ENERGY CROP SPECIES IN EUROPE

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1 INTRODUCTION

In 1996 the synthesis report of the European Energy Crops Overview (EECO) Project was published. The project was funded by the EC-FAIR programme and many national institutions. The goals of this final report were to summarize the achievements on energy crops production, processing and utilization reported in the country reports and to draw conclusions upon the current status of activities with respect to energy crops in Europe and to develop recommendations on how to proceed in this field.

Results of the EECO Project can be a help to evaluate the best energy crops to be cultivated.

1.1 European Energy Crops Overview

In the field of production of energy crops in all EU countries Table 1 shows the wide range of crops has been tested as energy crops in Europe.

Table 1 is based on information available in 1996. Maybe some figures have changed, but in general this table, listing all important energy crops is a useful help.

1.2 Some Remarks

Remarks to all following yield data and information: Often the information originates from research plots from which detailed information is available. However, the same results will usually not be obtained in practical farming as the level of crop care is different.

An example of how yield level can differ between different framework conditions within the same crop: Phalaris under Swedish conditions

total growth in trial plots	11 odt (tonnes of dry matter)
reduction in practice	15%
winter losses	25%
harvest losses	10%
storage losses	2%
net yield	6 odt

Table 1: Energy crop species in Europe
(areas are based on information from national reports)

Latin name	Common English name	Hectares
Brassica sp.	Rape seed	800,000
Eucaliptus sp.	Eucalyptus	500,000
Helianthus annuus	Sunflower	91,000
Salix sp.	Willow	18,000
Triticum aestivum	Winter wheat (GWC)	
Secale cereale	Winter rye (GWC)	
Triticale	Triticale (GWC)	
Hordeum vulgare	Spring barley (GWC)	
	Total for GWC (Grain Whole Crop)	9,370
	- ethanol use (grain only)	8,850
	- combustion of GWC	520
Beta vulgaris	Sugar beet	6,250
Phalaris arundinacea	Reed Canary Grass	4,050
Sorghum bicolor	Sweet Sorghum	1,500
	Fiber Sorghum	20
Populus sp.	Poplar	550
Cannabis sativa	Hemp	350
Miscanthus sp.	Miscanthus	170
Hibiscus cannabinus	Kenaf	65
Cynara cardunculus	Cardoon	55
Alnus sp..	Alders	15
Arundo donax	Giant reed	3
Helianthus tuberosus	Jerusalem artichoke	2
Camelina sativa	False flax	2
Robinia pseudoaccacia	Black locust	2

In the next step some climatic framework conditions, yields and advantages and disadvantages of the different energy crop species of Europe are discussed.

2 WOODY CROPS

2.1 Willow *(salix sp.)*

Willow is grown mainly in the northern parts of the EU. Sweden (17,000 ha), UK, Finland Denmark, Ireland and the Netherlands produce willow.

yield It is estimated that current net yield in Sweden is 8-10 odt/ha/year, in UK annual yields are between 8 and 20 odt/ha/year, Denmark is the mean yield 7-8 odt/ha/year and in Ireland only about 5 odt/ha/year. In Italy small research areas of *Salix alba* were investigated indicating annual yields of 15-20 odt/ha.

\+ The establishment is good and cheap.
Willow production seems to be environmentally friendly.

- The crop water requirement is high, and often water availability is the factor for the production.
Heterogeneity of fields has a strong influence on yield.
The long crop rotation, the lack of long-term legislation and the risk of increased pest problems are among the barriers.
The introduction of new technical development to farmer is a major bottleneck.
Accordingly, emphasis on good farmers advisory services when new crops are introduced is a key point.

more The economic analysis shows large variations between countries, the estimated costs per odt delivered 50 km to the plant ranging from 38 to 86 ECU (remark: data of 1996).
For the future a cost reduction is essential.
To reduce establishing costs, trials with chopped willow material which is laid horizontally in the ground using a sugar cane planting machine were suggested.

