Promising resources and systems for producing bioenergy feedstocks

Switchgrass Production in the USA

Switchgrass is a warm-season grass native to North America. It has been chosen as one of several plant species with high potential for supplying bioenergy feedstocks in the United States. While not necessarily the highest yielding bioenergy feedstock in biomass trials, it has been found to be a highly reliable producer over a range of soil types and climate conditions.

IEA Bioenergy

IEA Bioenergy Task 43: 2011:03

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Wright L.L., Wrightlink Consultants, Ten Mile, TN 37880
Perlack, R.D., Turhollow, A.F., Eaton, L.M. Oak Ridge National Laboratory
Oak Ridge, TN, 37830
wrightlld@gmail.com, perlackrd@ornl.gov, eatonlm@ornl.gov, eatonlm@ornl.gov

KEY MESSAGES

As a cellulosic biomass crop, switchgrass has many benefits and some risks. Major benefits include;
(1) ease of incorporation into a farming system where conventional equipment can be used,
(2) low input requirements when compared with annual crops,
(3) enhancement of soil carbon levels,
(4) an increase of habitat for desirable bird species.

Risks are mainly associated with confined harvesting periods and the need for storage if a continuous supply of biomass material is required by conversion facilities.

Methods for establishing, managing and harvesting switchgrass are similar to those for any traditional hay crop. Good yields have been obtained on land used previously for pasture or for other crops. Across the US, upland ecotypes have averaged 8.7 ± 4.2 dry tonne ha^{-1} and lowland ecotypes have annually averaged 12.9 ± 5.9 dry tonne ha^{-1} Annual yields of the best lowland ecotypes under best southern conditions have averaged 15.5 to 22.6 dry tonne ha^{-1} in regional field trials.

Production costs to farm gate are estimated to be about $65 per oven dry tonne (~3.60 per GJ). These can be somewhat reduced with the introduction of technical improvements in crop establishment, harvesting equipment, and handling methods and with production experience. As with most other bioenergy crops, the major contributor to the lowering of production costs will be through the development of genetically superior varieties with characteristics of;

- high yield potential
- resistance to drought, pests, and diseases.

Cover Picture: Alamo switchgrass in trials at Oklahoma State University, Tulsa, Oklahoma (Courtesy of Lynn Wright/Oak Ridge National Laboratory)

INTRODUCTION

Switchgrass (*Panicum virgatum*) is a forage crop that has received attention from the United States Department of Energy Feedstock Development Program. It was chosen as a model for herbaceous bioenergy crop development, based on its high yield; relatively low energy and resource requirements; potential for improving soil quality and wildlife habitat; and compatibility with conventional farming equipment and management practice. Research information about switchgrass is reviewed and results from multi-year trials in many locations throughout the USA are summarized. Analysis of a base-case scenario suggests that production costs are similar to other bioenergy crops in the US and are likely to decrease as growers become familiar with the crop and improvements in technology (breeding; harvesting) are put into practice. Biomass yields are reported throughout as oven dry weight in both metric and English units.

Switchgrass characteristics

Switchgrass is a perennial, (rhizomatous) high-yielding, warm-season grass, native to the United States of America (USA). It was an important component of the original tall-grass prairie in the central USA. A considerable amount of prairie land has been converted to cropland, and natural switchgrass populations are currently confined to thinly-dispersed small stands in diverse locations. These include grassland and open forest to the east of the Rocky Mountains.

Figure 1 Mark Downing in field of "Alamo" switchgrass in Alabama, USA. (Photo courtesy of Oak Ridge National Laboratory)

The C4 photosynthetic metabolism, typical of all warm-season grasses, and a deep-rooting habit enable switchgrass to survive and thrive under conditions that are unsuitable for many of the species used in row cropping (Moser and Vogel 1995). *Panicum virgatum* is a genetically-diverse, open-pollinated species. Two main ecotypes occur naturally: a lowland ecotype that has thick stems and is adapted to warm, moist sites in the south; and an upland ecotype that has thinner stems and tolerates drier soils and cooler climatic conditions. The variety "Alamo" (Figure 1) is an example of the lowland ecotype and "Cave-in-Rock" is an upland variety. Switchgrass has been planted for forage in the Great Plains region for over 50 years. It is one of the grasses used to restore soil quality under the federal Conservation Reserve Program.

Benefits of using switchgrass for bioenergy

- As a warm-season grass with a C4 photosynthetic pathway, switchgrass utilizes nutrients and water more efficiently than most temperate-zone crop species that have a C3 carbon metabolism and thus is drought tolerant.

