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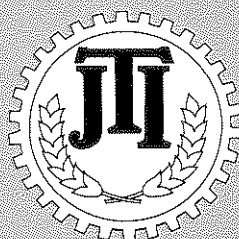
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# **European Energy Crops Overview**

## **Country Report for Sweden**

Gunnar Hadders  
Rolf Olsson



**1996**

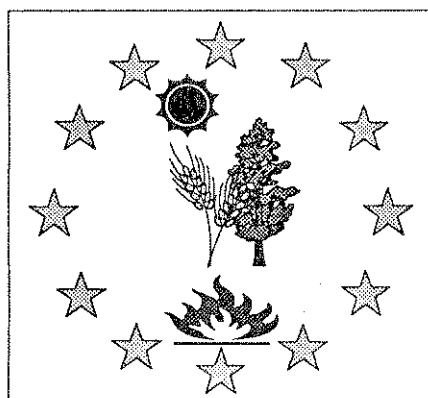
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Swedish Institute of Agricultural Engineering



Swedish University of Agricultural Sciences  
Department of Agricultural Research for Northern Sweden  
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# European Energy Crops Overview

## *COUNTRY REPORT FOR SWEDEN*

*European Commission - Directorate General XII - Science, Research and Development - Agro Industrial Research (FAIR)*

Gunnar Hadders  
Rolf Olsson

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Tryck: Jordbrukstekniska institutet, Uppsala 1996  
ISSN 0346-7597



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**EU FAIR Contract no.: FAIR1-CT95-0512**

September 1, 1996

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## **PREFACE**

### ***Background***

Energy crops are agricultural and woody crops which can be used for energy generation. Two of the main reasons to consider energy crops are 1) they are a renewable, CO<sub>2</sub> neutral source of fuel supply, and 2) they can be grown on set-aside land. This European Union Concerted Action has been initiated to summarize the state-of-the-art of the use of energy crops across Europe.

*The goal of this Concerted Action is to:*

- 1) *give a concise picture of how energy crops are used across Europe;*
- 2) *identify which parties are using energy crops;*
- 3) *stimulate new research and new developments in all areas of energy crop production, processing, and utilization.*

Country reports have been commissioned to assess the situation of energy crops in each country. This report contains the latest advances in energy crops for **Sweden**.

### ***Definition of scope***

Energy crops discussed in this study comprise crops grown specifically for end-use as heat, electricity, or liquid fuel. Examples include short-rotation woody crops such as eucalyptus, poplar, and willow, and agricultural crops such as canary reed, hemp, miscanthus, reed, and sorghum. For Sweden the presentation is limited to willow and reed canary grass, the two most promising energy crops so far. Normal forest woods harvested in a long rotation and used in CHP plants or lumber mills are not included here. Straw is also not included, as it is a by-product of cereal production. In certain cases, straw technologies may be described when other energy crop technologies do not exist. This study therefore is not concerned with biomass in general, but energy crops in particular. However, as energy crops information will often exist in the context of biomass in general, biomass topics and goals will be included to the extent necessary.

*The goal of this report is to review the latest advances of energy crops in Sweden, and to identify research gaps and collaboration opportunities for energy crops' future in the energy supply of this country.*

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## **Audience**

This report is intended as a state-of-the-art overview for potential end-users of energy crops. In addition, it is intended as a resource for policy makers and planners who need concise, complete information on energy crops, as well as consultants and advisors to the energy sector.

## **Methodology**

The Swedish country overview was carried out by contacting the relevant experts and institutions in three categories of energy crop use: production, harvesting & processing, and utilization. The intention of the study is to utilize the most up-to-date published and existing information. No new research was done, rather, the report was compiled from existing reports and information from institutes. References and contacts are listed beginning on page 93.

The report is divided into the following chapters:

- 1 National Overview** Summary and national overview of energy crops in Sweden.
- 2 Production** Including everything up to the moment of harvest.
- 3 Harvesting & Processing** Including everything from harvesting to the utilization plant gate.
- 4 Utilization** Including everything from the plant gate to the useable form of energy.
- 5 Conclusions**

Within each chapter the key technical, agricultural, financial, economic, energy, and environmental aspects are reviewed as section topics. The same format has been followed for each European country to allow comparison between sectors. The findings of the country reports will be summarized in a final report and presented at the 1st European Energy Crops Conference on 30 September and 1 October, 1996, in the Netherlands.

The exchange rate between Swedish currency and the ECU used in the report is 8.30 SEK/ECU, which was valid the 20th May 1996.

## CONTENTS

INTRODUCTION .....	9
NATIONAL POLICIES AND MAJOR PARTIES .....	9
National policy on energy .....	9
Historical background .....	10
Energy and environmental taxes .....	11
Major parties .....	13
PROGRAMMES AND PROJECTS .....	14
Short rotation willow coppice .....	15
Grass and straw .....	15
Utilization technology .....	16
PRODUCTION .....	17
NATIONAL AGRICULTURAL POLICY ON ENERGY CROP PRODUCTION .....	17
AGRICULTURAL ASPECTS .....	17
Overview information on energy crop production .....	17
Production of willow ( <i>Salix</i> sp) .....	19
Production of reed canary grass .....	22
TECHNICAL ASPECTS .....	25
Salix .....	25
Reed canary grass .....	28
ENVIRONMENTAL ASPECTS .....	29
ENERGY ASPECTS .....	30
ECONOMIC ASPECTS .....	31
HARVESTING & PROCESSING .....	32
OVERVIEW INFORMATION ON HARVESTING AND PROCESSING .....	
OPERATIONS .....	32
AGRICULTURAL ASPECTS .....	32
Salix .....	32
Reed canary grass .....	33
TECHNICAL ASPECTS .....	34
Harvesting .....	34
Fuel Packaging .....	36
Transport .....	38
Drying and storage .....	39
ENVIRONMENTAL ASPECTS .....	42
ENERGY ASPECTS .....	43
ECONOMIC ASPECTS .....	46
UTILIZATION .....	50
OVERVIEW OF UTILIZATION .....	50
AGRICULTURAL ASPECTS .....	51
Salix .....	51
Reed canary grass .....	52



TECHNIQUES/TECHNOLOGIES .....	55
Grass in a 2 MW <sub>th</sub> district heating system .....	55
Salix in a 4 MW <sub>th</sub> heating system .....	56
Large scale combustion of willow chips .....	57
Reed canary grass as fuel powder in a 30 MW <sub>th</sub> district heating system .....	58
Production of fuel powder from reed canary grass .....	59
Pressurized gasification of biomass .....	60
CONCLUSIONS AND RECOMMENDATION .....	62
CROP PRODUCTION .....	62
Salix .....	62
Reed canary grass .....	63
HARVESTING AND PROCESSING .....	63
Salix .....	63
Reed canary grass .....	63
UTILIZATION .....	64
Salix .....	64
Reed canary grass .....	64
Annex 1 - PROJECT COORDINATORS AND MAJOR PARTIES .....	65
Annex 2 - REFERENCES .....	67

## **1 INTRODUCTION**

### **1.1 NATIONAL POLICIES AND MAJOR PARTIES**

#### **1.1.1 National policy on energy**

As a result of the oil price shock in the 1970's, the political interest in exploitation of alternative energy sources was awakened. Mainly in order to reduce the dependency on oil, energy policies was directed towards increased support for bioenergy production. Later, alarming reports on the greenhouse effect has been an important driving force. The last ten years there has also been a need for alternative use of agricultural land due to surplus production of food.

The overall political aim in the 1990's has so far been to provide an energy supply based to a greater extent on renewable energy resources and techniques with few pollutants and low net contribution of greenhouse gases.

There are four basic political agreements on the strategy of energy "production" in Sweden:

- 1 The nuclear power is to be closed. This was the result of a referendum 1980.
- 2 New large hydro power stations are not allowed to be built
- 3 The net emissions of CO<sub>2</sub> is to be reduced to the level of 1990 by year 2000 and after that continuously reduced
- 4 The industry with heavy demand of electricity shall not suffer any substantial damage caused by lack of electricity to reasonable prices

The realism of combining the four objectives and the actual meaning of the referendum and parliament decision following the referendum concerning nuclear power are continuously discussed. However, these four points are at the moment the official politic.

Natural gas is available along the west coast of Sweden. More gas could be distributed from Norway and from Russia via Finland. At the moment there are no pipelines built connecting Sweden to existing pipelines. If a new line through Sweden should be built, this would in all probability have a very negative impact on the expansion of the use of biofuels in the area close to this line.

In changing the energy system, big expectations are put on forestry, where Sweden has its largest potential of biofuels. Forest energy is already well adapted on the market. 1994 the use of forest energy was some 250 PJ. The biggest part, 170 PJ, was used within the forest industry, the rest, 38 PJ, in district heating plants and in private houses. According to most experts this amount could, both practically and biologically, be doubled to 500 PJ per year. The practical potential in agriculture is in different studies estimated to be between 50 and 170 PJ per year. The use of agricultural fuels the winter of 1995/96 has been between 800

and 1 000 ha of *Salix* (0,4 PJ), some hundred tonnes of grass (0,003 PJ) and some 20 000 tonnes of straw (0,3 PJ). The total use of energy in Sweden 1994 was 1 400 PJ.

### 1.1.2 Historical background

As a result of the oil crisis a broad research approach for biofuels was started in Sweden. For energy crops the concentrated efforts started with broad leaf trees including willow from 1975. During the period 1981-1986 a broad approach for energy crops through the research programme Agrobioenergy was performed with the Swedish University of Agricultural Sciences (SLU) and the Swedish Institute of Agricultural Engineering (JTI) as main actors. Many different agricultural crops were investigated concerning yield and their potential for solid fuel and/or biogas and liquid fuel applications.

High yields were obtained with different poplar, willow and alder species and of all tested grasses reed canary grass gave the highest yields. As the economic analysis showed that the potential was highest for willow the energy research programme was concentrated to different species of *Salix* with a dominance to select and evaluate different clones of *Salix viminalis*. The research programme has been covering all aspects of importance for the introduction of willow as production biology and technique for production of cuttings, plantation technique and harvesting technique. In later years the governmental programme has been concentrated to more basic research concerning biological and environmental aspects and the technical development has been concentrated to an applied programme administered by the Swedish Farmers Association for Research and Development (SLF). The combined programmes have been successful as high yielding clones with good tolerance to frost, pest and rust have been developed. The technical development for plantation has also been successful as the new technique has decreased the plantation costs to about 600 ECU per ha today compared to about 1 200 ECU 1990. The harvesting technique development has also been successful and the direct chipping method developed can today be used on a commercial basis.

For reed canary grass the research efforts has been much lower. In 1989 a research programme for development of the crop for north Swedish conditions started. This programme was concentrated on the development of new harvesting methods with less weather dependence. The studies resulted in a proposal for development of the delayed harvest method, that is harvest during winter or spring. In 1992 a national programme started with the main goal to evaluate the agronomic possibilities for this new method in Sweden. Field trials were established all over Sweden and harvesting technique studies were started using conventional hay and straw making technique.

The first evaluations from the programme have been published and the conclusion is that the delayed harvest method can be used all over Sweden. The net yields have so far been highest in the north parts of Sweden. As the amount of fields trials in the south has been low, it is still not possible to estimate the long time yield in this area. The trials have also demonstrated that conventional hay making and straw handling equipment can be used although a technique modified to this very dry and brittle material will lead to a smaller

harvesting loss. In the delayed harvest system the yield and quality of the crop has increased with age of the leys which has not been the case in conventional harvest systems.

For northern parts of Sweden latest calculations show that fuel from reed canary grass can be produced at price levels comparable to other biofuels, industrial waste products excluded.

The commercial introduction of willow and reed canary grass started 1991 when Sweden got a new agricultural policy to decrease the overproduction of food. The intension of the new policy was a complete deregulation of the agricultural business over a period of five years. The guaranteed price level for grain and oil seed was gradually lowered. To give the farmers an opportunity to develop the production of new crops and new markets there was a one time grant per hectar paid to those who applied for it. The grant, based on average grain crop yield in the production area, was up to 1 450 ECU/ha and the granted acreage could be up to all of the land earlier used for grain and oil seed. To keep the grant the farmers was not allowed to produce any grain or oil seed during the period up to 1/7 1996.

Beside the above mentioned grant a financial support of 1 200 ECU/ha for willow plantation was introduced. This was available up to the establishment period of 1996. The new policy led to a rapid increase of willow as well as of reed canary grass establishments. After the spring 1996 there will be about 16 500 ha of willow plantations. An extension of the establishment support for Salix at the level of that in UK (£400 per hectar) is at the moment discussed. The latest estimation of the reed canary grass acreage, made 1992, was 4 000 ha.