2.2 Poplar *(Populus sp.)*

Poplar can be grown in warmer climates than willow. In some countries like the UK. Ireland, Belgium, Austria and Germany both species are grown. Plant density varied between 700 and 1,700 plants/ha. Establishment costs are estimated to about 1,600 ECU/ha (remark: data of 1996). Harvest intervals of 4-6 years are common.
In the Netherlands about 32,000 ha of poplar has been established but not for energy purposes. In France about 350 ha has been established used for pulp production and a planting density of 2,000 plants/ha was used.

yield Annual yields expected mean 10-15 odt/ha. In Italy 15-20 odt/ha/year have been obtained under irrigation in small research plots. In France annual yields of 6-12 odt/ha are estimated under commercial conditions.

\+ Compared to willow poplar seems to be more resistant to pests and disease.

- High establishing costs

Poplar did not tolerate high soil contents of heavy metals.
Wild animal may however cause problems
Demand for irrigation (was mentioned from Italy)

more Poplar has been investigated in central European countries and the UK since long. Poplar is used for pulp production and information on poplar appears rather scattered and not as focused on energy utilization as for willow.

2.3 Eucalypt *(Eucalyptus sp.)*

The largest European areas of eucalypt in short rotation has been established in Portugal where approximately 500,000 ha is grown for pulp production. Almost entirely the species *E. globulus* is used which is very frost sensitive and cannot be grown north of the Iberian peninsula. Usual plant density is 1,100 plants/ha and harvest is normally done with 8-10 years of interval. In France a total of about 500 hectares of eucalypt are planted for pulp production (density 1,250 plants/ha) and in Greece and Italy only small test plots of a few hectares for research have been established..

yield In Portugal the potential of production with irrigation and fertilization is over 20 odt/ha/year. In France under commercial conditions 8-14 odt/ha/year are estimated. In Greece on good soils above 20 odt/ha/year have been registered in two-year-rotation and on less fertile field only 6 odt/ha/year. In Italy 15–20 odt/ha have so far been registered.

\+ The very large commercial areas of eucalypt in Portugal has provided substantial experience on production, harvest and delivery to the pulp plants. This experience can be easily transferred to the use of eucalypt for energy purposes.
Greece noticed that eucalypt appears to be an interesting option compared to crops with a higher demand for irrigation.

- Very frost sensitive.
Yields vary very much in dependence of climatic and soil conditions.

more In France production costs for eucalypt are estimated to 46 ECU/odt (remark: data of 1996). However, for Portugal was noticed in the EECO final report, that such initial use of wood fibres for paper or the like and later energy utilization of the used product is a smart combination and should not be changed.

3 HERBACIOUS CROPS

3.1 *Miscanthus* sp.

Miscanthus was introduced to Europe as an ornamental plant some 50 years ago. It is a C4 perennial grass, and therefore adapted to warmer climates. In Denmark about 30 ha are established, while in Germany there are about 100 ha, and France and Austria a few hectares. In Belgium, Greece, Ireland, UK, Italy, Portugal and Spain small research plots have been established as part of the European Miscanthus Network.

yields In Denmark yields in experimental fields were between 7 and 14 odt/ha of dry straw at spring harvest. At commercial conditions in Denmark 7-8 odt/ha on sandy soils and 8-9 odt/ha on clay soils are reported. Winter losses of leaves and tips are about 30% in Germany and yields in the range 6-7 odt/ha at spring harvest. In Greece yields of 18-29 odt/ha have been registered with irrigation when harvested in November. In Italy 20-25 odt/ha are expected in commercial conditions. In Portugal(Lisboa) by harvest in December mean yield has been 24 t/ha with a moisture content of about 44%.

\+ The crop is considered as environmental sound.
Nitrate leaching from fully established Miscanthus is very low.