- As a perennial, thin-stemmed grass, it can be planted, maintained and harvested with standard, readily-available equipment (Figure 2). The stands are viable for 10 years or more but reversion of the land to traditional crop species would be a simple matter if energy cropping were to become uneconomic.

- During the first year or two after planting, a large proportion of the metabolites are allocated to root growth (Figure. 3). This results in increased rates of absorption of water and nutrients from deeper soil layers, increased transfer of carbon compounds to the soil, increased activity of soil micro-organisms; and an increased capacity for storage of metabolites needed for regrowth after cutting or grazing (McLaughlin and Kszos 2005).

- The amounts of fertilizer and herbicide required for realization of the high yield potential are smaller than those needed for production of most annual agricultural crops (Ranney and Mann 1994).

- When placed between a field of an annual crop and a stream bank, a switchgrass plantation can capture nutrients and sediment that would otherwise enter the waterways. Erosion control provided by stream-side vegetation can be enhanced. Sediment loss from established switchgrass plantations is considerably less than that from annual commodity crops requiring tillage, and similar to that from crops grown under no-till conditions. It also has greater tolerance to flooding than annual crop species.

- Switchgrass can utilize some forms of wastewater as a source of nutrients (e.g. excess irrigation water) and also limited amounts of livestock manure.

- In an agricultural landscape where annual commodity crops predominate, switchgrass can provide visual and indigenous biologic diversity and also habitat for a wider range of insects, birds and mammals.

- When used as a biomass crop to displace fossil carbon energy sources (coal, oil, natural gas), switchgrass can help to reduce carbon dioxide emissions to the atmosphere if fossil fuel inputs required for crop production are minimized.

- As a high-yielding perennial plant, switchgrass requires a smaller area of land for production of a unit of biomass than many other species. This results in greater management efficiency and shorter transportation distances. Switchgrass cropping may be less expensive than the gathering of forest or agricultural residues over extensive areas.

Figure 2 Switchgrass being windrowed and baled with conventional farm equipment. (Courtesy of Oak Ridge National Laboratory)

Figure 3 Container-grown “Alamo” switchgrass showing potential for very high allocation to root biomass. (Courtesy of Lynn Wright/Oak Ridge National Laboratory).

Risks associated with using switchgrass for bioenergy

- Allocation of metabolic resources to root growth during the first year after planting means that the amount of above-ground material is about 1/3 of maximum yield during the first-year harvest. Maximum annual biomass yield is usually achieved by the end of the third year.

- As with most bioenergy crops, yields can vary +/- 50% of average yields annually as a result of varying climatic conditions, stand maturity, and other factors. Figure 4 discussed later in this paper is one example of yield variation in a stand followed for 13 years.

- Fertilizer requirements are lower than those for many herbaceous species, but higher than those for woody biomass crops. This is mainly due to removal of a greater proportion of site nutrients during harvesting. Litter fall from woody species returns a greater proportion of nutrients to the soil.

- If a year-round supply of biomass is needed, some storage of harvested material will be necessary. Long-term storage of switchgrass will result in losses due to decomposition. Well managed storage will be required to minimize these losses.

- Seed of the varieties of switchgrass best suited to bioenergy production may not be readily available from commercial forage seed companies. Establishment of a stand to provide a seed source 1-2 years in advance of large-scale planting may be necessary.

- Although it is possible to produce clonal switchgrass by micro-propagation techniques, costs currently outweigh the benefits for bioenergy production purposes.

SWITCHGRASS CROPPING TECHNIQUES

Methods for establishing, managing and harvesting switchgrass are similar to those for any traditional hay crop, and existing agricultural equipment can be used. Good yields have been obtained on land used previously for pasture or for other crops.

Establishment

Switchgrass can be established without tillage following a crop that leaves a lighter residue, such as soybeans (*Glycine max)*. However if planted after a crop that leaves a heavier residue, such as maize (*Zea mays)* or sorghum (*Sorghum bicolor)*, tillage or some other method of reducing the residue may be necessary, followed by packing to firm the soil (Mitchell et al 2010). Application of fertilizer and herbicides follow seedbed preparation. Pasture land may need additional site preparation such as additional tillage or weed control.

Switchgrass is established from seed which is normally available from commercial suppliers. Seed of an appropriate variety and known viability is sown in a firm seedbed. Typical row spacing is 19 to 25 cm (7.5 to 10 inches) (Mitchell et al 2010). Row spacing can be increased to 80 cm (32 inches) without yield loss (Ma et al 2001) and this flexibility improves the attractiveness of switchgrass stands as game bird cover.

