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IEA Bioenergy: Task 17

Short-Rotation Crops for Bioenergy

Proceedings of the Third Meeting of IEA, Bioenergy, Task 17 in Auburn, Alabama, U.S.A., September 6 9, 1999

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Preface

These proceedings are the results of the third meeting of Task 17 (Short-Rotation Crops for Bioenergy) within the framework of International Energy Agency (IEA), Bioenergy. (Minutes from the meeting can be seen at page 91.) The meeting was held in Auburn, Alabama, USA, September 6–9, 1999. The meeting was held soon after President Clinton of the United States signed Executive Order No.13134: DEVELOPING AND PROMOTING BIOBASED PRODUCTS AND BIOENERGY on August 12, 1999. Executive orders in the United States are official documents, through which the President of the United States manages the operation of the Federal Government. This order outlines the administration’s goal of tripling the use of biomass products and bioenergy in the United States by the year 2010. During the time of this meeting, it was also known from sources in Europe that the European Union (EU) commission was working on draft instructions to its member countries on how to increase the use of renewable energy from six to twelve percent in Europe within 10 years.

Task Objectives

The objectives of Task 17 support the goals of member countries for bioenergy production and use. These objectives are as follows:

- to stimulate the full-scale implementation of energy crops in the participating countries
- to strengthen the contacts and co-operation between participating countries, scientists, biomass producers, machine developers, entrepreneurs, and end users to select the most urgent research and development areas and suggest projects of co-operation
- to inform Ex-Co- members
- to deliver proceedings from the meetings

Task Organization

The Operating Agency for the Task is The Swedish National Energy Administration represented by Dr. Lars Tegnér and Dr. Björn Telenius.

The Task leader is Professor Lars Christersson, Swedish University of Agricultural Sciences, Uppsala, Sweden.

The country participation in Task 17 at the time of the meeting included Australia, Canada, Croatia, Denmark, France, Italy, The Netherlands, Sweden, the United Kingdom, the United States, and the Commission of European Communities (CEC).

The representatives of member countries were

Australia	Dr. Stephen Schuck
Canada	Dr. Andy Kenny
Croatia	Dr. Davorin Kajba
Denmark	Dr. Uffe Jörgensen
France	Dr. Hilaire Bewa
Italy	Dr. Georgio Schenone
The Netherlands	Dr. Leen Kuiper
Sweden	Dr. Lars Christersson
United Kingdom	Dr. John Seed
United States	Dr. Lynn Wright
The CEC	Dr. Ann Segerborg-Fick

Task Meetings

The following meetings have been held with these listed published Proceedings:

1. Uppsala, Sweden, June 4–6, 1998
   Proceedings: IEA, Bioenergy, Task 17: Short-Rotation Crops for Energy Purpose. Editors, Lars Christersson and Stig Ledin. Department of Short Rotation Forestry, Box 7016, SLU, 750 07 Uppsala Sweden. Rep 64. 1999.

2. Laguna, Los Banos, The Philippines, March 3–9, 1999.
   Proceedings: IUFRO, Division 1.09 and IEA, Bioenergy Task 17, Joint Meeting on Short Rotation Forestry. Editor, S. Saplaco. Institute of Renewable Natural Resources, University of the Philippines Los Banos, College, Laguna, Philippines.

3. Auburn, Alabama, USA, September 6–9, 1999.
   Proceedings: IEA, Bioenergy, Task 17. Short-Rotation Crops for Bioenergy. Editors, Lars Christersson and Lynn Wright (this issue.)

4. Albany, Western Australia, March 5–10, 2000.
   Proceedings: Manuscripts submitted. Editor, John Bartle.

Acknowledgments

The September 6–9, 1999, meeting of Task 17 members was hosted by Dr. David Bransby of Auburn University and organized by Wilma McNabb of Oak Ridge National Laboratory. In addition to the papers and topics included in this proceedings, there were several presentations given on short-rotation crops research being performed by scientists at Oak Ridge National Laboratory and Auburn University. The tours organized by Dr. Bransby included a visit to a biomass waste burning facility, a tour of a co-firing test facility, a tour of switchgrass planted on farmland in Alabama, and a tour of the Auburn Herbaceous Crops field research plots. Our thanks are expressed to Dr. David Bransby and Wilma McNabb for a well-organized and interesting set of meetings and tours.

Editors

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Meeting Photographs

Participants on the field tour of Auburn University agricultural research plots, September 7, 1999.

Dr. David Bransby explains results of mimosa research to tour group.

Dr. Bransby describing switchgrass scale-up efforts to tour group.

Dr. Bransby describing differences among herbaceous crop species on Auburn University small plot trials.

