



Energy from field energy crops – a handbook for energy producers

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Jyväskylä Innovation Oy, P.O. Box 27, FI - 40101 JYVÄSKYLÄ, Finland
Tel. +358 14 4451 100, fax +358 14 4451 199

Layout: Katja Maunonen, Jyväskylä Innovation Oy

Photos on cover page: Timo Lötjönen, MTT, Lorenzo Corbella, ETA & Michael Finell, SLU

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Preface

This handbook contains practical information on the utilisation of field energy crops for heat and power. The crops discussed are reed canary grass (RCG), willow, hemp and poplar. Production of biogas from energy crops is also introduced. The handbook details cultivation and harvesting of crops, logistics, energy production technologies, rationality and economics of production. Other important issues, including support and incentive mechanisms, are also discussed. These crops were chosen because they are the energy crops with the greatest potential in the project countries: Finland, Sweden, Italy, Spain, Germany and Austria. Miscanthus and cereal straw, for example, are not discussed in the handbook because their use is already well reported elsewhere.

The handbook is mainly targeted at authorities, project developers, investors, plant operators, potential bioenergy users, the applied research community and representatives of companies involved in the crop-to-energy production chain. This handbook was produced as a result of a project that promoted the production and utilisation of energy crops in Europe (ENCROP - Promoting the production and utilisation of energy crops at European level, EIE/07/073). In addition, five national handbooks were produced during the project, which give more precise information on selected crops than this compilation. Those books are available at www.encrop.net.

The ENCROP project was funded Intelligent Energy for Europe programme of the European Commission., the Ministry of Employment and the Economy (Finland), Vapo Ltd., the Swedish Energy Agency, Kempestiftelsen (Sweden) and the Swedish University of Agricultural Sciences. The following organisations contributed to Encrop practical information in Spain: Ciemat, Salixphere, Valoriza Energía, and ADABE (National Association for Biomass). We would like to acknowledge all co-operation and support.

The text for this handbook was produced by Peter Rechberger (European Biomass Association, AEBIOM), Timo Lötjönen & Katri Pahkala (Agrifood Research Finland, MTT), Petri Vesanto & Matti Hiltunen (Novox Ltd., Finland), Shaojun Xiong & Michael Finell (University of Agricultural Sciences, SLU-BTK, Sweden), Lorenzo Corbella & Maurizio Cocchi (Energia, Trasporti, Agricoltura srl, ETA, Italy), Margarita Salve Diaz Miquel (ESCAN, S.A., Spain), Wolfgang Gabauer (Universität für Bodenkultur Wien, BOKU, Austria), Dominik Dörrie (German Society for Sustainable Biogas and Bioenergy Utilization, GERBIO, Germany) and Tytti Laitinen (Jyväskylä Innovation Ltd., JI, Finland). The editing work was done by Timo Lötjönen.

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15.06.2009

Timo Lötjönen
project manager
MIT Agrifood Research Finland

Tytti Laitinen
project coordinator
Jyväskylä Innovation Ltd., Finland

List of concepts and abbreviations

Bioenergy = Energy from biomass (does not include e.g. wind, solar or hydroelectric power).

Bioenergy crops = The crops cultivated in the field for bioenergy purposes.

Biofuel = Solid, liquid or gaseous fuel produced from biomass. For example, wood chips, ethanol and biogas.

Biomass = The biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetable and animal matter), forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste.

CHP-plant = Combined heat and power plant.

dm = dry mass, oven-dried biomass

1 EJ = 10^3 PJ = 10^6 TJ = 10^9 GJ = 10^{12} MJ = 10^{18} J = 277.78 TWh

Feed-in tariff = Extra payment (€/kWh) for renewable energy producers (usually for electricity producers), which is paid over and above the normal market prices.

Fouling = Condensation of gaseous emission into particles and deposition on cold surfaces in boiler or steam tubes.

1 J = 1 Ws

GHG = greenhouse gases

GW = 10^9 W

Miscanthus = A perennial bioenergy crop (*Miscanthus giganteus*).

MW = 10^6 W

MW_{el} = Electrical power in megawatts

MW_{th} = Thermal (heating) power in megawatts

RCG = reed canary grass

Slagging = For example, production of the hard formations when fuel ash is smelted in a boiler.

SRF = Short rotation forestry (for example, willow, poplar)

toe = tonne of oil equivalent = 42 GJ = 11.6 MWh

TW = 10^{12} W

1 Introduction

What is biomass?

According to the new EU Directive on renewables, "biomass" describes the biodegradable fraction of products, wastes and residues *of biological origin from agriculture* (including vegetable and animal substances), forestry and related industries, *including fisheries and aquaculture*, as well as the biodegradable fraction from industrial and municipal wastes.

Biomass includes a broad variety of raw materials such as wood, agricultural crops, by-products of wood processing, agricultural and forestry industry products, manure and the organic fraction of waste streams.

Forest and wood-based industries produce wood, which is the largest source of solid biomass. The sector covers a wide range of different fuels with different characteristics -

logs, bark, chips, sawdust and more recently pellets, which generate high energy levels and have standard characteristics.

Biodegradable waste covers the organic fraction of municipal solid waste, wood waste, refuse-derived fuels, sewage sludge, etc.

Agriculture can provide dedicated energy crops as well as by-products in the form of animal manure and straw. Land can be used for growing conventional crops such as rape, wheat, maize etc. for energy purposes, or for cultivating new types of crops such as poplar, willow, miscanthus and others, which maximise the yield of dry matter per unit area.

Biomass currently accounts for 2/3 of renewable energy in Europe and bioenergy will play a key role in achieving the ambitious targets approved by the renewable energy



Straw is a by-product of cereal production, which is insufficiently utilized as a bioenergy source in many countries. (Photo: Timo Lötjönen, MTT)

directive. 20% of the final energy consumption has to be provided using renewable sources by 2020. This is an ambitious target considering the current 8.5 % share. According to the results of a study done by the European Environmental Agency, the potential from agriculture is still largely underexploited and this sector is expected to have the highest growth rates in the coming years.

Food vs. fuel

This debate is largely driven by rising grain prices, which were blamed on increased production of first generation liquid biofuels such as biodiesel and bioethanol. While any use of arable land can influence prices for agricultural products, many factors, both structural and cyclical, can have a substantial impact on food prices, including:

- Weather conditions
- Oil price
- Growing demand from emerging economies

- Low investment in agricultural research
- Export/import policy
- Speculative investment
- Competition for arable land (urbanisation, forestation)

It is important to note that after the relatively high grain prices at the end of 2007, wheat prices fell to very low levels in early 2008, as for many other commodities, including metals, oil, cement, etc.

Global grain consumption increased by over 300 million tonnes during the last 10 years. Almost three quarters of the additional demand was for food, industry and especially animal feed. Biofuels from protein-rich feedstock produce valuable animal feed as a by-product thereby lowering the environmental impact of increased meat production. In Europe about 5 million tonnes of grain were used for the production of bioethanol in 2008 while fluctuations in grain harvest attributable to the weather can easily reach 50 million tonnes. Currently less than 3 % of cropland in Europe is used for energy production.



Maize is an important fodder and food crop. On the other hand it can be used as a raw material for bioethanol and biogas production. (Photo: Timo Lötjönen, MTT)

The European agricultural policy has also contributed greatly to the current situation as has subsidised production, resulting in surpluses sold cheaply to developing countries, thus hindering development of their domestic agricultural sector. Developing countries should be supported to become less dependent on food produced by Europe and the USA. Taking this into account, Europe could use even more arable land for energy generation without jeopardising the security of food supply or increasing commodity prices. Furthermore, sub-optimal and set-aside land could contribute to bioenergy production.

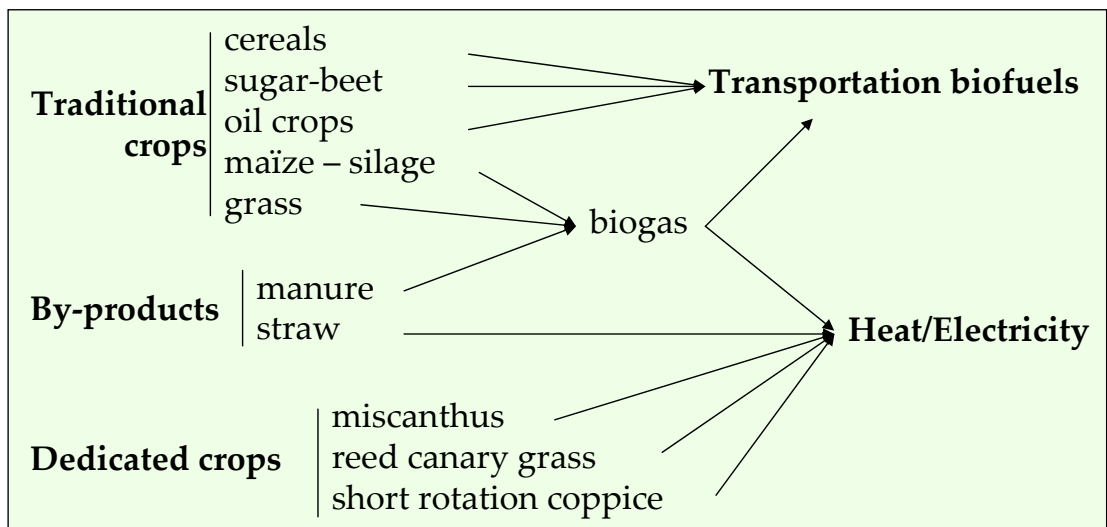
In summary, the food vs. fuel debate is largely based on assumptions and does not always take into account all the facts. One cannot judge the impact of biofuels on global nutrition and prices without looking at the whole agricultural production system of which biofuels represent a component.

Energy crops - current situation in Europe

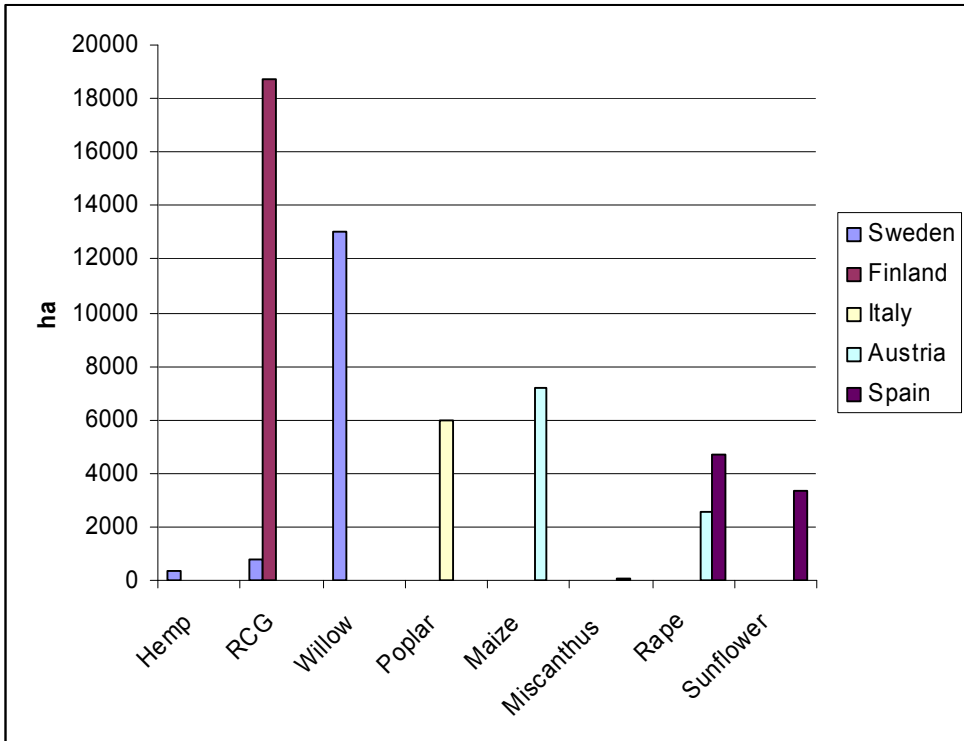
High yielding energy crops are already used frequently in well-tested systems such as

agricultural biogas production (maize together with manure). The biogas is normally used for CHP plants (generating from a few hundred kW up to 40 MW; 20 MW_{el} and 20 MW_{th}), which are especially popular in Germany, Austria, Italy and Denmark. The use of upgraded biogas as a transportation biofuel is a relatively new development, but might drive the increased use of maize and other energy crops in the future. For 2006, AEBIOM estimated that around 600,000 ha of arable land were used to produce energy crops for biogas production plants.

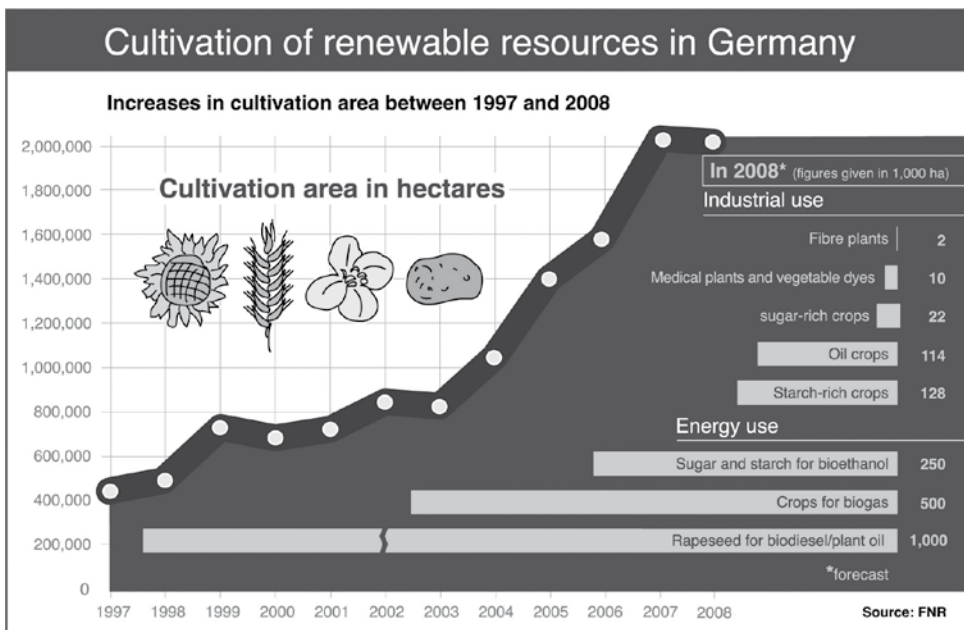
In Europe, solid biomass energy crops covered about 50,000 – 60,000 ha of land in 2007. It is a rather small area compared with that used for traditional energy crops grown for transportation biofuels, which cover about 2.5 million ha (mostly cereals and rape). The largest areas of energy crops are found in the UK (mainly miscanthus and willow), Sweden (willow, reed canary grass), Finland (reed canary grass), Germany (miscanthus, willow, etc.), Spain and Italy (miscanthus, poplar). Statistics of energy crop plantations for solid biofuels are almost inexistent in many European countries.



Routes of agricultural crops to bioenergy.



Energy crops in selected European countries in 2008. Data refer to hectares of cultivated land. Note that data are missing from important energy crop producers like Great Britain, Denmark and Germany. (Source: AEBIOM 2009)



The situation of Germany shows that energy crops for first generation biofuels utilize the largest part of agricultural land for energy production. Maize, sugar beet and other crops for biogas production were planted on 500.000 ha agricultural land.

Energy crops - potential in the near future in Europe

In 2008 the European Union ambitiously committed to increase the proportion of renewable energy to 20 % of total energy consumption by 2020. It was also agreed that 10 % of transportation fuel should be biofuel by 2020. The necessary growth of bioenergy will mainly come from forestry, but field crops will also be needed to reach the target.

Biomass produced from fields consists of residues (straw, tops etc.) and specifically cultivated crops (for example, miscanthus, poplar, willow, reed canary grass, rapeseed, maize). Not all residues are available for bioenergy production because they are needed for livestock feed and litter and to maintain soil fertility. In the EU-27 countries available crop residue potential is estimated to be 1 – 3 EJ according to different studies (1 EJ = 10^{18} J).