Maximum annual yields will not be achieved until 2-3 years after planting. Weed control is important during the first year (Wolf and Fiske 1995). Herbicides used for pre- and post-emergence use on non-grazed grass include atrazine, quinclorac, and 2,4-D; application rates and effectiveness will vary from region to region and with latitude. High temperatures encountered in Texas, for example, can increase the activity of some herbicides, making them toxic to switchgrass. Efforts are ongoing in the US to find substitutes for atrazine which is slow to break down in soil and water and which has an ability to disrupt and interfere with hormones. Atrazine is currently banned in the European Union.

Water and Nutrient management

The ability of switchgrass to sustain good growth during periods of infrequent rainfall can be attributed to its deep and extensive root system. In the mid-Atlantic region, values for root mass have been found to be comparable to those for annual above-ground biomass production (Parrish et al. 2003). While demonstrating drought tolerance, economic production of switchgrass is generally limited to the eastern half of the US.

Permanent irrigation is usually considered to be too costly for herbaceous energy crop systems, but experience in Texas identified that a watering interval of 7 days or less was critical to obtaining seedling survival of 90% or more in all soils (Ocumpaugh et al. 2003). Sharing of irrigation equipment between several fields particularly during the establishment phase may be worth considering. In regions that lack summer moisture (e.g. western United States), irrigation may be necessary to grow switchgrass and other warm-season grasses (Fransen, 2009).

Nitrogen is the only nutrient element that consistently stimulates switchgrass yield. Potassium and phosphorus are usually applied in amounts equivalent to those removed at harvest. No nitrogen is applied in the establishment year. Based on Mitchell et al (2010), our economic analysis assumed annual application after the establishment year of 6.5 kg N per dry tonne (13 lb N per dry ton) of yield. Switchgrass productivity may become less dependent on nitrogen fertilizer as the amount of nitrogen in roots, crowns and soil organic matter accumulates (Parrish et al. 2003; Bransby 2002).

A long period of continuous switchgrass productivity recorded for "Alamo" planted in 1988 at Auburn, Alabama showed high but variable yields (13-year annual average 23.7 dry tonnes ha^{-1} (10.6 dry tons ac^{-1})). Also, the stand appeared to become increasingly resistant to drought over time (Bransby 2002) (Figure. 4). The grass was sown in 1988 and harvested twice each year (early July and September). Neither the decline in yields from 1991 – 1997, nor the increase in yields from 1998 through 2001 can be directly correlated to rainfall levels. The production site was located on alluvial soils that often include subsurface water channels and layers of nutrient rich soils. While no proof is available, Bransby speculates that during the several dry years, switchgrass roots penetrated deeper into the soils finding not only enough water to maintain the stand but also a source of nutrients not previously accessible (Bransby, 2002).

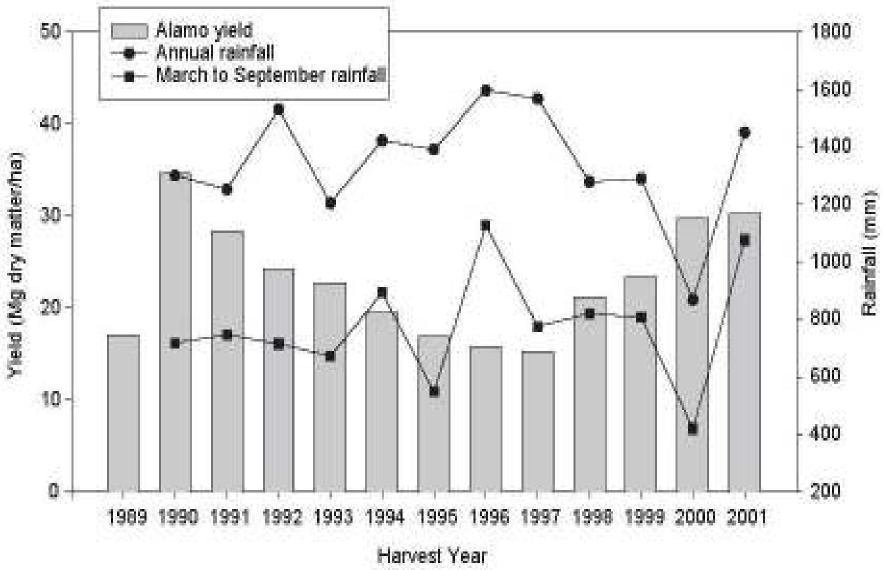

Figure 4. Annual rainfall and annual yields of "Alamo" switchgrass in Auburn, Alabama, USA. Source: Adapted from McLaughlin and Kszos, 2005.

