NL Agency
Ministry of Economic Affairs, Agriculture and Innovation

Sustainable Biomass

Switchgrass (*Panicum virgatum* L.)

A perennial biomass grass for efficient production of feedstock for the biobased economy

>> Focus on energy and climate change

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Executive summery

English name: Switchgrass
Common names: vingergras, (Dutch), pasto varilla (Spanish), Rutenhirse (German), panic érigé (French).
Latin name: *Panicum virgatum* L.
Plant Family: Poacea
Origin: North America
Occurrence: Mainly in North America and it is tested and developed worldwide as a low cost, low impact lignocellulosic biomass crop.
Current uses: Fodder, ornamental, erosion control and land reclamation. In development as a biomass crop for fuels and chemicals.
Growth habit: Perennial rhizomatous C_4 grass up to 2.5 meters in height.
Growth cycle: 10 to 20 years when used for biomass production.
Ecological demands (climate, soil, etc.): Wide adaptation. Performs best on good, well drained soils but will also be productive under low pH conditions and soils that are undated temporarily.
Yields: Currently between 8 and 14 tons DM per ha per year mostly with unimproved varieties. More than 20 tons DM per ha is possible.
Biobased applications/conversion and quality aspects: Switchgrass is a model biomass crop which has been developed in quite some detail over the last 25 years mainly in North America and that has been introduced in Europe and other parts of the world. For thermal conversion the quality is worse than for wood and better than for most herbaceous biomass such as straw.
Costs: Cost estimates start at €35,- per ton for local delivery. Cost depend strongly on yields and cost of land.
Sustainability/Impacts: favourable when compared to most biomass crops due to low input requirements and efficient nutrient and water use and due to high soil carbon storage potential.
Outlook: Switchgrass is one of the main perennial crops than can be used to produce low cost, low impact lignocellulosic biomass. The crop can have a large impact as demand for second generation fuels increases which require lignocellulosic biomass. Switchgrass is also one of the crops that may be able to produce reasonable yields at low cost on marginal and lower quality land. This may be one of the ways to source biomass without competing with food crops for land. Thus avoiding the so-called Indirect land use change effect (iLUC).

1 Centre of origin, climate and soil requirements and current distribution

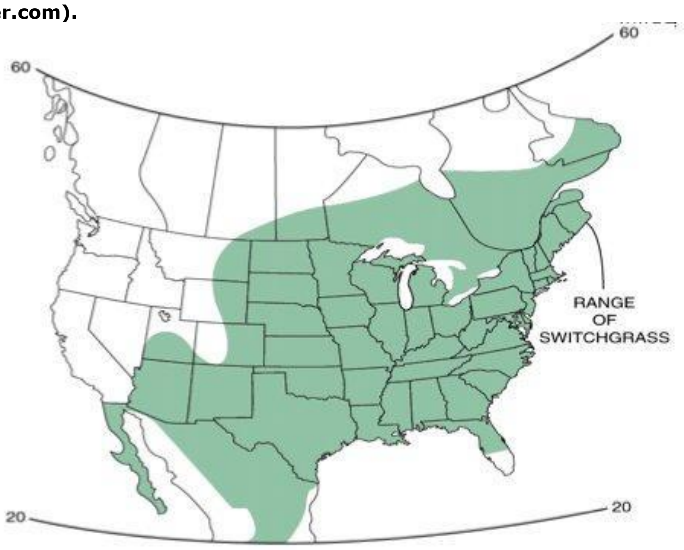
1.1 Plant description

Switchgrass (*Panicum virgatum* L.) is a perennial warm-season grass that resembles a bunchgrass, it spreads slowly by seeds and rhizomes. The plant has erect stems that can be between 0.5 and 2.7 m tall and often have a reddish tint. The inflorescence is an open panicle 15 to 50 cm long. The root system can be up to 3 m deep (Beaty et al., 1978; Christian and Elbersen, 1998; Moser and Vogel, 1995).

Figure 1: Switchgrass in summer in Greece, and in Ukraine

Switchgrass is native to the North American tall grass prairies, where it occurs naturally east of the Rocky Mountains and from southern Canada down to Mexico and Central America (see Figure 2). Switchgrass has the C_4 photosynthesis system, typical of tropical and warm season grasses, making it very efficient in biomass production compared to grasses with the C_3 photosynthesis system. Under the right condition C_4 grasses can produce up to 2x more biomass per day using relatively little water and requiring little nutrients and other inputs as compared to C_3 grasses. To achieve this high growth rate, high light intensity and high temperatures and an adequate supply of water and nutrients are required.

