducts Innovation Network**	• Farmers know the productivity and limitation of their land very well, and will manage the energy crops accordingly based on pricing. • Farm cooperative supply model could be appropriate for the biomass volume OPG needs. • Food versus fuel could be a public relation issue for OPG. • In the future, OPG may be competing with other end-users for biomass from energy crops. • Extracting valuable chemicals from the biomass before burning for energy is the efficient utilization of resources. • If there is an attractive economics, energy crop industry could be developed within three years.
Kevin Montgomery **OMAFRA**	• Almost all arable land in Ontario are in use. Conversion of some agricultural land is necessary to meet OPG's demand. • Accurate estimates of available class 3–4 lands in Ontario may require overlaying the current municipal maps and soil maps, which were mostly created in 1970s, on a county basis.
Don Nott **Switchgrass grower** **Nott Farms** **Clinton, Ontario**	• Switchgrass is not invasive. No serious pests or disease problems experienced so far. • Switchgrass yields on different soil types are relatively the same. • Switchgrass can be grown in crop rotation with cash crops. Higher yields can be expected for subsequent crops due to soil improvement by switchgrass. • Fuel quality of switchgrass can be improved by harvest timing. • About 20% of crop land can be assumed less productive land. • Cattle industry of Ontario is declining. Therefore, 40% of hay land can be easily converted to energy crops. • It may take 3 years to develop the supply chain to meet OPG's demand of 5 million tons/yr. • Guaranteed market is important for adoption of energy crops. • Subsidy of $2/GJ for switchgrass pellets should accelerate the adoption of switchgrass by farmers. • Energy crop development would improve rural economy and good for Ontario agricultural sector.
Jordon Solomon **Ecostrat Inc.**	• Biomass pellets from energy crops would be cheaper than wood pellets from the forestry sector for OPG's Lambton and Nanticoke generating stations. • The supply contract should be in place in 2009 to get the complete supply chain ready for 2015.
Gord Surgeoner **Ontario Agri-Food Technologies**	• Miscanthus is not invasive, since it is sterile and produces no seeds. • Growing miscanthus on class 1–2 soils would be cost competitive. This would also improve biodiversity, since less land is required in comparison to growing on class 3–4 soils. • Biomass fuels for OPG's year-round operation should come from combined agricultural residues and mixed energy crops. • In adoption of energy crops, which are usually productive for 10–15 years, farmers may have the concern of missing higher grain prices of major field crops in the future. • Due-diligence statement of biomass suppliers to comply with the intellectual property right of crop breeders should be included in the supply contracts. • Ontario agricultural sector can provide both food and fuel. This would improve farm income and ensure viability of the agricultural sector.

Industry Experts	Highlights of Opinions/Discussions/Comments
Dean Tiessen **BiCAN** **Pyramid Farms**	• Miscanthus is not invasive. • Miscanthus would be the highest yielding energy crop in Ontario. • Mixed varieties of miscanthus should be planted in a given plot for polyculture benefits. • Miscanthus planter developed by BiCAL, UK can plant 60 acres/day. • Fuel quality of miscanthus can be improved by over-wintering the biomass in the field. • Establishment grants may not be necessary if biomass is attractively priced with a long-term contract. • Total 100,000 ha of miscanthus plantation can be completed in three years. First year plantation can be used for propagation in following years. • Establishment cost of miscanthus could be $1,000/acre for farm cooperative order of about 40,000 acres plantation. • Some miscanthus varieties may yield less, but have better fuel characteristics. • BiCAN is working with OMAFRA on field trials of miscanthus varieties in Ontario. • End-user like OPG needs to formulate the strategy to manage the intellectual property associated with energy crop varieties.