Crop protection

Most switchgrass management guides suggest that no insects are currently recognized as a major threat to switchgrass including a guide revised in 2010 (Christenson and Koppenjan, 2010), however, that guidance is likely to soon change. A recent survey of insects and nematodes in switchgrass and Miscanthus plantings in six crop producing states in the US identified at least two nematode species infesting switchgrass in all locations (University of Illinois at Urbana-Champaign). The nematode species are similar to those known to reduce yields in other grass crops. The best defence is selection of genotypes resistant to nematode damage.

When grown within its zone of natural adaptation, switchgrass is usually resistant to most foliar pests. In recent years, increased occurrence of leaf disease has been observed in the larger plantings of certain varieties in the Mid-west. Specific crop protection strategies for leaf disease have not yet been developed yet.

Yield Factors

A summary of yield results of field trials supported by the US Department of Energy/Oak Ridge National Laboratory between 1989 and 2001 is shown in table 1. Better performing varieties were identified, and the importance of timing and frequency of harvest was demonstrated. Lowland varieties produced higher yields in Alabama and Texas when harvested once a year between late August and mid-September, or twice a year in early July and November. While two harvests tended to produce higher yields, a single harvest was found to have environmental benefits. In Alabama a single harvest reduces nitrogen removal (when compared to a double harvest) by about 60% to 15-25 kg N ha^{-1} (13-22 lb N ac^{-1}) (Bransby 2002).

For highest yields, it is important to use varieties suited to local conditions. After ten years of production in field research plots “Alamo” (a lowland ecotype) is considered to be the best commercial variety for the deep South, “Alamo” and “Kanlow” (lowland ecotypes) for mid-latitudes, and “Cave-in-Rock” (and upland ecotype) for northern latitudes (Parrish et al. 2003; Bransby 2002). Annual yields (dry) of the best southern varieties under best conditions have averaged 15.5-22.6 tonne ha^{-1} (6.9-10.1 tons ac^{-1}) in regional field trials.

A recent analysis of all trials of switchgrass in the US showed considerable variation (Wullschleger et. al, 2010.) Across the US upland ecotypes have averaged 8.7 ± 4.2 tonne ha^{-1}(3.9 ± 1.9 tons ac^{-1}) and lowland ecotypes have annually averaged 12.9 ± 5.9 tonne ha^{-1}(5.75 ± 2.6 tons ac^{-1}). Yield variation was attributed to growing season precipitation, annual temperatures, N fertilization levels and ecotype. Yields of about 17.9 tonne ha^{-1} (8 tons ac^{-1}) were achieved by the 3rd year of commercial production of Alamo by farmers on 3000 acres in Tennessee in 2009.

Table 1: Annual yield data for switchgrass varieties grown in field trials throughout the USA (after McLaughlin and Kszos 2005)

Location and no. of sites	Year of sowing	Test years	No. of harvests per year	Varieties tested *	Best varieties (highest annual dry yield)			
					Best two yielding varieties	**All-site average yield (tonne/ha)**	**All-site yield range (tonne/ha)**	**Highest single-year yield (tonne/ha)**
Virginia (3) Tennessee (2) West Virginia (1) Kentucky (1) North Carolina (1)	1992	1992-2001	One	***1, 5, 8, 10. 11, 19***	Kanlow Alamo	13.9 13.8	10.9-17.5 -	23.4 27.4
Virginia (3) Tennessee (2) West Virginia (1) Kentucky (1) North Carolina (1)	1992	1992-2001	Two	***1, 5, 8, 10. 11, 19***	NC1 Alamo	15.6 15.6	11.3-19.7 12.4-21.6	27.2 25.4
Texas (3: Dallas College Station Stephenville)	1992	1995-2000	One	***1, 3, 5, 8, 12, 13 16,17***	Alamo PMT-785	13.5 10.7	8.1-16.5 5.5-13.3	24.7 18.7
Texas (1) Stephenville	1993	1995-2000	One	***1, 3, 5, 8,12,13, 16, 17***	Alamo	16.1	-	19.8
Texas (2) Arkansas (1) Lousiana (1)	1997	1998-2001	One	***1***	Alamo	19.1	10.7-19.5	Not recorded
Iowa (1)	1997	1998-2001	One	***1, 2, 3, 4, 5, 7, 8, 15, 18, 19, 21, 22***	Kanlow Alamo	13.1 12.1	- -	- 17.5
Alabama (1)	1988	1989-2001	Two	***1, 2, 5, 8, 9***	Alamo Kanlow	23.0 18.2	- -	34.6 -
Alabama (5)	1992	1994-2001	One	***1, 5, 8***	Alamo Kanlow	12.9 11.6	10.4-15.8 8.3-15.8	- 24.6
Alabama (5)	1992	1994-2001	Two	***1, 5, 8***	Alamo Kanlow	16.2 15.5	13.0-20.5 10.8-19.1	30.4 -
Georgia (2)	unsure	1996-2001	One	***1, 5, 8, 14, 18, 22***	Alamo Kanlow	16.2 15.7	16.1-16.3 15.5-15.9	- 23.2
Nebraska (1)	1998	1999-2001	One	***, 5, 7, 8, 17, 18, 19, 20, 21,22***	Kanlow Cave-in-Rock	20.6 16.3	- -	Not recorded
Kansas (1)	1998	1999-2001	One	***2, 5, 7, 8, 18, 19, 20, 21,22***	Blackwell Shelter	9.5 9.47	- -	Not recorded
North Dakota (2)	1999	2000-2001	One (Sept.)	***5, 6, 18, 20, 21,22***	Sunburst Trailblazer	11.0 9.9	9.8-12.2 9.1-10.8	13.8 12.1