The perennial grass Miscanthus has high yield potential for energy production. Unfortunately its frost durability is low. (Photo: Timo Lötjönen, MTT)

The major part of this energy is contained in straw and the greatest potential is in Germany, France, Spain and Great Britain. Denmark is the current leader in straw utilisation for energy production.

When estimating the potential of bioenergy crops it is first necessary to approximate the area needed for food production. In the EU-27 this is calculated to be about 111 million ha of arable land and about 69 million ha of permanent grassland. The population of EU-27 is unlikely to increase rapidly in the near future. Holm Nielsen et al. (2007) estimated that if our diet were moderate (mixed vegetable-animal products), we would need about 62 % of the arable land to feed the population of EU-27. The world population is expected to exceed 9 billion by 2050. To feed this population with a moderate diet would require 65% of all globally available arable land. According to this study, we could use 10 – 30 % of arable land for bioenergy crops in EU-27. This would produce 2 – 6 EJ of bioenergy if the yield were assumed to be $10 \text{ t}_{\text{dm}}/\text{ha}$.

Pahkala et al. (2009) estimated that energy crop potential would be about 3 EJ by 2050 in EU-27 if our diet were moderate. If our diet were rich (based heavily on animal products) there would not be such marked potential. The greatest possibilities to increase energy crop production are in Eastern Europe where the food product yields are reaching the level of those of Western Europe. The specific bioenergy crops are unlikely to change from those currently in use because they have been intensively studied for several decades (miscanthus, reed canary grass, willows, poplar, maize and clovers for biogas, wheat and rapeseeds).

Crop residues and dedicated bioenergy crops together constitute 3 – 9 EJ of bioenergy potential. This is about 4–13% of the estimated total energy consumption in EU-27 for 2020. Biogas from manure is not included in these figures, but biogas from energy crops is.

Energy crop fuel characteristics

The best energy crops are durable, their dry matter yields are high and constant and their production costs are low. A perennial growth habit, low agrochemical requirements, effective conversion of solar energy to biomass and ease of conversion back to useful energy guarantee that energy efficiency of production is high and environmental impacts are low. For combustible crops it is practical if the crop can be harvested when it is dry. Transportation, storage and combustion are easier and heating value is high. For biogas crops, a low moisture content is not as important because the crops are usually stored as silage. For biogas production the crops should be harvested when their gas production is at an optimum level.

It is advantageous if an energy crop is suited to existing power plants and is co-combustible. This keeps investment costs low, requiring, for example, only crushing and feeding lines for biomass bales. Ash content should be low, ash smelting point should be high enough and combustion should occur without production of harmful elements such as chlorine and heavy metals. Chopped energy crops are usually suitable for co-combustion with wood chips, peat or coal. For example, reed canary grass, hemp and straw have higher chlorine content and lower ash smelting points than wood-based fuels, a fact that has to be taken into account when fuel mixture ratios are being planned. Differences in heating values are minor if dry matter contents of biofuels are considered (table 1). In practice, the water content of the biofuel reflects its heating value.

Table 1. Typical values of fuel characteristics (Strömberg 2006, Alakangas 2000, Finell, Xiong & Olsson, 2006, AEBIOM 2007, VTT & Vapo 2009). In practice, the variation can be high.

	Unit	Willow	Hemp* (spring)	RCG (spring)	Poplar	Soft Wood
Water content at harvest	%	50	10-15	10-15	50-55	50
Dry mass yield	t _{dm} /ha/year	6-10	5-10	4-10	10-20	3-5
Ash content (dry)	%	2.9	1.5	1.0- 8.0	0.5-1.9	1-2
Gross calorific value (dry)	MJ/kg	19.97	18.79	19.20	19.43	20.3
Net calorific value (dry)	MJ/kg	18.62	17.48	17.28 – 18.72	18.10	18.97
Carbon (C)	% DM	49.8	47.3	48.6	39.7	50.6
Hydrogen (H)	% DM	6.26	6.0	6.1	7.7	6.24
Sulphur (S)	% DM	0.03	0.04	0.04 – 0.17	0.2	0.03
Nitrogen (N)	% DM	0.39	0.7	0.3 – 2.0	0.9	0.1
Chlorine (Cl)	% DM	0.03	0.01	0.01 – 0.09	0.04	0.01
Aluminium (Al)	g/kg of ash	2.2	2.1	2.8	16,7	16.0
Calcium (Ca)	g/kg of ash	243.0	240	66.5	189.3	238.8
Potassium (K)	g/kg of ash	123.3	44.7	129.5	28.6	80.7
Magnesium (Mg)	g/kg of ash	23.4	24.0	21.7	42.9	31.4
Sodium (Na)	g/kg of ash	2.5	3.5	7.0	3.6	4.6
Phosphorus (P)	g/kg of ash	36.9	49.3	32.3	17.9	12.4
Silicon (Si)	g/kg of ash	93.3	160	218.3	178	73.9
Ash smelting point, (DT/A)	°C	1490	1610	~1400	1160	1200

* Only one study from northern Sweden, harvested in May 2005.

Top incentive schemes (support systems)

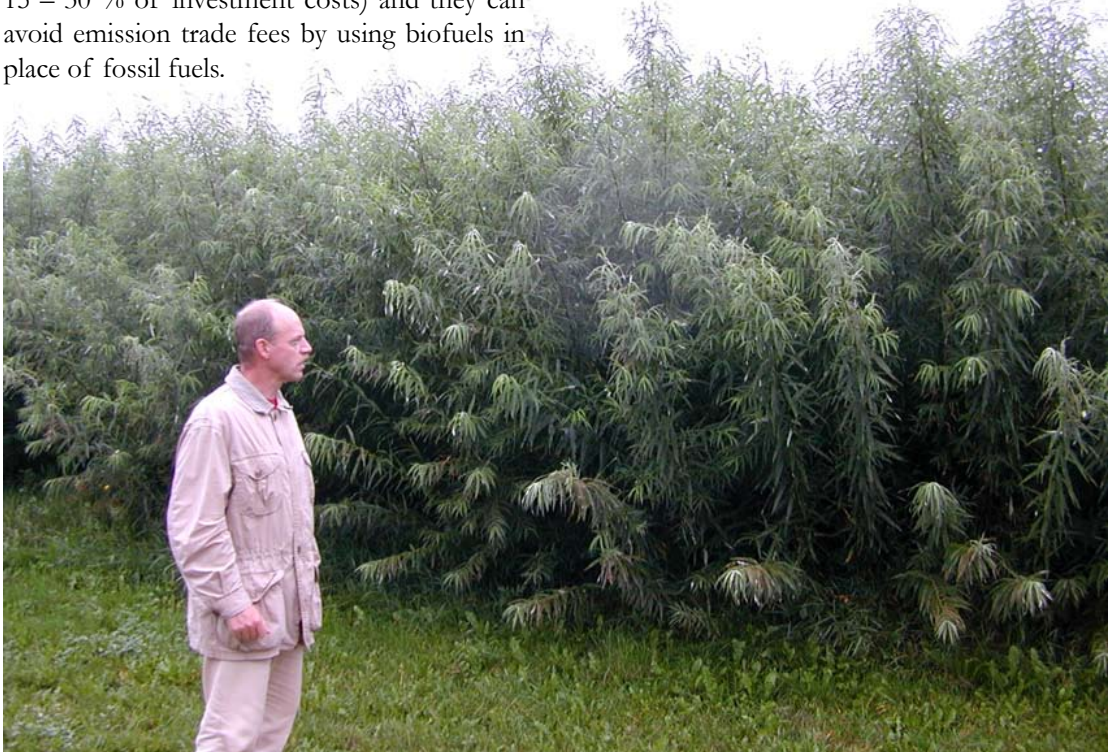
Because energy crop chains, from cultivation to power plant, are quite complex and investment costs for the plants are higher than for fossil fuel plants, it is clear that utilisation of energy crops cannot be profitable without financial support. Different countries have adopted different kinds of support systems, which are briefly discussed.

In Finland agricultural subsidies for cultivating reed canary grass are the same as the subsidies for other field crops (500 – 700 €/ha/year). This is essential for the economy of the RCG fuel-chain. On the other hand, because the subsidy is the same for all crops, the system does not encourage farmers to cultivate RCG if the fuel price is low. Establishing energy crop plantations or using energy crops for energy production is not supported in Finland. The power plants can get investment support (e.g. 15 – 30 % of investment costs) and they can avoid emission trade fees by using biofuels in place of fossil fuels.

In Italy, since January 2009, a new support scheme has updated the green certificate mechanism that supports production of electrical energy only from utilisation of biofuels: small plants (< 1MW) receive a tariff of 0.22 €/kWh, whereas bigger plants receive the green certificates (based on a variable market price), plus an additional 10 % bonus.

In Spain, top incentives include mainly the “regulated tariff”, using energy crops for electricity generation. According to this the regulated tariff for the ≤2MW producer for the first 15 years is 0.1696 €/kWh and 0.1559 €/kWh for the >2MW producer.

In Sweden, taxes, subsidies and support schemes for using renewable energy have been applied since the early 1990s. The most significant component is taxation on the emission of carbon dioxide from combustion of fossil fuels to produce heat, which was first introduced in 1991. The users of renewable sources, such as biofuels, are exempted from the carbon tax.



Willow is a popular energy crop in Sweden, where the farmers receive a subsidy for establishment costs of the plantation. (Photo: Timo Lötjönen, MTT)

The level of the carbon tax has increased from about 0.025 € (0.25 SEK) per kg CO₂ in the early 1990s to 0.063 € (0.63 SEK) in 2002, and on top of which another 0.006 € (0.06 SEK) per kg CO₂ was added in 2007. Sizeable subsidies have been available for development of CHP plants using biofuels since the 1980s. For example, Enköping CHP plant received subsidies of 400€ (4000SEK) per kW of electricity generating capacity, about 40 % of the total investment. In addition, CHP plants using biofuels can be also supported through other schemes such as the Green Electricity Certificate, Emission Trading, Program for Energy Efficiency in industry (PFE), etc. To encourage farmers to start in the willow production business, a programme has been in operation since the end of 1980s. Farmers currently get subsidies of about 5000 SEK (about 500 €) from the government, although it was 10,000 SEK at the start of the programme. Unfortunately there is no similar subsidy available for establishment of other energy crops.

In Austria, for electricity production from biogas, a fixed feed-in tariff of between 11.30 cent/kWh (power > 1000 kW) and 16.95 cent/kWh (power < 100kW) is guaranteed over 10 years. In year 11 the plant owner gets 75 % of this feed-in tariff and in year 12, 50 %. Due to high substrate costs for energy crops, the Austrian plant owners got an additional commodity bonus of 4 cent/kWh in 2008. This government aid for new biogas plants is limited to 5.1 M€ per year.

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2 Reed canary grass in Finland

*Timo Lötjönen, Katri Pabkala,
Petri Vesanto & Matti Hiltunen*

Current production and potential in the near future

Production of reed canary grass (RCG) for energy production has increased rapidly in Finland during the past decade. In 2008 the production area of RCG was about 20,000 ha in Finland. In Sweden the production area is under 1,000 ha. In other EU-countries RCG is not cultivated with the exception of small experimental plots. RCG is well suited to the Nordic countries, where the winter is cold. Crop quality improves during the winter and the spring harvest method produces dry, high quality fuel.



*Reed canary grass is a well suited energy crop for Finland and northern Sweden, where the winters are cold.
(Photo: Timo Lötjönen, MTT)*

The Ministry of Agriculture and Forestry of Finland has set a target to increase the field area of energy crops to 100,000 ha before 2016. In Finland about 1.8 million ha is needed for domestic food and feed consumption. Thus it would be possible to use about 0.5 million ha for other purposes such as energy use. In addition, there exist dozens of power plants in Finland that could use RCG in bales or as a fuel-mix.

The realistic yield level of RCG in Finland is $4 - 7 \text{ t}_{\text{dm}}/\text{ha}$, when harvest losses are taken into account. Fields have produced $10 \text{ t}_{\text{dm}}/\text{ha}$ yields, but especially young RCG fields have produced only $3 \text{ t}_{\text{dm}}/\text{ha}$. Because the energy content of RCG is about $4.5 \text{ MWh}/\text{t}_{\text{dm}}$, current production is about 450 GWh/year, if the yield level is assumed to be $5 \text{ t}_{\text{dm}}/\text{ha}$. If the RCG area were increased to 100,000 ha, annual energy production would be about 2.25 TWh. This represents about 0.6 % of total energy consumption in Finland.

Technologies in cultivation and harvesting

Cultivation of reed canary grass

Reed canary grass is a winterhardy, highly productive and durable grass crop. The oldest experimental fields have been productive more than 15 years in Finland. An RCG plant develops its root system during two summers and the first yield is harvested two years after sowing. The crop produces the best yields when it is older than three years.

RCG grows well in all soil types, but the best yields have been recorded from moist mold and fine sand soils. Fields for RCG should be flat and stone-free so that is possible to cut

the crop close to the soil surface, leaving a short stubble. Couch grass and old ley have to be destroyed during the previous summer in a field intended for RCG because a young RCG crop is a very poor competitor against weeds. RCG is sown like forage grasses, but the best results have been achieved without cover crops. The crop is fertilised in spring after harvest at 60 – 80 kg N/ha. Even old peat bogs are suitable for RCG cultivation after adequate liming and fertilisation.

The plantation can be broken up quite easily if the farmer wants to change a crop. Glyphosate is sprayed during June-July and the field is ploughed in autumn. In the following spring a competitive crop (e.g. oats) is sown and harvested in autumn. Subsequently glyphosate is sprayed again and the field is ploughed. The RCG should then have been removed completely.

Yield quality

In Finland and Sweden RCG is harvested in spring after the snow melts because the crop is then dry and fuel quality is high. In the spring-harvested crop ash content is lower and ash smelting point is higher than in an autumn-harvested crop. Also Cl, K, Ca, N and P contents have decreased during the winter. Ash content can range between 2 % and 10 % according to fertilisation and soils. Ash content is lower in stems compared with leaves. At spring harvest up to 70 % of the biomass can be represented by stems.

Harvest of reed canary grass

The first crop can be harvested two years after sowing. Subsequently the crop is harvested annually during April–May. If there is ground frost, RCG can be harvested immediately after the snow melts. If there is no ground frost the



Disc mower with conditioner mowing RCG in spring. The snow has pressed the crop very near to the soil surface and it is therefore important to set stubble height as short as possible. (Photo: Timo Lötjönen, MTT)

soil has to be dry enough to bear the combine harvester. RCG should be harvested before the new growth exceeds 10 – 15 cm. Cutting green biomass decreases the fuel quality and delays growth of the new crop. Moisture content of RCG is usually 10 – 15 % during spring harvest. Contractors are often used to harvest the crop because harvest machinery is expensive.

Mowing and windrowing

Disc mowers with or without a conditioner are commonly used to mow RCG. For spring harvest the stubble height has to be set as short as possible. Mowing a badly lodged crop can easily leave the stubble too long and harvest losses increase. If a conditioner is used, it is important to adjust the conditioner tender to avoid draught losses in a very dry crop. If a disc mower without a conditioner is used, the growth has to be windrowed before harvest. The same rotary rakes as used to rake silage are suitable.

Bale harvest

In Finland round balers are the most commonly used to harvest RCG. Round balers are cheaper and lighter than large square balers. However,

large square balers have higher capacity, produce tighter bales and are of a better shape than those produced by round balers. It is possible to make 30 – 50 % heavier loads for transportation by using good large square bales rather than round bales. For these reasons use of large square balers is becoming increasingly common for RCG harvesting.

The target for baling has to be very dense and well-shaped bales of suitable dimensions for transportation. Bale dimensions are defined when making the contract for growing RCG. Dry RCG is not very easy to compress, thus adjustments to the balers have to be made to get tight, compact bales. Normally density of good round bales is 130 – 150 kg_{dm}/m³ and density of large square bales 170 – 200 kg_{dm}/m³. Round balers use bale net or rope for tying and large square balers use only rope.