\- Crop establishment is expensive. Costs are much higher than for other perennial crops like Salix or Reed Canary Grass. Establishment costs in Germany 2,500-5,000 ECU/ha (remark: data of 1996) which, when depreciated over crop lifetime, constitutes 50-60% of annual variable costs.
The establishing phase is environmentally critical.
Weed treatment during establishment is essential. “Roundup” may be used in spring. Mechanical weed treatment with a long tine harrow and row cultivation is possible.
Low first winter survival that has occurred mainly in the northern parts of EU.
Winter loss of the crop may reach 50%. When harvested in spring yields constitute only about half of the biological production as leaves and top are lost during winter.
Miscanthus is most often harvested in spring when it is dry. The harvest window is though limited.
Due to drought and late spring frosts yields will be lower. Due to an age effect, especially at the highest planting density yields will be lower too.

more A low-cost method for the establishment has been tested (about 1,000 ECU/ha) in Denmark. The investigations in the Netherlands confirm results of about 80% cost reduction and improved establishment. A lily bulb harvester or adapted potato harvester was used to collect the rhizomes and planting was done by an adapted potato planter. When rhizome pieces were planted within few days after harvesting, the emergence rate was 70-95%. Apart from the lower costs, a better winter survival rate is obtained due the use of larger rhizomes and shorter time between rhizome harvest and planting.
The estimated costs per odt delivered 50 km to the plant range from 34 to 73 ECU (remark: data of 1996).

In Denmark production costs are calculated to be reduced from 76 to 44 ECU per odt (remark: data of 1996) when changing from spring to winter harvest, due to the yield increase and the reduced storage costs as direct delivery to the heating plant is anticipated.

3.2 Reed Canary Grass *(Phalaris arundinacea L.)*

Reed Canary Grass (RCG) is native in Sweden as in many other parts of northern Europe. Several thousand hectares of RCG has been established in Sweden due to earlier grants for converting from food crops into non-food crops. However, only very little of the grass is used for energy, as the Swedish market for straw/grass combustion is not developed. Of 15 plant species investigated for non–food purposes in Finland, RCG turned out to be the most promising for Finnish conditions and so about 50 ha have been established. Furthermore through an EU-project on RCG small research plots have been established in the UK, Ireland, Germany and Denmark.

yields Energy crop production of 8-12 odt/ha has been measured in field trials. In spring harvest, yields of 6-8 odt/ha are expected when harvested under commercial conditions. Results of Finland are the best growth is obtained on organic soils (pH well over 4) where experimental yields of 8-14 odt/ha have been recorded at spring harvest. On mineral soils only 5-8 odt/ha have been recorded.

+ Low costs for establishment compared to other perennial crops like Salix or Miscanthus, as the crop is sown.
By harvesting in spring the minerals are leached from the grass during winter which reduces the fertilizer requirements and improves combustion quality. During winter the contents of Cl and K are reduced about six times.
RCG can be grown on most soil types.
High competitiveness to weeds after the year of establishment.
The crop tolerates drought periods and also flooding for some weeks.
No requirement for special agricultural machinery.
One advantage mentioned, compared to e.g. willow, is that it keeps the rural landscape open, as it only during a short period in autumn reaches about 2 meters height. As the crop is not growing very high it can be used in parts of the agricultural landscape, where high woody crops or Miscanthus is undesired.
Easy reclamation if the land must be turned into food crops again.

- Weed treatment is advised for the year of establishment.

more The economic analysis indicated production costs of 66 ECU/odt in Sweden and of 59 ECU/odt in Finland (remark: data of 1996). The costs are in both countries 7-8 ECU higher than for willow chips. This difference is due to lower expected yields in RCG. The good storage ability of RCG improves security of delivery.

3.3 Cynara *(cardoon)*

Cynara cardunculus is a perennial thistle-like plant. Cynara seems to be well adapted to dry Mediterranean conditions where most precipitation occurs during the winter season.