Figure 2: Switchgrass native occurrence in North America (Ref http://www.switchgrass-rer.com).



Switchgrass will grow best on well drained good quality soils but will also sustain lower quality acid soils. The grass is generally not found when precipitation is below 300 mm per year. Most switchgrass varieties can tolerate shorter periods of water logging.

Switchgrass can be categorized into two groups or ecotypes; the upland ecotype and the lowland ecotype. The upland ecotype is generally finer stemmed and shorter than lowland ecotypes (see Figure 3) and is adapted to drier and wetter environments and is generally derived from accessions collected in northern regions of North America.

Crosses between upland (mostly octoploid) and lowland (tetraploid) genotypes are incompatible, tetraploid cultivars from each of the two ecotypes have been crossed and produced fertile offspring with traits of both ecotypes.

Figure 3: Upland (left) and lowland (right) switchgrass ecotypes in fall showing the typical differences in growth habit and earlier senescence of the upland variety (left).

2 Current uses and status as a biomass crop

Switchgrass domestication only started in the 1930’s and 1940’s when the first varieties were released in the USA. These varieties were mostly just collected, local populations with no selection for improved traits. Most of these varieties have the name of the location where the variety was selected from wild plants.

2.1 Current uses of switchgrass

Erosion control:	One of the first uses of switchgrass has been for erosion control. In experiments switchgrass has shown excellent capabilities to intercept runoff and nutrients, even better than C_3 grasses.
Set aside and wild life habitat:	Switchgrass is one of the main grasses used for long term set-aside under the USA conservation reserve program. It is often also used as wildlife habitat.
Fodder:	Switchgrass is a so called warm-season grass used in the USA (and potentially in similar climates in South America and China) to provide fodder during hot summers when cool season (C_3) grasses have reduced productivity due to heat and drought stress. The grass is used both for grazing and hay production. For this purpose it can also be found in Argentina and in Africa.
Ornamental:	Switchgrass is a well-known ornamental grass used in gardens and the inflorescence is also used in bouquets. Varieties such as 'Heavy Metal' and 'Rehbraun' are well known ornamental varieties sold in Europe and are fairly common in gardens and parks.

Switchgrass is also used for phytoremediation and as substrate for mushroom culture. Switchgrass has also been tested for paper pulp production mainly in Canada with positive results. No commercial use is known at this moment. Uses that have been developed more recently include thermal conversion to electricity and heat and production of fuels and chemicals. This is discussed in more detail in chapter 5. These applications have been developed mainly in the USA where switchgrass was chosen as a model energy crop in the early 1990’s. It was also introduced and tested in most west and southern European countries and more recently in eastern Europe including Poland and Ukraine. As yet no real large scale commercial production is known and also no specific locally adapted varieties have been developed.

Switchgrass can be found (as a fodder crop) in tropical areas but no reports are known of it being tested as an energy crop.

3 Switchgrass management

Managing switchgrass for biomass (energy) production is quite different than managing switchgrass for fodder production. In Table 1 some of the differences in requirements and management are shown. Switchgrass is seed propagated and takes 3 to 4 to reach maximum yields, depending on climate, soil type and variety. In the first year yields are often too low to harvest especially in northern ranges.

When growing switchgrass for biomass, the crops is established for 10 to 20 years before reseeding is required, generally due to reduced yield mainly caused by stand loss. The stand lifetime depends on how well it is managed and in how far the variety is adapted to local conditions. In general one harvest after a killing frost (or later in winter) is optimal. Yields may be slightly higher in a 2 cut system (summer and winter), still the extra cost, extra fertilizer need and reduced biomass quality, especially for combustion purposes will not make this an attractive option. The 2 cut-system also may reduce stand maintenance and require earlier need for reseeding and thus increase biomass cost.

Table 1: Differences between switchgrass for fodder production and hay production and for biomass/energy production

	Fodder / hay	Biomass / energy
Desirable attributes	High leaf to stem ratio	High stem content
”	High protein and nutrient content	Low protein and nutrient content
Harvest	At least 2 cuts per year	One cut system after a killing frost
Row spacing	Low	High
Nutrient off-take	High	Low
Fertilization level	Higher	Lower

3.1 Location and variety choice

Switchgrass is well adapted to a wide range of soil types and climates. Though well drained soils with a neutral pH are preferred switchgrass can also grow quite well on acid soils. Liming to increase soil pH is an option though may often not be cost effective. Also measures to reduce weed pressure by sowing a grain crop in the previous year and weed control measures can be used.
A range of switchgrass varieties are available and new varieties have been developed specifically for bioenergy in recent years. Table 2 gives an overview of available varieties and their origin. The origin of a variety is relevant as it gives an indication of the range of adaptation of a variety.