Prospects for Bioenergy from Short-Rotation Crops in Australia

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Introduction

Australian Biomass Taskforce and Australian IEA Bioenergy Task 17 Collaborators' Group

The Australian Biomass Taskforce (www.users.bigpond.com/steve.schuck/abt) was formed by a group of Federal Government organisations wishing to promote and foster a biomass energy industry in Australia. Incorporated in the Memorandum of Understanding that set up the Taskforce was the clear intent of participating in IEA Bioenergy. Funding support for participation in IEA Bioenergy Task 17, *Short Rotation Crops for Bioenergy*, was obtained through the Joint Venture Agroforestry Program, administered by the Rural Industries Research and Development Corporation. An Australian IEA Bioenergy Task 17 Collaborators' Group was formed, including the Western Australian Department of Conservation and Land Management, Victorian Department of Natural Resources and Environment, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Forestry and Forest Products, Forest Products Association of New South Wales, State Forests of New South Wales, Queensland Department of Primary Industries, and the Biomass Taskforce.

The role of the Biomass Taskforce in Task 17 is that of convenor and facilitator of the Australian Collaborators' Group. Purpose-grown biomass for energy and residues from short-rotation crops are seen to be important for a biomass energy future. Values that should flow from the broader adoption of biomass are increased jobs (particularly in rural areas), industry development, landcare (salinity and erosion control), provision of energy in a responsive and flexible manner, greenhouse friendly electricity and energy, and a lesser impact on the local environment. The outcomes the Biomass Taskforce wants are an increased awareness, understanding, and adoption of biomass energy in all its forms, including that from short-rotation forestry and crops.

Bioenergy in the context of Australia's National Greenhouse Strategy

Australia (current population 19 million) has an abundance of energy resources that have influenced the structure of the economy and trade profile, a dispersed population with a consequent high dependence on fossil fuel based transport, and a relatively fast rate of population growth. Australia's total energy consumption has increased on average by 2.6% per annum over the last 25 years and was estimated to be 4 810 PJ in 1997/98. In 1997/98, energy consumption was dominantly across three major sectors: electricity generation (28.3%), transport (25.2%), and manufacturing (24.9%) and was sourced from oil (34%), black coal (29%), natural gas (18%), brown coal (13%), and renewables (6%). In 1997/98, Australia had an approximate trade balance in oil, gas, and petroleum products, but was a significant net exporter of energy, mostly as black coal (4 613 PJ) and uranium (3 015 PJ).

Australia contributes only approximately 1.4% of global greenhouse gas emissions, but per capita emissions rank third amongst industrialised countries. Excluding that associated with land clearing, Australia's annual net greenhouse emissions increased by 8.9% from 385 Mt CO_2-e in 1990 to 419 million Mg CO_2-e in 1996. In 1996, emissions were distributed amongst the sectors (Mt CO_2-e): Energy (331.8), Industrial processes (9.2), Agriculture (84.3), Waste (16.7), and Forestry & Other (but excluding land clearing) (–22.7). The dominance of the energy sector in emissions (79% of total), particularly that from stationary sources (55%), which includes power stations, is evident.

In the absence of measures to reduce emissions of greenhouse gases, Australia's emissions are projected to be approximately 552 million Mg CO_2-e in 2010, a 43% increase from 1990 levels. As a result of the Kyoto Protocol, developed countries, as a whole, will strive to reduce their greenhouse gas emissions from 1990 levels by at least 5% in the period 2008–2012. Australia's requirement is to limit its net greenhouse gas emissions in the first commitment period to no more than 8% above 1990 levels.

Interest in renewable energy sources in Australia is largely driven by a need to respond to greenhouse issues and to promote technological development rather than energy availability and energy costs. Particularly, the Prime Minister's November 1997 statement, *Safeguarding the Future: Australia's Response to Climate Change,* included mandatory targets for electricity retailers and large electricity purchasers to source an additional 2% of their electricity from renewable or specified waste product energy sources by 2010. Amongst several objectives of this measure is the development of internationally competitive industries which could participate effectively in the Asian energy market.

The additional 2% renewables target has stimulated electricity suppliers to develop *Green Power* schemes whereby consumers may choose to purchase electricity generated from renewable energy sources. A national accreditation system has been developed for this purpose. An emphasis in *Green Power* schemes is the development of new generators, and by the end of 1999 at least 60% of such power must be obtained from generators installed after January 1997. This required minimum proportion will rise to 80% from July 2001. Retail premiums for *Green Power* are typically 3 cents/kWh above current grid-electricity prices of approximately 10 cents/kWh.

In 1995/96, energy production from renewable sources in Australia was approximately 263 PJ (compared with total primary energy demand of 4495 PJ) and was dominated by (PJ): bagasse (90.3), residential wood (82.1), macro-hydro (54.8), industrial wood (27.6), landfill and sewage gas (3.8), and solar water heaters (3.7). The share of renewable energy in national electricity production was approximately 10–11% in 1996–97. Under the additional 2% renewables target, approximately 10 000 GWh/year (36 PJ/year) electricity will be required from renewable energy sources in 2010, representing an increase of over 55% in renewable energy electricity production from the 1996–97 level. The potential increase in renewable capacity from using current identified renewable sources is estimated to be insufficient to reach the 2% target, so more new investment in renewable sources will be required. The ranges of renewable energy sources, including hydro, wind, solar voltaic, solar thermal, biomass, municipal solid waste and wastewater, marine, and geothermal, have been recently analysed as to their potential to contribute to the 2% renewables target (REM 1999a, b). The biomass sources include bagasse, pulping liquor from paper production, forestry residues and wood processing residues, energy crops, crop residues, and wet wastes from agriculture and food processing. The analyses concluded that biomass energy sources have the potential to contribute significantly to the 2% renewables target.