The Swedish entrance to the common market 1995 with increased subsidies for grain production has dramatically changed the situation in Sweden. A deregulation of regulations is no more the case. For reed canary grass, which has not a well established market for the fuel, a dramatic decrease in the acreage can be seen. It is in many regions more profitable to grow grain than energy grass again. For willow, with an established market, a slow increase in plantation is foreseen. The pace will very much depend on the size of a possible support. For the development after 1996 a support to the plantation costs is needed to overcome the still high establishment costs and to motivate the farmers to start with a crop which need a production time of at least 15 years, maybe many more, to give full economic payment.

In 1991 an investment support of 120 MECU (one billion SEK) was allocated for production in biomass fuelled combined heat and power production during a period of five years. Additional 75 MECU (625 MSEK) were allocated for demonstrations with new and more efficient techniques for biomass based electricity production.

### **1.1.3 Energy and environmental taxes**

The Swedish system of energy and environmental taxation distinguishes between taxes on industry and taxes on other users. Since 1993, the general energy tax on industrial activities has been levied at only 25 % of the rate applicable to other users. There will be a rise of the general energy tax of 11 % the 1st of September 1996 and another 11 % the 1st of July 1997.

When producing electricity through combustion there is no tax levied on the fuel used. Instead, a tax is put on the consumer price of the electricity. This tax varies with type of customer. Industry pays no tax on electricity. The producer of the electricity has to pay a fee for the emission of sulphur when burning oil, coal and peat though.

**Table 1.1 General energy and environment taxes for industrial users on gas oil, heavy oil, coal and natural gas as of the 1st January 1996, excluding value added tax**

Fuel	General energy tax	Carbon dioxide tax	Sulphur tax	Total	Tax ECU/GJ
Gas oil (<0.1% S), ECU/m <sup>3</sup>	-	31.8	-	31.8	0.90
Heavy fuel oil (0.4 % S), ECU/m <sup>3</sup>	-	31.8	13.0	44.8	1.14
Coal, ECU/tonne	-	27.6	18.1	45.7	1.67
Natural gas, ECU/1 000 m <sup>3</sup>	-	23.7	-	23.7	0.60
Peat, ECU/tonne	-	-	4.82	4.82	0.50

**Table 1.2 General energy and environment taxes for other than industrial users on gas oil, heavy oil, coal and natural gas as of the 1st January 1996, excluding value added tax**

Fuel	General energy tax	Carbon dioxide tax	Sulphur tax	Total	Tax ECU/GJ
Gas oil (<0.1% S), ECU/m <sup>3</sup>	71.1	127	-	198	5.56
Heavy fuel oil (0.4 % S), ECU/m <sup>3</sup>	71.1	127	13.0	211	5.42
Coal, ECU/tonne	30.2	110	18.1	159	5.82
Natural gas, ECU/1 000 m <sup>3</sup>	23.0	94.9	-	118	3.05
Peat, ECU/tonne	-	-	4.82	4.82	0.50

Biomass from field and wood are exempt from taxes on sulphur and carbon dioxide emissions.

All energy plants with combustion and gas turbines with a yearly production of more than 144 TJ pays a fee of 4,1 ECU/kg emitted NO<sub>x</sub>. Fees are neutral relative to the national budget, whilst those with lower emissions than the average of the year will receive the gathered sum of fees as refunds. The system provides a strong financial incentive for investments in equipment intended to reduce the NO<sub>x</sub> emissions.

The tax system has favored biomass in front of fossil fuels. Several district heating plants have since 1970 been converted from oil to wood fuels. The development during 1980-1994 is shown in figure 1. In 1993, 190 district heating plants were in operation. About half of these used wood fuels as main fuel, and approximately 30 could produce both heat and electricity. Besides the use in district heating, 170 PJ of wood fuels were used in industry (1994).

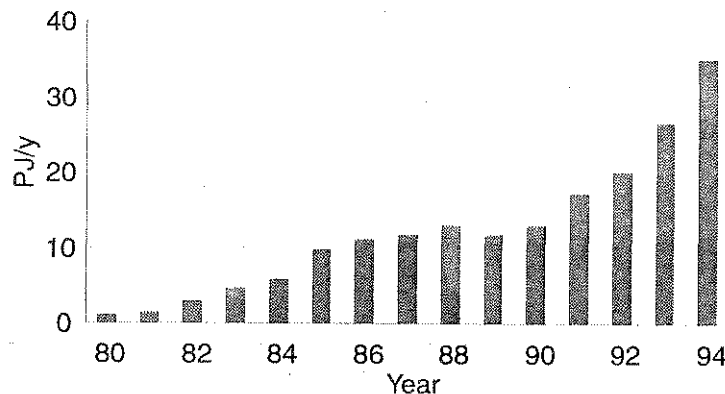


Figure 1. Use of wood fuels in Swedish district heating systems<sup>56</sup>

The price for biomass fuels, not upgraded, used in the district heating and power plants vary between 2.0 and 4.2 ECU/GJ with an average close to 3.7 ECU/MJ. The corresponding price for coal, taxes included, is 7.5 ECU/MJ.

#### 1.1.4 Major parties

Major organisations taking part in the development of energy crops are on the financing side Swedish State Technical Board (NUTEK) and the Swedish Farmers' Foundation for Agricultural Research. Substantial contributions have also come from Swedish Board of Agriculture, the Swedish Council of Forestry and Agricultural Research and the state owned electric company Vattenfall.

Research and development is mainly conducted at some twenty departments within the Swedish University of Agricultural Sciences and at the Swedish Institute of Agricultural Engineering. The commercial implementation of Salix is to a high degree conducted by a development company "Agrobränsle AB" owned by Swedish farmers' organisations.

Addresses to the parties mentioned are available in Annex I.

## 1.2 PROGRAMMES AND PROJECTS

Table 1.3 Overview table of research programmes concerning Salix and reed canary grass

Programme	Short rotation willow coppice - research	Short rotation willow coppice - development	Straw and grass fuels	Wood fuels
Crop	Salix	Salix	Reed canary grass	Forestry
Period of activity	1993-96	1992-95	1994-1997	1993-1996
Budget, MECU	4.7	3.6	1.2	3.9
Project coordinator Nos. (Annex 1)	1	2	2	1

Programme	Biogas	Demonstration energy crops	Ethanol	Ethanol
Crop	Ley crops		"Wood"	"Wood"
Period of activity	1993-96	1991-		94-96
Budget, MECU	1.4	1.8	0.7/y	5.4
Project coordinator Nos. (Annex 1)	2	2	1	1

The total public budget distributed by the Swedish State Technical Board (NUTEK) during the period of 1975-1995 to research on the use of biomass for energy purposes has been 400 MECU, 20 % of the budget on the production of the fuel and the rest on conversion technology. This includes also bioenergy from forest. Concerning conversion, just about all research is about wood fuels. In addition to the public programmes administrated by NUTEK, there are other organisations dealing with financial support to various R&D programmes.

R&D in the field of energy crops has been conducted by government support since 1975. In the beginning the programme was directed towards plantation of fast growing broad-leaves trees on peat and marginal agricultural land. In a programme running 1981-1986, a large number of potential crops were tested. The crops with highest potential yield in this study was reed canary grass (*Phalaris arundinacea*) and willow (*Salix viminalis*). The economical analysis at that moment showed that willow had a potential to be developed to an competitive energy crop whereas reed canary grass with existing technique could not be competitive. The development was of these reasons concentrated to willow. The development of reed canary grass did not start until 1991, when new production methods described later was suggested. These two crops, Salix and reed canary grass, has been

considered to be the ones practically and economically easiest to introduce in the energy system.

The total budget for energy research at the Swedish University of Agricultural Science 1992/93 was 7 MECU. Approximately 2/3 of these were connected with agricultural energy crops. More than 85 % was put in research of the biological system. The number of projects running are in the magnitude of hundreds.

### **1.2.1 Short rotation willow coppice**

The national programme for short rotation coppice is divided into sub-programmes for basic and applied research. In the short term, the aim of the basic programme is to increase fundamental knowledge on biology, ecology and cultivation techniques so that a high production of the crop can be kept under sustainable conditions. The aim in the long term is to establish short rotation coppice as economically competitive towards other fuels from biomass.

The most important areas in the basic research programme are:

- Biological investigations. Conditions, methods and materials for cultivation
- Plant breeding. Aimed at increasing the yield of the plants and their resistance to attacks from disease and vermin.
- The environmental impact of the production; soil impoverishment, nitrogen uptake etc.

The sub-programme on applied research is focused on the economical, technological and biological premises for production of short rotation willow coppice in agriculture for deployment in the wood fuel market. The short term goal is to lower the fuel production costs. Furthermore, it is important to achieve increased reliability in cultivation and to map the environmental impacts from plant cultivation to final use. The aim in the long term is to make the crop economically viable as a fuel.

### **1.2.2 Grass and straw**

The first R&D programme for energy from grass, and also from straw, started in 1991. This programme was initiated with the objective to examine the economical, biological and environmental premises in using grass for energy production. The programme covered the whole system, from breeding and growing to handling of products, analysing the premises for harvest in spring and other questions about production and fuel quality.

As a continuation of the grass efforts, the programme for straw fuel (grass and straw) was started. This programme has an extended direction and support is given to research, development and demonstrations.

The overall aim of the straw fuel programme is to support research and development to strengthen the economic conditions for deployment of straw fuel. The programme shall cover the whole system, from growing to handling of products.



### 1.2.3 Utilization technology

Present research on energy supply is divided into four sectors: fuel technology, combustion technology, methods of electricity and thermal technology.

Efforts in technology concentrate on development of indigenous fuels with the aim of making them competitive, also on reducing the environmental impact of their use to a minimum. The most important of these fuels are wood fuel, short rotation coppice, peat and various types of waste.

Combustion and gasification are concerned with the chemical and physical processes of combustion and the technologies of combustion and gasification. The programme is concerned primarily with combustion of solid fuels. Much of the work is aimed to reducing the pollution caused by combustion. Within the applied combustion research the fluidised bed combustion has attracted considerable interest.

In Sweden, gasification of biofuels is of primary interest. The reason is that by introducing a gasification step the efficiency in the production of electricity in a power plant can be increased. Research is conducted both at universities and in private companies. In Värnamo there is a pilot plant with a pressurised fluid bed gasifier for wood fuels in a combined cycle process of Finnish design owned by the electric company Sydkraft. The plant generates 6 MW/s of electricity and 9 MW/s of district heating.

Electricity production technology embraces all methods apart from hydro and nuclear power. The two important parts are thermal power production technology and wind power. Thermal technology covers the production and distribution of heat.

## 2 PRODUCTION

### 2.1 NATIONAL AGRICULTURAL POLICY ON ENERGY CROP PRODUCTION

Farming in Sweden are offered the grants of EU set aside programme. Besides this, during the period of 1991-1996 there has been a grant for establishing Salix of 1 200 ECU per hectare. No other grant for energy crop production exists.

Further information is given in part 1.1.1.

### 2.2 AGRICULTURAL ASPECTS

#### 2.2.1 Overview information on energy crop production

Table 2.1 Overview on plant species tested as energy crops in Sweden<sup>58-60</sup>

Plant genus	Salix, "middle" Sw (w. of Stockholm)	Salix, south Sw	Phalaris, north Sw	Phalaris, "middle" Sw (w. of Stockholm)
Plant species	viminialis and dasyclados	viminialis and dasyclados	arundinacea	arundinacea
Common name, English	Willow	Willow	Reed canary grass	Reed canary grass
Energy utilization	Solid fuel	Solid fuel	Solid fuel	Solid fuel
Current total area (ha), commercial (C), demonstration (D), and research (R)	C+D: 14 500 R: <200 totally	C+D: 2 000 R: <200 totally	C: 1 000 (1992. Today smaller.) R: 5	C: 3 000 (1992. Today smaller.) R: 2
Size of plantation area (+,0,-)	+	0	-	-
Mean net yield in commercial production, ODT/(ha·y)	S. viminialis 10 S. dasyclados 8		7,5	6,5
Possible yield increase in 10 years due to R&D. Basis for estimation.	+2 ODT/(ha·y)  Plantbreeding, better techniques for cultivation and harvest		+10 %  Plantbreeding, better techniques for cultivation and harvest	

## Willow

Advantages with willow in Sweden:

- A good market for the fuel due to the established CO<sub>2</sub> tax and a lot of boilers built for wood energy chips use
- A well established organization in new companies organizing the supply of cuttings as well as plantation, harvesting and marketing support
- Commercially functioning technology is available

Main barriers for willow:

- High establishment costs and the need to keep the crop for many years to get full economic compensation
- The farmers attitude to this new crop and difficulties with succesful cultivation
- The dependency on agricultural, energy and environmental policy in Sweden and in the Common market

## Grass

Studies of different grasses for energy production in Sweden started in 1981 and revealed that reed canary grass was the most interesting species because of its high yield, good quality and sustainability<sup>1,2</sup>. Miscanthus sinensis and giganteus has been tested in different parts of Sweden, but can only be grown in the southernmost part of Sweden due to too cold climate in the other parts.