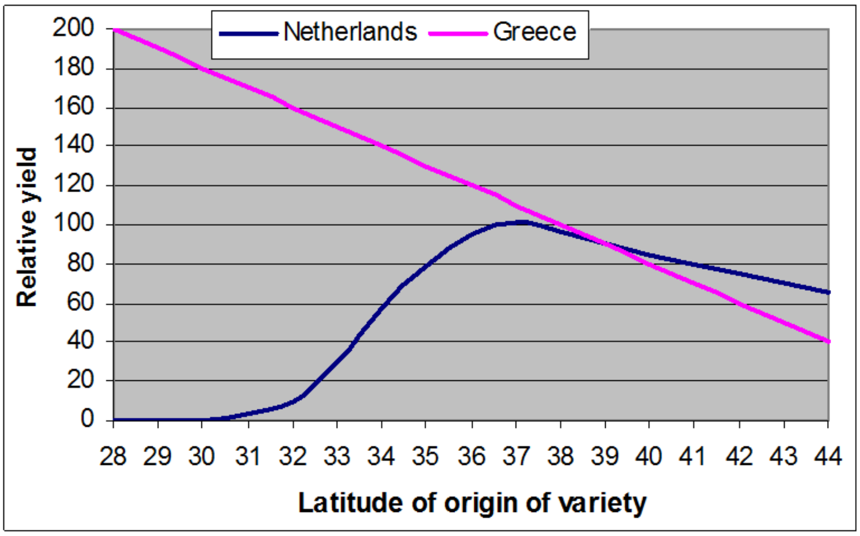
In general switchgrass varieties grown too far north (from the latitude of origin) will not flower or will flower later and will not mature before onset of winter. This will lead to relative high yields in the first year but it will also lead to winter damage of the stand and less re-growth in spring. This will depress yield in the second and following years and will lead to low stand maintenance over time. Later maturing varieties will also have higher moisture contents when harvested leading to higher storage and drying cost. Later maturing varieties will also have higher nutrient contents which lead to lower quality (for combustion) and increased fertilization cost.

Table 2: List of switchgrass varieties and their origin.

Variety	Ecotype	Ploidy level	Origin
Alamo	lowland	Tetraploid	South Texas 28°
Blackwell	upland	Octoploid	Northern Oklahoma 37°
Caddo	upland	Octoploid	South Great plains 35°
Carthage = NJ-50	?	?	North Carolina 35°
Cave-in-Rock	Intermediate?	Octoploid	Southern Illinois 38°
Dacotah	upland	Tetraploid?	North Dakota 46°
Forestburg	upland	Tetraploid?	South Dakota 44°
Kanlow	lowland	Tetraploid	Central Oklahoma 35°
Nebraska 28	upland	?	Northern Nebraska 42°
Pangburn	lowland	Tetraploid	Arkansas 34°
Pathfinder	upland	Octoploid	Nebraska / Kansas 40°
REAP 921	upland	Tetraploid	Southern Nebraska 41°
Shelter = NY4006	mixed?	Octoploid?	West Virginia 40°
Summer	upland	Tetraploid	South Nebraska 41°
Sunburst	upland	?	South Dakota 44°
Trailblazer	upland	Octoploid	Nebraska 40°

Choosing the right variety for a given location is therefore a compromise between yield and winter survival and quality of the biomass. This is illustrated in Figure 4 for different switchgrass varieties (ordered according to latitude of origin) and expected (long term yields) in The Netherland and in Greece.

Figure 4: Expected relative yields of varieties from low and high latitude of origin when grown at a northern location (52° north, the Netherlands) and at a more southern location (38° north, Greece).



3.2 Switchgrass establishment

Switchgrass is established by seed. This makes establishment relatively cheap but it is also difficult. Still, if the right management measures are applied, establishment is generally successful and low in cost relative to grasses which are established by rhizomes (such as *Miscanthus x giganteus*).

One challenge in establishing switchgrass is seed dormancy which means that generally not all the viable seed will germinate in the field. It is strongly advised to do a germination test just prior to seeding to determine germination potential and to adjust the seeding rate accordingly. A seeding rate of 200 to 400 is generally recommended (Sanderson et al., 2012). Though this may be lower if conditions are optimal and weed pressure is limited. Approximately 100 to 200 seedlings emerging per m^2 should be sufficient. This will generally require between 5 and 15 kg of seed per ha. A common cereals seed drill can be used for seed drilling. One important rule is to roll the seedbed before and after seeding. This is necessary for good seed to soil contact and to be able to place the seed at a depth of 0.5 to 2 cm. If the soil has a courser texture deeper seeding may be recommended. No-till establishment is also possible, but may require a higher seeding rate and

Weeds will generally pose problems during establishment because switchgrass seedlings grow slower than weeds under low temperatures that are common in spring. This is also the reason switchgrass (just like maize) is generally seeded later in spring than most crops. Because of slow growth in spring, weeds generally outcompete switchgrass in the establishment year, as illustrated in Figure 5.