This paper considers biomass sources from short-rotation crops that are presently used operationally or are under investigation for energy production in Australia. There appear to be no schemes in Australia where bioenergy from short-rotation crops (agricultural or silvicultural) is the sole or principal product. This is not surprising because of the relatively low economic cost of energy from other sources. Most of the current work is concerned with biomass residues or by-products from crop growing or crop processing. In this paper, emphasis will be given to those residues which are or have an economic prospect of being harvested and brought to an energy generation facility.

Agricultural Crops

In Australia, several analyses of the potential of agricultural cropping residues, particularly straw and stubble from cereal cropping, have concluded that this is a relatively large resource, but because of the cost of collection and transport, bioenergy production using this material is economically uncertain if not unviable. In contrast, residues from processing agricultural crops, particularly where it is necessary to bring large quantities of biomass to a mill may be economically more attractive. However, the seasonality of supply of crop-growing or crop-processing residues may be a limitation to efficient use of a generating plant unless stockpiling is feasible or alternative off-season fuel sources are available.

Three biomass sources from agricultural crop-processing residues are considered in the following sections. This is not an exhaustive analysis of such residues, but represents a very wide range in potential to contribute to renewable energy generation in Australia.

Sugar cane

The Australian sugar cane industry is based largely on the eastern seaboard with 28 mills between Lismore (New South Wales) and Cairns (Queensland). In 1996, bagasse (the residual fibre from raw sugar processing) yield totaled 11.4 million Mg fresh weight (FW). Bagasse currently provides 90 PJ or about 2% of Australia’s total primary energy demand. The energy is used to work the processing machines, provide processing heat, and for electricity co-generation. Bagasse is available for about half of each year during the harvesting and crushing season (June to November). Estimated current electricity exports range from 170 to 250 GWh.

Further development of this renewable energy resource depends on greater use of bagasse and cane trash (currently only 50% of cane biomass is collected), technology development (including gasification), and obtaining alternative fuels in the off-season. With the application of advanced conversion technologies to bagasse and harvest residues, the current cane crop could generate an estimated average 3400 MW electricity (20 722 GWh/year) of power. This would give a CO_2 reduction of 16.5 million Mg/year or nearly 10% of the total Australian greenhouse gas (CO_2-e) emissions from stationary energy plants.

Sugar cane is one of the lowest cost (delivered) forms of biomass and, if fully developed in Australia, could alone meet the entire additional 2% renewables target. However, an outstanding issue is whether there will be regional or state targets set within the national target.

Cotton

The Australian cotton growing industry is largely based in northern New South Wales and southern Queensland. Cotton processing residues are estimated to be approximately 1 million Mg/year at a number of gins. Gasification using cotton-gin residues appears to be competitive at a small scale, and the maximum generation potential is estimated to be 50 MW of electricity.

Rice

The Australian rice-growing industry is centered on Deniliquin in southern New South Wales and relies on irrigation. There are approximately 100 000 Mg/year of rice hulls available from rice cleaning, and while this biomass could support approximately 5 MW of electricity generating capacity, the economic viability is disputed.

Silvicultural Crops

As in agriculture, in forestry analyses of biomass sources, such as silvicultural residues (e.g., non-commercial thinnings), harvesting residues (e.g., wood which is currently non-merchantable), and timber processing residues (e.g., sawdust) have been conducted. These biomass sources are more relevant to IEA Bioenergy Task 18 *Conventional Forestry Systems for Bioenergy* and will not be dealt with in any detail here. However, it is useful to note that public perceptions of intensification of harvesting to collect silvicultural and harvesting residues from native forests will in Australia be inextricably linked with issues of timber harvesting from these forests per se (including the emotive issue of ‘woodchipping’), perhaps to the extent that accreditation of such biomass sources for *Green Power* schemes may be difficult. In contrast, intensification of harvesting from plantations, in a similar way to that for agricultural crops, should be dominated by technical issues of sustainability (e.g., Brand 1998) particularly with respect to protection of soil and water resources.

The use of short-rotation forestry crops for bioenergy in Australia is largely under-explored. It is recognised that the economic viability of bioenergy projects is strongly dependent on the cost of the feedstock and the revenue gained from the energy-based product. Considering that some forest companies, along with electricity generators and steelmakers, are actively exploring the options for producing electricity and charcoal, respectively, from forest biomass, it is pertinent that the most cost-effective and environmentally acceptable forest growing and harvesting practises in Australia are explored.