* Varieties evaluated: ***1***-Alamo; ***2***-Blackwell; ***3***-Caddo; ***4***-Carthage; ***5***-Cave-in-Rock; ***6***-Dacotah; ***7***-Forestburg; ***8***-Kanlow; ***9***-Kansas Native; ***10***-NC1; ***11***-NC2; ***12***- NCSU1; ***13***-NCSU2; ***14***-NE Late ***15***-Pathfinder; ***16***-PMT279; ***17***-PMT785; ***18***-Shawnee; ***19***-Shelter; ***20***-Summer; ***21***-Sunburst; ***22***-Trailblazer;

Harvesting, handling and storage

Harvesting of switchgrass has usually been accomplished using conventional mowing, raking, and baling equipment on slopes of less than 35 degrees. Harvest may occur twice during the growing season if harvested for forage, but a harvest once per year, after a killing frost, is generally recommended when bioenergy is the primary use. A late fall harvest maximizes nutrient translocation back to the roots which supports stand longevity. Harvest can take place during the winter and early spring as long as weather conditions permit, though there will be some loss of biomass with delayed harvests.

Moisture content of the standing crop in humid areas of the USA will vary from 75% early in the growth season down to about 45% (on a wet mass basis) by late fall and down to 20% if the standing crop is left over winter. In a somewhat dryer area, the range has been documented to be 65% to 12.5% moisture content by late fall (Ogden et al. 2010).

A moisture content of 20% or less is required for storage as bales and this can be attained with field drying when the crop is harvested at a higher moisture content. Field drying will be faster with use of a mower-conditioner, followed by raking into windrows. The grass is normally collected in large round or rectangular bales which are moved to the field edge for storage.

Storage is very short for portions of the year and adds no additional cost except for handling. Long-term storage options for bales include (1) storage outside with no protection (~$1.12 per tonne), (2) storage outside on a gravel pad with a tarp cover (~$10.87 per tonne), and (3) storage inside a building (~$25.20 per tonne) (Turhollow et. al.2009). Storage of the switchgrass as silage and as wet piles has also been investigated. In the latter two cases, the mown switchgrass is harvested with a silage chopper, rather than a baler. The best storage regime is dependent on the climate patterns at the switchgrass production site and the intended end-use.

The harvest, handling and storage assumptions used for analysis of base case production costs in the south-eastern US are described below. Haulage costs have normally been calculated for bales loaded onto to flatbed trucks for removal to the final destination.

ECONOMICS OF SWITCHGRASS PRODUCTION AND DELIVERY

At the present time, energy crops are not marketable commodities in the USA and no data exists for actual prices received by producers, factor input costs for energy crop establishment and maintenance, or returns to management and risk. Estimates of the cost of bioenergy materials must be derived from economic modelling and research results.

Our analysis of the economics of energy crop production has used standard budgeting procedures and full cost-accounting for all resources. Crop budgets include variable cash expenses (planting material, pesticides, fertilizers, fuel, labour, etc.), fixed cash expenses (farm overheads, interest on operating loans), capital replacement, short-term operating capital, land costs (rental value or opportunity cost in alternative production), and unpaid labour. Methods described by Walsh and Becker (1996) were updated according to recommendations of the American Agricultural Economics Association (AAEA 2000) and the American Society of Agricultural Engineers (ASAE 2001) and run by the authors of this paper with current assumptions. It was assumed that taxes and insurance on land are included in the land rental rate. Fuel, equipment, and labour costs were updated to 2006 levels. Costs were discounted at a real rate of 6.5% and evaluated over a 10-year production cycle. Commercial production of switchgrass for bioenergy purposes is most likely to occur in regions suited to the highest-yielding variety where land costs are low, and so labour and equipment costs in the Southeast region (Figure. 5) was used in the analysis.