Advantages with reed canary grass in Sweden:

- High acceptance from the farmers to the crop (easy to cultivate)
- Low establishment costs and the possibility to use conventional machinery for the production
- Possibilities for an extra income to the farmers by upgrading the fuel on a smale scale industry level to e.g. briquettes

Main barriers for reed canary grass:

- The market with suitable boilers are undeveloped
- The technology is not fully developed for the whole chain
- The dependency on agricultural, energy and environmental policy in Sweden and the Common market

The state of the art on reed canary grass as a solid fuel was presented by Hadders in 1994<sup>32</sup>.

### 2.2.2 Production of willow (*Salix* sp)

Since 1975 when the Swedish bioenergy research programme started intensive studies have been performed concerning research and development of different short rotation coppices in Sweden. Most effort has been done on different species of willow. Two main species, *Salix viminalis* and *Salix dasyclados*, have been studied. Basic studies concerning breeding of willow are performed by the department of Plant breeding at the Swedish university of agricultural sciences and a commercial breeding programme is performed by the company Svalöf-Weibull AB. The commercialization of the crop has also started and about 17 000 ha have been established. Main contributions in this are performed by a number of new companies owned by different farmer organizations or by the farmers directly. The new companies are engaged in the production and control of selected cuttings to interested farmers as well as in the development of plantation and harvesting machinery. Other important contributions from these new companies are to organize the marketing of this new fuel and to sign delivery contracts to heat producing companies using biofuels as well as to give advisory support to the farmers. The small companies owned directly by the farmers are often using the produced fuel in small heat generating units owned by the company. The fuel from willow plantations are often used together with wood fuel chips in the plants. The market for the fuel is good and rapidly increasing partly depending on the Swedish system with CO<sub>2</sub> taxes for fossile fuels. A large part of the plantations are situated in a belt between Stockholm and Gothenburg. The largest farmer owned company, Agrobränsle AB, today has contracts with about 850 farmers with a total plantation area of about 14 500 ha of willow. A major part (99 %) of the planted material is of the species *S. viminalis*. Harvested area during the winter 1995/96 was between 800 and 1 000 ha.

#### Genetic material

An intensive breeding programme is going on in Sweden. The main goals in this programme is to increase yield, tolerance to frost, rusts and insect attacks. The main materials available for plantation so far are selected clones but the first varieties from breeding are under introduction.

Different varieties of *S. viminalis* are used to 99 % but varieties of *S. dasyclados* are also used.

*S. viminalis* has a rapid development with higher yields and stem density compared to *S. dasyclados*. In areas with high risk for frost damage or soils with a high content of organic materials *S. dasyclados* is recommended but these varieties normally show a lower tolerance to rusts compared to *S. viminalis*.

The establishment of *Salix* plantations is done with cuttings from controlled plantations produced by farmers specialized in this production. The shoots are harvested each year in the dormant stage and stored in dormancy stage until plantation.

### **Crop establishment**

The experience from growing different clones of *Salix* on different soils and their sensibility to frost, and diseases is still small in Sweden. In practical crop production this has resulted in a general recommendation to use at least three different clones in each establishment to get a more safe production.

A technical description of the recommended routines for the establishment is given in chapter 2.3.1.

### **Fertilization**

The experimental experiences concerning nitrogen fertilization is still limited in Sweden. With a calculated soil nitrogen mineralization of about 100 kg/ha the average yearly need for N fertilization is believed to be between 70 and 90 kg/ha. For soils with an average content of available P and K level the recommended application of P is 10 kg/ha and year and for K 25 kg/ha and year.

### **Weed and pest treatments**

The technical application is described in chapter 2.3.1. Weed control systems are still not fully developed.

Weeds of dicotyledon origin are treated with Gardoprim 500 FW or similar type. The dosage must be increased with increasing content of organic materials and increasing content of clay minerals. The amounts recommended varies from 1,5-6,0 l/ha.

Before plantation the use of glyphosat is recommended. In established crops a pesticide like Focus ultra is used in dosages 2,0-6,0 l/ha. Sometimes there is also a need for weed control after harvest. For treatment after harvest both mechanical and chemical alternatives are being tried out.

Pests are normally not treated in willow production in Sweden. Actual clones has been selected for resistance.

### **Harvest interval and harvest time**

With the high establishment costs for willow the production period need to be long to reach an acceptable economy. In today's calculus it is assumed that the crop is kept for 24 years. The harvest interval assumed is four years. The crop, which is normally harvested with a direct chipping method for direct distribution to the boiler, can under Swedish conditions with frozen soil be harvested during the period of December to April. The mean moisture content is normally about 50 % but there are exceptions. During the season 1994/95 the mean moisture content in crops harvested in the area west of Stockholm was about 54 %. The reasons to this are not fully analyzed. As long as the harvest is done in the dormant stage no growth disturbances has been reported.

### **Biological growth**

As the growth is strongly depending on the actual precipitation and the experience still limited the average possible yield is very difficult to estimate. In a 10 year perspective, a possible increase in yield to 12 ODT/ha is estimated. The basis for this is genetic improvements on frost tolerance and increased knowledge concerning water requirement on different soils and in different regions.

Harvest and storage losses are described in chapter 3.2.1.

### **Cultivation experiences**

The early strategy for cultivating willow in Sweden started with the assumption that the crop was suitable for marginal agricultural lands. After the first evaluations, a new strategy was established in 1985. In the south and middle parts of Sweden, the furthest north some hundred km north of Stockholm, new plantations were established on conventional agricultural fields with the goal to evaluate the long term production capacity for willow in Sweden. These crops now have been harvested twice. The yields have been evaluated against an established growth calculation model, from which results have been transformed into economic calculations<sup>3</sup>. The result of the evaluation shows that the yields have a large variation and that only the best fields have reached the calculated yield of 12 tonnes of oven dried material per ha and year. The yields achieved on the farms have so far been only 40-60 % of the calculated ones. This is due to for instance older genetic material, other soils, bad weed control and no fertilizer application. Since the planting has been paid with a grant there has been no strong reason to take optimal care of the crop.

The analysis of the trials can be summarized in the following way:

- Willow is a difficult and sensitive crop which needs a good farmer experience. The average competence among the participating farmers have been too poor and a successful development is heavily depending on a good organization of advisory staff for the introduction.
- The technique for weed treatment is not fully developed.
- The frost influence on yield has been larger than expected.
- The long-term production capacity is strongly influenced and dependant on a good establishment.
- The water requirement is higher than earlier expected.
- Inhomogeneity in the quality of fields has a strong influence on the yields as well as has harvesting losses, depending on cutting heights and the size and form of the field.
- Fertilization below recommendation is expected to have decreased the average yield with about 20 %.
- Fertilizer effect is strongly depending on a successful weed treatment.
- Highest yields have been obtained on soils with a high content of organic materials and a good availability of water.

In many cases the yield has been low as the plantations have not been fertilized. The lack of fertilizer application has been calculated to decrease the yields with about 20 % in the above mentioned trials.

Irrigation is normally not used in Swedish willow production as it has been expected to be too expensive. During the experimental period from 1991 it has been a deficit in precipitation in large areas in south and middle parts of Sweden. In a recent study<sup>4</sup>, growth of willow under conditions existing in the area west of Stockholm has been calculated to 6,3 g dry biomass per kg of transpired water. This means that the crop to get the calculated yields of 12 tons of dry weight per ha and year must have 430 -555 mm of available water. As the average precipitation in southern Sweden is 350-550 mm and in many places lower during the actual period it must be concluded that water is a crucial factor for the yield.

### **Influence on cropping system**

As the crop system is based on 24 years of cultivation, willow cannot be used in a normal crop rotation system. The experiences in breaking up a willow crop after a longer period of time is still limited.

### **2.2.3 Production of reed canary grass**

The following facts are mostly based on research by field trials.

#### **The new production method**

Since 1990 a new production method<sup>5</sup> for reed canary grass, which was developed in Umeå, is in focus. The principle for this method is that the harvest (once a year) is delayed until the crop reaches a good quality for biofuel use. For Swedish conditions the suitable harvest time is early the following spring, just before the new growth starts. The crop is left on the field during the winter and harvested as wilted material the following spring. It is then possible to harvest during favourable weather conditions and to obtain dry and storable material. Reed canary grass harvested as wilted material in early spring has shown very good quality as biofuel in contrast to the same grass harvested in the end of the summer<sup>6</sup>.

There are indications that the rhizomes of reed canary grass will be more well developed and dense in a delayed harvest system, since the grass is allowed to grow undisturbed during the whole growing season. A well developed rhizome system with a good storage of carbohydrates will probably contribute to a more vigorous growth of the above ground crop<sup>7</sup>.

The delayed harvest system for reed canary grass has been proven, by studies during five years so far, to be beneficial for both biological production and use of the harvested material for energy purposes. However, the long term (10-15 years) production and sustainability of reed canary grass in this new delayed harvest system has to be studied, since that is of great economical importance for decisions on new energy production systems.

### **Genetic material**

Reed canary grass (*Phalaris arundinacea* L.) is a tall rhizome grass which is native in Sweden and many other northern countries. Only varieties intended for fodder use is available on the market. According to variety trials in ley I-III the best variety so far is Palaton (fr. USA). The proportion of stem is about 70 % in Palaton. Breeding of new varieties suitable for energy purpose is under way in Sweden (by Svalöf Weibull AB) with a planned market introduction in year 2001.

### **Crop establishment**

Reed canary grass is established by sowing seeds, ca 15 kg/ha. The grass should not be undersown in any other crop. Reed canary grass is light dependent for germination and should therefore be sown very shallow (1 cm). Reed canary grass develops rather slowly the first summer and should therefore be sown in spring or early summer to obtain a well established stand before the winter.

### **Weeds and pests**

In a well established stand the reed canary grass has very high competition ability against weeds and other grass species. Need for treatment of weeds therefore occur only during the establishment year. Chemicals such as MCPA (1 l/ha) can be used. No serious attacks of diseases or pests in reed canary grass have been observed and therefore is no pest treatment necessary.

### **Growth**

Since reed canary grass develops slowly, the stand is rather thin and give a low yield the first ley year. From the second year ley and up to at least 8 years reed canary grass has been proven by many field trials all over Sweden to be sustainable and high yielding (8-12 ton DM/ha)<sup>7</sup>. In commercial production reed canary grass is expected to be productive for 10-15 years without new establishment.

### **Climatic impact**

In northern Sweden the yield increases until the end of September, but in southern Sweden there is no marked increase in growth after the end of August. During the winter the losses of biomass in field trials were about 15 % of DM in northern Sweden and about 25 % of DM in southern Sweden. It is likely that cold and relatively dry conditions will preserve the grass better during the winter than warmer and rainy conditions, and therefore lower "winter losses" were obtained in northern than in southern Sweden. Results from field trials have so far shown about 12 % higher yield in northern than in southern Sweden when harvested in spring.



### Soil type

Reed canary grass can be grown on almost all soil types. It thrives particularly on wet humus rich soils and has proven to give high yields there. Heavy clay soils (> 40 % clay) have indicated to be less suitable for establishment and early growth. The ash content varied more with the soil conditions than with harvest time. Grass samples from trials on clay soils had higher ash content than samples from humus rich sandy soils<sup>7</sup>. The range of soil conditions studied are still too small for safe conclusions.

### Harvest time

Different harvest times have been tested in field trials, end of summer (August), end of vegetation period (October) and following spring. The dry matter content of the grass at harvest was on average 30 % in August, 42 % in October and 85 % in spring. The ash content was lower in the crop at spring harvest than in August. The concentrations of the undesired elements Cl and K were about six times lower in the crop in spring than in August. Concentrations of most elements were much lower in stems than in leaves. In contrast to harvest in August, both the total yield and the proportion of stems in the crop increased with increasing age of ley during the first three years in the spring harvest system<sup>7</sup>.

### Fertilization

The amount of nutrients removed from the field with the harvested crop showed great difference between August and spring harvest. When the grass was fertilized with 100 kg N, 100 kg K and ca 25 kg P per ha, nearly all these amounts were removed with the crop in the August harvest. But, in the spring harvest only about half of the supplied N and P were removed with the crop and for K it was only about one third of the supplied K that was removed. This implies that plant nutrients can to a large extent recirculate in the delayed harvest system, and this will reduce the fertilization required<sup>7</sup>.