Three short-rotation silvicultural crops where biomass for bioenergy is not the principal product, but potentially significant, are discussed in the following sections. The first two crops are the focus for research and development work on bioenergy by some members of the IEA Bioenergy Task 17 Australian Collaborators’ Group and are presented in some detail. The third is the focus of much current silvicultural research in Australia and, while arguably more relevant to Task 18, is of interest because of the use of relatively short rotations.

Oil mallee

The mallees are a group of *Eucalyptus* species, typically from low-rainfall areas throughout southern mainland Australia. They are characterised by a multi-stemmed habit and substantial belowground growth (lignotubers). Many species have been identified as having a high oil concentration in their leaves, although only one species, *E. polybractea*, is currently used for commercial oil production in New South Wales and Victoria. Western Australian species of mallees are being developed for their potential for oil production, and pre-commercial plantings of *E. horistes*, *E. kochii*, *E. angustissma*, *E. loxopheleba*, along with *E. polybractea* have been made in concentrations at six wheatbelt locations. For most of these species cineole is the dominant oil fraction (90%), and for elite lines, total oil content averages 3.2% of leaf fresh weight.

The large-scale planting of oil mallee in Western Australia (WA) is being actively promoted by the WA Department of Conservation and Land Management (CALM) as a key strategy in the reduction of potentially catastrophic salinity problems in Western Australia’s low rainfall zone (WA Salinity Action Plan 1996). Much of the WA wheatbelt is in this zone and is already showing salt damage. It is predicted that land lost to salinity could increase from the present 9% to 32% of the total of 18 million hectares of agricultural land in WA. The downstream consequences for water resources, biodiversity, and infrastructure from salinity are at least as severe as the land loss (Bartle 1999b). Tree crops used in parallel with traditional annual plant crops provide an option to better manage the groundwater and thereby the salt problem. After some years of testing CALM has selected oil mallee as the most suitable 'tree crop' for this role. Planting of oil mallee has commenced, with 12 million trees (approx 9000 ha) in the ground to 1999.

An important reason for the selection of mallee is its commercial potential. Mallee produces *Eucalyptu*s oil that initially has markets in the fragrances and pharmaceuticals industries. In the longer term it is hoped that economies of scale in production will allow the oil to be marketed as a solvent degreaser, a natural alternative to the recently banned halogenated hydrocarbon solvents, such as trichloroethane, that damage the ozone layer (Bartle 1999a).

Production of *Eucalyptus* oil alone only utilises the leaves of the mallee trees. To better utilise the whole tree an Integrated Mallee Processing (IMP) plant has been proposed. Such plants would be located in each mallee growing area and would operate as follows:

- Coppiced mallee trees are mechanically harvested, and the whole tree is transported to the processing plant.
- The wood and the leaves are separated.
- The leaves are crushed, and the oil is distilled (using steam from the wood processing).
- The wood is carbonised to charcoal. The combustion of volatiles in the wood during this stage releases much of the energy in the wood as heat, which may in turn be used to raise steam.

The charcoal may be sold, or processed further, and then activated with steam to produce activated carbon. During the activation step most of the energy remaining in the wood is released as water gas, which may be used for heat, steam, or as a fuel for a gas engine or turbine.

Independent of the work by CALM, CSIRO Forestry and Forest Products has for some years been developing processes for energy recovery and the manufacture of charcoal and activated carbon products from wood. These processes have been developed initially at the laboratory scale and more recently at a pilot plant constructed by CSIRO in Victoria. Preliminary product trials of activated carbon produced have shown it to perform very well when compared with commercial carbons.

IMP production can be reasonably summarised as follows, although there are important variations with age, harvest frequency, season, and species in fresh to dry weight conversion and leaf to wood ratios. Linear hedges (twin rows) will be harvested on a 2-year cycle yielding approximately 20 Mg/km FW. Dry weight is approximately 50% of fresh weight (FW), and leaf is approximately 50% of total harvested biomass. For a full-scale plant accepting 100 000 Mg/year of mallee (i.e., 50 000 Mg each of leaves and wood), production would be approximately as follows:

Eucalyptus oil	1 600 Mg
Charcoal (if no activated carbon made)	8 300 Mg
Activated carbon (100% pelletised form)	5 000 Mg

If the plant produces oil and charcoal, the annual energy generated will be made up as follows:

Electrical energy (via steam turbine)	2.3 MWh
Energy contained in charcoal product	8.6 MWh

If the plant produces oil and activated carbon, the energy generated will be:

Electrical energy (via gas and steam turbines)	5.1 MWh

These figures include energy recovery from combustion of the leaves after oil extraction. In addition to electrical energy, substantial quantities of thermal energy as heat or low-pressure steam will be generated and will be available for other uses.

A 100 000 Mg/year FW IMP plant would require 10 000 km of mallee hedge, which if planted in an alley-farming configuration at 50 m intervals would be spread across 50 000 ha (Bartle 1999a). Assuming a 10% uptake by farmers, the IMP plant would receive biomass from 500 000 ha, or an equivalent radius of 40 km around the plant. Clearly, an efficient materials handling system is fundamental to the successful development of the oil mallee industry at this scale.