Figure 5. Economic Regions of the United States

Full-resource cost-accounting may overestimate actual out-of-pocket costs incurred by energy farmers because all factor inputs are assumed to have an economic cost. On a diversifying farm the required equipment (e.g. tractors and attachments) and support infrastructure are already owned by the operator. Expenses such as equipment depreciation, insurance, property taxes, land purchase, and general farm overheads have probably been incurred already and may not affect the decision to grow an energy crop. This is more likely to be influenced by the variable costs associated with planting, growing, and harvesting, and perceptions of returns and risk. The decision by a biorefinery company to purchase or rent land for energy cropping would involve other factors such as the cost of alternative energy resources.

Production costs at the farm gate (i.e. excluding storage and delivery)

Switchgrass stands can be expected to produce for at least 10 years before replanting is required. Of these only 9 are productive, the first year being an establishment period with no harvestable volume. Management practices assumed for the economic analysis are outlined below. These are the management practices considered to be appropriate on land previously used for other crops in the Delta or Southeast regions of the United States.

Year 1 –Establishment – no harvest:

- One disking; drill-sowing.
- 5.6 kg seed ha^{-1} (5 lb ac^{-1}) (“Alamo”).
- One application of lime [4.5 tonne ha^{-1} (2 tons ac^{-1})].
- One application of fertilizer;
    - [phosphorus as P_2O_5 – 44.8 kg ha^{-1} (40 lb ac^{-1});

- potassium- 88.6 kg ha^{-1} (80 lb ac^{-1});
- no nitrogen required].
- Three applications of herbicide;
- [2,4-D – 1.12 kg active ingredient (a.i.) ha^{-1} (1 lb a.i. ac^{-1}),
- atrazine - 1.12 kg a.i.) ha^{-1} (1 lb a.i. ac^{-1}), and
- Quinclorac - 0.56 kg a.i. ha^{-1} (0.5 lb a.i. ac^{-1})]

Year 2 – Reseeding

- 25% of stand reseeded

Years 2-10 – Maintenance and harvesting:

- One application of fertilizer [phosphorus as P_2O_5 – 44.8 kg ha^{-1} (40 lb ac^{-1}); potassium as K_2O – 88.6 kg ha^{-1} (88 lb ac^{-1}); nitrogen 88.8 kg ha^{-1} (79.3 lb ac^{-1}) except nitrogen in year 2 is 59.2 kg ha^{-1} (52.9 lb ac^{-1})].
- Mow; rake; bale (large, round type); move to field-edge; store on gravel pad).
- One application of 2,4-D in year 5 [1.68 kg a.i. ha^{-1} (1.5 lb a.i. ac^{-1})]

For first-rotation costs, an average annual dry yield of 13.7 tonne ha^{-1} (6.1 tons ac^{-1}) was assumed (Year 1 yield = 4.6 tonne ha^{-1} (2.0 tons ac^{-1}) or about 1/3 average yield; Year 2 yield = 9.1 tonne ha^{-1} (4.1ton ac^{-1}) or 67% of the average annual yield achieved in years 3-10.)

Land prices are a major component of energy crop production costs at the farm gate. Table 2 shows the range of land rents in regions suited to grow switchgrass. These suggest that the first commercial establishment of switchgrass crops is likely to occur in the Southeast region, where land prices are lowest. The land cost used in the base-case analysis would be considered in this region to be low for cropland and high for pasture.

Table 2. Land rents in regions of the USA suitable for growth of switchgrass. (Source: USDA/NASS 2010)

Region	Cropland		Pasture	
	$/ha	$/acre	$/ha	$/acre
Northern Plains*	107-240	44-97	32-40	13-16
Lake States	200-279	81-113	59-79	24-32
North East	109-173	44-70	63	25
Corn Belt	222-432	90-175	59-99	24-40
Appalachians	69-231	28-94	47-59	19-24
Delta States*	128-165	52-67	37-40	15-16
South East*	84-121	34-49	35-59	14-24

* Non-irrigated land.

Table 3 contains a summary of estimated farm-gate economic costs for growing and harvesting switchgrass, based on management outlined above and land costs of $118 per ha ($48 per acre). This is only one of many possible scenarios.