In its natural cycle it sprouts in autumn and passes the winter as a rosette. In the spring a floral scape is developed which dries during summer and the whole crop can be harvested dry (10-15% water) in late summer. By this growth cycle the winter rains are used for the energy crop production.
In Spain about 50 ha of experimental fields have been established. Light, deep and limy soils are the best. The crop is sown either in spring or in autumn depending on the climatic conditions of the location. Between 7,500 and 15,000 plants/ha are established, the highest number where the best water availability can be expected. At least 400 mm of precipitation during autumn, winter and spring is required to obtain a good yield.
In Greece green Cynara forage cuttings during winter have been tested. The amount of dry energy crop biomass harvested in summer was reduced. The same experimental investigations as in Greece were done in Portugal and Italy which participated in the Cynara network as well.

yields Spain: with 450mm rainfall a production of about 20 odt/ha can be harvested. The harvested material consists of about 33% leaves, 22% stems and 45% capitula. The seeds in the capitula (2.5-3 t/ha) contains oil which may be extracted. In Greece about 30 odt/ha was obtained. Best yield were obtained at planting densities of 30,000 plants/ha or more, which however may change when the crop grows older.

+ In Italy the crop is considered to be interesting due to the low costs of establishment by seeding.
In Greece Cynara is considered promising for non-irrigated, low fertility, sloping soils as the perennial growth reduces the risk of soil erosion.
From the second year the crop covers the ground.
No irrigation during summer is necessary. It can produce high yields without irrigation in contrast to crops like Miscanthus, sorghum and *Arundo donax*.
The possibility of harvesting the crop for fodder.

- During the year of establishment weed treatment is necessary.
A barrier seems to be the risk of pests recorded from Spain.
The harvest and utilization of the crop is not well developed.

more At first the pest effects on production should be quantified to access if the pest treatment is really economical. At last, breeding or selection of resistant genotypes may be another way of reducing the need of pesticides. The economic calculations from Spain indicates costs of Cynara biomass as delivered to the energy plant of about 24 ECU/odt (remark: data of 1996). The low costs are due to low establishment costs, low input of fertilizer and irrigation and a high yield.

3.4 Sorghum *(Sorghum bicolour)*

Sorghum is an annual C4 crop of tropical origin. It is therefore mainly adapted to southern Europe. However, in Mediterranean zones its main growing period coincides with the dry season and the crop will need to be irrigated. Under these conditions however, very high yields can be obtained. Both sweet sorghum and fibre sorghum is experimented for energy utilization. Spain, Greece, France (about 15 ha), Belgium, Portugal and Italy produce sorghum.

yield In Spain up to about 30 odt/ha of sweet sorghum (of which about 10 odt is sugar) has been harvested in experiments. Dry matter content was about 30%. The test fields were irrigated with 600 mm annually.
In Greece lower plant densities than originally used (143,000 plants/ha) seems to improve yield. Yields up about 30 odt/ha are obtained on fertile soils and the crop is also mentioned to be adapted to more poor soils.
Yields of 6-15 odt/ha are obtained in northern France and 8-20 odt/ha in southern France. Planting densities of 150,000-200,000 plants/ha seems optimal which is higher than in Greece.
In Belgium 200,000 plants/ha are recommended. Yields of 5-8 odt/ha are obtained in colder areas while 12-15 odt/ha are obtained in the warmer regions. In Portugal at a density of only 40,000 plants/ha with regular irrigation mean yields of 30 t/ha have been obtained. In Italy annual yields up to 25 odt/ha were measured.

\+ Establishment is easy and cheap by seeds.
The crop can be grown at a total water supply of 400 mm which is less than needed for the production of maize in France.
Very high yields can be obtained with irrigation.
Sorghum fits well into the crop production.
Is not dependent of long term stability of the Agricultural Policy.
Existing agricultural machinery can be used for crop establishment, care and harvest.

- Need to be irrigated.
Atrazine is used against weeds (Belgium).
Further barriers are susceptibility to lodging, short processing period for ethanol, and lack of appropriate harvesting equipment.

more Very high productivity of sorghum is possible in southern Europe under irrigated conditions. However it needs to be evaluated whether the necessary water resources for bioenergy production of sorghum are available. One option could be to irrigate the crop with waste water.
Production costs per odt are between of 48 ECU in Spain and 65 ECU (remark: data of 1996) in France.