Loose harvest

The advantage of loose harvest is that it produces a short chop already during the harvest, which is suitable for feeding lines in power plants. Crushing the bales is not needed with loose harvest. The loose harvest method is suitable if the distance from the RGC fields



Advantages of a large square baler are the tight and well-shaped bales. (Photo: Timo Lötjönen, MTT)

to the power plant or to a fuel terminal is 10 – 15 km at most. Using this method the RCG is harvested by a self-propelled or a tractor-powered silage chopper. The chop is transported by tractors to storage areas and the heap is covered with a tarpaulin. Afterwards the chop is mixed with fuel peat or wood chips and transported to the power plant.

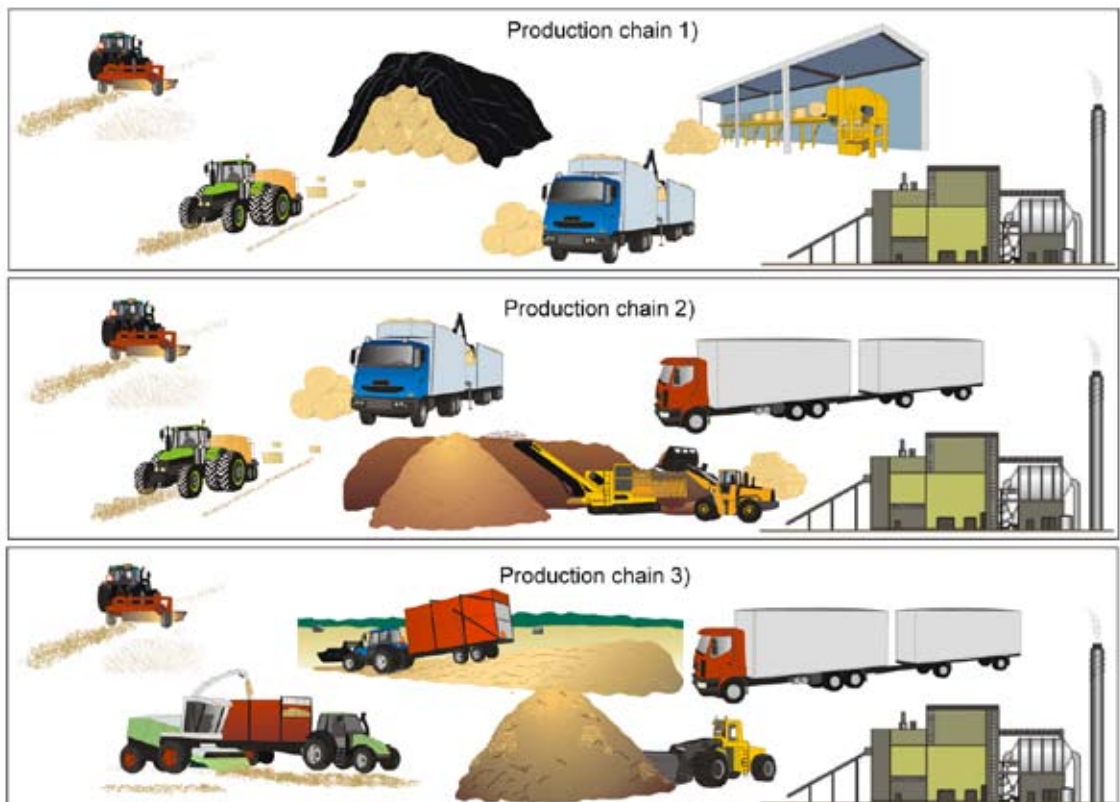
Field transport and intermediate storage

Reed canary grass bales have to be transported from the field to intermediate storage to await truck transport or have to be placed in terminal storage. If the fields are near to the power plant (< 30 km), the bales can be transported directly from the field to storage at the power plant. Short-distance transport is normally performed using front-loader tractors and trailers.

It is important that bales keep their shape and do not break up during short-distance transport. Shapeless bales will cause problems during loading on to trucks and when feeding the bale crusher. It is wise to make the bale heap as high as possible and to cover the heap with tarpaulin to protect the bales against moisture. It is worthwhile weighing down tarpaulin edges with a layer of soil to keep the tarpaulin in place. Working phases from cultivation to intermediate storage are usually the farmer's responsibility.

Long distance transport and logistics

RCG is usually transported in bales or mixed with the principal fuel because the density of RCG chop is very low ($70 \text{ kg}_{\text{dm}}/\text{m}^3$). A full 150 m^3 truckload is only about 10 tonnes if loose RCG chop is transported. The truckloads



Typical RCG production chains in Finland. (Picture: Jyväskylä Innovation Ltd).

can be 15 – 18 tonnes with round bales and 20 – 25 tonnes with large square bales. RCG in bales is profitable to transport up to distances of 70 – 80 km.

Density of RCG can also be improved by pelletizing or briquetting. Transport and combustion of pellets and briquets are easy and effective. However, the high costs of pelletizing and briquetting are the reasons that these technologies are not usually used with RCG in Finland.

Typical production chains of RCG in Finland are indicated:

- **Production chain 1 (Bale chain):** mowing, baling, intermediate storage, long-distance transport, automatic crushing, automatic mixing, combustion
- **Production chain 2 (Combined bale and loose chop chain):** mowing, baling, transport to terminal, terminal storage, crushing, mixing with main fuel, long-distance transport, combustion
- **Production chain 3 (Loose harvest chain):** mowing, loose harvest, transport to terminal, terminal storage, mixing with main fuel, long-distance transport, combustion

Energy production technologies

Reed canary grass as a fuel

In Finland RCG is used in a mix with a main fuel in CHP plants. The main fuel is peat in most cases, which is mixed with RCG chop before feeding into the boiler. The main fuel can also be wood or a mix of wood and peat. RCG is transported to power plant in bales, in loose chop or as a complete mix. For feeding into the boiler, RCG chop must be < 50 mm to prevent blockage problems in feeding lines.

At the moment there are no power plants designed originally for RCG firing. RCG has low density, higher chlorine and alkali content and lower ash smelting point compared with typical solid fuels like peat, wood or coal. For these reasons the RCG proportion is usually limited to 10 – 20 % of total energy content of the fuel mix. This represents a 20 – 40 % proportion in volume of an RCG-peat-mix. Firing pure RCG would lead to corrosion risks, boiler fouling and ash smelting, which can cause malfunctions in the boiler. Probably firing of pure RCG would be possible in boilers designed for firing straw. There is no yet practical evidence of this.



*Preparation of reed canary grass-peat-wood mix with a wood crusher on the yard of a power plant.
(Photo: Timo Lötjönen, MTT)*

Preparation of fuel mix

The simplest way to mix RCG with the main fuel is to spread peat or wood chips and RCG in layers by wheel loader and to load the fuel bed into the storage heap, transport truck or directly feed it into the boiler. However the mixing result is often uneven when this method is used.

RCG is thoroughly mixed with wood chips if the bales are crushed together with the wood using a wood crusher. The crusher can be mobile or part of a feeding line of a power plant. However, RCG decreases crushing capacity compared with pure wood crushing.

If there is only a bale crusher line for RCG bales, the RCG chop can be fed on to the main fuel conveyor as the fuels are being mixed or the RCG chop can be fed directly into the boiler pneumatically via a pipeline. The pneumatic feed system has to be planned carefully in order to get the RCG sufficiently well mixed to form a fluidized bed and avoid separate and rapid combustion of RCG in the feed area.

Combustion technologies

In Finland there are mainly three types of boiler used in CHP plants and heating plants:

- grate boilers
- bubbling fluidised bed boilers
- circulating fluidised bed boilers

The grate system is typically used for a range of boilers, from 10 kW heating boilers to 25 MW industrial and district heating boilers. In the simplest case the grate is an inclined fire-grate, but in the bigger boilers the grate is usually moved mechanically. In Finland grate boilers are often designed to use wood chips, bark, sawdust and sod peat. The feed systems of grate boilers do not suit feeding light RCG chop, thus RCG has to be mixed thoroughly with the main fuel. If the mixing is uneven RCG chop easily flies away with flue gases and the fuel bed becomes cratered, leading to difficulties in controlling the combustion. The grate should move to prevent an ash smelting

problem. In straw boilers these challenges are solved because straw is even more difficult a fuel to combust than RCG.

Bubbling fluidised bed boilers are multifuel boilers that can use biofuels, peat and even sludges. In these boilers the fuel is combusted on a very hot sand bed at the bottom of the boiler. Combustion air is blown through the sand bed. Output capacity varies between 5–250 MW. The circulating fluidised bed boilers are normally even larger, 20–550 MW. They are also multifuel boilers, which can use biofuels and peat, but also coal. Hot sand circulates in the boiler and fuel is fired in the sand. Control of combustion and emissions is very good.

The fluidised bed boilers are well suited to burn RCG if it is mixed with the main fuel and the proportion of RCG is relatively small. Peat is a very good main fuel to use with RCG when combusted in fluidised bed boiler.

Reed canary grass in fluidised bed combustion

RCG is as reactive fuel as other biofuels and combustion is rapid and complete. RCG has higher chlorine content than peat or wood and during combustion chlorine salts are produced with potassium and calcium, which can lead to boiler fouling and corrosion risks in superheaters. In addition, the ash smelting point of RCG can be low in certain circumstances. In fluidised bed boilers bed-sand fluidization is an important factor in usability, good combustion and emissions. Agglomeration or sintering of bed sand is not desirable and in peat firing it is exceptional. If pure wood or RCG is used, there is a risk of sintering. When RCG is co-fired with wood, there is a risk that silicate (SiO_2) of RCG ash reacts with the potassium from wood ash and generates sticky “glass”.

Peat is a very good main fuel with RCG because peat ash does not react appreciably with RCG ash, but the sulphur in peat reacts with potassium in RCG to generate potassium sulphate, which prevents formation of corrosive potassium chloride.

Recommendations are indicated in the table 2, which indicate the maximum “safe” proportions of RCG in fuel mixtures. These proportions are fairly large measured by volume and they do not easily limit the use of RCG. Very often fuel feeding lines have lower capacity and it is not possible to use the maximum proportion of RCG.

Energy and greenhouse gas balances

Carbon dioxide, which is emitted during RCG combustion, can be taken up by growing plants. For this reason RCG belongs to CO₂-neutral fuels and is free from emission trade fees.

RCG cultivation, harvest, transportation and treatment on the power plant require non-renewable energy in the form of fertilisers and engine fuel. However, calculations show that the production chain consumes only 6 – 8 % of the energy released during combustion (table 3). Likewise, greenhouse gas emissions (CO₂, CH₄ and N₂O) are small compared with released energy. When RCG is combusted in large-scale power plants, energy and greenhouse gas balances are only slightly weaker compared with balances for wood fuels. Refining field biomass directly into heat and electricity is more energy efficient than refining it into vehicle fuels.

Markets and economics of production

In Finland agricultural subsidies for RCG are the same as those for other field crops. In addition, new RCG fields are entitled to a permanent grassland subsidy. Agricultural subsidies for RCG are about 500 – 700 €/ha, which corresponds to about 25 – 35 €/MWh. Subsidies play a very important role in calculating profitability of RCG production. The market price for farmers of RCG stored

on the roadside is currently 4–8 €/MWh. The distance between fields and the power plant influences the market price to a large degree: the maximum distance can be about 80 km. Production on fields distant from a power plant is not profitable. Nowadays production of RCG is moderately profitable for farmers and RCG is also a competitively priced fuel for the plants.

RCG fuel is not subsidised in Finland and its use is most profitable in power plants bigger than 20 MW. These plants can avoid emission trade fees by using biofuels instead of fossil fuels. It is estimated that emission trade fees will rise substantially in the future as the demand for biofuels and their prices rise. There are currently about 35 heating and power plants in Finland using RCG and use of RCG would be possible in at least 100 power plants. The use of uncrushed bales in the plants requires some investment in crushing and feeding lines, which restricts use of RCG as a fuel. It is possible to get support (e.g. 15 – 30 %) for investment costs.



RCG can also be harvested as a chop, when it is easy to mix with main fuel at fuel terminal or on the yard of a power plant. (Photo: Timo Lötjönen, MTT).

Table 2. Recommended maximum proportions of RCG together with wood or peat when a fuel-mix is used in a fluidised bed boiler. (Source: Vapo Ltd, Novax Ltd.).

Fuel mixture	Max. proportion of RCG of energy content	Max. proportion of RCG of volume
Reed canary grass and peat	20 %	about 40 %
Reed canary grass and wood chips	10 %	about 20 %
Reed canary grass, peat and wood chips; proportion of peat > 50 %	15 %	about 30 %

Table 3. Energy and greenhouse gas balances for different biofuels. Energy balance should be clearly < 1 and greenhouse gas balance should be clearly < 0.1 (balance of petrol) for biofuel use to represent a sensible option. CO₂, CH₄ and N₂O have been taken in account in calculating greenhouse gas balances. (Source: Mäkinen et al. 2006)

Biofuel	Energy balance GJ _{input} / GJ _{output}	Greenhouse gas balance, tonne CO ₂ -ekv/GJ _{output}
RCG, harvest and transport as loose chop, CHP	0.078	0.015
RCG, harvest and transport as bales, CHP	0.077	0.015
Wood chips from logging residuals, CHP	0.025-0.027	0.002
Wood chips from stumps, CHP	0.038	0.003
Wood chips from small diam. trees, CHP	0.036	0.003
Ethanol from barley	0.8	0.105
Biodiesel from rape seed	0.5	0.11
Fisher-Tropsch-diesel	0.5	0.02-0.03

Good case example

The power plant of Kokkolan Voima Ltd. was commissioned in 2001. The fluidised bed boiler with steam turbine can produce 20 MW of electricity and 50 MW of district heat. During 2008 the plant used peat for about 170 GWh, residues from the forest industry for 50 GWh, wood chips for 95 GWh and RCG for 5 GWh. During 2006 – 2007 the company built a new crushing and feeding system for field biomass. The system consists of a storage hall, a crushing line for the bales and a pneumatic feeding line to the boiler.

Crushing technology is based on the method developed by the Danish Reka company, which was designed originally to crush straw in large square bales. Nominal capacity of the crusher is 1000 kg/h. The system includes a nearly 50 m long bale conveyor on which the bales

are loaded twice a day. The remainder of the time the crusher works automatically and is unmanned. As the crusher is a low speed type, the crushing does not cause dust problems and thus represents a reduced fire hazard and the environment stays cleaner. The crusher can accommodate both large square bales and round bales.

The screw below the crusher drum moves RCG chop into a pneumatic pipeline through a feeder device. The diameter of the pneumatic pipeline is 100 mm and its length from the crusher to the boiler is more than 100 m. The feeding point for the RCG is at the same level and on the same side of boiler as the feed for the main fuel.

The system is designed to process 15 GWh field biomass annually, which is about 5 % of total energy used on the plant. RCG is mainly



Power plant of Kokkolan Voima Ltd. Reed canary grass chop is transported pneumatically to the boiler via the pipeline on the left. (Photo: Timo Lötjönen, MTT).

bought from about 50 contract farmers. The RCG cultivation area is about 600 ha. Farmers from the neighbouring area transport the bales directly to the storage facility of the power plant. The RCG produced far from the plant is stored near the fields and transported to the plant with logging residue trucks, which can take about 70 round bales (15 tonnes). By using large square bales the load mass can be higher. Purchasing RCG directly from farmers involves significant administrative work for the plant.

Pros and cons:

- + RCG is transported in bales to the plant – effective transport logistics
- + Covered storage assures high fuel quality and independence from transport logistics
- + Quality of crushing is high and energy efficient
- + Using this method RCG does not cause problems in treatment and feeding the other fuels
- The method requires investment and sufficient space at the power plant

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3 Willow and hemp in Sweden

Willow

Willow (*Salix* spp.) includes several tree and shrub species, some of which grow fast and have been cultivated for energy generation in “energy forests” in Sweden since the first oil crisis in the 1970s. Clones of *Salix viminalis* are mainly used in the energy forests. Other species such as *Salix dasyclados* have also been cultivated, but to a much more limited extent. Willow has almost the same net heating value as the wood fuels, approximately 18.6 MJ/kg_{dm} (see comparison with other biofuels and energy crops in Table 1 of Introduction).