Crop yield was found to be the factor having the greatest influence on production costs and profitability to the farmer. The yield level in the base-case scenario was selected from the higher end of predicted commercial-scale yields given earlier in this report because increases are expected once farmers become familiar with the crop. Site-specific management and continued genetic improvements can be expected to increase the dry yield of a second or third switchgrass rotation to the current best experimental level of 18 to 22.4 tonne ha^{-1} yr^{-1} (8-10 tons ac^{-1} yr^{-1}) in appropriate regions.

Total production costs (including storage and delivery

Table 3. Summary of estimated costs (2009 US dollars) of switchgrass production on cropland in the Southeast. Average annual dry (mature) yield is assumed to be 13.46 tonne ha^{-1} (6.1 tons ac^{-1}).

	$ per hectare			$ per acre		
	Yr 1	Yr 2	Yrs 3-10	Yr 1	Yr 2	Yrs 3-10
Variable costs						
Establishment/maintenance						
Seed	271.70	67.93		110.00	27.50	
Fertilizer	334.12	229.96	265.90	135.27	93.10	107.65
Chemicals	111.12			45.03		
Fuel/lube	22.91	2.66	0.79	9.27	1.08	0.32
Repairs	28.24	3.18	1.11	11.43	1.29	0.45
Harvest						
Fuel/lube	22.44	30.20	40.70	9.09	12.22	16.48
Repairs	30.60	41.77	58.38	12.39	16.91	23.63
Twine	15.07	30.13	45.20	6.10	12.20	18.30
Total	836.60	405.82	412.07	338.58	164.30	166.83
Fixed costs						
General Overhead	34.58	34.58	34.58	14.00	14.00	14.00
Insurance, housing, taxes	7.30	5.37	7.06	2.95	2.18	2.86
Interest (operating loan)	12.45	6.04	6.14	5.04	2.45	2.48
Total	54.33	46.00	47.78	22.00	18.62	19.34
Owned resources						
Capital replacement	55.06	39.92	51.68	22.29	16.16	21.00
Non-land capital	23.5	17.37	22.86	9.52	7.03	9.26
Land rent	148.20	148.20	148.20	60.00	60.00	60.00
Labor	53.25	37.47	46.00	21.56	15.17	18.62
Total	280.01	242.96	268.92	113.36	98.36	108.88
Total cost	**1170.64**	**694.73**	**728.77**	**473.94**	**281.29**	**295.05**
Average cost per unit dry weight at farm gate*			**65.86** per tonne			**59.72** per ton
Additional on-farm storage cost		**$0-11**	**$0-11**		**$0-10**	**$0-10**

* Net Present Value, assuming a discount rate of 6.5% and Year 1 and 2 yields of 0 and 9 tonne ha^{-1} (4 tons ac^{-1}). Thus the discounted average cost of $5641.09/ha is divided by the discounted yields summed to year 1 of 85.66 dry tonne to result in a net present value of $65.86 per dry tonne.

The development of new biofuel facilities based on cellulosic biomass is more likely to occur in areas where land rental rates are lower. Total delivered costs to such end-users include the farm-gate component and all costs associated with storage and transportation. Storage may be necessary at the farm site, at the conversion facility, and/or at an intermediate location. There are many ways in which biomass material can be stored. Examples are wet storage in piles; storage as silage; and storage in square or round bales. Costs range from zero (no storage required) to $11-16.5 per tonne ($10-15 per ton). For the base-case scenario it was assumed that switchgrass material would be air-dried and would contain 15-20% moisture prior to baling. This may be optimistic for areas such as the eastern US, where harvesting, drying and baling between rain events may not be possible.

Transportation is a major element in the cost of delivered biomass, especially if bales have to be moved. For analysis purposes, average transport costs (including loading and unloading) are often assumed to be $11 per tonne ($10 per ton). Consideration of wet storage could include the possibility of chopping and compressing the material before removal. Distance to the conversion facility will affect storage costs and will be determined by demand. Analysis of these factors is outside the scope of this paper. Description of current and future alternate harvest, handling and storage options including wet storage, and alternate cost scenarios that include transport have been recently described by Sokhansanj et al (2009).

As land cost and yield changes, obviously estimated switchgrass production costs also change (Table 4). As farmers become more familiar with the crop and purchase new equipment (e.g. larger balers), production efficiency may increase.

Table 4. Effect of switchgrass yield and land rental rate on estimated production costs in the Southeast and Delta regions of the US. Use of a small baler system is assumed

Land rental rate	**Yield (tonnes ha^{-1} yr^{-1})**			**Yield (tons ac^{-1} yr^{-1})**		
$/ha ($/acre)	**9.0**	**13.4**	**18.0**	**4**	**6**	**8**
	---------$US/Mg--------			--------$US/ton--------		
99 (40)	82	62	53	74	56	48
148 (60)	88	66[1]	56	80	60[1]	51
198 (80)	94	70	59	86	63	54

[1]From scenario used for detailed costs (Table 3).