To the *first ley year* it is recommended an ample fertilization for optimal growth, which for Swedish soil conditions (on average) is about 150 kg N, 100 kg K and 30 kg P per ha. Amounts of P and K are of course depending on the nutrient status in the soil. From the *second ley year* and onwards the fertilization can be reduced due to recirculation of nutrients. Recommended amounts in general for reed canary grass in the spring harvest system are therefore 80 kg N, 30 kg K and 10 kg P per ha. Grass ash have been used in field trials with good results on both yield and quality<sup>7</sup>. There is also indications that sewage sludge can be used in reed canary grass with good results.

### Ending the production

There have been no problems recorded in ending the production of reed canary grass. With a correct cultivation and ploughing, the rhizomes are not strong enough to come back in other crops<sup>44</sup>.

## 2.3 TECHNICAL ASPECTS

### 2.3.1 Salix

Since Salix appears as a commercial crop there are quite detailed recommendations available for the production. The methods and recommendations described below are a synthesis of available results from research<sup>8,16,26-31,37,38</sup>.

#### The year before planting

Because the young Salix crop is very sensitive to competition from weeds it is very important to control the weeds in advance, as well as during the first year. The weed control is done with both mechanical and chemical means.

The year before planting should be used to minimize the amount of couch-grass (*Agropyron repens L.*). The best result is reached with one year of fallow during which the land is treated with glyphosat. Mechanical treatment alone is seldom enough.

#### Planting

The crop is planted in the spring using 200 mm cuttings. On one hectare 16 500 cuttings are used. They are planted in double rows so that the distance between every second row is 1 500 and 750 mm respectively. The distance between the cuttings in the rows today is 500 mm. This recommendation may be changed to 600 or 700 mm in the future. Except for the planting, ordinary agricultural machines are used in the establishment work.

The spring farming operations before planting are equal to those for other crops. The depth of tillage should be 60-100 mm. After planting, chemical weed control with in first case Gardoprim 500 FW, or with Printop 500 FW, is recommended. However, on organic soils, the effect of Gardoprim may be small. On these soils a treatment of glyphosat before planting is an alternative or a complement.

Salix is planted with two different machines. One of them handles whole shoots which are cut into 200 mm pieces on the planting machine. This machine needs two persons plus tractor driver for operation when planting two double rows. The other machine handles 200 mm cuttings which are accelerated down into the ground totally automatic. Both machines have an output of approximately one hectare per hour.

The cutting should normally end approximately 1 cm above ground. The dryer the ground, the more important the cutting is put deeply down. A roller can be used to increase the contact between soil and cutting.

A commercial company, Henrikssons Salix AB, in the very south of Sweden since three years practice an alternative method for establishment<sup>9</sup>. Using "Austoft Plantmaster" planting machine for sugar cane, Salix cuttings are placed horizontally in rows in a similar way to potatoe planting. So far the company uses 60 000 cuttings per ha, e.g. three times more than

in the technique described above. The cuttings have been 150-250 mm long and produced either manually in an electric wood saw or with the Austoft sugar cane harvester which the company uses for harvest of Salix. The quality of the cuttings from the harvester are not quite as good but much cheaper. However, this is believed possible to compensate by planting more cuttings per ha.

Advantages with this technique are said to be closer stands and a substantially lower cost. Experiences so far indicate that the generally recommended cutting of the crop one year after plantation can be omitted. Since the same machine can be used for both harvesting and the production of cuttings, this machine will be more efficiently used. The planting method is offered for 540 ECU per hectare including the cuttings. The technique is not studied in any official trials.

### Weed control in crop

Three options for weed control in connection with planting are given:

**1 A combination of chemical and mechanical treatments.** Immediately after planting, the land is sprayed with half a dose of a soil-applied herbicide using a conventional agricultural boom sprayer. At the end of the season, the weeds are kept under control by means of implements between the rows of Salix. If further chemical treatment is needed later the same year, a band sprayer between rows should be used.

**2 Pure chemical treatment.** If mechanical treatments are excluded a full dose of a soil-applied herbicide is recommended. This treatment is aimed to last for the full season.

**3 Pure mechanical treatment.** This is a possible option although it demands a lot from the farmer. The weeds must be fought often and never left to grow big. A good rule is to start weed control as soon as there are more than three weed plants bigger than 20 mm under your hand.

There may also be a need for weed control after each harvest. For this both mechanical and chemical methods are being tried out<sup>25</sup>.

Examples of machinery being used for mechanical treatment are different kinds of cultivators, hoes and harrows, often slightly modified to avoid damage to the Salix plants. Rotary implements is another example. The mechanical treatments tried so far have not controlled the weeds between the Salix plants in the row. This is an important disadvantage, especially on organic soils. There are farmers who claim they can drive across the rows without serious damage to the crop, but this has not been studied in any trial.

One technique tried but so far not widely used is weed wiping (contact application).

On organic soils it is almost impossible to manage the weed control without some kind of chemical treatment.

The working capacities are very much dependent on working width and speed, amount of water used in spraying and distance between field and filling point while no figures are given here.

### **Fertilization**

During the first and often also the second year after planting and harvest fertilization is done with ordinary agricultural spreaders for commercial fertilizer. Boom spreaders can be used in higher crop than disc broadcasters.

When the shoots get high, taller than 2-3 m, special machinery is necessary. Available today are three techniques: 1) machines broadcasting the fertilizer 36-40 m over the top of the crop, either with discs or an oscillating spout (5 ha/h), 2) a broadcaster trailed through crop between the rows of Salix by a 4-wheel motorcycle (2 ha/h) and 3) a device mounted to a 4-wheel motorcycle for fluid nitrogen fertilizer (1,5-2 ha/h).

The use of helicopter has also been evaluated. However, the accuracy in the broadcasting is too poor.

Sludge is spread only when the crop is low and therefore with conventional spreaders for that type of material.

### **Cutting back one year after planting**

Today the general recommendation is to cut back the crop in winter after planting to increase the numbers of shoots per plant. An exception is when the sugar cane planting technique has been used.

The crop is cut back with a grass mower, a pasture topper or a similar equipment.

### **Pest treatment**

Chemical treatments to avoid pest is so far of no interest.

### **Irrigation**

Irrigation with clean water is at the moment of no commercial interest in Sweden. Trials with spreading of sewage water are made though.

### **Converting short rotation forestry back into the crop land**

There has been some trials in this field, however only on very young crops, 5-8 years of age. In these cases there has been no major difficulties. One method used was loosening the stumps from the ground with a conventional agriculture plow. After this the stumps were collected in different ways and brought away from the field. Also a rotovator has been studied.

#### **2.3.2 Reed canary grass**

##### **Establishment and care**

The machines needed for the establishment and care are all conventional implements used for grain and ley crops.

## 2.4 ENVIRONMENTAL ASPECTS

Table 2.2 Environmental impact from energy crop production vs. standard wheat production<sup>58-60</sup>

Crop	Willow "middle" Sw	Willow south Sw	RCG north Sw	RCG "middle" Sw
Herbicide load (++/+0/-/-)	+	+	++	++
Insecticide load (++/+0/-/-)	++	++	++	++
Fungicide load (++/+0/-/-)	++	++	++	++
Pesticide transport by leaching (++/+0/-/-)	++	++	++	++
by soil erosion (++/+0/-/-)	++	++	++	++
Nutrient balance biomass yield per nutrients applied (++/+0/-/-)	++	++	++	++
mineral leaching (kg/(ha·year) or ppm in percolation water)	++?	++?	≈0	≈0
Soil erosion compared to wheat production (++/+0/-/-)	++	++	++	++
compared to green fallow (++/+0/-/-)	0	0	++	++
Crop water use increase (+) or decrease (-) of ground water recharge compared to wheat (++/+0/-/-)	--	--	-	-
compared to green fallow (++/+0/-/-)	--	--	0	0
Carbon balance (++/+0/-/-)				
total plant prod. above ground, (ODT/ha)	16	11	11	11
below ground (ODT/ha)	5	?	?	?
harvested (ODT/ha)	10	10	7,5	6,5
increasing or decreasing soil humus content	++	++	++	++
Emission of other greenhouse gases	-	-	-	-
Landscape impact (public conception: fully acceptable (++), not at all acceptable (--))	0/+ (+ on plains)	0/+	++	++
Biodiversity impact compared to wheat production (++/+0/-/-)	+	+	+	+
compared to green fallow (++/+0/-/-)	+	+	0	0
Any experiences from treating organic wastes, ashes etc.	Ashes, sludge and sewage water <sup>34-36,39-40</sup>		Ashes, sludge and sewage water <sup>41</sup>	
Other environmental effects assessed	Salix can be used to clean the ground from cadmium <sup>33-34,43</sup>			

## 2.5 ENERGY ASPECTS

There are at least two studies over energy aspects on the use of Salix and reed canary grass conducted. The figures presented in table 2.3 are based on a quite detailed such<sup>10,11</sup>. This studie has been criticized for not using values from practice for the diesel consumption in the field operations. The fuel consumption given in the table is probably overestimated. In table 2.3, the figures from this study are adjusted to more recent knowledge on net yields and need for fertilizer.

One misstake sometimes being made is to multiply the effect necessary in the tractor for the implement used with a figure for the fuel consumption per kW. This will give the wrong result since the average effect used is far smaller then the maximum effected needed.

A second energy study has focused on the amount on electricity possible to yield out of different crops and techniques<sup>12</sup>. In this study the figures for cultivation and harvesting of Salix and reed canary grass differs from these below. This is due to different assumptions on net yields, need for fertilizer and used harvesting technique, but also to a big difference in the vaule for the energy consumption for producing one kg of nitrogen. <sup>12</sup> uses 69 MJ/kg while <sup>10,11</sup> uses 43.2 MJ/kg.

More about energy aspects, including input/output ratio, is given in part 3.5.

Table 2.3 Energy input in energy crop production, GJ/ha and year as average over lifetime. Figures based on reference <sup>10,11</sup> adjusted on use of fertilizer

Crop	Salix	Reed canary grass
<i>Preconditions</i>		
lifetime (years)	25	10
harvest intervals (years)	4	1
fertilizer (N/P/K), average, kg/ha and year (N 43,2 MJ/kg; P 15,0 MJ/kg; K 9,0 MJ/kg)	80/10/25	80/10/25
Cuttings/seed	0.16	0.015
Fertilizer	3.8	3.8
Diesel for establishment, care and field clearing	0.73	0.56
Indirect energy in machinery for establishment, care and field clearing	0.14	0.12
Total input in production (=cultivation)	4.83	4.50
Total output and relation input/output	See tabel 3.7	

## 2.6 ECONOMIC ASPECTS

For information on economics, see part 3.6.



### 3 HARVESTING & PROCESSING

#### 3.1 OVERVIEW INFORMATION ON HARVESTING AND PROCESSING OPERATIONS

Table 3.1 Harvest & Processing Overview

Case	Salix, big scale Chips directly to a 100 MW CFB, 2 000 ha	Salix, small scale Stored shoots, 0,5 MW chip furnace, 200 ha	Grass, big scale 30 MW powder burner, 2 000 ha	Grass, small scale 2 MW straw furnace, 200 ha
Status and scale	Demonstration 50 TJ 1996 Potential 300 TJ/y	Demonstration	Research	Demonstration Bjästa 150 ODT/y
Handling	Cut and chip harvester, com- mercial vehicle transport to utili- sation plant	Shoot harvester, storage of shoots over summer, agr. wood chopper, tractor transport to plant	Grass mower, 500 kg square bale, commercial vehicle transport to powder production industry and to utilisation plant	Grass mower, 100- 200 kg bales, tractor transport, storage over summer, district heating plant
Utilisation process	CFB	Wood chip furnace	Powder burner	Straw furnace

#### 3.2 AGRICULTURAL ASPECTS

##### 3.2.1 Salix

In Sweden Salix is harvested during the months of December to April. Favorably the ground should be frozen and the amount of snow small. At 20 cm of snow there has been difficulties in the cutting operation and with more than 40 cm there are problems just advancing in the stand.

The yield of a mature and well kept Salix crop is at harvest time in the region of 80 wet tonnes, 40 ODT, per ha. The dry matter content is approximately 50 %. Snow and ice will lower the content. Depending on in what furnace the fuel is to be burned it may be of great importance not to mix in snow and frost.

The crop is standing up 5-8 m high, stems normally between 30 and 50 mm in diameter. During autumn and early winter most of the leaves have fallen off and are hence not included in the harvest.

During harvest there are two types of loss. One is dropped material and the other material left in stumps longer than the stump length wanted. The total loss in a few observations has been between 0,5 and 2,0 ODT per ha.

### 3.2.2 Reed canary grass

After several years of studies in harvesting grass for combustion during summer, today only delayed harvest, i.e. harvest during late winter or spring, is of interest. This is due to difficulties in getting the grass dry enough for storage before baling in the Swedish summer climate. When hay is made the farmers generally dry the grass through active ventilation in barns. This technique is because of the costs out of question for fuel production. Delayed harvest also implicate a smaller removal of plant nutrients and a better quality of fuel.