Current production and potential in the near future

Willow is mostly cultivated in the fields of southern Sweden, where about 1,250 farmers work with commercial plantations currently totalling about 13,500 hectares. The establishment period and intervals between harvests are 3 – 5 years and the yield can reach about 8 – 10 tonnes dry mater per hectare

per annum, but significant variation occurs according to region and year.

Currently about 20 % of total energy consumption in Sweden is from bioenergy. The biofuels from direct bioenergy farming make a very small contribution (< 1 TWh in 2008, not including crops produced for biogas), compared with those from wood industry residues. There is a great untapped potential, however, and bioenergy could contribute up to 220 TWh, 10 % of it coming from long-term energy farming. To date, willow chips for direct combustion are the most commonly used products on the market.

Technologies in cultivation and harvesting

Willow plantations are established from cuttings during spring. Planting material should be bought from a reputable source to ensure good stock quality. Willow is usually supplied as 2 – 3 meter long branches that are cut between December and March when the buds are fully dormant. These can be planted immediately or carefully stored in cool conditions (-2 – -4°C) until they are used. It is necessary to protect the planting material from moisture loss and during storage prior to planting. Cuttings with burst buds should not be planted because they will not root easily.

Special designs (twin rows) and techniques for willow plantation establishment have been developed. Willow branches 2 – 3 m length are cut into 15 – 20 cm sections immediately before planting. The twin-row design allows a spacing of 0.75 m between rows and 1.5 m between twin rows,



Twin row design for establishment of willow using a Step Planter. (Photo: Lantmännen Agroenergy AB)

leading to a planting density of about 13,000 cuttings per hectare.

Weed control during the first year is very important. The willow root system establishes in the first year, during which it is not tolerant of weed competition. Measures that can ensure weed-free sites at planting have to be taken to achieve successful establishment. The site must be prepared using a deep plough in the previous autumn. Broad spectrum contact herbicides, such as glyphosate (a type Roundup Bio), are often used to control perennial weeds before any cultivation and even 2 – 3 weeks afterwards. Mechanical weed control is an alternative. In addition, residual soil-acting herbicides can be also used to control germinating weeds. Detailed recommendations can be obtained by contacting a dealer such as Lantmännen Agroenergi in Sweden. The willow crop foliage can shade out the weeds when it is well-established.

Willow plantations are very demanding of water and nutrients, generally requiring 3 – 5 mm of water per day during the growing season. The demand for nutrients varies according to age of the plantation and stage of crop development. For example, no N fertilisation is recommended in Sweden during the year of establishment, but 45 kg N per hectare should be applied during the second (i.e. the first harvest) year, and 100 – 150 kg N during the third and fourth years. Studies have suggested that an economic and environmental benefit may result from using waste water for irrigation, and sludge together with ash from biofuel combustion as fertiliser. Research has also demonstrated that willow can remediate soil contaminated by organic pollutants and heavy metals.

Pest and disease control has to be managed. Fungal pathogens and leaf-eating insects can damage willow. Planting mixtures of different varieties or species is always recommended. Research has led to development of new vigorous willow varieties with increased resistance to diseases such as melampsora rust

and damage by insects including the willow beetle. Chemicals control of insects is not recommended from an environmental point of view, but a limited application of insecticides can be allowed to control willow beetle in some cases.

Willow is preferably harvested during the winter when the ground is frozen and the moisture content in the biomass is at its lowest (ca. 50 %). Willow is harvested after 3 – 5 years of growth. Harvesters that can cut-and-chip in one or two operations and are capable of cutting two rows in one pass (i.e. suitable for twin row design) are mostly used in Sweden.

Logistics

Willow biomass is usually harvested directly by cutting and chipping in the field. The chips are then transported to district heating or CHP plants where they are stored and used. The same equipment can be used for producing and supplying willow chips for a CHP plant as is used to produce conventional wood chips. There is no major difference either in storage conditions used for willow or conventional wood chips. Willow can be stored in bundles over a longer time period without significant reduction in quality.

Energy production technologies

Willow chips are mostly used as solid fuel for direct combustion in heating or CHP boilers. However, they currently contribute up to 20 % of fuel mixtures because willow contains elevated levels of problematic elements for combustion (such as K, Cl, Na, N, Mg etc.) in comparison with other wood fuels, leading to a higher risk of corrosion, slagging etc. In other respects willow chips are used in the same way as wood chips and have similar calorific values. Studies testing combustion of willow powder and pellets or briquettes have been conducted and it is expected that a co-firing willow and other fuel types will be studied in the future.

National law and incentives programmes

In Sweden, as in other European countries, energy farming is encouraged to promote sustainable development. Therefore, energy farming of willow has been required to have no deleterious effects on food safety and security for future generations and if possible willow should be rotated with food and other industrial crops without lowering production capacity. There should be no disturbance to the soil and landscape characteristics, the ecology of the production area should not be disturbed unduly and the production process should be in line with urban environmental aims.

To reach these goals, some restrictive rules and regulations must be adhered to in willow production management:

- Sludge and other solid organic components must be used carefully
- Nitrogen run-off should not exceed 10 kg/ha/year
- Phosphorus loss to watercourses should not exceed 0.2 kg/ha/year
- Agrochemicals application for pest/disease/weed management cannot exceed 0.7 kg/ha/year
- No activities are allowed that could increase in heavy metal content of the soil.

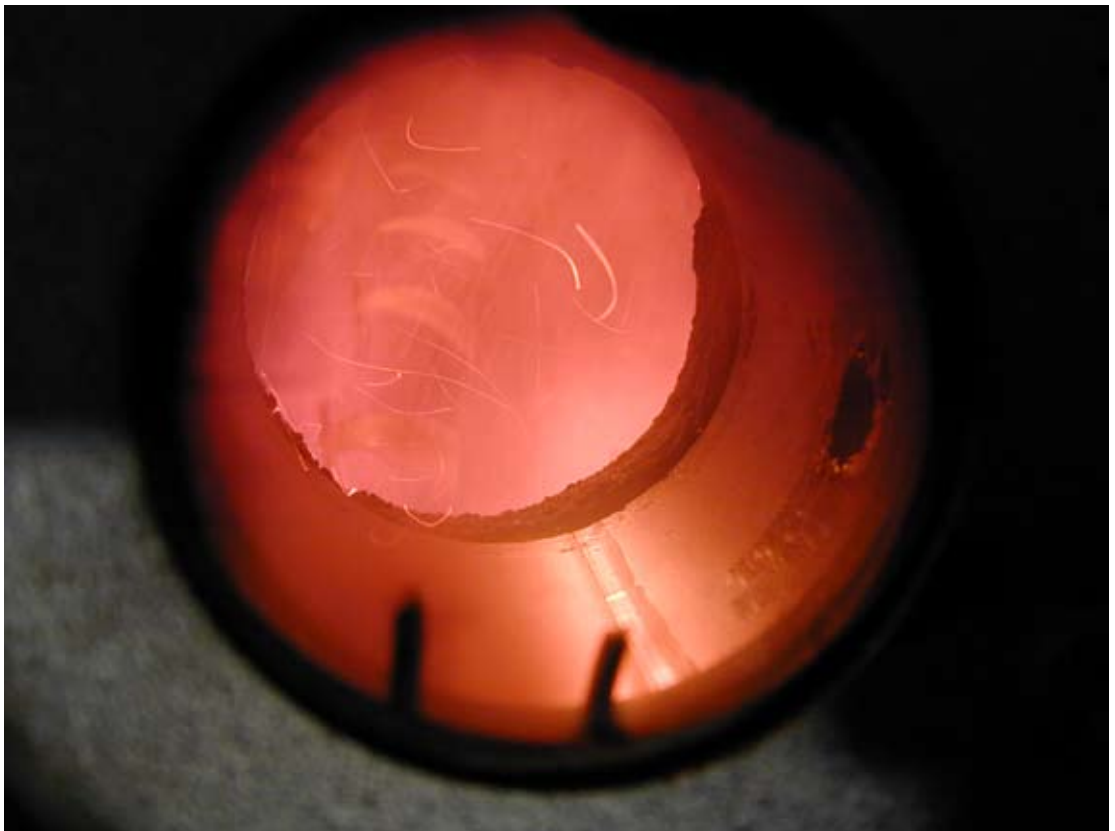
When the willow biomass is used as a carbon neutral biofuel and has low sulphur emissions, the user can be rewarded by state policies and incentives. The most important state policy in Sweden to promote the use of biofuels is taxation on the emission of carbon dioxide. This has been in operation since 1991. Biofuels are exempt from the carbon tax. CHP plants



Willow harvesting (Photo: Theo Vernijst)

using biofuels may be also supported through other schemes such as the Green Electricity Certificate, Emission Trading, Program for energy efficiency in industry (PFE), etc.

To encourage farmers to start the willow business, some incentive programmes have been implemented since the end of 1980s. Currently farmers can get subsidies of about 5,000 SEK (about 500 €) from the government to establish willow plantations.



*The field energy crops can be transformed efficiently to energy in fluidised bed combustion at CHP-plant.
(Photo: Timo Lötjönen, MTT).*

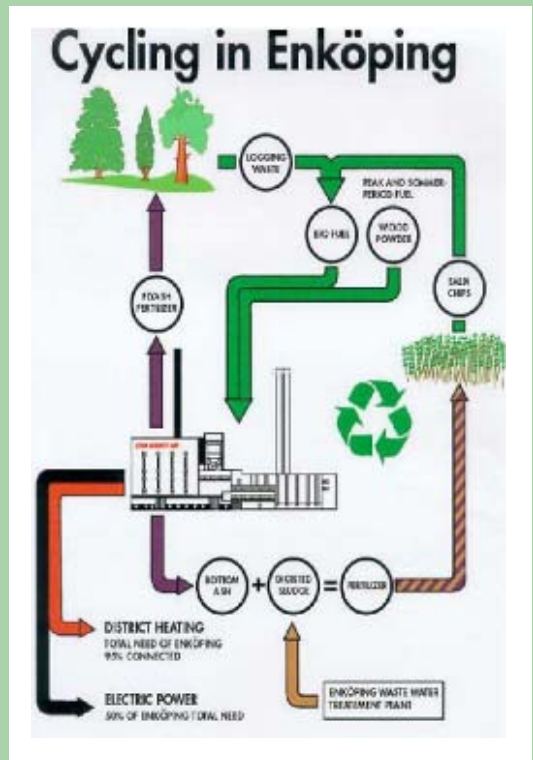
Good case example

The multifunctional willow plantation in Enköping is one of the most successful cases of large-scale energy farming. Wastewater treatment, sludge recycling, leakage water filtration and heavy metal purification are combined with willow biomass production. The biomass of willow is then supplied in chips to the ENA Energy's CHP plant in Enköping, which has the capacity to produce 23 MW of electricity and 55 MW of heat. It generates 350 GWh (100 GWh electricity, 250 GWh heat) every year.

The original concept comprises about 80 hectares of willow plantation, an irrigation system and 3 ponds connected to the municipal waste-water treatment plant. Each year, approximately 200,000 m³ of nutrient-rich water, after a conventional purifying process, is distributed through the 350 km irrigation pipes to the 80 hectares of willow plantation. The planning was initiated in 1993 – 1994 and the system was ready to use in 2001.

Benefits of the ENA Energy concept can be summarised:

- Use of a local energy resource - shorter distances and lower expenses for transporting fuel
- The waste from society can be recycled as fertiliser – reduces uses of commercial fertilisers and environmental problems
- Reduction of nitrogen leakage into the Baltic Sea – also minimises environmental risks
- Saves the costs for building conventional nitrogen removal facilities
- Saves energy used in waste handling
- Improvement of soil environment through remediation by willow



Schematic layout of cycling in Enköping.

Hemp

Hemp (*Cannabis sativa* L.) is an annual, dioecious, herb. It is a multi-purpose plant that has been domesticated for the bast fiber in the stem, a fixed oil in the seeds, and an intoxicating resin secreted by epidermal glands. Most of the hemp grown in Europe is used for fibre production. The fibres are used in the pulp and paper industry and the residual shives are used as animal bedding. Energy production in the form of solid fuel from the whole hemp stem is a relatively new use for the crop.

Current production and potential in near future

Hemp is currently only grown on a small scale for energy production in Sweden. Farmers, however, are interested in this crop because it is an annual and allows more flexibility in cropping systems than perennials such as willow or reed canary-grass.

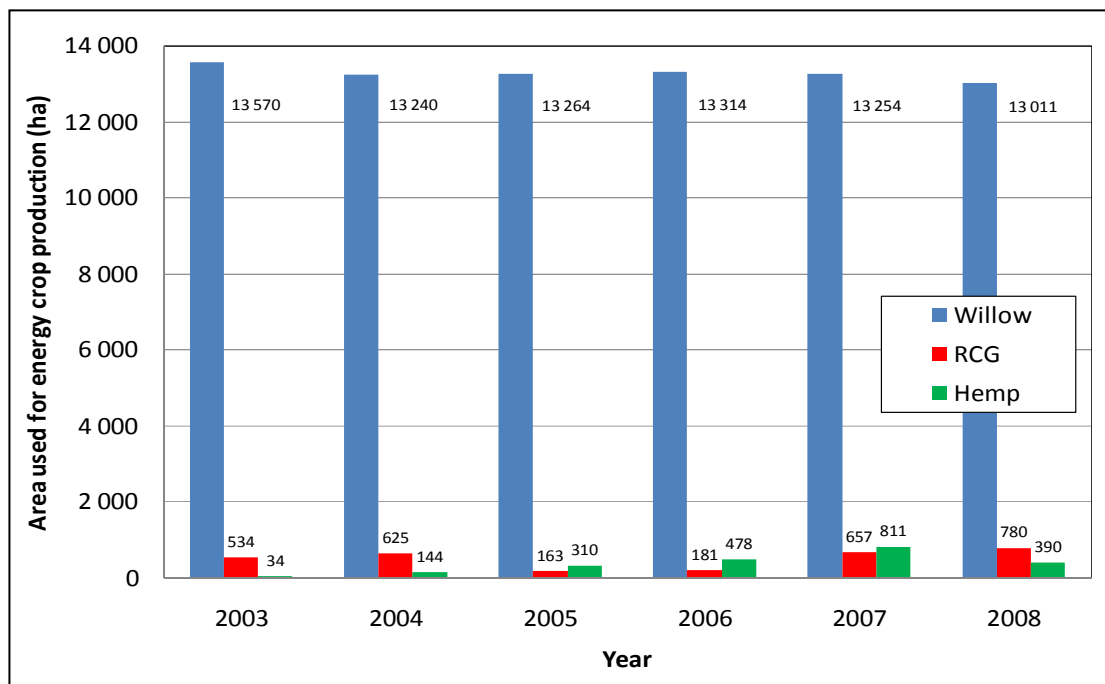
Hemp is also interesting from an organic farming point of view because it usually requires

no pesticide or fungicide application. Hemp can be used for weed control as a dense hemp stand will shade out competing weeds. The goal of the government is that at least 20 % of Swedish farming should be certified organic by 2010. Hemp is considered an interesting component for crop rotations in organic farming.

The enclosed figure shows the area used for willow, RCG and hemp production in Sweden from 2003 to 2008. There was a steady increase in hemp cultivation from 2003 to 2007, reaching a maximum of about 800 ha. In 2008, however only half of that area (about 400 ha) was used for hemp production.