USE OF SWITCHGRASS AS A BIOFUEL

Switchgrass biomass is suitable for both biochemical and thermochemical conversion into bioenergy products. Its mineral content is higher than that of willow and poplar biomass, but acceptable unless there is contamination with dirt. Ash content is likely to be between 3 and 5%. Switchgrass in the US has been typically assumed to have a [higher] heating value (HHV) of about 17.45 GJ per dry tonne (15 million Btu per dry ton (Anthony Turhollow, personal communication). Recent measurements of switchgrass harvested during summer and fall, then dried (to about 7.5% moisture content) and ground for proximate analysis showed no significant difference in calorific value with harvest date but a very wide range in observed values (Ogden et al. 2010). The means values in May, June, October and November (after adjustment for moisture content) were respectively 18.39, 18.64, 17.04, and 19.70 GJ/od tonne with the October and November samples showing higher standard deviations. The HHV mean would appear to be about 18.4 GJ/od tonne, with “as delivered” heating values (assumed moisture content of 15%) of about ~15.6 GJ/od tonne. Ogden et al. concluded that harvesting switchgrass in late fall (November) would be the preferred option for use as a boiler fuel due to reduced levels of ash fouling and slagging minerals and standing crop moisture contents as low as 12.5% thus a heating value of about 16.1 GJ/od tonne. At present, switchgrass is not used for biofuels or bio-power production on a large commercial scale. However by fall 2010, a cellulosic to biofuel demonstration facility in Tennessee, USA (Dupont Danisco Cellulosic) will begin obtaining switchgrass feedstock from Genera Energy (a feedstock supply company contracting with 61 farmers for production of switchgrass on about 2274 ha (5100 acres) of land). The demonstration facility anticipates beginning the conversion of switchgrass to ethanol sometime in 2011.

Power-producers have conducted pilot tests on the combustion characteristics of switchgrass at two or more locations and results have encouraged further interest in switchgrass bioenergy cropping systems. A long-term test burn was completed in 2006 at the Ottumwa Generating Station in Iowa with the facility operating 24 hours a day, 7 days a week over about a 3 month period. The project collected valuable performance data and experience. Over 31,568 bales of locally grown switchgrass were delivered for the test burn that generated 19,607,000 kilowatt-hours of electricity. Though the testing was a major success, the timing was not right for the generating facility to begin commercial production of power from switchgrass. The project was put on hold for several years, but in 2010, the Prairie Lands Bio-products cooperative purchased the biomass project’s assets with plans to actively pursue research and commercial opportunities (Prairie Lands website - www.iowaswitchgrass.com).

Switchgrass is being genetically improved for deployment as a bioenergy crop by multiple commercial firms and it is being tested by universities, private companies, and federal research agencies at multiple locations around the country. The likelihood of switchgrass being included in the mix of commercial bioenergy feedstocks in the USA is very high.

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ACKNOWLEDGEMENTS

Preparation of this paper was sponsored by the Department of Energy's Biomass Program and performed at Oak Ridge National Laboratory (ORNL). ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725. The long-term support of the DOE Biomass Program and especially of John Ferrell has been greatly appreciated. Much credit goes to former ORNL Biomass Feedstock Development staff (Sandy McLaughlin and Lynn Kszos) for their valuable contribution to managing switchgrass crop development subcontract work and summarizing that work in excellent papers. Shahab Sokansanj and Erin Webb of the current Biomass Program at Oak Ridge National Laboratory are also thanked for their valuable inputs to the paper. Very importantly, we wish to recognize the many researchers across the USA who actually conducted the switchgrass crop development research and summarized the results in reports to Oak Ridge National Laboratory and the U.S. Department of Energy.

IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

IEA Bioenergy Task 43 – Biomass Feedstock for Energy Markets – seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This will be achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstock, including biomass markets and the socioeconomic and environmental consequences of feedstock production. Task 43 currently (Jan 2011) has 14 participating countries: Australia, Canada, Denmark, European Commission - Joint Research Centre, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, USA.

Further Information

Task 43

Website www.ieabioenergytask43.org

Göran Berndes – Task leader

Email: goran.berndes@chalmers.se

This publication was produced by Task 43 within the Implementing Agreement on Bioenergy, which forms part of a programme on international energy technology collaboration undertaken under the auspices of the International Energy Agency.