So far delayed harvest has only been evaluated as spring harvest. The reed canary grass has been harvested after the snow has melted away. In Sweden this normally means during March through May depending on where in the country. At this time the grass is totally dead and the D.M. content between 80 and 90 %, sometimes even higher<sup>13</sup>. At this content the plant is very brittle why the mechanical losses easily get very high. In the first studies, where ordinary hay making technique was used, the loss averaged 2 ODT per ha<sup>14</sup>. Today it is expected that the loss quite easily could be limited to on average 1 ODT per ha or less<sup>15</sup>.

Spring harvest has been practiced in full scale during five years. At the most some hundreds of ha totally have been harvested during one year, 130 ha on one farm alone.

### 3.3 TECHNICAL ASPECTS

#### 3.3.1 Harvesting

Table 3.2 Technical aspects of harvesting

Case	Salix, big scale Direct chopping to chips in the field	Salix, small scale Harvests of whole shoots	Grass, big scale Mower conditioner, 500 kg square bale	Grass, small scale Mower conditioner, 100-200 kg bales
Product form and D.M. content	Chips, 47-52 %	Whole shoots, 47-52 %	500 kg bales, 80-90 %	100-200 kg bales, round or square, 80-90 %
Technique	Cut and chip harvester, towed high-level delivery trailer or transport vehicle driven alongside, unloading into containers or in a pile, direct transport to utilisation plant with commercial vehicle	Selfpropelled (1 and 3) or towed (2) shoot harvester with storage, piles at field side (1 and 3) or all over the field (2), use of forwarder, storage of shoots near field over summer. Possibilities for unloading into vehicle driving alongside (1).	Grass mower, 500 kg square bale (Hesston 4800/4900), storage on farm over summer	Grass mower, 100-200 kg round and square bales, tractor transport, storage on farm over summer
Status of machines	Demonstration	Demonstration (1) and development (2 and 3)	Commercial	Commercial
Number of machines	Four models of harvester, totally four prototypes working in demonstration	Three models of harvester, one working in demonstration, two in development stage	Thousands of mowers, <50 balers, up to 20 years of age	Thousands of mowers and round balers, <100 square balers
Harvesting rate (example)	10-20 ODT/h at a yield of 30 ODT/ha	(1): 12 ODT/h at a yield of 30 ODT/ha (30 ODT/h if unloading while driving)	15-20 ODT/h at yields over 5 ODT/ha	Round: 5-10 ODT/h, Square: 15-20 ODT/ha (at yields over 5 ODT/ha)
Bulk density of harvested product	0,33 wet ton/m <sup>3</sup> (0,16 ODT/m <sup>3</sup> )	Not available	130-150 ODT/m <sup>3</sup>	Round: 70-100 ODT/m <sup>3</sup> Square: 130-160 ODT/m <sup>3</sup>

## Salix

The furthest developed technique for harvest of Salix, which also seem to be the cheapest, is the direct chipping. There are four prototypes working: the sugar cane harvester Austoft 7700, the Swedish Bender 85 kW and Bender 125 kW and field chopper Claas Jaguar 695 with a special developed Salix header. Other techniques, where the shoots are put down on the ground at least once and therefore need to be picked up again, tend to be substantially more expensive.

The chipping is done much cheaper than is chipping of logging residues. This is due to the fact that the material to be chipped is evenly distributed over the field in straight rows, easy to harvest without any crane or similar equipment. This means the chipper will operate at a constant high load a big part of time.

However, it might not be possible to use the direct chipping method in all applications. One reason is that the water content at harvest is rather high, too high for many boilers. By letting the Salix shoots dry in piles over summer the content of water will decrease. Another reason is that the market may not be able to accept all of the production during the period which is suitable for harvest. In such case there is a need for storage. If it is possible to store Salix chips over summer without negative effects are yet not known. Storage of wood chips in small scale is strongly advised against because of health hazards due to fungi spores.

The handling of whole shoots is so far not well developed. There is one prototype, the Swedish Empire 2000, with high capacity driving in the row. So far it has to stop for unloading which gives an overall capacity 60 % lower than that possible if unloading while driving in the row. After the shoots are stored in a pile, they have to be picked up, a technique not adapted to Salix at all. Today chippers and cranes from forestry are used.

Quite detailed data about the harvesting capacity are available<sup>16</sup>. They have been presented like the example in table 3.3.

**Table 3.3** Estimated capacity when harvesting Salix based on several field studies: example direct chipper with a trailer for containers, 35-38 m<sup>3</sup>, driven along side the harvester<sup>16</sup>

Stand, tonnes of fresh wood/ha	Speed, km/h	Harvest, ha/h	Harvest, tonnes of fresh wood/h	Harvest, tonnes of fresh wood per 12 h
30	8.0	1.1	34	320
40	6.0	0.8	34	320
50	5.5	0.8	39	370
60	5.0	0.7	42	405
80	4.0	0.6	45	430

### **Reed canary grass**

So far, in most cases mower conditioners has been used for cutting the grass, although they are actually too rough for the brittle material. The reason to use this machine is simply that it is available everywhere. Mowers without conditioning equipment has been tried out but does not work since there will be no swath formed of the stiff material. A selfpropelled windrower, 5,5 m wide, with a short finger bar worked very well. Also direct cutting field choppers can be used. Two important disadvantages with the chopped grass are low bulk density and dust.

The smallest loss of small pieces of the plant was achieved with the selfpropelled grass windrower. However, at this width, 5,5 m, the stubble was 40 mm longer and the losses in left lying straw bigger than with the 2,4 m disc mower (70 mm stubble length). The difference was calculated to correspond to 0,5 ODT/ha in losses.

### **3.3.2 Fuel Packaging**

Fuel packaging is used for one or more of the following reasons:

- Makes automatic handling possible and easier
- Lowers the cost for transport and/or storage
- Reduces the risk for dust explosion and fire, compared to the situation with powder
- Makes it possible to reach other markets, e.g. small scale plants, 0,01-1 MW, and big plants with milling equipment and powder burners

In Sweden a tax on coal used in district heating plants has made it profitable to exchange coal with wood powder. This has created quite a market for pellets, which are milled in the existing coal mills at the heating plants before burning. In 1991 the production of pellets in Sweden was some 10 000 tonnes per year. Today the production capacity for pellets has grown to over 500 000 tonnes per year. The fuel is pelletised because powder is more risky and more expensive to transport. Big volumes go by ship from the coast in northern Sweden to for instance Stockholm.

The capacity for briquettes, pellets and powder from biomass all together is in April 1996 over 1 million tonnes per year. Briquettes are mainly used in heating plants 1-10 MW.

The raw material was for a long period only dry by-products from the forest industry. Today most upgrading plants have a dryer so that they also can use wet raw materials, e.g. Salix. However, the drying is an extra cost. This is where reed canary grass may come in.

The ash content in pure wood is about 0,5 % of D.M. In reed canary grass it is between 2 and 12 % depending on among other things the soil type. Because of the higher ash content in the grass, at the moment it is believed that it is better to mix in a small portion of grass

in the wood rather than trying to market a pure grass fuel, at least concerning briquettes and pellets. Studies on the process and of the pellet fuel when mixing grass with wood is running 1996.

Salix has so far, from what is known, not been upgraded to briquettes or pellets.

**Table 3.4 Technical aspects of packaging<sup>17</sup>**

Case	Briquetting, 2 000 tonnes/year	Briquetting, 25 000 tonnes/year	Pelletising, 10 000 tonnes/year	Pelletising, 50 000 tonnes/year
Crop/material	Grass and dry forest products	Grass and Salix together with forest products	Grass and dry forest products	Grass and Salix together with forest products
Technique	On farm site equipment: one piston press 0,8 ton/h, 2 500 h/y, labor 2 000 h/y	Industry: six piston presses 0,8 ton/h, 330 days/y, 4-7 employees depen- ding on material	Small industry: one press 4-5 ton/h, 2 500 h/y, labor 8 000 h/y	Industry: two presses 5 ton/h, 330 days/y, 12-14 employees depending on material
Bulk density, m. c., %	550-650 appr. 10	550-650 appr. 10	600-700 appr. 9	600-700 appr. 9
Status of machines	Commercial	Commercial with forest products	Commercial with forest products	Commercial with forest products
Number of plants	None outside of the wood industry	13 + appr. 30 presses at wood industries	A total of 17 plants with capacities 10 000-65 000 ton/y	

A plant for powder production is described in part 4.3.5.

Small briquetting plants used on farm sites were tried on straw in the middle of the eighties, in Denmark also mobile ones. Under Swedish conditions they did not work very well. One reason was that the moisture content of the straw could not be kept low enough. Also, the briquetting presses had too many breakdowns, possibly as a result of the wet straw. These problems could be overcome. The cost for the machinery is quite high why there are very obvious advantages in running the briquetting on a bigger scale. The press should ideally work 24 hours a day and most of the year.

Handling spring harvested grass generally generates quite a lot of dust. When pelletizing the amount of dust spread can be reduced by using water sprinklers or steam and by mixing in other raw materials with the grass.

During the nineties a mobile pelletizing unit has been put together by a farmer in an area with big acreage of reed canary grass. For several reasons, not only technical, the unit has so far run very few hours.

The farmers cooperation in the most southern county of Sweden, Skåne, produce some 15 000-20 000 tonnes of straw pellets each year.

### **3.3.3 Transport**

#### **Small-scale transport**

Wood chips are transported on tractor trailers only in very small scale. During harvest specially designed tractor trailers are used to transport material from the harvester to field end or a nearby storage area. There are also tractor wagons carrying standard containers which on the road go by commercial vehicles.

All types of bales can easily be transported on traditional farm trailers for e.g. grain. However, the loads will be quite small. For that reason many contractors and farmers have used commercial trailers, usually 12,5 m of length. Combined with a trailer of 5 m - allowed vehicle length is 24 m - a load of square bales will be 15-17 tonnes. The commercial trailers are quite heavy, dimensioned for road transports at high speeds, why the use of them may lead to not wanted compaction and tracks.

Another alternative for short distances are the selfloading wagons for round and square bales that are available in many countries in Europe. The biggest of these have a load of 90 m<sup>3</sup> which for the most dense bales of spring harvested reed canary grass corresponds to 13 tonnes. One valuable advantage with these wagons are that they in short time both gather and load the bales in the field with the use of just one person and one tractor.

#### **Commercial transport**

##### *Salix*

In Sweden vehicles on standard roads may be up to a maximum of 24 m in length. On the best roads the total weight of the vehicle is allowable to be up to 60 tonnes. On these roads the axle weight, one axle and not driven, may be up to 10 tonnes. The maximum possible load is often in the region of 30 tonnes but varies with type of vehicle.

Just about all Salix chips go by standard 30 m<sup>3</sup> containers on commercial vehicles. This is a well developed system used when fetching wood chips from forest areas. Each vehicle takes three containers, one on the lorry and two on the trailer. The total load is approximately 33 tonnes (16,5 ODT).

There are also vehicles which take 120 m<sup>3</sup>. Since they must wait while being loaded they are not of interest during harvest. Besides that the load of 120 m<sup>3</sup> Salix chips would be too heavy to be legal. This type of vehicle fits in where there is some kind of terminal handling.

Whole Salix shoots should normally not be transported on roads. After storage over summer on or close to the field where it has grown it will be turned into chips. There are specially designed commercial vehicles for logging residues which could be used for whole shoots. They have a loading volume of 90 m<sup>3</sup>.

#### *Reed canary grass*

The commercial handling of reed canary grass is so far less than 1 000 tonnes per year. The grass marketed is used together with grain and rape seed straw in district heating plants in the size of a few MW each. The total amount of straw and grass burned in plants with a thermal effect bigger than 1 MW is approximately 10 000 ODT per year (150 000 GJ). Just about all of this is transported with farm tractors.

There is also a market for straw as forage and as bedding material, probably substantially bigger than the one for the fuel. To serve this market commercial vehicles are used. A 24 m standard vehicle can take a load of some 15 tonnes (15 % m.c.). A few contractors use vehicles specially adapted for square bales. These vehicles are loaded by a standard crane for forest logs mounted at the rear of the lorry. To be able to fill the 12,5 m trailer without disconnecting it from the lorry the floor on the trailer has been made hydraulically movable. There are also trailers with a lower load bed, 0,9 m above ground, than standard, which is 1,4 m. With this height it is possible to get an extra layer of bales put on top. With such a trailer connected to a standard lorry the total load on the vehicle can reach close to 20 tonnes (15 % m.c.).

The value of straw for feeding and bedding is bigger than is the value as fuel. The fuel value does not cover the cost for long transports. Therefore it fits best in local systems where the tractor alternative is most competitive. This has been showed to be the case for up to 30 or 40 km of one way transport<sup>18,19</sup>. If the use of commercial vehicles for transport of fuel grass and straw can be justified at all, the loading and unloading must be very efficient.