Wastewater-irrigated plantations

Interest in the establishment of forest tree plantations on irrigated and non-irrigated sites in the southern Australia, and particularly in the southern Murray-Darling Basin (MDB), for commercial and other objectives has increased in recent years (e.g., Bren et al. 1993, Baker et al. 1994, Stackpole et al. 1995, Baker et al. 1999). This interest has resulted from a wider recognition that integration of trees into farming systems is an essential component of halting land degradation from rising groundwater and consequent salting, of sustainable agricultural production, and also of the commercial prospects for farm forestry plantations. There has also been increasing environmental and regulatory pressure to replace wastewater disposal to waterways and water bodies with land application, and a general development of a philosophy of beneficial re-use over that of simple disposal (e.g., EPA 1996).

Growth of tree plantations in much of Australia is constrained by lack of water. In order to achieve high rates of production, short-rotation crops will therefore need to be intensively managed, including being irrigated. Sources of water include freshwater, municipal and industrial effluents, and groundwater. However, freshwater is in strong demand for irrigated agriculture and horticulture, and much groundwater is often too saline (for example, with an electrical conductivity > 2 dS/m) to support fast tree growth. Use of municipal wastewater irrigated onto land owned by water authorities is the most obvious candidate for bioenergy production from irrigated plantations. Here, land, irrigation infrastructure, and water costs may be considered to form part of the total water treatment costs, and not part of the costs of biofuel production. The issues for the authorities choosing land disposal of wastewaters are therefore the costs and revenues from alternative crops (agriculture, silvicultural), sustainability, and risk-management.

The potential for wastewater-irrigated plantations for bioenergy production can be illustrated using Victoria as an example (for which data on wastewater volumes are readily at hand). In Victoria, treatment plants receive approximately 450 000 ML of wastewater annually. Of this, 317 000 ML (70%) is received by the Melbourne Western (Werribee) and Eastern (Carrum) plants. Availability and cost of land near these two major plants may be a significant restraint for development of wastewater-irrigated plantations, and these will not be considered further here.

Assuming that only two-thirds of the water received by a treatment plant is available for irrigation (because of evaporation losses), and that a minimum of 1000 ML/year irrigation water is required for a viable plantation project (200 ha irrigated at 5 ML/ha.year), then apart from the two Melbourne wastewater plants, there are 25 other plants in regional Victoria which could be considered. The total intake of these 25 plants is 100 000 ML/year, with a potential to irrigate up to 13 000 ha. Assuming growth rates of 30 Mg/ha.year dry matter (DM) (see later discussion), approximately 400 000 Mg/year DM could be produced which could support a total electricity generating capacity of 50 MW.

Much of the early data for irrigated plantations in southern Australia come from wastewater irrigated trials established in Victoria during 1975–1980, including those at Werribee, Mildura, Robinvale, Merbein, Horsham, Dutson Downs, Wangaratta, and Wodonga (Stewart et al. 1982). A trial established at Kyabram in 1976 (irrigated with freshwater) (Stewart et al. 1982, Heuperman et al. 1984) was in fact the first Australian experiment to examine bioenergy production and was initiated in response to the 1970s world 'energy crisis.'

Results for *Eucalyptus grandis* from the Wodonga study (irrigated with municipal effluent) and from the Kyabram trial (irrigated with freshwater during the first few years and then tapping groundwater to some extent) illustrate a three-fold range of growth potential on sites in the southern MDB [mean annual increments (MAI) = 15 to 45 m^3/ha at age 10 years] (Baker 1998) where irrigation water salinity and initial soil salinity were not significant problems.

At Wodonga, species ranking for growth (stem volume, m^3/ha; aboveground biomass Mg/ha DW) to age 4 years was *E. saligna* (134; 84), *E. grandis* (126; 80), *Populus deltoides x nigra* (85; 47), *Pinus radiata* (61; 42), *Casuarina cunninghamiana* (43; 49), and *E. camaldulensis* (40; 52) (Stewart et al. 1988). At Kyabram, species ranking (volume index, m^3/ha) at age 4 years was *E. grandis* (34), *E. saligna* (29), *E. globulus* (24), and *E. camaldulensis* (23) (Baker 1998). Unfortunately, from a bioenergy perspective, the data from both the Kyabram and Wodonga trials are confounded by differences in initial planting densities.

Renewed interest in wastewater-irrigated plantations in Australia occurred from 1990 with studies established at Werribee, Victoria (1990); Bolivar, South Australia (1990); Wagga Wagga, New South Wales (1991); Shepparton, Victoria (1993); and Muswellbrook, New South Wales (1999). These studies variously investigated species differences, growth, water use and nutrient uptake, the environmental effects on soils and groundwater, and the silvicultural regimes for specified products (including bioenergy production). While only the Werribee, Shepparton, and Muswellbrook studies specifically address silvicultural aspects of short-rotation bioenergy plantations (density, rotation length), all contribute information on species performance.