Technologies used in cultivation and harvesting

To make full use of the growing season hemp should be sown as early in the spring as is possible. Seed is best sown at 2 – 3 cm depth and at a row distance of 25 cm. Although the seedlings will germinate and survive at temperatures just above freezing, soil temperatures of 8 – 10 °C



Willow, reed canary-grass and hemp production in Sweden from 2003 to 2008.

are optimal. Good soil moisture is necessary for seed germination, and adequate rainfall is needed for good growth, especially during the first 6 weeks. For energy purposes a seeding rate of 20 – 40 kg/ha is recommended. Growing hemp may require addition of up to 110 kg/ha of nitrogen, and 40 – 90 kg/ha of potash. Nitrogen fertilisation in excess 200 kg/ha has however been tested with good results.

Hemp is harvested for energy use as wilted, dry material in late winter or spring after the growing season. This means that the whole growing season is used, giving a high biomass yield. During winter the leaves fall off and the ash content is lowered. Some of the unwanted elements (N, S, Cl) are leached out of the material during winter, which produces better fuel than grass.

Hemp can be harvested by cutting and baling or can be cut by a precision chopper and collected

as loose material. Bales can be stored indoors or in a covered pile to protect them from rain. Loose material can be stored in covered silos or in tubes. Harvesting hemp with conventional machinery can sometimes be troublesome because the strong fibres have a tendency to get stuck in rotating machine parts. The enclosed picture shows hemp harvesting equipment.

Logistics

As with other energy materials, including reed canary grass and straw, logistics are challenging. The crop is only harvested once a year, often in spring when the need for raw material by heating and power plants is low. This means that storage of the harvested material is often required.

Baling offers an effective means to collect, handle and store the material, but it is also a significant cost item in the production chain.



Demonstration of a newly developed small, flexible harvester for hemp in Grästorp, Sweden, April 2009. (Photo: M. Finell, SLU).

Using hemp in large-scale heating and power plants requires that the material is cut and mixed with other fuels before combustion. This has led to a focus on loose handling of hemp. The enclosed photo shows trials for compressing hemp to improve transport.

Different methods for compacting loose hemp material have been studied to improve transport of the material. It is suggested that the material is collected at terminals where chopped hemp is mixed with other fuels such as wood chips, bark or peat. The mixture is then transported to a heating and power plant for combustion. In this way the dry hemp material could be used to improve the energy value of very moist materials (e.g. bark).

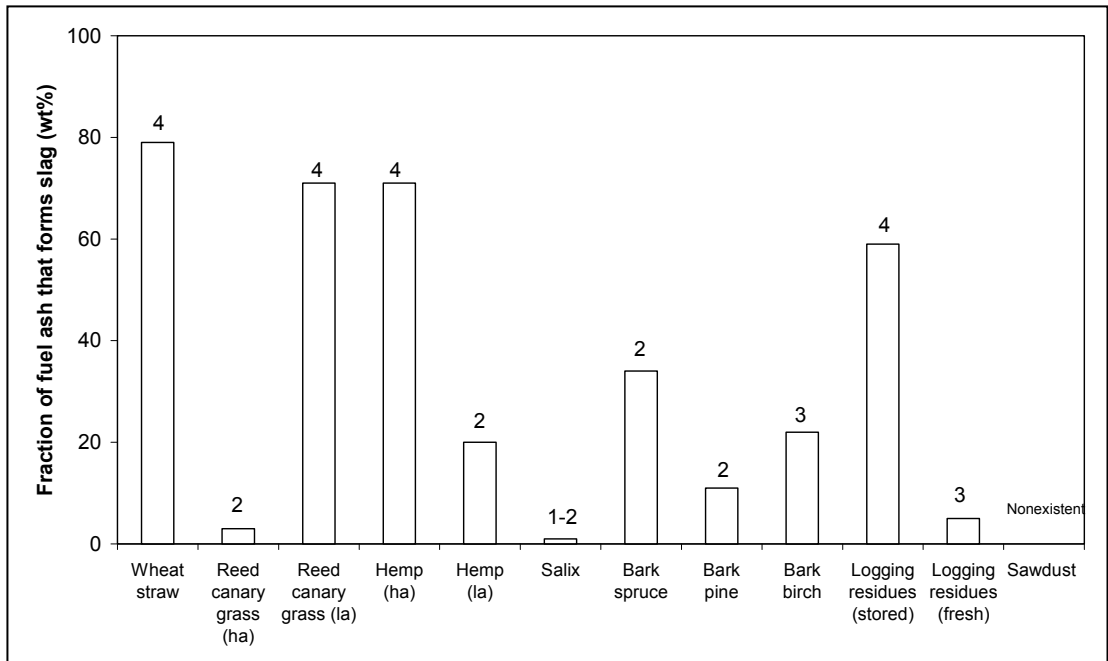
Energy production technologies

Hemp can be refined into briquettes or pellets to increase the energy density and to improve handling characteristics. This material can be used for heat production by the general public (burner, stoves and boilers) or in larger scale heating and power plants.

When using hemp in larger scale heating and power plants, briquetting and/or pelletising of the material is often not necessary. Loose handling and mixing with other fuels in similar ways as for reed canary grass and willow is currently being investigated.



*Compressing trials with spring-harvested hemp using a "Roll-pac" on.
(Photo: Y. Söderström, Övik Energi AB).*



Fraction of fuel ash that forms slag for some different fuels. Categories of sintering are specified above the corresponding bars: Category 1, non-sintered ash residue, i.e. non-fused ash; Category 2, partly sintered ash, i.e. particles contained clearly fused ash; Category 3, mostly sintered ash, i.e. the deposited ash was fused into smaller blocks; and Category 4, totally sintered ash, i.e. the deposited ash was totally fused into larger blocks. (Source: Öbman et al. 2006)

In many combustion applications, ash related problems, such as slagging tendency, are important. In enclosed figure some new fuels, including hemp with a high (ha) and low (la) ash content are compared with sawdust for ash-forming tendency.

National laws and incentive programmes

In Sweden, hemp has been grown as an energy crop since 2003. The difference with other crops is that only EU certified “industrial hemp” varieties can be used. The certified varieties have a tetrahydrocannabinol (THC) content of less than 0.20 %. A subsidy of 45 €/ha is available for hemp, as for other energy crops in Sweden, but this will probably be discontinued beyond 2009.

Good case example

The cultivation of hemp is limited to small-scale trials in Sweden. A good example of small-scale hemp production for bioenergy is Gudhems Kungsgård in Falköping. At this family-owned farm about 100 ha of hemp is grown and refined into biofuel briquettes. Hemp briquette production started there in 2004. The briquettes are sold in the surrounding area to local end users. The farm reports a biomass yield of about 10 tons/ha at a moisture content of 11 %. Hemp is harvested in winter/spring with a self-propelling precision chopper (Claas Jaguar). The chopped material is then stored indoors and/or fed directly to the briquette press. The briquette press is a German made RUF with a capacity of 300 kg/h for hemp. The hemp briquettes are sold in small (15 kg) and large packs (600 – 700 kg) and the price to the consumer is between 1.50 and 3 SEK/kg.

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4 Poplar in Spain and Italy

Lorenzo Corbella, Maurizio Cocchi & Margarita Salve Diaz Miquel

Current production and potential in the near future

Poplar (*Populus* spp.) is a tree belonging to the Salicaceae family widely used in traditional arboriculture and forestry. It is tolerant of a wide range of soil conditions, but generally grows in deep fertile soils and it is best suited to the Mediterranean climate since it is very sensitive to frost. Under optimal conditions SRF (short rotation forestry) poplar plantations can reach a productivity level of about 20 t_{dm}/ha/year.

Poplar is currently the most important species for SRF in Italy. All the existing commercial

plantations are based on poplar clones grown in the northern regions of Italy (Lombardia, Piemonte, Veneto, Friuli, Emilia Romagna) and to a less extent in central Italy (Marche, Umbria, Lazio and Toscana) with a total estimated harvested area of about 5,700 ha.

The first commercial experiences with SRF began in early 2000 in Lombardia thanks to the availability of Rural Development Program funds and additional regional subsidies. Initially the Swedish model was adopted, (density of plantations, harvested each year) and results were encouraging, but suffered from lack of best practice knowledge by farmers, who often dedicated only marginal lands to SRF and did not put enough effort into maintenance and fertilisation of the plantations.

The presence of large operators willing to invest in biomass power plants will lead to a strong potential market for wood-fuel in the near future. However, the interest of farmers in SRF has declined during the last two years due to fluctuations in profitability of cereal crops. SRF remains profitable, but is not considered competitive in comparison with traditional crops at this point in time. Possible solutions in Italy to further promote the cultivation and utilisation of wood-fuel from energy crops are:

1. **Negotiation of improved contract conditions and incentives with farmers.**
2. **Maximisation of energy efficiency through:**
 - Combined Heat and Power instead of power generation only
 - Promotion of local small-medium scale supply chains for district heating and CHP to reduce transportation costs



Mature poplar plantation in the spring time just before harvest.
(Photo: L. Corbella & M. Cocchi, ETA)

Table 4. Demonstration areas for energy crops in Spain, 2006-2007. Source: Ciemat.web: www.oncultivos.es

ENERGY CROP	Hectares
SORGHUM	104
BRASSICA NAPUS	348
BRASSICA CARINATA	23
POPULUS SPP.	18
MAIZE	31
WHEAT	15
BARLEY	16.5

In Spain, the ON CULTIVOS Project (2005 – 2012) represents the principal national initiative where, energy crops include: carinata (*Brassica carinata*), poplar (*Populus spp.*), forage sorghum (*Sorghum bicolor*) as well as cereals for bioethanol production and rapeseed (*Brassica napus*) (table 4).

The estimated demonstration area at the end of the project is about 10,000 ha involving regions in north (Navarra, Aragon, Cataluña, Castilla y Leon), central (Castilla la Mancha, Madrid) and south-eastern (Andalusia, Extremadura) Spain. Applications under this initiative include energy production for heating, power generation, development of biofuels and gasification.

The aim of studying *Populus* clones and hybrids is to generate knowledge and experience for sustainable production in the Spanish context. Efficiency of utilisation of scarce resources, such as water, optimisation of production regarding spacing/rotation, selection and monitoring of machinery adapted to harvesting and associated logistics, and economic, energy and environmental equilibria are of major interest for promotion of poplar as an energy crop.

The objectives for biomass production in the Spanish Renewable Energy Plan specify 40% for energy crops. According to the plan they must reach 1.9 Mtoe per year in electrical and thermal applications by 2010 and 2.2 Mtoe per year as biofuels.

Technologies for cultivation and harvesting

Research on SRF in Italy has been on-going since the early stages of bioenergy crop production using poplar and has mainly focused on genetic improvement and clone selection, optimised cultivation techniques, harvesting and mechanisation and storage and logistics of biomass production. Research efforts during recent years have yielded important results.

Regarding the optimisation of the cultivation techniques, some important steps forward were taken in the following fields:

- Establishment of plantations: plantations are established with cuttings (20 – 30 cm in length) during spring. Research on mechanisation has led to optimisation of a mechanised transplanting unit (developed by the Italian company Spapperi), which has a working capacity of up to 35,000 cuttings per day under optimal conditions;
- Identification of optimal coppice rotation: research confirmed that under optimal pedo-climatic conditions one harvest every other year yields better results in the long term than annual harvesting. Under less favourable conditions, 3-5 year rotations are more sustainable.
- Plantation density: from the initial Swedish model, based on one year harvest cycles and 10,000 to 15,000 plants per hectare, the trend is now to aim for a density of 7,000 to 10,000 plants/hectare for 2 – 3 year harvest cycles and 2 – 3,000 for 5 years cycles. Trees are planted in single rows instead of double rows.
- Fertilisation: initial fertilisation before planting is suggested and can be done with a combination of mineral fertilisers and organic fertilisers in order to achieve slow release of nutrients. Depending on the expected target productivity, it is also possible to apply nitrogen fertilisers periodically among rows (around 60 – 80 kg/ha N) soon



*Poplar plantations are established with cuttings semi-automatically.
(Photo: L. Corbella & M. Cocchi, ETA)*

after harvesting, in order to promote rapid growth of the new shoots.

- Removal of the plantation: at the end of the cycle (10 – 12 years) SRF poplar plantations can be easily removed at low cost (around 300 €/ha) using traditional forestry machinery (milling cutter); poplar roots contain a substantial amount of water and roots tissues are relatively soft.

Research on mechanisation of SRF has been extensive. Concerning harvesting, initially the only available means for harvesting SRF was by using a Claas Jaguar self-propelled harvester. From the start two main limiting factors were evident: the high cost of the harvester led to the need for larger plantations to increase the annual number of working hours of the machine and reduce unit costs, and the difficulty for the Jaguar to harvest trees more than 6 cm diameter, which were common in 2-3 year old coppice plantations.

During recent years three main harvesting models were identified that have overcome these problems:

- Fully mechanised harvesting with a self-propelled Claas Jaguar harvester and a modified GBE harvesting head: the BIOMASSE EUROPA GROUP developed a new harvesting head (GBE-1) suitable for Claas combine harvesters that works well in 2-3 year coppices and is affordable;
- Fully mechanised tractor-powered SPAPPERI harvesters. These are less expensive machines, ideal for small and medium scale plantation extensions and 2 – 3 year coppice cycles;
- Salixphere Bender VI, is “non-row-specific” and allows cutting and chipping in any plantation of 2 – 3 year rotations. The device is well adapted to irregular soils with costs intermediate between those for Claas and Spapperi harvesters;



A modified self-propelled forage chopper cuts the poplars, makes woodchips and blows the chips into a transport trailer. (Photo: L. Corbella & M. Cocchi, ETA)

- 3 step harvesting with traditional forestry techniques and equipment, ideal for longer cycles (3 – 5 year harvest cycles). In this case the plantation density is reduced and tree height at harvesting exceeds that in 2 year coppices. Trees can be harvested following a 3 step model: felling (with cutters or by hand with chainsaw), stacking logs in the field with tractors and forklifts, and successive chipping with individual chipping units.

Logistics

Energy crops are generally distributed by local companies in the proximity of the energy conversion plant and can be used in the existing systems for other biomass (herbaceous or woody) processing. Plantations are often in locations close to an energy plant to reduce road transport costs. The maximum capacity of trucks is 90 m³.

Storage

Poplar grown as an energy crop is seasonal regarding production and harvest, while the energy plant runs throughout the year. It is therefore necessary to store the biomass to ensure a reliable supply of wood. Long periods of storage affect the cost, quality (calorific value, moisture, mould, ash) and reduction in dry matter.

Storage can take place at different sites (close to the production area, close to the plant, at an intermediate location).

Table 5. Storage options for poplar biomass.

Open air storage	Piles of chips
	Piles of bundles
	Piles of bales
	Shelter (semi-covered)
Enclosed warehouse (i.e. as pellets)	Enclosed and ventilated warehouse
	Silo



Poplar chips are stored here in an open concrete silo. This type of storage is suitable only for short-term storing because the moisture content of fresh poplar chips is high. (Photo: L. Corbella & M. Cocchi, ETA)

The moisture content of fresh poplar biomass at harvest is around 55%. For this reason outdoor storage in large bulk piles of woodchips can lead to fermentation and subsequent loss of dry matter of up to 5% per month.