### **3.3.4 Drying and storage**

#### *Salix*

For, among others, economical reasons Salix chips should not be stored. The fuel should preferably go directly to the utilization plant, which today is usually the case. This is possible because the amount is small and serves as a complement to forest residues. If the volumes get big there will arise a need for storage since harvest is limited to the period December to April, maybe even a shorter period.



If the ambient air temperature exceeds 0° C chips of *Salix* should not be stored without treatment. In stacks of chips, 3 m high and 6 m long, continuous ventilation from Januari to May has proved to keep the hygienic quality in the fuel and also to somewhat lower the moisture content. Today the cost for ventilation and the price for the fuel in most cases makes it impossible to compete with other fuels<sup>20</sup>.

Storage of *Salix* chips over summer are at the moment being studied. No results are yet available.

Whole shoots of *Salix* can be stored over summer without big loss of dry matter and health risks, such as spore release. The dry matter content in the shoots will increase from 50 % to between 65 and 75 %<sup>20</sup>. If left also during autumn the D.M. content will decrease again due to rain. When storing logging residues in the forest the top of the piles are often covered with a paper material to prevent precipitation to penetrate the stack. This is made also with *Salix* shoots in an ongoing trial.

For drying of *Salix* chips techniques for forest residues can be used. The consumption of energy in conventional methods vary between 2 800 and 4 500 kJ/kg of water evaporated. There are other techniques with lower needs, for instance steam drying where 600-900 kJ/kg can be enough. As a comparisson, the loss of energy when burning wet fuel without condensing the water in the flue gas is 2 400 kJ/kg water<sup>12</sup>.

No data from drying trials with *Salix* are available.

#### *Reed canary grass*

So far, delayed harvest of reed canary grass has meant spring harvest. The harvest then appears at the end of the period when fuel for heating is needed. For that reason most grass has been stored until next autumn and winter.

One of the valuable advantages connected to spring harvested grass is that the possibilities to harvest the crop at a high dry matter content are good. Experiences so far indicate that generally it is possible to hold the content above 80 % and that it often will be between 85 and 90 %<sup>13</sup>. Referring to knowledge from storing summer harvested grass and straw, at these levels there should be no risc for mould during storage and thereby caused hygienical problems. No studies on this in spring harvested reed canary grass have been conducted.

To be correct, the accepted minimum D.M. content at harvest in many cases actually sets the limit for the start of the harvest. The higher the requirement in this matter, the shorter the period for harvest.

If the harvest is done during winter or very early in spring the average D.M. content will be lower than stated above. The variation within the material, as in a bale for example, will then also probably be substantially bigger. If the grass can be delivered and used directly after harvest the D.M. content is of less importance, provided the variation is of no complication.

Several farmers and also scientists have tried to store baled straw and grass outside. It has proved to be quite difficult to succeed in this. For big amounts, 1 000 tons, there is a technique used in United Kingdom and in Denmark where in principle the straw is used as building material for a storage. The pile of bales is so big that the damage of the bales in the top layer is accepted and looked at as marginal. There are also different alternative use for these bales.

In Sweden there is quite a lot of rain falling during July-December (300-500 mm). During the autumn there are one or more quite heavy storms. This makes it difficult to preserve a good quality of bales stored outside.

### 3.4 ENVIRONMENTAL ASPECTS

Table 3.5 Checklist on environmental aspects

Harvesting Machines	Salix cutter		Bale press
Impacts	Soil compaction: weight from 7 up to 16 t (16 t including trailer)		Soil compaction
Packaging Process			
Process	Briquetting	Pelletising	
Impacts	Dust, noise	Dust, noise	
Transport (farm)	Chips		Bale transport
Vehicle mass (t), estimated ground pressure, soil condition (dry, wet, frozen, variable)	Up to 20 t or more. Variable soil conditions, sometimes frozen		Tractor: 5-10 t. Trailer: 6-12 t. Usually dry conditions
Impacts	Heavy compaction		Heavy compaction
Transport (commercial)	Salix		Bale transport
Vehicles on fields	Sometimes		Seldom
Impacts	Heavy compaction		
Drying and storage	Salix chips		
Environmental and safety concerns	Health hazard		
Measures being suggested to reduce these impacts	Direct delivery		

### 3.5 ENERGY ASPECTS

In table 3.6 some examples of the energy consumption in the production are given. They should be treated just as examples and not used for further calculations.

**Table 3.6 Checklist on energy aspects. Notice that the figures are from different references and therefore not directly comparable.**

Harvesting machines	Claas Jaguar 695	Empire 2000	Big balers
Description	Self propelled harvester making wood chips	Self propelled harvester collecting whole shoots	By tractor trailed balers: round or square bales, 100-500 kg
Diesel use (example) - l/h - l/ODT of product	40 <sup>16</sup> 2.7 at 15 ODT/h	30 <sup>16</sup> 2.5 at 12 ODT/h	10-20 1-2
Packaging Process	Briquetting	Pelletizing	
Description	Piston press	Roller die press	
kWh electricity per ODT (example)	100 <sup>17</sup> (actually per tonne product)	120 <sup>17</sup> (actually per tonne product)	
Transport (farm)			Square bales
Diesel use, l/ODT of product transported, including loading and unloading (example)			4.6 l/ODT for 1 + 15 km, e.g. two cycles of loading and unloading <sup>11</sup> 0.8 l/km transport <sup>21</sup>
Transport (commercial)	Salix chips	Salix shoots	
Diesel use, (example)	0.5 l/km and vehicle <sup>22</sup> , 16.5 ODT/load equals 0.30 l/ODT and km	0.5 l/km + 4 l/load for loading <sup>22</sup> , 12 ODT/load equals 0.42 l/ODT and km + 0.35 l/ODT for loading	
Drying and storage	Wood chips <sup>12</sup>		
(example)	exhaust gas dryers 2.8-4.5 MJ/kg H <sub>2</sub> O other conventional techniques 2.8-4.5 - " - two effect dryers 1.7-2.7 - " - steam dryers 0.6-0.9 - " - dryers with heat pump 0.3-1.0 - " -		

The use of diesel and electricity is given quite little attention since it's effect on the overall monetary cost often is marginal. One mistake sometimes being made is to multiply the effect being necessary in a tractor or an electric motor with a figure for the fuel consumption per kW. For instance, a big square baler may need a 100 kW tractor. The fuel consumption is said to be appr. 250 g of diesel per kW and hour. So the calculated fuel consumption will be 25 kg/h (30 l/h) while it in practice most often is smaller than 20 l/h. The explanation is that 100 kW is the maximum effect necessary and that the average effect used is way under 100 kW.

The input/output ratio of the production is seen in table 3.7. Of great importance for the input/output ratio in energy terms is the amount of fertilizer used, the average net yield achieved with this amount of fertilizer and the size of material loss in the process.

In both the production of Salix and reed canary grass the input in the establishment is parted out over several years. This is an advantage of perennial crops.

Table 3.7 Energy input in energy crop production, GJ/ha and year as average over lifetime. Figures based on reference <sup>10,11</sup> and adjusted on net yield and use of fertilizer

Case	Salix chips	Reed canary grass bales
<i>Preconditions</i>		
lifetime (years)	25	10
harvest intervals (years)	4	1
fertilizer (N/P/K), average, kg/ha and year (N 43,2 MJ/kg; P 15,0 MJ/kg; K 9,0 MJ/kg)	80/10/25	80/10/25
yield (ODT/year as a mean of the crop lifetime)	10	7.5
net calorific value (GJ/ODT)	16.2	16.9
efficiency in burning (%)	90	90
Cuttings/seed	0.16	0.015
Fertilizer	3.8	3.8
Diesel for establishment, care and field clearing	0.73	0.56
Diesel for harvest	1.2	2.54 (transport included)
Diesel for transport, 30 km for Salix, 1+15 km for grass	1.86	
Indirect energy in machinery for establishment, care and field clearing	0.14	0.12
Indirect energy in machinery for harvest and transport	0.60	0.98
Added 10 % of indirect energy for maintenance	0.07	0.1
Total input exclusive of resources in energy production plant	8.56	8.12
Total output, thermal	145.80	114.08
Input/output (%)	5.87	7.12
Output/input ratio	17.04	14.04

### 3.6 ECONOMIC ASPECTS

There is a thesis coming up about the business economics in the production of Salix<sup>24</sup>. This will deal with all important questions about the production economy. There is a very detailed calculation model available. There is also a version of the same model for reed canary grass.

The economy is quite dependant on the net yield of the crops as well as of the amount of nitrogen fertilizer needed to achieve this yield.

A couple of examples of economic analysis are given in table 3.9. In these analysis the cost for labor and investments are included at their full rate.

The cost for tenancy of land is not included. At the moment the tenancy in Sweden varies between 0 and 250, maybe even more, ECU per hectar. This corresponds to between 0 and 1.5 ECU/GJ for Salix and between 0 and 1.9 ECU/GJ for reed canary grass.

The costs for fieldvisits, administration and marketing in table 3.9 has been fetched from two different sources and are actually not comparable.

#### Salix

The cost for producing Salix chips can roughly be divided like the following:

	% of cost
Establishment and plant protection	20
Fertilization	20
Harvest	30
Transport on road	20
Administration	10

There is a big investment in the beginning of the production. The income is distributed over a long time and every forth year. This puts special stress on the enterprice solvency. In Sweden this strain has so far been eliminated by a establishment grant which has covered the total establishment cost.

The costs for Salix cuttings is approximately 0.036 ECU/piece. 18 000 cuttings per hectar makes 650 ECU/ha. The Henriksson method for establishment is offered for 540 ECU/ha including cuttings.

The labor resource needed in Salix production is smaller than in grain production. Instead more services from outside the farming enterprice is needed.

**Reed canary grass**

The cost for producing bales of reed canary grass can roughly be divided like the following:

**% of cost**

Establishment and plant protection	10 (9)
Fertilization	25 (24)
Harvest	40
Storage	10
Transport on road	15
Administration	2

The reed canary grass seed is quite expensive compared to other grass seed. 1995 the cost was 11 ECU/kg. If seeding 15 kg/ha the seed cost will be 160 ECU/ha. There has been no grant for seeding reed canary grass corresponding to that for Salix.

**Table 3.8 Economical aspects. Notice that the figures are from different references and therefore not directly comparable.**

<b>Harvesting machines</b>	Salix direct chipper	Salix shoot harvester	Big square baler (Hesston 4800/4900)	Square and round baler, 100-200 kg bales
Contractor rates for harvesting (ECU/h)			Mowing: 40-50 (35 ECU/ha) Square: 100-120, Round: ca 50 Extra for chopping eq. 6-10 ECU/tonne	
Investment, kECU <sup>16</sup>	Austoft: 200 Claas: 210 Bender 125 kW: 63+tractor Bender 85 kW: 40+tr.	Empire: 120	Refer to commercial dealer	
<b>Packaging process</b> 1992 <sup>17</sup> 1996 <sup>42</sup>	Briquetting <sup>17</sup> 1: 2 000 t/y 2: 25 000 t/y	Briquetting <sup>42</sup> 8 000 t/y	Pelletising <sup>17</sup> 1: 10 000 ton/y 2: 50 000 ton/y (with dryer)	Pelletising <sup>42</sup> 25 000 t/y
Investment, total plant, kECU	1: 300 2: 2 500	235 (no build.)	1: 600 2: 4 500	1 200
Calculated cost, ECU/GJ	1: 3.3 2: 1.5	1.1-1.7	1: 2.0 2: 1.3	0.9-1.2



Transport (farm)			Square bales	Round bales
Calculated cost, (ECU/ODT of product transported)			Gathering of bales in field and transport 10 km to storage: 7.0 ECU/ODT 10 km transport to user: 6.6 ECU/ODT (1994) <sup>23</sup> 6.8+0.33/km (1990) <sup>19</sup>	Gathering of bales in field and transport 4 km to storage: 9.2 ECU/ODT 10 km transport to user: 8.7 ECU/ODT <sup>23</sup> (1994)
Cost of diesel	0.52 ECU/l (4.30 SEK/l)			
Transport (commercial)	Salix chips	Salix shoots	Square bales	
cost of moving product (ECU/ODT of product transported)	9.4 in 90 m <sup>3</sup> container, (30 km, 1993) <sup>24</sup> 4.6+0.13/km in container, 2.7+0.11/km in chip lorry (20 km, 1991) <sup>22</sup> 7+0.1/km (1990) <sup>19</sup>	3.5+0.13/km, 2.3+0.09/km if compacted (20 km, 1991) <sup>22</sup>	16.4+0.08/km (1990) <sup>19</sup>	
Cost of diesel	0.51 ECU/l (4.20 SEK)			
Annual tax on vehicle	appr. 4.800 ECU/y			