Switchgrass seedlings must develop two or more tillers to survive winter (O'Brien et al. 2008).

Figure 5: New switchgrass stand infested with broad leaf weeds.

Weed control with herbicides, to check broadleaf weeds, is possible though simple mowing the weeds just above switchgrass height is also an effective measure (see Figure 6). In the first year focus has to be on establishment and less on yield especially at northern latitudes. The goal is for seedlings to develop at least two tillers in order to survive winter (O'Brien et al. 2008). And to have a seed

Figure 6: Mowing weeds just above switchgrass height is an effective weed control measure when establishing switchgrass.

In Figure 7 a switchgrass seedling is shown. The internode between the seed and the crown is characteristic and may help to identify switchgrass seedlings in the field.

Figure 7: Picture of switchgrass seedling a few weeks after emergence. Notice the internode connecting the seedling and the crown from which two crown roots emerge (ref: Oklahoma State University).

3.3 Switchgrass management for biomass

3.3.1 Fertilization

Switchgrass makes very efficient use of nutrients especially if delayed harvest in winter or early spring is practiced. When fertilization levels are sufficient (for N, P. and K) the general recommendation is to not fertilize in the establishment year as this will only benefit the weeds. In the following years a fertilization equal to the nutrients removed is generally sufficient to reach optimal yields. The removal of nutrients is low when the crop is delayed harvested (in winter or early spring) due to translocation of nutrients to the below ground parts, and the shedding of tops and part of the leaves, which contain most of the nutrients. During winter, minerals such as K (and Cl) are leached out of the biomass, thus increasing quality for thermal conversion (see below) and further reducing the need for fertilization. On top of this the large root system is able to scavenge nutrients, in particular phosphate, very efficiently. This probably explains why generally, no response to phosphate fertilization is found.
In general after the first year fertilization equal to the removal of nutrients may be recommended if the nutrient levels at the start are adequate.

3.3.2 Yields

Switchgrass is not grown extensively for biomass production and accurate yield predictions are therefore difficult to make especially when delayed harvest (in winter) is used. In general it will take several years (2 to 4) for switchgrass to reach maximum yield potential.

In general lowland varieties will have higher yields than upland varieties. Wullschlager et al (2010) found on average a yield of 8.7 ± 4.2 for upland varieties and 12.9 ± 5.9 Mg/ha for lowland varieties from 1190 observations of yields from 39 field trials conducted across the United States. At the same time maximum yields for switchgrass have been reported of over 20 tons DM both in the southern USA and in southern Europe.

4 Harvest and logistics

4.1 Harvest time

As explained above when switchgrass is harvested for biomass production, harvesting after a killing frost or later in winter or even early spring is generally practiced. This will maximize biomass quality (low moisture, low nutrients, low ash, low K, low Cl) and will reduce nutrient removal. This is illustrated by Table 3, which shows the effect of harvesting switchgrass in fall versus early spring.
Potassium (together with chloride) reduces ash melting temperature of ash during combustion. This in turn leads to slagging in boilers or may require lower burning temperatures which lead to lower conversion efficiencies when producing electricity.

Table 3: Nutrient content (% of dry matter) of fall vs winter/spring harvested switchgrass in Rothamsted (Christian et al., 1999).

Harvest time	N	P	K
Fall	0,46	0,12	0,95
Winter/Spring	0,33	0,04	0,06

Loss of biomass during winter is a drawback of the delayed harvest system. The loss can be up to 30 to 40% compared to maximum yield if the crop were harvested in the fall (September/October).

4.2 Harvesting

In general switchgrass will be mowed and baled using common farm machinery, such as machinery used to harvest and bale straw. The moisture content is often below 15% and preferably 10% when harvested in winter or early fall. If the moisture content is above 15% field drying will be necessary. The switchgrass is then baled and stored before it is shipped for processing into pellets or other products.