To overcome this problem, research is actively seeking to identify the best storage solutions. Current trends are:

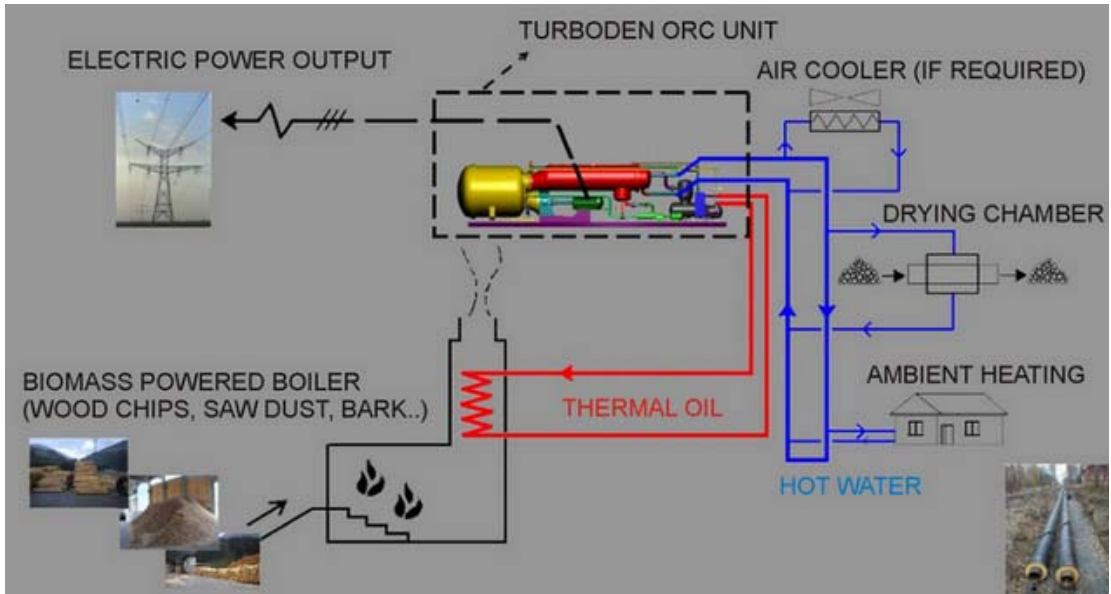
- Storage under cover (feasible only for small volumes of woodchips)
- Identification of optimal pile dimensions. Pile dimension influences the balance between evaporation and rainwater absorption capacity
- Use of canvas (plastic net) or special fabrics (Top Tex) that let moisture out but are impermeable to rainwater (this looks like a very efficient solution at present).

For long periods of storage the “bundler format” is more convenient than chips, as it reduces biological activity and degradation associated with green woody biomass (table 5).

Energy production technologies

The OCR turbines are able to produce heat and electricity for small to medium scale systems (from 200 kW_e up to 2 MW_e per unit) by using the technology of the Rankine cycle. The turbo-generator coupled with a diathermic oil boiler is a perfect example of a highly efficient CHP plant (18 % for electricity and 79 % for thermal output). The diathermic oil boiler, fed with woody biomass, heats the oil up to 300°C, providing the required heat for the turbo-generator, which produces electric energy and a thermal output of 90 °C.

These systems are suitable for case studies where the local biomass availability is limited and the reduced plant size, apart from reducing the general plant complexity and optimising the costs for storage, transport and logistics, permits enhanced utilisation of the co-generated heat with clear environmental, energy and economic benefits.



Organic Rankine Cycle (ORC), heat and energy production from a biomass powered boiler. (Source: Turboden S.r.l.)

Direct co-combustion with coal in a 50 MW_e plant in northern Spain using Technology Atmospheric Fluidized Bed Combustion (AFBC), at a thermal efficiency of 82.59 %, uses 59.8 % rejected coal, 35.3 % coal, and 4.9% wood biomass. The absorbent material is limestone (95.5 % CaCO₃). Fuel consumption is around 64 t/hour and absorbent consumption 5 t/hour. Woody residual biomass and energy crops represent advantages at the plant site in terms of forest valuation, CO₂ emission reduction and increased local employment.

Energy and greenhouse gas balances

The utilisation of biomass for energy must comply with environmental sustainability criteria and each step of the production, conversion and utilisation process has to be evaluated in order to assess accurately the energy and emission contributions. In the table 6 the resulting CO₂ emissions for the production of one TJ in the entire cycle for different fuels is reported. The

Table 6. CO₂ emissions from wood biomass fuel compared with fossil fuels according to Italian data.

CO ₂ Emissions (kg/Tj of usable energy)	Woody biomass	Diesel fuel	Natural gas
Emissions due to combustion	150000	78700	57700
Emissions due to the procurement of fuels	-148000	11900	7900
Indirect emissions related to the construction and management of the plant	1460	1370	771
Total	3460	91970	66371

Table 7. Poplar crop energy balance (AGROSOST project 2004 – 2007. UAB, ARU, CIEMAT, Spain)

Type of energy	MJ produced	MJ consumed
Direct energy stored in biomass	18200	368
Calorific energy production (85%)	15470	
Electric energy production (27%)	4910	

(*) Main energy consumption stages include agrochemical production (42%); transport (39%)

impact of woody fuels is markedly lower in comparison with diesel fuel and natural gas.

Experiments in northern Spain with poplar SRF indicate very positive energy balances as seen in the table 7.

The energy inputs are estimated at between 2% and 7% of the energy produced.

The use of mineral fertilisers and herbicides (production and application) are the most critical environmental costs for the system, representing 40% to 96% of the total environmental impact of the categories analysed.

The utilisation of solid biomass in a large power plant for the production of electrical energy demands the use of filters for near complete reduction in emission of fine particles. Italian technical regulations clearly define strict emission limits and filter technologies are well developed from a technical point of view and are economically viable.

Markets and economics of production

In Italy there are currently two markets for biomass from SRF poplar plantations:

- Biomass power plants and small to medium sized CHP/district heating
- Industry for panel production and timber for furniture

There are around five operating biomass plants in northern and central Italy that accept woodchips from SRF (almost 60 MW_e installed capacity). For the near future some important

operators have expressed interest in supplying biomass power plants with woodchips from SRF plantations. In particular:

- ENEL: the largest national energy company and electricity provider plans to introduce co-firing with biomass from SRF in four of its coal plants;
- POWERCROP: a company of the Eridania-Sadam Group (sugar industry) plans to commission 4 biomass power plants by 2011 after decommissioning sugar plants following sugar policy reforms.

SOME FIGURES for Italy:

- Average fuelwood price: 40-50 €/t biomass delivered to plant gate (40 % moisture)
- Average price paid to farmers for standing trees: 18-20 €/t fresh biomass (harvesting and transportation costs excluded, paid by buyer)
- Average revenues for 35 t fresh biomass/ha: 630-700 €/ha per year
- Average annual plantation costs (including plantation establishment): 350-500 €/ha per year
- Grants from Rural Development Program available for initial establishment of plantation (around 40 % of direct costs)

There is not a clearly established Spanish market as energy crop production is still at an early stage. Some important Spanish companies have shown interest in using woody biomass from SRF plantations alone or mixed with other fuels:

- ACCIONA: a large national energy company, electricity producer, owner of an emblematic 25 MW_e biomass power plant fed with cereal straw.
- VALORIZA: an important energy company, electricity producer, owner of some electricity biomass plants using olive oil waste and poplar in the near future.
- HUNOSA: a coal company that plans to implement co-combustion of coal-wood biomass, including willow.
- ENCE: big pulp and paper company involved in Biomass plants at Peninsula Iberica and in Latin America.

Due to the lack of historical data at country level, a regional location in the south of Spain has been selected as example. Other territories might produce different data. Some estimated figures are provided:

- Average fuelwood price 40 – 50 €/t fresh biomass on site.
- Cuttings 0.12 – 0.15 €/unit.
- Maintenance cost 560 – 570 €/ha/year mainly for fertiliser and irrigation.
- Planting mechanised 0.1 €/plot and manual 0.14 €/plot.

National laws and incentive programmes

In Italy support measures dedicated to renewable energy and bioenergy projects are in force, although several uncertainties due to the evolution of the current legal framework have slowed down the development of long-term and large-scale projects. This section will give an overview of the existing measures in Italy.

● *Measures of the Rural Development Program 2007-2013*

As in other EU member states, in Italy EC regulations are applied through the implementation of regional development plans produced by each regional authority in compliance and coordination with a National Strategic Plan. The measures contained in the programmes are basically addressed to farmers and local authorities of rural areas.

The incentives are usually allowed in the form of grants that may cover 35 to 55 % of the initial investment costs for the setup of bioenergy projects, such as small-scale heating application in rural buildings, district heating, co-generation with biomass and



The Italian company Spapperi has developed harvest technology for small and medium scale poplar plantations. The trees are first cut down (on the left) and subsequently are chipped and blown into a transport trailer (on the right). (Photo: L. Corbella & M. Cocchi, ETA)

pure vegetable oil or anaerobic digestion. In most regional plans, grants are allowed also for the establishment of permanent plantations of energy crops such as SRF of poplar or other species, as well as for buying harvesters and other machinery or equipment.

- **Measures of the Regional Operative Programmes**

The European Regional Development Fund (ERDF) established according to Reg. EC 1783/99 is another EC structural fund aimed at increased social and economic cohesion among the different European regions.

- **National measures and incentives for green electricity**

The Italian legislation for incentives for green electricity is evolving. As far as

the electricity produced from biomass is concerned, two distinct schemes operate at present:

The standard Green Certificate scheme

As for all other renewable energy systems (excluding PV that has a special support regime), the production of electricity from biomass (solid biomass, biogas or pure vegetable oil) is eligible for a green certificate, in addition to the sale of the electricity itself to the grid, which can be exchanged on the market or delivered at a fixed price to the GSE (the national manager of electric services) that acts as a national “clearing house”. In this case, the Financial Law of 2008 introduced an additional 10 % price premium over the value of the green certificates that is awarded exclusively for electricity produced from biomass.



The GasEK small scale CHP-plant is a brand new Finnish innovation, which can gasify wood chips of under 40% moisture content. Total output of the plant is 90 or 150 kW, which includes about 33% electricity. (Photo: Timo Lötjönen, MTT)

Incentive tariff scheme

- For small-scale biomass units with a nominal capacity up to 1 MWe, it is possible to obtain a single incentive tariff of 0.22 €/kWh (that substitutes for green certificates and the standard tariffs for the sale of traditionally produced electricity).
- Furthermore, in the case of smaller systems than 200 kW_e (i.e. small-scale vegetable oil, CHP or biogas plants), it is possible to adopt the “net metering” scheme, with which the producer price for the green electricity fed into the grid is the same as the consumer price. The advantage of this system is mainly for energy users who want to produce electricity for their own needs. If the electricity produced is equal to the electricity used it is possible to achieve zero energy costs.

- Tax deductions for private users and small-scale biomass applications

The Financial Law of 2007 established the possibility for private non-commercial users to obtain a tax deduction up to 55 % of the initial costs paid for energy efficiency and “advanced” technology applications in buildings. In this context the substitution of traditional fossil fuel boilers with biomass boilers attracts this incentive, provided that the technologies adopted are compliant with the minimum energy efficiency requirements, that is:

- Compliance with class 3 of the EN 303-5 norm for boilers less than 300 kW;
- Minimum 82 % efficiency rate for boilers larger than 300 kW

In Italy no specific incentive schemes are in force for energy production based on the utilisation of biomass from energy crops.



*Poplar woodchips are travelling to power plant.
(Photo: L. Corbella & M. Cocchi, ETA)*

Table 8. Legislation and support systems for bioenergy in Spain.

SUMMARY REFERRED TO BIOMASS						
LEGISLATION	Group	Subgroup	Power	Period	Regulated Tariff cent/kWh	Market Reference Prime cent/kWh High limit cent/kWh Low limit cent/kWh
RD 661/2007 published on May 2007 and corrected on December 2007	b.6	b.6.1 Energy crops	P≤2MW 2MW≤ P	First 15 years Since then First 15 years Since then	16.96 12.59 15.65 13.18	12.79 0.00 11.26 0.00 17.76 16.45 15.24
Law 24/2001, December 27th, Fiscal, administrative and social measures	The current norm for corporation tax establishes a 10 % deduction for activities aimed at environmental protection. According to this, the investments made in new material assets destined for use as renewable energy sources, due to contributions to the reduction of the contaminant emissions, have the right to claim for a 10 % deduction cost in the cost quota itself. This deduction is only applicable in the use of renewable energy sources which consist of equipment and facilities destined for the following: Using biomass as a combustible coming from waste of agricultural and woody factories and energy crops for transforming in gas or electricity					
National Energy program (PROFIT 2008 – 2012)	Grants for projects or actions that contribute to reduce the environmental impact of energy generation by the development of more efficient and less contaminant systems. The classification of the renewable energy projects included in this document are the following ones: <ul style="list-style-type: none"> ● Project or technological action individual ● Project or technological action in cooperation with research industrial projects 					
Lines of credit ICO-IDEA for energy efficiency and renewable energy projects	Investments projects on new active material goods destined to use renewable energy sources, like the thermal use of biomass in buildings, the energy efficiency improvement, the facilities, equipments and the needed expenditures to run them (engineering, insurance, transport and so on) can apply for the financial line. The highest bankable amount is 100 % of the investment net project with a maximum of 1,5 M € (VAT non included).					
Subsidies from Autonomous region and Local Institutions	Each one or two years every Regional Community publishes a subsidy line for renewable energy installations. One of these is for example, the thermal application of biomass, specially, its application in buildings. The amount of this subsidies ranges between 10 % and 50 % of the total investment.					
R.E.C.S Certificate	Public supports rates per tonne of CO ₂ avoided					

Good case examples

Municipality of Apiro: Italian medium-scale district heating and CHP plant

The “Clean Energy Project” was introduced by the municipality of Apiro, (a small town in Central Italy with a population of 2,500), with the aim of promoting the adoption of innovative and sustainable land management and the production of renewable energy in the municipality. The project is based on the implementation of a CHP plant that supplies district heating to five large buildings owned by the municipality (the city hall, two schools, a theatre and a hospice) and that will eventually be extended to supply heat to private residential and commercial buildings.

The district heating scheme was inaugurated on March 31 2008, but the CHP unit will be installed in the future. All public buildings are already served by the district heating, whereas the connection of the residential blocks close to the plant will be made in the forthcoming months. The heat generator is a 1.44 MW boiler equipped with a moving grid in the combustion chamber that will allow combustion of several feedstocks with different moisture and ash contents.

The supply of woody biomass is partly provided through establishment of a short rotation poplar plantation of 122 hectares in a nearby farm owned by the municipality. The farm is situated 4km from the plant and has two depots with covered rooves for safe storage and drying of woodchips, located 0.5 km from the plantation. In 2007 ten hectares of SRF poplar were already established and will be harvested in 2009, but the target is to scale up production to 60 hectares of SRF, and include fibre sorghum for energy use and traditional crops (cereals, legumes etc.).

Valoriza Energy Plant (10MW_e) at Puente Genil, Spain

The complex is dedicated to energy recovery from the olive industry, other Mediterranean biomass crops and poplar energy crops. Logging wastes, chipped at their origin, are transported to the plant where they are stored in large piles. The olive oil waste is also stored in piles after drying. The ideal collection radius is 30 km, although it could be extended to 100 km depending on olive oil waste availability.

The main objective of the plant is to accommodate all available agricultural biomass, find an intelligent solution for generating electricity and to improve rural economies. The plant is able to use different types of biomass because the fuel supply system is double entry. There is a continuous supply of biomass of 45,000 t/year in the area, which is mainly olive oil waste at 10 % moisture content.

Location advantages:

- Areas supporting high growth biomass.
- Possibility energy crops include sorghum and poplar.
- Proximity to other biomass production from forest residues.
- Electricity lines of 132 kV and 66 kV.
- Irrigation and natural gas available: gas pipeline.
- Good communication and distant from urban centres.
- Zone of the largest area of olive trees in the world (> 50 %).
- Large number of highly efficient irrigated olive groves (<1500 m³ water / ha).

The objective of the industrial process is the integral use of a waste from initial pressing of olive oil spinning mass, which is generated



VALORIZA's plant in Puente Genil, Spain. (Photo: ESCAN)

in large quantities at the mills (almazaras) and recently became an environmental problem with serious consequences for water discharge into rivers (Alpechín).

The electrical plant includes biomass boilers and a steam turbo-generator of 10 MW_e. The combustion system is based on a mobile oscillating grate, which is moved by a hydraulic system of spreaders that feed the biomass in suspension allowing uniform combustion by only permitting the larger/moist particles to be burned on the grate.

There are continuous monitoring systems for emissions of particles, CO and O₂, and advanced technology allows hourly and annual levels to be monitored as required.