Table 3.9 Example of economic analysis of energy crop production, SEK/(ha year) unless otherwise stated<sup>24</sup>

Crop	Salix	Reed canary grass
<i>Preconditions</i>		
year of calculation	1993 (fertil. 1995)	1995
lifetime (years)	24	10
fertilizer (N/P/K), average, kg/ha and year	80/10/25	80/10/25
max yield from year no	8	3
harvest intervals (years)	4	1
dry matter content when fed into burner (%)	50	85
interest on top of inflation (%)	6	6
yield (ODT/year as a mean of the crop lifetime)	10.0	7.5
net calorific value at this D.M. content (GJ/ODT)	16.2	16.9
Crop establishment	672	341
Fertilization	991	915
Plant protection and weeds after establishment	80	0
Harvest	1 231	1 467
Storage	-	414
Transport, Salix 50 km, grass 20 km	672	518
Field clearing (perennials)	59	0
Fieldvisits, administration and marketing	480	85 (adm. deliv. only)
Tenancy for land	0	0
Tenancy for turnlands (10 % of cultivated area)	0	-
Total costs per ha, SEK/(ha-year)	4,185	3,740
Energy crop grants per ha	-	-
Net costs SEK/ODT	489	547
ECU/ODT	59.0	65.9
ECU/GJ	3.64	3.90
Market price of similar biomass to district heating plants (ECU/GJ) <sup>42</sup>	Average appr. 3.7 ECU/GJ (110 SEK/MWh) Interval 2.0-4.2 ECU/GJ	
Market price of coal to industry and to other than industry (ECU/ton and ECU/GJ) <sup>42</sup>	Ind.: 118 ECU/ton, 4.3 ECU/GJ Other: 200 ECU/ton, 7.5 ECU/GJ	
Market price of light oil to industry and to other than industry (ECU/ton and ECU/GJ) <sup>42</sup>	Ind.: 220 ECU/ton, 6.1 ECU/GJ Other: 420 ECU/ton, 9.8 ECU/GJ	
SEK/ECU (20th May 1996)	8.30	

## 4 UTILIZATION

### 4.1 OVERVIEW OF UTILIZATION

Case	<b>Salix, big scale</b> 140 MW Gasifier, forest fuel	<b>Salix, big scale</b> Chips directly to a 115 MW CFB, 2 000 ha	<b>Salix, small scale</b> Stored shoots, 4 MW chip furnace, 200 ha	<b>Grass, big scale</b> 30 MW powder burner, 2 000 ha	<b>Grass, small scale</b> 2 MW straw furnace, 200 ha
Status and scale	Research Potential 150 000 Odt/y	Demonstration 50 TJ 1996 Potential 300 TJ/y	Demonstration Såtenäs	Research Potential 30000 Odt/y	Demonstration Bjåsta 150 Odt/y
Energy crop	Not tested	Willow in mixture with forest fuels	Willow	Reed canary grass	Reed canary grass
Utilization Process	Pressurized gasification, Integrated Gasification Combined Cycle	Circulated fluidized combustion	Moving grates	Powder burner	Moving grates
Product	Heat and electricity	Heat and electricity	Heat	Heat	Heat
Production capacity	60 MW <sub>th</sub> , 59 MW <sub>el</sub>	80 MW <sub>th</sub> , 35 MW <sub>el</sub>	4 MW <sub>th</sub>	30 MW <sub>th</sub>	2 MW <sub>th</sub>

## 4.2 AGRICULTURAL ASPECTS

### 4.2.1 Salix

Table 4.1 Fuel characteristics for Salix dried in bundle and Salix direct chopping. The presented data are given in % of DM unless otherwise stated.

Parameter	Dried in bundle	Direct chopping
Gross calorific heat value, MJ/kg	19.6	19.5
Net calorific heat value, MJ/kg	18.4	18.3
Ash	2.1	1.6
Carbon	48	49
Hydrogen	5.9	6.0
Nitrogen	0.4	0.4
Sulfur	0.1	0.03
Chlorine	0.05	0.01
Volatile matter	-	82
Major inorganic elements:		
Potassium	0.47	0.20
Calcium	0.59	0.44
Magnesium	0.05	0.006
Sodium	-	0.003
Phosphor	0.08	0.05
Silicon	-	0.01
Minor elements µg/g:		
Cadmium	4.1	1.8
Lead	2.4	0.14
Mercury	<0.05	-
Zinc	11	75

The analyses<sup>48,49</sup> are unfortunately not from the same field and therefore there are difficult to make safe conclusions. There are generally not great differences in fuel characteristics of importance between dried Salix in bundles and direct chopped Salix. The ash content in Salix are comparable to forest fuel, but higher than for wood chips (from steam). The content of potassium in salix is rather high and it might cause problems with deposits in the boiler and in the particle reduction equipment. The content of cadmium is generally significantly higher compared to reed canary grass and forest fuels<sup>50</sup>. The calorific heat value in DM for salix is approximately 3 % higher than for reed canary grass but wood fuels have in average approximately 5 % higher calorific heat value in DM comparing to Salix. There are no available data for the ash fusion for Salix published at this time.

### **Influence of growing conditions**

Analyses on the ash formation elements from different growing places show no great variation, as most a factor 2. The analyses shows that the elements Mn, Si, Al, Cd and Na have variation higher than 50 %. Elements with variation less than 50 % are N, P, K, S and Ca.

#### **4.2.2 Reed canary grass**

The loss of nutrients in grass on the field during the winter reduce the ash content but the silica content increases. The delayed harvesting system improves the fuel quality in reed canary grass compared with harvest in late summer<sup>6,47</sup>. The great loss of chlorine and the increase of the ash melting point in the delayed harvested crop has significant importance for most combustion processes. Some of the investigated fuel parameters have shown insignificant differences between summer and delayed harvested reed canary grass. These parameters are calorific heat value, carbon-, hydrogen- and volatile matter-content. The contents of arsenic, cadmium, lead and mercury in summer and delayed harvested reed canary grass do not show high concentrations. However, there are a raising level during the winter period of arsenic- and lead content in delayed harvested grass.

Table 4.2 The influence of harvest time on fuel characteristics for reed canary grass. The presented data are mean values and standard deviations (in brackets) of recordings of 15 places throughout Sweden and 22 experimental years, % of DM unless otherwise stated.

Parameter	Summer harvest <i>July-October</i>	Delayed harvest <i>Mars-May</i>
Gross calorific heat value, MJ/kg	19.1 (0.91)	18.8 (0.85)
Net. calorific heat value, MJ/kg	17.9 (0.91)	17.6 (0.85)
Ash	6.4 (1.92)	5.6 (1.82)
Carbon	46 (1.20 )	46 (1.53)
Hydrogen	5.7 (0.30)	5.5 (0.26)
Nitrogen	1.33 (0.42)	0.88 (0.22)
Volatile matter	71 (1.9)	74 (1.0)
Initial ash deformation, ° C	1074 (61)	1404 (183)
Major elements:		
Sulfur	0.17 (0.05)	0.09 (0.02)
Chlorine	0.56 (0.27)	0.09 (0.07)
Potassium	1.23 ((0.46)	0.27 (0.17)
Calcium	0.35 (0.11)	0.20 (0.06)
Magnesium	0.13 (0.05)	0.05 (0.02)
Phosphor	0.17 (0.06)	0.11 (0.04)
Silicon	1.2 (0.65)	1.85 (0.77)
Sodium	0.02 (0.009)	0.02 (0.012)
Minor elements mg/kg		
Cadmium	0.04 (0.02)	0.06 (0.05)
Lead	1.0 (0.7)	2.1 (1.4)
Mercury	0.03 (0.01)	0.03 (0.01)
Arsenic	0.11 (0.03)	0.22 (0.13)

### Influence of growing conditions

Different soil types affects the uptake of ash formation elements significantly in reed canary grass. Plant materials grown on heavy clay soils gives the highest ash content in the crop. The content of humus in soil seam to affects the uptake of ash formation elements in grass. For plant material growing on humus rich soils the ash content is 2.5 times lower than the mean value of ash content from all field trials. It is to early to confirm the effect of the annual growing season on the uptake of ash formation elements in plant material but the influence of soil type seam to be most significant at the time.

Fuel characteristics for reed canary grass growing on humus rich soils are in most cases comparable to forest fuels - especially for the heat value, the ash content and the initial ash deformation temperature.

**Table 4.3** Mean values for characterization on reed canary grass compared with the most extreme differences in recorded plant materials from 14 places. The presented data are given in % of DM unless otherwise stated.

Parameter	mean values 15 places	clay soil	humus rich sand soil
Net. calorific heat value <i>MJ/kg</i>	17.9	16.6	19.3
Ash	5.6	10.1	2.2
Sulfur	0.09	0.10	0.10
Chlorine	0.09	0.10	0.05
Potassium	0.27	0.30	0.12
Calcium	0.20	0.17	0.15
Magnesium	0.05	0.06	0.04
Silica	2.1	3.2	0.56
Initial ash deformation °C	1 404	1 540	1 220

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### 4.3 TECHNIQUES/TECHNOLOGIES

#### 4.3.1 Grass in a 2 MW<sub>th</sub> district heating system

##### Description of the plant

The district heating plant is owned and operated by three farmers. It was build in 1992 and delivers heat to the community Bjästa, 20 km south of Örnsköldsvik. The main fuel are dry wood chips from saw mills. The investment costs is approximately 650 kECU. During 1995 and 1996, 200 tons of reed canary grass (1 500 GJ) have been burned in the heating plant. The installed power capacity on the boiler is 2MW<sub>th</sub> and the annual use is approximately 5 000 h. The grass roundbales are cutted in a fraction between 50-150 mm. Normally the moisture content is around 15 % for the used fuels, and the allowed moisture interval for the boiler is 10-35 %. The combustion furnace has moving grates. The fluegas is cleaned from particles by a multicyclon. The ash is handled in wet conditions (water bath) and the ash material is screwed from the boiler to a container.

##### Experience burning reed canary grass

Comparing to wood fuel there are no technical problems of importance burning reed canary grass, except for a higher amount of ash and unburned material in the end of the grate<sup>51</sup>. However, mixtures of reed canary grass and wood chips gives less of these problem. The emissions are totally lower using reed canary grass in mixtures with wood chips. No problem with sinder ash or ash deposits has been registered in the boiler using delayed harvested reed canary grass. Earlier tests with summer harvested grass gave problems with soft deposits (probably KCl) on the convection parts.

Using only reed canary grass the emissions of NO<sub>x</sub> and particles are significantly higher than for wood chips. Emission for wood chips have the following values: NO<sub>x</sub> 38 mg/MJ, particles 61 mg/Nm<sup>3</sup> at 13 % CO<sub>2</sub>. The higher NO<sub>x</sub> emission comparing to wood chips (table 4.4) is probably caused by higher nitrogen content in reed canary grass.



Table 4.4 Testing values from combustion with reed canary grass (18 % moisture content)

Parameter	
Power at measuring period	1 600 kW <sub>th</sub>
Particles	105 mg/Nm <sup>3</sup> 13 % CO <sub>2</sub>
NO <sub>x</sub>	213 mg/MJ
CO	28 ppm
O <sub>2</sub>	8.7 %
CO <sub>2</sub>	11.7 %
Efficiency	89 %

#### 4.3.2 Salix in a 4 MW<sub>th</sub> heating system

##### Description of the plant

The district heating plant is owned by VL-Energi. It was built in 1992 and delivers heat water to Sätenäs military air base near the city of Lidköping. The investment cost is around 1 500 kECU. The main fuels is straw, dry wood chips and willow. The installed power capacity of the boiler is 4 MW<sub>th</sub> and the furnace has moving grates. The construction is nearly the same as in Bjästa. The fluegas is cleaned from particles with a multicyclon and textile filter. The ash is handled in wet condition (water bath) and the ash material is screwed from the boiler to a container. The straw bales, HD-bales and round bales, are cut in a fraction between 50-150 mm. Putting chips of willow or wood on top of the HD-bales is the method used for mixtures of other fuels with straw.

##### Experience from burning of willow dried in bundles

Willow as fuel is possible but some problems in combustion have occurred during the test period<sup>52</sup>. Deposits in the furnace and on the convection area have been noticed. Volatile inorganic compounds such as K and Cl evaporates in combustion and condense on cooler areas. These substances (sublimates) also causes problems stocking the textile filter. In the furnace problem exists to reach a glowing fuel bed in the end of the grate. It probably depends on the high volatile matter content in willow fuels. Most of these problems are solved when willow is used in mixtures with straw. The burning test of Willow gave low emissions (table 4.5).