5 Biobased Economy applications

Switchgrass is probably best known as an energy crop. In the 1980's switchgrass was selected as a model energy crop in the USA and has since been developed mainly for production of (second generation) ethanol production. Switchgrass was selected because it is a native grass (to North America) and because of its relatively high productivity with low inputs (nutrients, water, pesticides). Much development has also taken place in Canada where the crop has been developed mainly for fibre and energy pellets. Starting in the 1990's the crop was also evaluated in Europe, first in the UK at Rothamsted and later also in in several projects in Europe (see: www.switchgrass.nl; Monti, 2012). Two main production pathways can be identified when using switchgrass in the biobased economy, the biochemical pathway and the thermal conversion pathway.
Energy, energy carriers and chemicals can be produced from switchgrass biomass through a wide range of biochemical and thermochemical pathways. Switchgrass biomass has been tested in a wide range of these conversion technologies which was recently reviewed by Balan et al (2012).

5.1 Switchgrass biochemical conversion

The biochemical pathway generally includes a pre-treatment to open up the lignocellulosic matrix followed by enzyme hydrolysis into C6 and C5 sugars. This is followed by a microbial fermentation of the sugars into an energy carrier or chemical compound such as ethanol or butanol. For these processes the main quality requirement is the content of C5 and C6 sugars and the easy with which they can be made available and fermented into products. Typical composition of switchgrass is given in Table 4.

Table 4. Chemical composition of untreated and pulped switchgrass samples from different sources (ref. www.switchgrass.nl).

	Kanlow	Cave-in-Rock	Pulped Cave-in-Rock	Radiotis	Madakadze
Ash	1.9	1.8	2.6	1.5	4.8
Extractives	10.4	9.5	-	1.6 [c]	6.9 [d]
Lignin	18.9	19.5	22.5	21.8	23.9
Cellulose	30.5	28.8	33.6	43.4	43.4
Hemi-cellulose	30.4	31.2	31.5	35.9	30.5
Pectin	1.4	1.3	1.7	-	-

A calculation can be made of the potential ethanol production by adding up all the fermentable components and multiplying them with conversion factors to sugar and then from sugar to ethanol. This gives a potential ethanol yield of 262 kg ethanol/tonne dry matter for second year winter harvested Kanlow and Cave-in-Rock samples grown at a sandy site in Wageningen. This yield is comparable to the theoretical ethanol yield from hard woods like willow.

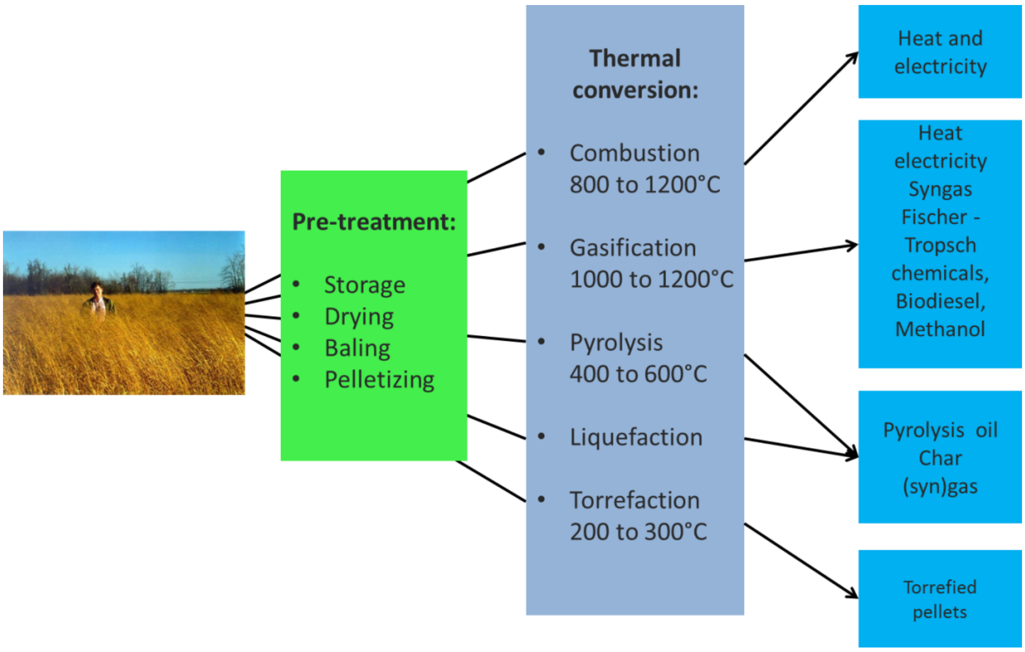
The practical ethanol production from switchgrass has been tested using a wide variety of pre-treatment methods. The yield has been between 0.14 and 0.19 g ethanol per gram of DM biomass (when microorganisms were used that only convert C6 sugars into ethanol). This indicates that under relatively low input conditions 2 tons of ethanol production is possible per ha assuming a moderate biomass yield of 10 tons DM per ha, while the theoretical yield could be 2.6 tons of ethanol per 10 tons of biomass.