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5 Biogas from crops in Austria and Germany

Wolfgang Gabauer &
Dominik Dörrie

The production of biogas from energy crops as well as from bio-waste or municipal waste is very popular in Austria, Denmark, Germany and Italy. In recent years the increase in number of biogas plants was 20 to 30 percent per year and led to considerable establishment of national biogas markets in those countries. Nowadays, the era of biogas pioneers is over and high-end biogas technology is generally used. National markets for biogas play an important and independent part in the fast-growing renewable energy industry. Numerous experienced and specialised manufacturing companies are working in the field and use modern technologies. Many scientists conduct intensive research on the whole biogas cycle to improve the technology further.

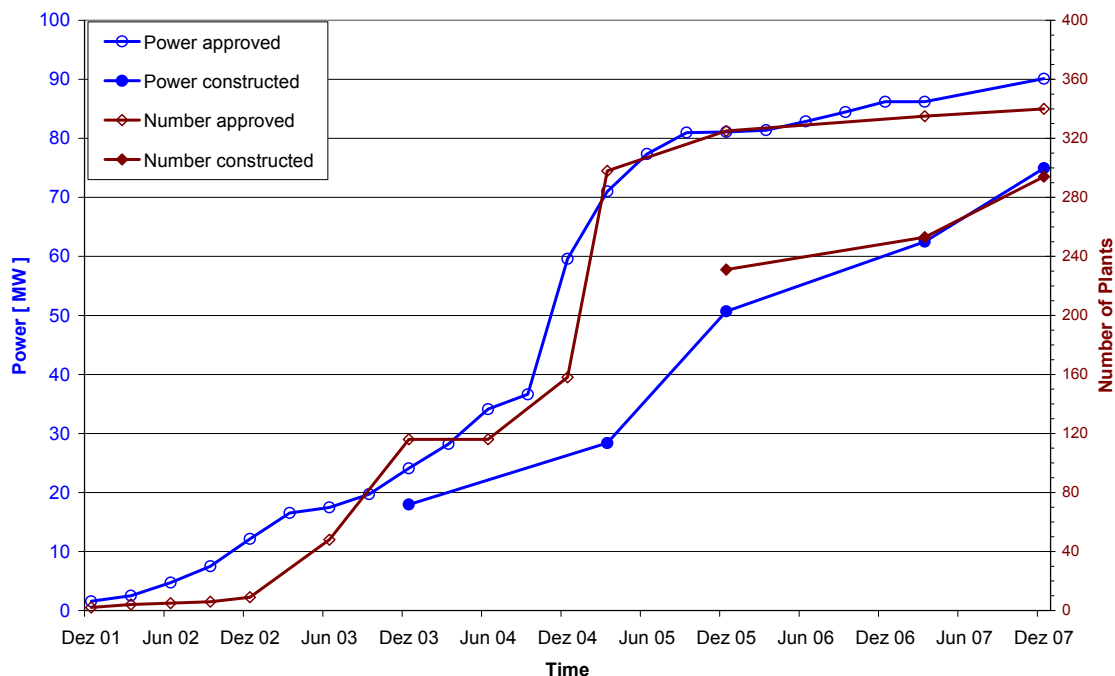
Biogas is most commonly used in combined heat and power units (CHP). Currently small biogas grids or biogas upgrades to bio-methane

represent the latest developments and represent new markets for biogas. Bio-methane is either fed into natural gas grids or used as vehicle fuel.

Experience shows that successful biogas plant operators, farmers and investors must have specialised knowledge on biogas production. This part of our publication provides an overview of biogas production.

Current production and potential in the near future in Austria and Germany

The enclosed figure shows the development of constructed and approved biogas and electricity power plants from 2001 to 2008 in Austria.



Development of biogas production in Austria (source: Ökostrombericht 2007)

In Austria the implementation of the green electricity law in 2002, with favourable buy-back rates for biogas electricity fed into the grid, has led to a marked boom in the construction of agricultural biogas plants. The number of approved biogas plants significantly increased from 9 in December 2002 to 325 in December 2005. Up to this date a total of 231 biogas plants with installed electric power generation of 50.67 MW were constructed.

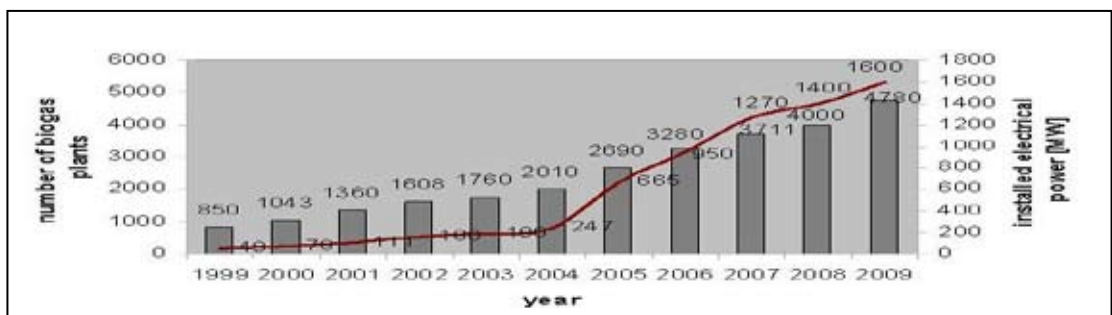
After 2005 the approval of new biogas plants stagnated in Austria. The reason for this was a new green electricity law introduced in 2006. The government limited support for new biogas plants to 5.1 M€ per year and the period for the guaranteed feed-in tariff was reduced. Today in Austria there are 340 approved (294 constructed) biogas plants with an approved power of 90 MW (75 MW currently operating). In 2007 the Austrian biogas plants produced 440 GWh of electricity.

In 2010 there will be a significant surplus of biomass on 26.2 % of the grassland in Austria. On 10.6 % of grassland will be a massive surplus and on 15.6 % will be an extreme massive surplus of biomass. A big advantage is that these areas do not compete with the food industry. The methane potential of this biomass ranges between 365 and 615 million m³ per year. This is equivalent to thermal power of 336 to 564 MW or 140 to 240 MW electrical power. As mentioned above, the current electrical power from all constructed biogas plants is 75 MW, so there is the potential to double or triple biogas production capacity.

The “Institut für Energetik und Umwelt” in Leipzig has investigated how much biogas can be fed into the natural gas pipeline in Austria. The study shows that between 1.7% and 6.7% of Austrian natural gas consumption can be substituted by biogas.

In Germany biogas technology and research are still regarded as being at an early stage of development since most of the biogas plants were built in recent years and depend on issues including public support and the price levels for food production. The total number of farm-based biogas plants increased from a few in the early 1980s up to about 4,000 with a capacity of about 1,400 MW. This has been mainly due to implementation of a national law that gives priority to the feed-in of electricity produced from renewable energy sources, with a focus on efficiency, ecology and emission reduction. As a result of public support, the share of energy crop utilisation markedly increased in Germany. With a revised support scheme in 2009, the contribution of manure is recovering. In addition, new biogas grid feed-in regulations have been in place since March 2008 and provide new incentives for on-farm biogas plants and waste treatment. This all contributes to reaching the German Government aim of 10 % biogas in the natural gas grid by 2030.

In addition, with other various biogas sources including organic waste from refuse tips (landfill gas) and communal waste water (sewage gas), the overall total potential for biogas production in Germany is estimated to be about 24 billion m³ per year. The corresponding energy



Development of the biogas production in Germany (source: BMU)

production would be 50 million MWh of electricity and heat. In terms of energy source potential, there should be 417 petajoules (PJ/a) available, representing 3 % of the total primary energy consumption of 13,878 PJ in Germany in 2007. The largest contribution, of about 85%, of potential biogas production comes from the agricultural sector.

Sustainable energy crop cultivation

The more energy crops are cultivated and needed for biogas production, the more important sustainable production becomes. Sustainability means a balanced economy and environment, i.e. cultivation of energy crops should yield a quantity of biomass that nature can cope with. Furthermore, social impacts like better working conditions, new income earning opportunities and a more value-added farm products have to be borne in mind. Biogas can be a good opportunity to protect and improve natural resources and the environment.

However, most biogas plants currently only produce electricity for feeding into the national grid because it has been profitable. The surplus heat is often not utilised. From a sustainability point of view, using only electricity from biogas and receiving compensation through a feed-in tariff is not efficient enough. Energy crop cultivation and utilisation only makes sense if the generated electricity and heat are used efficiently (e.g. combined heat and power). Experience shows that if there are no extra benefits through selling or using the surplus heat, the biogas plant owner has to struggle with short-term volatile and long-term rising production costs. Biogas plants are mainly decentralised and small-scale. In general, there are various opportunities for

using the surplus heat and thereby improving sustainability, but this requires precise preliminary planning and particular knowledge of the available techniques.

However, there are even more aspects that have to be considered for improved sustainable biogas production from energy crops, for instance that they should only constitute a fraction of a particular farm's production. According to experience, a maximum of 30%, in terms of land use, is the most sustainable area for energy crop cultivation and utilisation. Furthermore, diverse energy crops and newly-bred varieties can be used in crop rotations. New production techniques are a further option to reduce use of commercial pesticides and fertilisers that consume substantial amounts of energy during production. Biogas can be used as a regional policy instrument. Rural areas are often structurally disadvantaged, but biogas keeps the money in the region and generates new income. As a result, energy crops as a renewable energy source make such regions more independent as well as encouraging green energy production and reducing costs incurred through buying fossil fuels.



*In the center box for drying wood chips; on the right - facility for drying hay.
(photo: IEA Tulln, Gabauer)*

Harvesting and logistics of biogas energy crops

Four main technical processes can be discerned in the logistics of energy crop production, from harvest to spreading the digestate/manure:

Harvest

The picture shows the harvest of maize (whole crop) with a CLAAS self-propelled chopper. Afterwards the crop is transported with tractors and trailers to the silage clamp.

Grass, for example, is cut with a rotary mower and transported with self-loading trailers to the clamp.



Ensiling

Ensiling is a process used to conserve a crop. Fresh energy crops are available only during a short period. However, the supply of substrate is required to be continuous for generation of bioenergy.

This is wet storage under anaerobic conditions and heavy machines (e.g. wheel loader) are used to compress the energy crops to remove trapped air.



Feeding the digester

The picture shows the process of filling the feed-in unit with energy crops. This container is usually filled once a day with silage. The digester is fed automatically and at regular intervals with the substrate from this container.



Spreading out the digestate

At the end of biogas production the fermentation end-product (digestate) is spread out on agricultural areas.

Usually the digestate is carried with slurry tankers or pumped with long, flexible tubes to the fields.



(Photos: IFA-Tulln)

Energy production technologies

The following figure shows the scheme for the biogas plant in the village of Strem in Austria.

Substrate handling

The scheme above shows a biogas plant, which exceptionally uses green lignocellulosic such as maize, grass or sunflower material as a substrate. The storage of the substrate (in the form of silage) has to be done skilfully in order to avoid energy losses. Research showed that with a plastic cover, the mass losses reach 17%. If the substrate is inadequately covered with the dry digestate the mass losses can reach 30%. The silage/substrate is taken from the silo with a loader to the feed-in unit for solid substances. From this feed-in unit the digesters are regularly fed.

Digester

A digester is a container made of concrete or steel where the fermentation takes place. There are several types of digester currently in use. There are three main groups of reactors: batch reactors and one or two-stage continuously fed reactors. Two systems are established, fully stirred reactors and plug flow reactors. The plug flow reactor is a horizontal digester where the average retention time of the substrate is guaranteed. Digesters are also divided into “wet” and “dry” fermentation types. “Wet”

reactors operate with total solids of about 16 % and the “dry digestion” takes places with 22 % to 40 % solids.

Storage tank

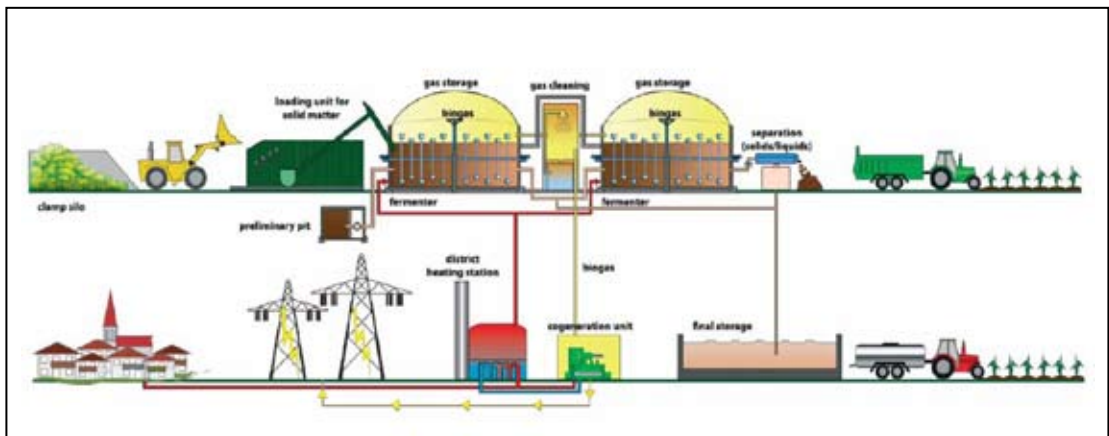
This is the final container where the digestate is collected. At the biogas plant in Strem (see scheme below) the digestate is divided into a liquid and a solid fraction. In Austria the digestate is used as fertiliser and spread on to the fields and meadows twice a year (spring and autumn). So the volume has to be large enough to store the digestate for approximately 180 days.

Gas storage

Biogas production fluctuates and so gas must be stored to feed the gas engine continuously. The gas storage volume should represent at least ½ day to 1 day. Within this period revisions of the gas utilisation unit should be finished. Overproduced biogas has to be burnt with a flare.

Combined heat and power unit

The most common use of biogas in Austria at the moment is to produce electricity in a combined heat and power plant (CHP). An important criterion for the overall efficiency of the biogas plant is use of the surplus heat produced. The surplus heat at the biogas plant in Strem is fed into the local district-heating pipeline.



Scheme for the biogas plant in Strem (picture: www.thoeni.com)

Energy and greenhouse gas balances

One of the most important issues for sustainability in biogas production is the amount of primary energy used in the energy conversion process and the emission of greenhouse gases (GHG). Primary energy is required during plant production for ploughing, sowing, production of fertiliser and pesticide, harvest and transport. Further primary energy inputs are needed for pre-treatment and processing of the plant material, for the fermentation, the recovery and purification of products and by-products.

If biogas is upgraded to bio-methane, more energy will be required compared with the common use of biogas in a CHP plant. Apart from the amount of primary energy required, the source of the process energy is especially important for sustainability. In bio-ethanol production for example, a considerable amount of the energy can be provided using renewable energy, e.g. anaerobic digestion of stillage. The energy input for the cultivation of perennial crops like miscanthus and willow is significantly lower than for annual crops like maize (table 9).

GHG emissions occur during the whole production chain, i.e. cultivation and harvest

of the biomass, transport, the conversion process and through the use of the products. Emissions vary according to the raw materials used for fermentation. If energy crops like maize or sugar beet are used, N_2O -emissions from fertilisation have a negative impact on a life cycle analysis (LCA).

Further emissions are produced (e.g. NH_3) if organic waste is used as a substrate in anaerobic digestion. Incomplete substrate degradation during fermentation can often cause additional GHG emissions (e.g. CH_4) from the uncovered storage tank. Moreover, incomplete combustion of methane in CHP plants can contribute to GHG emissions.

Because of the use of renewable resources, the utilisation of biogas reduces GHG emissions. However, there are many steps in the process chain where GHG (CO_2 , CH_4 , N_2O , NH_3 ,...) can be emitted. The overall positive GHG balance is reduced significantly by major emissions of the mentioned gases.