Table 4.5 Testing values from combustion with Willow (moisture content 26 %)

Parameter	
Power at measuring period	2 800-3 100 kW <sub>th</sub>
Particles	
- after cyclone	330-410 mg/Nm <sup>3</sup> dg 13 % CO <sub>2</sub>
- after textile filter	7 mg/Nm <sup>3</sup> dg 13 % CO <sub>2</sub>
NO <sub>x</sub>	70-90 mg/MJ
CO	60-200 mg/MJ
O <sub>2</sub>	6.5-7.1 %
CO <sub>2</sub>	13.4-14.0 %
Furnace temperature	700-740 °C
Flue gas temperature	140-160 °C
Efficiency	84 %

#### 4.3.3 Large scale combustion of willow chips

##### CFB-power and heating plant in Örebro

The CFB boiler was put into operation in 1989 and is one of the largest CFB-plants for biomass in Europe<sup>53</sup>. The useful effect is 165 MW (50 MW<sub>el</sub> and 110 MW<sub>th</sub>). The annual production of electricity is 840 TJ respectively 1750 TJ of heat. The efficiency is totally 90 % and for electricity only, 27 % net power. During 1993, the delivered amount of energy was 3 040 TJ to the CFB-plant. The distribution ratio for the used fuels was following in 1993: 220 TJ coal, 1 400 TJ peat and 1 400 TJ forest fuels. The annual use of the plant is 5300 h. To reach full power (100 %) in the boiler with wood fuels it is necessary to use 30 % coal, peat or oil as additional fuel. If 100 % of forest fuels or willow fuel is used the maximum power is decreased to 115 MW<sub>th+el</sub>.

Today there is approximately 2 000 ha of willow growing within 30 km radius from the Örebro power/heating plant. Willow have been tried as fuel in mixtures with forest fuels. During 1996 approximately 50 TJ of willow was delivered to the CFB-plant in Örebro. No technical or environmental problems have been registered using willow in mixtures with forest fuels.

Table 4.6 Environmental comparisons made between the different parts of the fuel chains for 100 % use of willow/forest fuel and coal (mg/MJ)

Emission	Forest fuels/willow	Coal
Sulfur (S)	3	50
Nitrogen (NO <sub>x</sub> )	40	40
Paricels	<10	<10
Nitrogen (N <sub>2</sub> O)	25	70
Carbondioxid (CO <sub>2</sub> )	0	92 000

Use of biofuel has several advantages compared to coal with regard to environmental aspects. A major advantage of biofuel is found in the greenhouse gas problem.

Combustion of biofuel give, in contrast to coal, no net emissions of carbon dioxide.

#### 4.3.4 Reed canary grass as fuel powder in a 30 MW<sub>th</sub> district heating system

##### Description of the plant

Reed canary grass has been used in a full scale milling trial and in a full scale combustion test in a 30 MW<sub>th</sub> powder fired boiler<sup>54</sup>. This heating plant was originally built for combustion of oil and later converted to solid pulverized fuels (coal, peat, oliveseeds, and wood powder).

##### Full scale milling trial

The experimental tests show that spring harvested and field dried reed canary grass (moisture content approximately 10 %) can be used as a raw material for powder manufacturing. It can be milled, handled and stored the same way as wood powder. The moisture content of the grass powder was 8.4 % with a variation (st dev.) of 0.55 %. The drying effect of milling was 1.4 %. The wood powder used as reference fuel has a moisture content of approximately 9 % which is optimal for the 30 MW<sub>th</sub> boiler used.

##### Full scale combustion

The reed canary grass powder was transported to the heat plant by road, (big lorries), and stored for a short time before further transportation to the burners. No specific problems could be seen. At the test 55 tons of reed canary grass powder was used, which was sufficient for about 9 hours of combustion. The combustion parameters for the boiler were set the same way as when burning wood powder. The test was short, but it can be stated that reed canary grass can be combusted without trimming the boiler. This was better then expected. The CO-content of the flue gas was relatively stable with a mean value over the hour of 150 ppm at remarkably low 1.6 % O<sub>2</sub> content (4.5 % O<sub>2</sub> for

wood powder). Besides showing that reed canary grass has combustion properties similar to wood, the test also showed that it is possible to produce a fuel with an even quality and satisfying fluid properties from reed canary grass. This can be confirmed since the systems for powder fuels are sensitive to fuel variations.

Two problem areas were noted during the test.

Ash properties: Powder from reed canary grass contains ten times much ash as wood powder. The grass ash has a high silica content, which gave soft fluffy deposits at some positions in the boiler and on the convection surfaces. The ash does not show any tendency to melt so it seems like conventional soot blowing techniques can be used to deal with the problem. There were also problems transporting the ashes out of the electric filters caused by the large volumes of ashes. The unburned material in the ash was 7.7 %. (23 % for wood ash)

NO<sub>x</sub>-emissions: Reed canary grass powder gave fairly high emissions of NO<sub>x</sub>, 210-290 mg/MJ, compared to the wood powder quality with the lowest NO<sub>x</sub>-emissions. The best wood powder from this point of view, emitted 70-100 mg/MJ. Reed canary grass has a higher content of nitrogen than wood, but this is probably not the only explanation. The test was too short to optimize the powder fraction in the mill to the burner.

The disadvantage of using reed canary grass or wood powder in a converted oil fired boiler is the reduced power for the boiler.

#### 4.3.5 Production of fuel powder from reed canary grass

Trials have shown that cutting and fine cutting of reed canary grass bales can be done with sufficiently high capacity using commercially available equipment<sup>55</sup>. The trials also show that there is no technical problem to finegrind field dried spring harvested reed canary grass. The powder shows a size distribution similar to commercial wood powder. The lowest total consumption of electricity for the production of powder from reed canary grass is approximately 1.7 % of the energy content in the grass.

Laboratory trials have shown that powder from reed canary grass in most cases has 10 - 15 % lower bulk density than wood powder. Powder from reed canary grass and wood has similar flowing properties.

The powder production costs are low for reed canary grass depending on the dry raw material, which eliminates the expensive drying process. The production cost for commercial wood powder is approximately 5.6 ECU/GJ, raw material included. For reed canary grass the powder production cost is between 0.7-0.8 ECU/GJ at 5 000-7 000 h annual production time. If the cost for the raw material (grass bales), 3.8-4.9 ECU/GJ, is added to the production cost, the total cost equals 4.5-5.7 ECU/GJ. The corresponding price for energy coal to other costumers than industry is appr. 7.5 ECU/GJ<sup>42</sup>.

**Table 4.7 Costs for powder production from reed canary grass in a existing available part of or whole industrial building<sup>55</sup>**

**Preconditions**

Investment in machinery and other equipment and installation 730.000 ECU

Annual production: 5 t/h, 5000 h per/year = 25.000 t /year.

**Costs, ECU/y**

	Pay off period	
	5 years	10 years
Capital cost	191.600	118.000
Wages	103.000	103.000
Electricity	48.000	48.000
Maintenance	25.000	25.000
Machinery rent	15.000	15.000
Total	382.600	309.000
ECU/t	15.3	12.3
ECU/GJ	0.90	0.74

#### 4.3.6 Pressurized gasification of biomass

Based on prestudies of different power generation technologies the IGCC (Integrated Gasification Combined Cycle) based on air blown gasification with hot gas clean-up and combined cycle was found to be one of the most promising technologies for power production from biofuels. The IGCC for biofuels is a new technology with several unproved process steps. To verify the performance of the critical process steps an extensive testprogramme has been carried out covering all aspects of a biomass fuel based IGCC<sup>57</sup>.

The most extensive program has been carried out concerning gasification and gas cleanup. The produced gas must contain a low content of dust, chlorine and alkali metals to prevent erosion and corrosion on the gas turbine.

The tests have been performed on wood fuel in a 400 kW<sub>fuel</sub> laboratory gasifier and in a 15 MW<sub>fuel</sub> pilot plant and also combustion of low calorific gas in a gas turbine combustor. The results from this tests gave the following conclusions:

- Steam drying of the fuel is possible to use without any technical problems.

- The ceramic high temperature filter has showed very good cleaning effect on alkali and dust which are at the level of demands from the gas turbine (used in this test) manufacture.
- The produced gas has a heating value of 4-6 MJ/Nm<sup>3</sup> which is enough for the gas turbine combustor used in this test.
- Most of the fuel bound nitrogen (60-80 %) is converted to ammonia in the gasification process. Partly (25-50 %) of the produced ammonia is converted to nitrogen oxides at combustion in the gas turbine. The calculated NO<sub>x</sub>-emission based on the trials are between 80-130 mg/MJ. This values have been reach using biofuels with 0.2-0.5 % nitrogen in DM.
- The ash from the gasifier is suitable for fertilization
- Willow has not been tested as fuel using IGCC technology

The IGCC plant based on biofuels with an estimated effect of 140 MW gives following distribution of power:

Electricity	59 MW
Heat	60 MW
Efficiency electricity net	42 %
Total efficiency net	85 %

The areas which can be pointed out for further development are the decomposition of ammonia in the fuel gas, conversion of ammonia in the gas turbine, methods for measurements of alkaline, long-term performance for the ceramic filter candles and further development of the feeding system for reduction of the inert gas consumption.

## **5 CONCLUSIONS AND RECOMMENDATION**

The conditions in Sweden for development and increase of the use of biomass in general is at the moment favorable. This is for one reason due to heavy taxation of fossil fuels in the sector for consumers other than industry and producers of electricity. There are also several activities on developing the utilization of biomass for production of electricity in new and more efficient processes.

The interest for increased use of biomass is high. The political ambitions are also high. At the same time, there are powerful parties with the opinion that a conversion to biomass to a large extent will lead to an unacceptable increase of the price of electricity.

The biggest potential is in wood fuel from forestry. There are 23 million hectares of forest land in Sweden, while less than 3 million hectar arable land. There is an old tradition of utilizing the energy resources in forestry within the forest and pulp industry. Also, the possible production of fuels in agriculture is substantial. However, the interest for these fuels at the moment comes in second place.

One important goal to achieve is to get an acceptance for energy crops from both farmers and costumers. At present, the market hesitates because it doesn't trust agriculture's possibilities to reliable deliveries. At the same time the farmers hesitate because they see no market for the agricultural fuels. At last, it all comes down to if there is a sustainable economy in the production or not.

### **5.1 CROP PRODUCTION**

#### **Salix**

Continued efforts must be done in breeding concerning frost tolerance and resistance to rust attacks. From an agronomic point of view the research and development must focus on methods for weed control as well as nutrient balance studies to get a better knowledge about the need of nutrients in different soils in different regions of Europe. The water requirements for production in different soils in different regions of Europe is also of vital interest for the further development of this crop.

The longtime yield of this crop is also of importance to follow - up as all calculations are based on a cropping time of 24 years.

Research and development for improved technology for establishment of plantations are also important to decrease the plantation costs.

**Reed canary grass**

Breeding efforts to get varieties suitable for energy purposes must increase and develop varieties for different regions of Europe. The most important goal in this is to increase the stem yield compared to the very leafy varieties now available for forage purposes. Other important goals for both breeding and production are to get a better understanding of the silica uptake to get varieties and production technology to decrease the silica content. Nutrient balance and water requirement studies are also important for evaluation of growth and fuel quality on different soils in different climates.

**5.2 HARVESTING AND PROCESSING****Salix**

The direct chipping method is now developed and used commercially in Sweden. If the soil is not frozen during the harvesting and utilization period, or if the use of willow chips will increase largely without cocombustion possibilities with wood fuels, also the whole shoot harvesting technology must be improved.

**Reed canary grass**

The mechanical losses at harvest need to be lowered from tonnes per hectare to some hundred kg.

The harvesting and handling system with bales represent a large portion of the total fuel cost. Alternative technologies without baling need to be evaluated. One such technology is direct cutting and storing outdoor in very large piles in or close to the field. The cut material is compacted only under transportation to the customer. Another interesting alternative is the compact roller technique developed in Germany.

The variation in harvest conditions and harvested amount of fuel between years need to be examined. Handling and market systems which compensate for the biggest variations need to be developed.



### 5.3 UTILIZATION

#### **Salix**

Energy production from fuel produced by the direct chipping method is working well in cocombustion with wood fuels. If burned as pure fuel, some severe disturbances has been reported in conventional boilers. One problem registered is the high moisture content. This problem can be met by cocombustion. Still, there is a need for further research on fuel characterization to make it possible to develop a better burning technology.

#### **Reed canary grass**

The fuel produced with the delayed harvesting method is very dry. This means that the fuel is very suitable for upgrading to briquettes, pellets and to fuel powder. In combustion, the high ash and silica content can cause problems with loose ash deposits in parts of the boiler. Development of cocombustion technologies with other fuels is one important way to solve this problem. Another way is to develop boiler systems which can handle this silica problem.

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