Ethanol production from switchgrass is affected by many factors such as switchgrass type, harvest time, pre-treatment, lignin content, glucan loading, enzyme loading, fermentation strain, and process configuration (Balan et al. 2012).
Apart from the main product (ethanol) lignin is also produced in the process, which can be used for energy generation for the whole production process.

5.2 Switchgrass thermal conversion

The thermochemical pathway includes torrefaction, pyrolysis into pyrolysis oil and char, hydrothermal processing (into an "oil"), gasification into syngas and combustion. The options are illustrated in Figure 8. Switchgrass has been tested with most of these technologies. The energy content (Higher Heating Value) of switchgrass is typically just under 18 MJ/kg DM which is slightly lower than the energy content of wood.

Figure 8. Thermal conversion options for switchgrass.



In thermal conversion, the inorganic composition, ash content, and especially the ash melting behavior is a very important quality characteristic. A low ash melting point it can lead to ash agglomeration in boilers and to corrosion as illustrated in Figures 9. A low ash melting temperature is caused mainly by high alkali (K and Na) composition of the ash combined with the Cl. Therefore managing switchgrass to reduce the K and Cl content, and thereby the ash melting point and corrosion potential is very important.

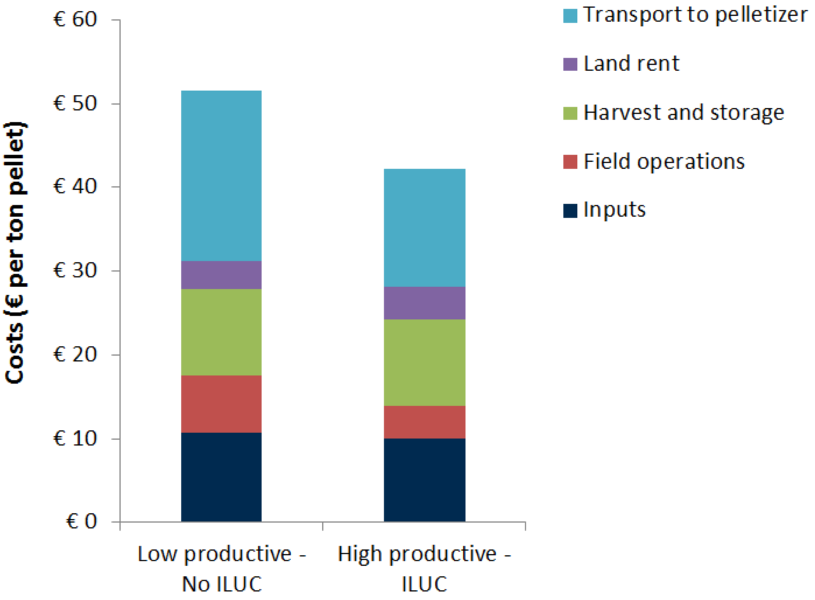
Typical ash melting points just above 1000°C can be found when the right management (delayed harvesting). This is lower than for clean wood and coal but above other herbaceous biomass such a wheat straw. The ash melting temperature is often more favorable than the ash melting behavior of *Miscanthus x gigantheus* although as concentration in switchgrass is typically higher compared to *Miscanthus*. In accordance the concentrations of ash, K and Cl are higher than for wood, but lower than for straw or grasses. It has been concluded that a moderate corrosion behavior for switchgrass can be expected.

Figure 8: Agglomerated ash produced in a boiler burning (high ash, low ash melting temperature) herbaceous biomass.

6 Economics

Extensive economic analysis of the production cost of switchgrass, grown as a biomass crop has been conducted in the USA and to a lesser extent in Canada and in Europe.
In Figure 10 the cost of switchgrass production is given for a case study in Ukraine. The cost of switchgrass delivery to the pellet plant was estimated at €52 per ton pellet under on abandoned land and, low productive conditions (assuming without ILUC) and €42 per ton pellet under high productive (assuming with ILUC) conditions.