Werribee. The Werribee Effluent-Irrigated Plantation project was established by the Centre for Forest Tree Technology (CFTT) in 1990 to evaluate the prospects for commercial timber production from hardwood plantations flood-irrigated with sewage and to demonstrate the longer-term viability of irrigating plantations as a means of sewage treatment (Benyon and Stewart 1993). The evaluation was to particularly focus on the silvicultural aspects of fast-growing eucalypt plantations.

Annual rainfall at Werribee averages 520 mm and pan evaporation is 1350 mm. Monthly averages of daily maximum and minimum temperatures are 13°C and 25°C respectively in January and 5°C and 13°C in July.

Field trials of approximately 8 ha each were planted at two sites representing the major combinations of soil parent materials (alluvium, basalt) and effluents (untreated, primary treated) at the Melbourne Western Treatment Complex near Werribee. The trials include the species *E. globulus*, *E. grandis*, *E. saligna*, and *E. camaldulensis* and include treatments with initial establishment at relatively high densities [1 333, 2 500 and 4 444 trees per hectare (tph)].

Stem volume growth to age 4 years across the range of planting densities varied (m^3/ha): *E. globulus* (57–108), *E. grandis* (46–89), and *E. saligna* (37–77) (Delbridge et al. 1998). Thus over a short rotation, tripling the planting density approximately doubled the potential yield. Regular growth measurements have been made in the trial with the next scheduled for age 10 years.

Bolivar. The Hardwood Irrigated Afforestation Trial was established by the South Australian Department of Primary Industries in 1990 at Bolivar near Adelaide, South Australia (Boardman et al. 1996, Shaw et al. 1996). The trial investigated the potential of using treated sewage to irrigate Australian native hardwood tree species and incorporated treatments of high and low effluent application rates and freshwater application. The trial was monitored for 6 years with studies focusing on tree water use, tree growth, nutrient uptake, and the environmental impact of irrigation on soils.

Average annual rainfall at Bolivar is 430 mm, and pan evaporation is 2080 mm. Even with correction of the water deficit using irrigation, the site was considered marginal for tree growth because of the saline and sodic nature of the soil, the highly saline groundwater [electrical conductivity (EC) approximately 35 dS/m] at 1.5 to 2.5 m depth, and the saline effluent (EC approximately 2.3 dS/m).

Nonetheless, initial tree growth rates were relatively high, and amongst the irrigation treatments, the species studied were ranked for stem volume growth (overbark, m^3/ha) to age 4 years: *E. globulus* (139 to 182), *C. glauca* (85 to 111), *E. occidentalis* (90 to 92), *E. grandis* (75 to 91), and *E. camaldulensis* (59 to 71). After age 4 years, because of increasing soil salinity resulting from irrigation practice restricting leaching of salt, growth of the more salt-sensitive species (*E. globulus*) declined relative to the more salt-tolerant species (*E. camaldulensis*, *E. occidentalis*).

Wagga Wagga. The Wagga Wagga Effluent Plantation Project was established by CSIRO in 1991 to study and develop national guidelines for sustainable management of water, nutrients, and salt in effluent-irrigated plantations in Australia. The site has a mean annual rainfall of 550 mm and mean annual evaporation of 1860 mm. The main focus of the project was to study biophysical processes under different rates of spray irrigation with effluent, namely the medium (M) rate of irrigation (rate of water use less rainfall), a high (H) rate of irrigation (about 1.5 times the rate M), and a low rate of irrigation (about 0.5 times the rate M). The H rate was chosen to determine whether effluent could be applied at an excessive rate and still meet regulatory requirements for groundwater quality. The L rate was chosen to determine whether under irrigation could still produce satisfactory rates of tree growth and thus maximise use of the effluent resource. The main species studied were *E. grandis* and *P. radiata*. Tree spacing was at 3 × 2 m. The project has:

- Provided National Guidelines giving a scientific basis for design and sustainable management of effluent-irrigated plantations (www.ffp.csiro.au/pff/effluent_guideline)
- Quantified the processes that regulate the mineralisation, transport, accumulation, and losses of nutrients
- Identified potential long-term risk factors contributing to soil degradation processes
- Quantified effects of effluent irrigation on groundwater quality and depth
- Identified best eucalypt species and radiata pine clones for effluent-irrigated plantations for sustainability and biomass production
- Quantified salt sensitivity in tree species
- Developed four computer models for extrapolating the results to other sites: (i) WATLOAD2 for designing effluent-irrigated plantations by bio-climatic zones within Australia, based on water balance; (ii) WATSKED for scheduling irrigation in plantations by managers; (iii) APSIM for Effluent for predicting environmental impacts of effluent irrigation; and (iv) WATCOST for economic evaluation of various effluent-irrigated plantation and crop options

This project, and others by CSIRO in freshwater-irrigated plantations, has studied in detail water use efficiency (Myers et al. 1996). A major outcome from the project was that, after 6 years, halving the rate of irrigation from theoretical optimum (the M rate to the L rate) led to only a 10% decrease in volume production—from a mean annual increment (MAI) of about 20 m^3/ha

(M rate) to 18 m^3/ha (L rate). Relative irrigation amounts were about 10 ML/ha.year (M rate) and 5 ML/ha.year (L rate). Other research characterised differences among species in water use efficiencies by comparing rates of tree transpiration (sap flow) with tree growth.