3.5 Energy grain (whole crop Triticale, wheat, rye or barley)

The production of cereals for combustion or for fermentation may be done like for production for food or fodder use. For fermentation use high grain yields must be obtained, while for combustion a high total yield is aimed at, as both grain and straw are used.
In Germany wheat, Triticale and rye are investigated. Wheat has the highest yield potential on good soils, while rye produces better on poor soils. Triticale performs intermediate and attracts interest for energy purpose, as it is not used for food production.

yield A mean total yield of 12 odt/ha (5,5 odt/ha of grain) is expected under German conditions and in Denmark total mean yields of 10,9 odt/ha at commercial conditions. In Austria total yields of about 10 odt/ha were obtained and in France yields of 10-14 odt/ha.

+ Cereals are highly developed crops due to their use for food production, and the knowledge of production is widespread among farmers. Therefore, energy grain production can easily be implemented in agriculture and high and stable yields can be expected.
The production fits into standard crop production.
The production is flexible as only planning for one year at a time is necessary.

- Grain loss during harvest is related to the harvest time.
Energy grain production is most often not profitable given the current market price of biomass for energy.
Further cost reduction is not likely as the production is already optimised.

more Production costs per odt are estimated to 76 ECU in Denmark and between 61 and 70 ECU (remark: data of 1996) in Germany depending on the yield level.
In Denmark a 50% reduction of Cl in the straw fraction was obtained by using chloride free fertilizer.

3.6 Hemp *(Cannabis sativa)*

Hemp as a long tradition as a fibre crop, but the energetic use of hemp is a new idea. For energetic use the whole crop is expected to be harvested.
In the Netherlands hemp is used for pulp production. For energy utilization approx. 5 ha is grown. An area of 1,00 ha is grown commercially for fibre use. In Austria 160 ha of hemp was grown for seed and fibre use.

yields In the Netherlands yields were found to be 10-17 odt/ha, with the highest yields on clay soils. In Austria yields of 6-14 odt/ha were achieved.

+ Easy production with low demands for pesticides and fertilizer.
Yields are relatively high compared to the inputs.
As an annual crop hemp fits well into crop rotation where it may serve as a sanitary element against pests.

- Fungi may cause problems in wet years.
There are some concern about the handling of the harvested material, the problem being fibres wrapping around shafts, bearings, drums etc..

more In the Netherlands costs of 84 ECU/odt (remark: data of 1996) were estimated, but storage costs were estimated very high and could be possibly reduced.

4 OIL SEED CROPS AND CROPS FOR FERMENTATION

4.1 Oil seed rape *(Brassica napus)*

Rape is without doubt the most grown energy crop in Europe. This is mainly due to the high stage of development of the agricultural production of rape for food and fodder, and the oil utilization and market introduction is relatively easy.
In 1995 in Germany 334,000 ha were grown, in France 320,000 ha, in UK about 80,000, in Denmark 40,000 ha, in Austria 13,600 ha, in Belgium 7,200 ha and in Italy 4,700 ha, Finland 4,000 ha.

yield No yield data on oil seed rape are reported in the EECO final report but in the country reports of this project some are published. Rape seed yields reported are: Austria 2.5 odt/ha, France national average 2.5 odt/ha, Germany 2.7-2.9 odt/ha and Italy 1.8-2.0 odt/ha.

+ Rape is a well known crop to European farmers, and they are eager to cultivate it for non-food purposes.
The energy balance seems positive, however not very high. If, however, the straw is utilized for energy as well the energy balance is improved.
It exists a well established market for non-food seeds.
In Denmark the possibility of using manure has been the main argument for oil seed rape production.
The production of an annual crop is not as risky within a changing agricultural policy as the production of perennial crops.

- The crop is a high input crop as it requires high N-fertilization and has low resistance to pests.
The environmentally sustainability of rape production has been questioned.

more The economic analysis on rape production indicates basic production costs of between 140 and 250 ECU/odt of seeds. However, the low price calculated for Ireland is due to very low machinery costs and in other countries production costs are over 200 ECU/ha (remark: data of 1996). With prices of non-food rape seeds of about 150 ECU/odt the production is not economic.
Anyway large areas are produced throughout Europe, which has several reasons: farmers are basically interested in producing crops on their land and weed problems may occur if set aside is included in crop rotation. If economics are calculated on marginal costs gross margin may not be negative.
Low-input production systems for non-food rape production were developed in Denmark

4.2 Sunflower *(Helianthus annuus)*

In Italy 55,000 ha of sunflower was grown commercially for biodiesel production. In Spain about 36,000 ha was grown mainly on rainfed areas and in Austria 360 ha was grown for non-food production.

yield In Italy the average yield is 1.7-2.4 odt/ha. In Spain the expected yield is only about 0,6 odt/ha seeds. In Austria the average yield is 2.6 odt/ha seed.