Figure 10: Delivery cost of switchgrass under low productive conditions and under high productive conditions. (reference: Lesschen et al., 2012)

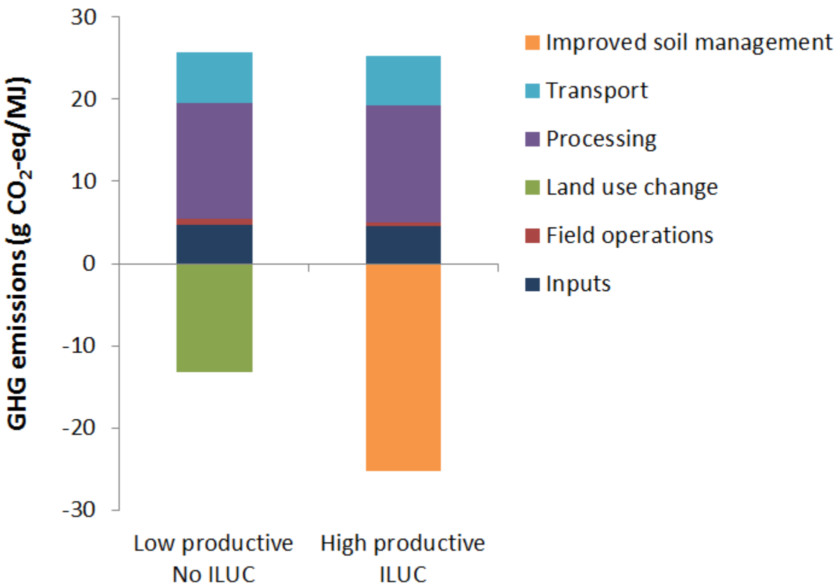


These costs are similar to the costs found in other analyses when low cost land is available.

7 Sustainability

Switchgrass is generally found to have low environmental impacts. This is mainly due to the high production that can be attained with very low inputs per hectare and per ton dry matter produced. Typical energy input/output has been reported to be between 1/8 and 1/54.
When a perennial grass such as switchgrass is grown on cropland, soil carbon is increased significantly each year at a rate of 1.1 to 1.2 ton C per hectare per year (IPCC, 2003). It has been estimated that over longer periods (10 to 30 years) soil carbon sequestration has be 0.78 to 0.53 tons of C per ha per year (Skinner et al., 2012). This is one of the reasons why the greenhouse gas (GHG) balance of switchgrass produced for pellets to replace coal for electricity production is very positive. Lesschen et al (2012) calculated a GHG balance (for electricity production) for switchgrass pellets grown under high and low productive conditions (in Ukraine) which is 99% better than the coal equivalent under high productive conditions and 86% better under lower productive conditions (Figure 11). As can be seen in Figure 11 the emissions of switchgrass production, logistics and processing are largely cancelled out by the accumulation of soil carbon.

Figure 11: Greenhouse gas emissions per MJ of pellet produced in Ukraine, including pelletization and delivery to a coal plant in the Netherlands for high and low productive switchgrass (reference: Lesschen et al., 2012).



When switchgrass is used for production of biofuels (second generation ethanol) the GHG emissions (compared to fossil gasoline) will be less favorable compared to electricity production (Coal as reference). Here estimates range from 43 to 79% GHG emission reduction compared to the fossil alternative (Skinner et al, 2012).
Currently the main unsolved sustainability issue of energy crops is the concern about competition with food (food versus fuel debate) and the concern that conversion of arable land to energy crops which may lead to indirect land use

changes (ILUC) and therefore GHG emission. Options to avoid this problem can be found in the use of by-products, crop residues and using marginal or abandoned land for biomass production (Fritsche et al, 2010). Switchgrass has been shown to be productive under low input conditions and may have a role to play in using this option for ILUC free biomass production on marginal land.

Invasiveness?

Switchgrass is native to North America. In other regions of the world switchgrass is not native and it is multiplied by seed which begs the question in how far switchgrass can become invasive. Still there is reason to expect that switchgrass will not become an invasive species because switchgrass has already been grown extensively outside of North America as an ornamental without any known reports of it being a pest. In North America it is not considered invasive and switchgrass is difficult to establish by seed and requires careful management under agricultural conditions.

8 Comparing switchgrass to *Miscanthus x giganteus*

Switchgrass is one of the main perennial biomass grasses that have been developed for efficient biomass production in North America and that also has been introduced and tested in Europe and other higher latitudes (China, Argentina). Other perennial biomass grasses to which switchgrass should be compared are *Miscanthus x giganteus*, Reed Canary Grass (*Phalaris arundinacea*), Giant Reed (*Arundo Donax*).

Figure 12: *Miscanthus* and switchgrass in July in Northern France.