Markets and economics of production

The main economic question concerns how might biogas as a renewable energy source become cost-efficient? Since a national compensation fee exists in Germany, there

Table 9. Overview of energy efficiency in biogas production using different substrates (Uellendahl et al. 2008)

Substrate	Fermentation process	Energy output / input
Maize	Biogas fermentation (no pre-treatment)	7.2 – 9.5
Maize	Biogas fermentation (with wet oxidation pre-treatment)	6.8 – 8.9
Miscanthus	Biogas fermentation (no pre-treatment)	6.9 – 7.8
Miscanthus	Biogas fermentation (with wet oxidation pre-treatment)	11.6 – 13.1
Willow	Biogas fermentation (no pre-treatment)	7.3
Willow	Biogas fermentation (with wet oxidation pre-treatment)	12.3

is fixed income for selling electricity over 20 years depending on the year of installation. The current compensation for 2009 ranges from 11.67 cent/kWh to a maximum of about 25 cent/kWh in Germany, with a similar compensation fee in Austria. Although the price of the surplus heat varies, it strongly depends on the market price for replaced energy sources. Hence, for the first 20 years, the operator only has to take care of the costs of producing biogas for the plant to be profitable. Simple feasibility studies of biogas plants consider investment costs over the average useful life of the plant (writing off, rate of interest) and annual operating costs (substrates, repairs, maintenance, or work input).

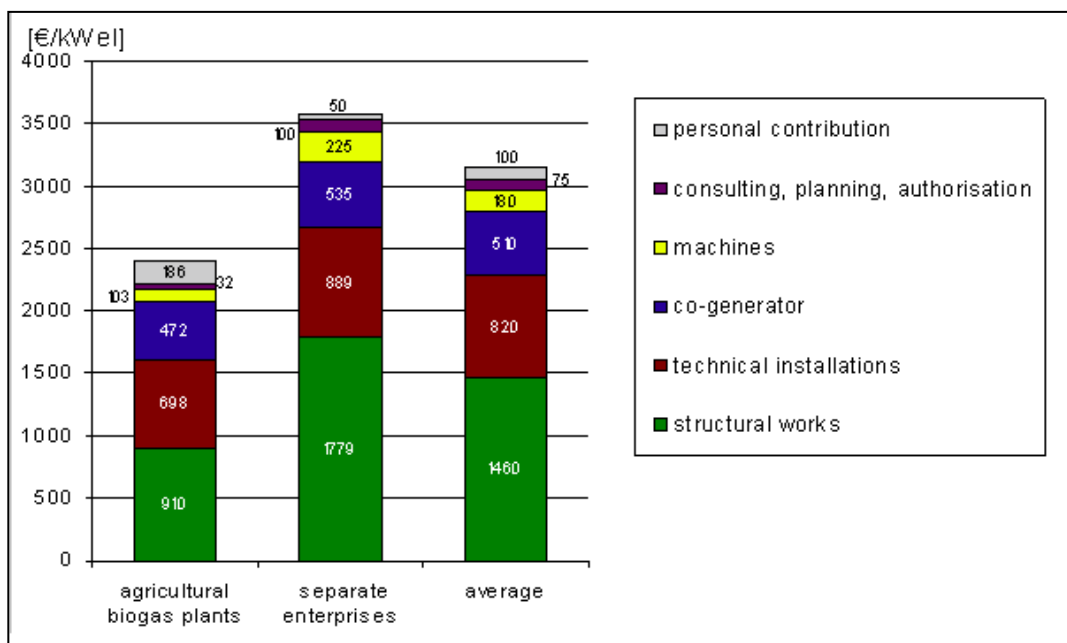
In general, investments for biogas plants using energy crops and liquid manure vary between 3,000 to 5,000 €/kW installed electrical capacity. In the agricultural sector, biogas plants cost much less on average due in part to the larger amount of the farmer's own personal contribution, as the following figure shows. Only larger industrial biogas plants with higher capacity could reach the same average price of about 2,500 €/kW_{el}, realising economies of scale.

The profitability of biogas plants is increased through low investment costs and reduced running costs, but requires to be well designed for the specific local conditions. If possible, public investment subsidies or substantial commitment of one's own labour helps to reduce the investment costs. Since substrates can represent more than half of the operating costs, operators look for opportunities lowering logistics, cultivation and harvesting costs. Other high running costs are those for maintenance, especially for CHP units. If possible, one should use additional existing biowaste material and manure. With rising prices for fossil fuels, the aim should be at a high degree of efficiency.

National laws and incentives programmes

AUSTRIA – Green Electricity Law for biogas plants

In Austria the production and feeding-in of renewable electricity is regulated by the Green Electricity Law. Fixed feed-in tariffs over a defined period guarantee the income for



Agricultural biogas plants require lower investments (Source LFL, GERBIO)

producers of green electricity. Favourable buy-back rates for biogas electricity fed into the grid have led to a marked boom in the construction of agricultural biogas plants using energy crops as a substrate.

The rate of the feed-in tariff depends on the installed electric power of the biogas plant. The higher the installed electric power, the lower the tariff for feeding-in green electricity to the public grid.

According to the Green Electricity Law from 2007, a fixed feed-in tariff of between 11.30 cent/kWh (electricity power more than 1,000 kW) and 16.95 cent/kWh (el. power up to 100 kW) is guaranteed over 10 years. In year 11 the plant owner gets 75 % of the feed-in tariff and in year 12, 50 % of the tariff. From the 13th year of commissioning the plant owners get the market price for the electricity produced.

Due to high substrate costs for energy crops, the Austrian plant owners got an additional commodity bonus of 4 cent/kWh in 2008. The government aid for new biogas plants is

limited to 5.1 M€ per annum. To get this aid it is necessary to produce a plan for using the heat produced. The minimum heat use has to be more than 60 %.

The table 10 shows feed-in tariffs depending on the electricity power of the biogas plant. The Green Electricity Law was modified since that introduced in 2002.

GERMANY – renewable energy law for biogas plants

The German Renewable Energy Source Act (Erneuerbare Energien Gesetz, EEG) ensures a fixed compensation fee over 20 years depending on the year of installation (table 11). With an amendment to this law, a biogas boom started around 2004 in Germany. At this time the national public guarantee was sufficient that increasing numbers of people invested in biogas technology. In addition, food prices reached a historic low around that time. This was caused by large surplus production from intensive cultivation and a single world market for food. Small margins in the food sector and

Table 10. Feed-in tariffs of the modified Green Electricity Law within the last years in Austria

Electric power	BGBI II 508/2002 2002-2004 (cent/kWh)	BGBI II 401/2006 2006 (cent/kWh)	BGBI II 401/2007 2007 (cent/kWh)
=100 kW	16.50	17.00	16.95
>100 - 250 kW	14.50	15.20	15.15
>250 - 500 kW	12.50	14.10	14.00
>500 kW - 1MW	12.50	12.60	12.40
>1 MW	10.30	11.50	11.30
landfill gas	6.00	4.10	4.05
gas WWTP	3.00	6.00	5.95
min. utilisation		60 %	60 %
co-substrates	-25 %	-30 %	-30 %
limit		30 % of 17 M€/a	30 % of 17 M€/a
guarantee	13 year	10 years year 11: 75 % year 12: 50 %	10 years year 11: 75 % year 12: 50 %

considerable public support with the German EEG led to a massive increase in biogas production from energy crops. There were up to 800 new installations in 2006.

With an increase in crop failures farmers could get higher revenue in the food sector for agricultural products, but an all-time high oil price had a huge direct impact on the costs of agricultural production. In this situation, selling biogas was getting less attractive for German farmers due to higher production costs for energy crops. Many people changed their plans and new installations decreased substantially to 200 in 2007. Year 2008 was characterised

by the preparation of an EEG amendment for 2009. The new renewable energy law of 2009 takes changing agricultural conditions into account and offers a higher compensation, especially for small-scale biogas plants and for using energy crops. With its coming into force, the EEG for 2009 should support a struggling biogas industry and boost investments in this new technology in Germany. As a result, energy crop cultivation and utilisation only takes place if there is enough financial incentive, which in the German case does not come from taxpayers' money, but from a levy every electricity consumer has to pay.

Table 11. Comparison of feed-in tariffs for the modified renewable energy law in Germany

Electric power based on the compensation in 2009	compensation EEG 2004 (Cent/kWh)	compensation EEG 2009 (Cent/kWh)	difference between EEG in force (2009) and former EEG (2004)
Basic compensation			
for the first 150 kW	10.67	11.67	+ 1.0
between 150 - 500 kW	9.18	9.18	0
between 500 kW - 5 MW	8.25	8.25	0
between 5 MW - 20 MW	7.79	7.79	0
Decrease per year	1.50 %	1.00 %	
Bonus compensation for using			
energy crops	4.0 – 6.0	4.0 – 7.0	+ / + 1.0
manure	0	1.0 – 4.0	+ 1.0 / + 4.0
landscape preservation	0	2.0	+ 2.0
innovative technology	0 – 2.0	1.0 – 2.0	+ 0 / + 1.0 / + 2.0
combined heat and power	2.0	3.0	+ 1.0
less emissions (clean air)	0	1.0	+ 1.0
Decrease per year	0	1.00 %	

Good case examples

AUSTRIA – Biogas production from green material in South Burgenland

Because of heavy structural upheavals, numerous farmers in the village of Strem had to reorganise their farms from fulltime to a sideline operations. As a consequence of this reorganisation there was a surplus of unused grassland. This was the reason why a group of farmers planned a biogas plant using technology for fermentation of green materials.

Since 2003 Strem has had a biomass heating plant with an integrated local heating grid – a good starting position for reasonable economic installation of a biogas plant. In 2003 Öko Energie Strem, together with the Institute for Agrobiotechnology (IFA, University of Natural Resources and Applied Life Sciences), as a new member of the national research network RENET, started to plan the innovative biogas plant.

Solid fermentation of clover, corn and whole crop silage at 49.5 °C is taking place in two thermally insulated silos made of ferro-concrete with a capacity of 1,500 cubic metres each. The biogas produced is supplied to two heat and power units situated in the power supply centre of the existing biomass heating plant.

The plant, which started operations in 2004, currently operates for 8,500 hours a year and has a capacity of 526 kW of electric power

and 600 kW heat for district heating. 1,200 households are supplied with electricity and 40 households are supplied with heat all year round.

Investment costs:	2,096,000 €
Electric power:	500 kW (station supply 25 kW)
Thermal output:	600 kW (station supply 90 kW)
Economical Life:	20 years
Feed-in tariff electrical:	14.50 cent/kWh
Tariff for heat sale:	2.18 cent/kWh
Commodity price:	2.20 cent/kWh

The key factor for the success of this project was the consortium with strong people and the closeness to Güssing, which is famous for “energy self-sufficiency”. Later the existing biomass district heating company needed additional heat for the whole year and farmers of Strem were offered a further source of income.

GERMANY

There are several good examples in Germany listed on the project's websites www.encrop.net or www.gerbio.eu .



Biogas plant with digester 1, digester 2 and final storage of the digestate (Photo: Resch)

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www.thoeni.com/2006

Further sources and information about biogas available from:

Austria:

- BOKU - Universität für Bodenkultur Wien (Austria), Department for Agrobiotechnology, IFA-Tulln, Environmental Biotechnology
 - www.boku.ac.at
 - www.ifa-tulln.ac.at

Germany:

- GERBIO - German Society for sustainable Biogas and Bioenergy Utilization (Germany)
 - www.gerbio.eu
- Fachagentur Nachwachsende Rohstoffe e.V. (FNR)
Agency for Renewable Resources e.V. (FNR)
 - www.bio-energie.de
- Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV)
Federal Ministry of Food, Agriculture and Consumer Protection (BMELV)
 - www.bmelv.de
- Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)
Federal Ministry for the Environment, Nature Protection and Reactor Security (BMU)
 - www.erneuerbare-energien.de
- Johann Heinrich von Thünen-Institut (vTI)
Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI)
 - www.vti.bund.de
- Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (KTBL)
Association for Technology and Structures in Agriculture (KTBL)
 - www.ktbl.de
- Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V. (ATB)

**Leibniz Institute for Agricultural
Engineering Potsdam-Bornim e.V.
(ATB)**

o www.atb-potsdam.de

- Fachverband Biogas e.V.

German Biogas Association e.V.

o www.biogas.org

- Deutsches BiomasseForschungsZentrum
gGmbH (DBFZ)

**German Biomass Research Centre
gGmbH (DBFZ)**

o www.dbfz.de

- **University of Hohenheim, Stuttgart**

o www.uni-hohenheim.de/
LABioenergie



*Sunset at the biogas plant in the village of Strem (Austria, Burgenland).
(photo: IFA Tulln, Resch)*

6 Conclusions

As this text shows, all field energy crop options presented here can work well in practice. Because input chains are at reasonable level and conversion technologies are based on CHP technology, energy efficiency and greenhouse gas balances for these chains are favourable. The potential of most energy crops is substantial so that the target of the year 2020 should be possible to match with other renewable energy sources. But in most cases the energy production is not profitable given current price levels, unless the production chains are supported economically. Another possibility is to raise bioenergy prices to cover production costs.

Different countries have found different ways to promote and support energy production from field crops. For example, Finland has higher agricultural subsidies for reed canary grass (RCG) cultivation than other countries, but utilisation of RCG is not supported. The RCG area originally increased to nearly 20,000 ha, but it has not increased much during recent years. Farmers are clearly waiting for a better price for RCG. A feed-in tariff for RCG electricity represents one solution.

Wood energy crops like willow and poplar are well developed in countries such as Italy, Sweden, the U.K and Poland. These crops are used for direct combustion in biomass plants. Ongoing research has achieved good results in adapting processes to different local climatic and agricultural conditions. New highly productive, pest resistant poplar clones have been selected by research institutes and plant breeders in Italy and are now being used for the new plantations.

Thanks to the advances in mechanisation, harvesting and logistics, the technologies used for short-rotation plantations have now reached full technological maturity and are ready to be

commercialised. Structural funds for farmers are available in Italy and other European countries to support the expansion of this sector through provision of partial grants for the initial establishment of plantations. In addition, many countries such as Sweden, Italy and Spain also introduced special feed-in incentive tariffs for renewable electricity produced from biomass.

Despite these incentives the cultivated areas of such energy crops have not grown very rapidly during recent times. In many cases this is due to the unattractive prices offered by plant managers to farmers for the energy crops produced. Possible solutions for this are an increased level of reuse of waste heat in combined heat and power plants, the promotion of local small to medium-scale supply chains for district heating and CHP to reduce transportation costs. In this way the higher revenues of the plant could be partly used to reward the farmers with higher feedstock prices.

Biogas from field crops has been a success story in Germany and Austria because production has been profitable for farmers, for contractors and for plant operators. The farmers are receiving nearly the same agricultural subsidies as for cultivating grass, clover or maize when they opt for biogas production cultivating other crops. Because there has been investment support for biogas plants and high feed-in-tariffs for biogas electricity, the plant operators have been able to pay an adequate substrate price to the farmers. Furthermore, feed-in tariffs have been even higher for field crops than for manure or other wastes. For these reasons, biogas production from crops has increased rapidly, but does not threaten food production in these countries.

It is clear that field crops, together with crop residues (e.g. straw), represent a huge energy potential and possibilities for increased

employment. Different studies show that sustainable bioenergy crop area could be reach 10 – 30 % of total field area in the EU, and possibly even worldwide. For this to be realised, production chains of energy crops need to be developed and farmers, energy producers and decision makers have to be informed about the possibilities for energy crops. Foremost, however, is a requirement that all parts of energy crop chains receive adequate economic compensation, as the good examples from Germany and Austria have demonstrated.



*Utilisation of energy crops demands some investments in power plants, but these are not necessarily very costly. Above RCG-bale crusher line at Kokkolan Voima Ltd.
(Photo: Timo Lötjönen, MTT).*

This handbook contains practical information on the utilisation of field energy crops for heat and power. The crops discussed are reed canary grass, willow, hemp and poplar. Production of biogas from energy crops is also introduced. The handbook details cultivation and harvesting of crops, logistics, energy production technologies, rationality and economics of production. Other important issues, including support and incentive mechanisms, are also discussed.

The handbook is mainly targeted at authorities, project developers, investors, plant operators, potential bioenergy users, the applied research community and representatives of companies involved in the crop-to-energy production chain.

www.encrop.net