+ Lower demands of nitrogen and pesticides than rape are mentioned in Italy.

- Sunflower oil has a high iodine number.

more Sunflower may in central and southern Europe be an alternative to rape as a low input oil crop. In Austia the basic production costs of seed are calculated to be about 250 ECU/odt and in Spain costs are calculated to 343 ECU/odt (remark: data of 1996) due to the low expected yields.

4.3 Sugar beet *(Beta vulgaris)*

Cultivation of sugar beets for energy purposes is not expected to be different from the production for sugar extractions. Accordingly, no breeding has been done targeted for energy utilization. In France 6,250 ha of sugar beets were grown for energy purposes in 1995 (ethanol/ETB).

yield In France yields of 70 tonne of beets per ha is harvested on a national average.

+ Sugar beet is a well established crop, which means that the farmers have the cultivation knowledge for the crop.

- Calculations made in Spain on energy aspects on full chain from field to ethanol show an energy balance of 0.66. This means that the amount of energy obtained is less than the energy consumed in the production and processing.

more The costs of ethanol from sugar beets in France are calculated to be 48.7 ECU/hl (remark: data of 1996). In Spain raw material costs of sugar beet are calculated to be 20.9 ECU/hl to which industrial costs should be added.

5 CONCLUSIONS AND RECOMMENDATIONS (PRODUCTION)

1. A large number of crops have been investigated for their potential use as energy crops in Europe. However, only a few have reached beyond the level of R&D and have become commercialised and grown on larger areas. These examples exists due to the political and financial support given by some countries, and they have provided valuable information on the future demands for the implementation of energy crops in European agriculture. Main examples on large scale commercial energy crop production are the production of oil seed crops for bio-diesel in France, Germany, Austria and Italy, and the production of willow for heat and power in Sweden. These examples differ basically in that liquid fuel crops such as rape and sunflower are well known crops in agriculture due to their use for food and cattle feed purposes, while the production of willow as an agricultural crop has to be developed in all aspects from breeding to harvesting methods.

2. The crops investigated are suited to different climatic conditions throughout Europe. Crops like Cynara, sorghum and eucalyptus are only grown in the most southern parts of Europe. On the other hand, Reed Canary Grass is the crop best adapted to the cold climate of Finland and northern Sweden, while willow and rape can be grown in most countries of northern Europe. Miscanthus is grown throughout the more central parts of Europe, however, as far apart as Denmark and Sicily.

3. Very high yields of 30-40 odt/ha have been registered for crops like sorghum, Miscanthus and *Arundo donax* in central and southern Europe, but this is only measured in small research plots and has often required irrigation. On the other hand, in Sweden current net yield of willow under commercial conditions is estimated to be 8-10 odt/ha/year and in many cases even less. This indicates the wide range within which the realistic yield level of solid energy crops in Europe can be found.

4. The yield level can furthermore be influenced by the time of harvest. With Reed Canary Grass and Miscanthus the full biological yield can be harvested in autumn, or harvest can take place in spring when the leaves are lost. By spring harvest yield is decreased by 25-50 %, but the fuel quality is increased since the biomass is dry and can easily be stored, and organic matter and nutrients are recycled to the soil. This means that the optimal production strategy, apart from the yield level, also depends on the fuel requirements of the energy sector and on ecological considerations.