Shepparton. The Shepparton Effluent-Irrigated Short Rotation Plantation project was established by CFTT in 1993 to investigate aspects of the productivity and sustainability of effluent-irrigated short-rotation tree plantations and their silvicultural management (Baker et al. 1994). Average annual rainfall at the Shepparton site is 480 mm, and average monthly maximum and minimum temperatures vary from 30 and 14°C respectively in January to 13 and 3°C in July. Average annual pan evaporation is approximately 1500 mm. Shallow groundwater at approximately 2.5 to 3 m depth has an electrical conductivity (EC) typically 2–5 dS/m.

The combined municipal and food processing industry effluent (after secondary treatment) is a high-Na water (EC approximately 1.4 dS/m) but with moderate concentrations of Ca and Mg and a resultant sodium adsorption ratio (SAR) of approximately 6. The pH of the effluent is approximately 8, and concentrations of N and P in the effluent average approximately 20 and 5 mg/L respectively. Annual irrigation rates have varied between 5 and 9 ML/ha, which is applied generally November to March.

The trial incorporates comparisons of tree species (*E. globulus* or *E. grandis*), planting density (1333 tph or 2667 tph), and coppice rotation length (3, 6 or 12 years). The 3-year rotation treatments were harvested at 3 years of age, and the second harvest of this treatment and the first harvest of the 6-year rotation will occur in September 1999.

Growth of both *E. globulus* and *E. grandis* is excellent, with average volume growth of *E. globulus* (172 m^3/ha) approximately 1.3 times that of *E. grandis* (128 m^3/ha) to age 5 years (Duncan et al. 1999). Tree volume growth trends to age 5 years for both species indicate that the trial plantation is amongst the most productive eucalypt plantations in Australia. For example, stem volume MAIs at age 5 years were 30 and 38 m^3/ha for *E. globulus* and 23 and 31 m^3/ha for *E. grandis* for the 1333 and 2667 tph densities respectively.

At age 5 years, aboveground biomass in the four treatments varied between 101 and 179 Mg/ha DM. Coppice growth rates at age 2 years varied between 31 and 42 Mg/ha DM amongst the treatments. Total biomass of the coppice at age 2 years was greater than that of the trees (grown from planted seedlings) at age 2 years.

Data from the present study are being used to model the effects of rotation length on biomass production and N sequestration (and therefore potential removal in whole tree harvesting) under different scenarios of effluent irrigation. Rates of effluent application for the 3-, 6-, and 12-year rotations are estimated to total 85, 100, and 110 ML/ha over a 12-year period to optimise tree growth and minimise the build-up of salt in the root zone of the soil profile. The projected biomass production for a 12-year cycle of rotations at 3-, 6-, and 12-years is 330, 390, and 350 Mg/ha DM respectively for *E. globulus* growing at an estimated peak MAI of 45 m^3/ha.

The estimated input of N in effluent of varying concentrations, in relation to the amount of N sequestered in the potentially harvestable biomass produced under the three rotation lengths indicates that: (i) N sequestration in potentially harvestable biomass is maximised for very short rotations (3 years), (ii) only for effluent N concentrations of less than approximately 15 mg/L can short rotations ensure that N inputs are approximately balanced by N removals in harvested biomass, and (iii) for longer rotations (12 years), average effluent N concentrations need to be reduced to approximately 5 mg/L to achieve a similar balance of inputs and outputs.

Muswellbrook. The Upper Hunter Valley of northern New South Wales has many open-cut coal mines, areas typically of 500 to1000 ha needing rehabilitation after cessation of mining. Overburden is replaced on cut areas, with or without topsoil. Mean annual rainfall is 640 mm and evaporation about 1800 mm. The combination of harsh soil conditions and relatively low rainfall lead to low rates of pasture or tree production, reducing the opportunities for sustained mine-site rehabilitation. CSIRO is investigating means by which various amendments can be utilised to increase tree production and site reclamation.

A trial was established in February 1999 to study the effects of four rates of effluent irrigation (water use rate, two-thirds and one-third the water use rate, and non-irrigated) on various tree species planted at 2 densities (3 × 3 m or 1.5 × 1.5 m spacing). The latter density is designed to maximise production of organic matter on rotations of 3 to 6 years. The trial is also testing the effects of composted biosolids on tree performance.