Figure 12 clearly shows the difference between *Miscanthus x giganteus* and switchgrass in growth habitat. *Miscanthus* has high production potential but also a high cost of establishment. In Table 5 data on biomass composition and ash melting point is presented of fall and winter or spring harvested switchgrass and *Miscanthus*. The ash content (3,63% for switchgrass and 4,53% for *Miscanthus*) in this example is relatively high because of the clay soil. On a sandy soil a 50% lower ash content may be expected. Harvesting in winter or spring harvest means that the biomass has weathered more leading to removal of easily dissolved components like K and Cl. The data support the general finding that *Miscanthus x giganteus* seems to have a lower ash melting point than switchgrass. which seems to be explained by the higher K concentration in the ash. A lower ash melting point will lead to sintering and ash agglomeration problems in combustion. Still direct side by-side comparisons of switchgrass and *Miscanthus* are very scarce. Keep in mind that *Miscanthus x giganteus* is by far the best known *Miscanthus,* but there are also other *Miscanthus* species (like *Miscanthus sinensis*) that have different characteristics.

In general switchgrass yields are lower than those of *Miscanthus x gigantheus* though good long term side by side comparisons do not exist. Lasorella et al (2011) compared the yield of winter harvested switchgrass and *Miscanthus* grown in the same location. They concluded that switchgrass yielded some 25% less DM than *Miscanthus* over the first 6 years. Heaton et al (2004) estimated that *Miscanthus x giganteus* yielded an average of 22 tons DM per ha compared to 10 tons DM for switchgrass.

Table 5: Ash and nutrient content of switchgrass and *Miscanthus* harvested at the same location and time (Groningen) and from two different sources (USA and Europe).

		Groningen 1)		USA 2)		Europe 2)	
		Switchgrass	***Miscanthus***	**Switchgrass**		***Miscanthus***	
		Spring	Spring	Fall	Spring	Fall	Winter
Ash	% DM	3.64	4.53	--	4.90	--	4.10
N	% DM	0.56	0.57	0.46	0.41	0.47	0.36
P	% DM	0.07	0.05	0.09	0.05	0.06	0.00
K	% DM	0.11	0.46	0.34	0.06	1.22	0.96
Cl	% DM	0.25	0.47	0.08	0.03	0.56	0.09
Ash melting							
Shrinkage start	°C	770	660				
Deformation start	°C	1140	670				
Hemisphere start	°C	1400	1080				
Flow Temperature	°C	1430	1160				

Reference: 1) Elbersen et al, 2013 2) Zegada-Lizarazu et al, 2010.

In Table 6 a comparison between switchgrass and *Miscanthus* x *gigantheus* is presented. The comparison supports the view that each of the perennial biomass crops switchgrass and *Miscanthus* may have a different niche.
Switchgrass has lower yield potential than *Miscanthus* but is very cheap to establish. This suggests that switchgrass may have an advantage on low quality soils where productivity potential is limited and where the high establishment cost of *Miscanthus* cannot be recovered.
Also under high capital cost conditions (high interest rates) and when the price of biomass is low and when the cost of land is low switchgrass may have an advantage.
Currently the switchgrass is grown commercially for fodder and conservation mainly in North America. In Europe the crop is only grown on small experimental or pilot scale. The crop can have a large impact as demand for second generation biofuels increases, which require lignocellulosic biomass as feedstock. Switchgrass is also one of the crops that may be able to produce reasonable yields at low cost on marginal and lower quality land. This may be one of the ways to source biomass without competing with food crops for land. Thus avoiding the so-called Indirect land use change effect (iLUC).
The availability of this type of land that may be released from normal agriculture is uncertain, but has been estimated at several million hectares worldwide. Krasuska et al (2010) recently estimated the availability of this type of released land in the

European Union at 13.2 million ha currently, 20.5 million ha in 2020 and 26.2 million ha in 2030.

Table 6: Comparison of *Miscanthus x giganteus* and switchgrass attributes based on different sources.

Attribute↓	***Miscanthus***	**Switchgrass**
Native Range	South East Asia, Japan	North America
Photosynthesis system	C_4	C_4
Height	Up to 4 m	Up to 2,5 m
Rotation time	15 years	15 years
Propagation method	Rhizomes	Seed
Harvest time	Fall to early spring	Fall to early spring
Energy output/input*	12 to 66	8 to 54
Yields (DM)*	10 – 40	6 – 25
Biomass quality for thermal conversion	Lower	Higher
Water use	Rel. Low	Rel. Low
Erosion control	Rel. Good	Very good
Establishment cost	€300/ha	€3000/ha
Productivity	Higher	Lower
Water use efficiency	High	High
Nutrient efficiency	Very high	High
Need for inputs	Low	Low
High yield under marginal conditions	Yes	Yes
Fits into rotations	No	No
Need for special machinery	Yes	No
Years to break even	Long	Shorter

*Venturi and Venturi, 2003; Zegada et a, 2010.

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