5. The first commercial willow plantations in Sweden have now been evaluated and have yielded the following conclusions:

   - good advice to farmers is essential,
   - weed treatment techniques need further development;
   - good and cheap establishment is essential for the long-term production capacity and for the economy;
   - crop water requirement is high, and often water availability is the limiting factor for production;

- heterogeneity of fields has a strong influence on yield;
- fertilization below recommendation has decreased yield by about 20%;
- fertilizer effect is strongly dependent on successful weed treatment;
- highest yields have been obtained on organic soils.

6. Economic calculations on energy crop production have been collected under the different national conditions like yield and cost levels. The basic costs of production and delivery to a plant for solid fuel crops are calculated to be in the range of 34-86 ECU/odt (remark: data of 1996) with the Swedish calculation of 59 ECU/odt willow as the most well-founded. In Spain it has been calculated that the costs of producing Cynara under non-irrigated conditions can be as low as 24 ECU/odt. These costs can be compared with current market prices on biomass residues like forest wood chips, the price of which in Sweden is 32-68 ECU/odt and in Denmark is about 80 ECU/odt. Mean market price of straw in Denmark is about 70 ECU/odt. The free market price of fossil fuels is lower than these prices of biomass when expressed in costs per unit of energy (ECU/GJ). However, in some countries taxes on fossil fuels have levelled the prices.

7. The above cost ranges indicate that basic production costs of energy crops in some cases can compete with existing biomass in market prices and with fossil fuels. However, land rental and profit for the farmer are not included in the calculations. Land rental is currently more or less covered by the set-aside regulation but this may not be the case in the future. This uncertainty is especially a barrier to the production of perennial energy crops. There is a need for long term stability with regard to the status of energy crops in the Common Agricultural Policy. Profit for the farmer can be created by fiscal regulations but may also be achieved by cost reductions in the bioenergy chain. Another way of increasing feasibility is by combined productions where a high value fraction of the crop can be extracted for other purposes. The co-production of high quality ground water due to low levels of nitrate leaching and pesticide use could also be a valuable output from energy crops production.

8. Even though rape production for energy utilization is not economic according to standard economic calculations, considerable rape production for biodiesel occurs throughout Europe. This has several rationales but basically indicates that European farmers do have interest in producing crops for energy purpose. However, they need stability about the CAP regulation which they find in an annual crop such as rape, they need a well established market, and they prefer to use well-known technology.

9. Cost reduction in energy crops has already taken place in rape, sunflower and energy again as they have been developed for food purposes, and only small adaptations and further cost reductions are expected when they are used for energy. Cost reduction is one of the major ongoing R&D task in new energy crops, and there seem to be good opportunities for reduction by the development to higher yields with lower costs. Illustrative are the results on willow in Sweden: by combining programs on fundamental biological and environmental R&D, and more applied programs as well, high-yielding clones with good tolerance to frost, pest and rust have been developed. The technical development led to a reduction of the plantation costs by 50% from 1,200 ECU in 1990 to ECU 600 in 1995. A

similar development has started in Miscanthus where breeding has been initiated, and a low cost establishment method has been tested which indicates that costs can be reduced from earlier 4,000-5,000 ECU/ha to less than 1,000 ECU/ha. Costs for harvest and storage have also been reduced in willow in Sweden and needs focus in other new crops.

10. The use of energy crops will save fossil fuel resources and reduce the emission of the greenhouse gas CO2. It is most likely that also the production of energy crops itself can be environmentally friendly, due to e.g. the low demands for pesticide use as the energy industry does not need a visually attractive product. Furthermore. several of the potential energy crops are perennial which reduce the risks of soil erosion, nitrate leaching and humus degradation. Energy crops could furthermore be a valuable tool for the safe conversion of waste water and sludge into useful biomass. However, water seems to be the major limiting factor to energy crop production, especially in southern Europe, but also in countries such as Sweden and Denmark. The perennial crops with a long growing season have the highest water use. As water, like energy, is a limited resource, the best utilization of available water resources should be analysed. This includes:

    - evaluation of crop water use efficiencies (e.g. higher biomass production per unit of water used in C4 compared to C3 crops);
    - suitable growing strategies of crops (e.g. Cynara is adapted to areas with a dry summer period); and
    - regional analysis of total water balances with different land uses.

6 REFERENCES

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