Saline groundwater is used for coal washing and dusting of roads. The availability of sewerage effluent for irrigation will always be limited, but saline water is plentiful. The water is moderately saline (4 dS/m) but, unlike effluent, has low concentrations of N and P. A trial is being established to test the effects of nutritional amendments (fertiliser, biosolids, composted biosolids, or nil amendment) on four tree species either irrigated or not irrigated with saline water. Spacing is at the conventional rate (3 × 3 m).

Pulpwood

As of 1998 Australia has approximately 1.25 million ha of plantations, of which 0.29 million ha (23%) are hardwoods (mostly *E. globulus*, *E. nitens*, *E. regnans*, and *E. grandis*) and 0.96 million ha (77%) are softwoods (mostly *Pinus radiata*, *P. elliottii*, *P. caribaea*, *P. pinaster*, and *Araucaria cunninghammii*). The softwood plantations are generally managed on rotations of 20 to 40 years for a variety of products (veneer logs and saw logs, posts, poles, and pulpwood), and while the potential for biomass energy from silvicultural and timber processing residues from such plantations is dealt with under IEA Bioenergy Task 18, the rapidly developing short-rotation (10 to 15 years) pulpwood industry for hardwoods is worthy of mention here.

New area planted to hardwoods in Australia has increased during the four years 1995 (19 000 ha/year) to 1998 (49 000 ha/year) with the area planted in this period (143 000 ha) being approximately half of the total current hardwood area. Planting rates in 1999 and 2000 are expected to exceed that of 1998. These plantings have been mostly for production of pulpwood on cleared agricultural land in southwestern Western Australia, southeastern South Australia, Victoria, Tasmania, and north-coastal New South Wales where annual rainfall exceeds 700 mm.

Assuming an average annual growth rate of 20 m^3/ha.year (over a 15-year rotation), a whole-length-tree harvest index of 0.9, with a merchantable (pulpwood) harvest index of 0.8, an average wood basic density of 500 kg/m^3 DM, and an ultimate estate of 500 000 ha, there is potentially 500 000 Mg/year DM of wood residue available from this industry for bioenergy production. The plantations are being established within economic haulage distance of processing centres/export ports, and harvesting and transport systems for pulpwood crops may be easily adaptable to also allow economic production of fuelwood in addition to pulpwood.

Harvesting and Utilisation

Harvesting

In contrast to the research and development work undertaken over the past 25 years into growing short-rotation silvicultural crops, work on harvesting these is relatively new in Australia. The Western Australian Department of Conservation and Land Management has as part of their work with the Oil Mallee Company developed a prototype combined harvester and chipper to produce a material suitable for large-volume materials handling systems and low-cost feedstock for production of oil, charcoal, and thermal energy. The machine is to be capable of (i) harvesting mallee stems up to 6 m height and 150 mm diameter at ground level while traveling continuously, and (ii) chipping the harvested material as coarsely as possible to render the wood fraction into a flowable chip form with minimal damage to the leaves. The aim is to harvest 60 Mg/hour at a ground speed of 5 km/hour. The leaf material is subsequently separated from the other material at the IMP plant prior to oil distillation. While having these specific requirements, the system being developed for the oil mallee industry has kept open the option for application of the harvester to any short-rotation tree crop.

Utilisation

Processes and conversion techniques for utilizing biomass for energy include combustion (co-generation, co-firing), gasification, pyrolysis (charcoal, gas, liquids), digestion, and fermentation. Research into biomass for energy generation faces a number of challenges in Australia due to the low cost of electricity, although many biofuels would be cost-competitive (Fung 1997).

CSIRO Forestry and Forest Products has two projects investigating options for utilisation of biomass. These include (Fung 1997):

- A fluidised bed system for carbonisation which is suitable for producing carbon and energy co-generation through the burning of the volatile and combustion gases. Charcoal fuel briquettes and activated carbon have been developed from the fluid bed carbon.

- A gasification system on a pilot scale. The dispersed nature of the forest biomass resource provides opportunities for decentralised power generation in regional and remote regions where low-cost wood residues are available.

State Forests of New South Wales in collaboration with steelmakers is currently evaluating the potential use of forest biomass for charcoal production and electricity generation and particularly looking to characterise the quality of biomass fuel realised from a number of species growing across various sites and under different silvicultural regimes (e.g., effluent irrigation stands), Australia-wide. The physical, anatomical, and chemical properties (e.g., ash content of various radial zones of the stem, sap wood volume, and moisture content) of species growing under intensive short rotations will be characterised. As part of this activity, moisture loss from log samples will be measured to determine the rate of drying of intensively tended and extensively grown forest biomass.

State Forests of New South Wales is also working with electricity generators to develop feasibility studies for new wood-based biomass energy plants. The generators are favoring co-firing rather than co-generation due to the lower amount of capital required to replace a portion of the coal feed with wood fibre. Essentially, for co-firing, existing pneumatic feed systems used for coal firing can be adapted for wood feedstock. The lower capital expenditure required for co-firing means that generators might be able to justify a higher price for biomass than those contemplating a stand-alone generation plant. Currently a 5% trial replacement of coal with wood residues from solid wood processors is being tested. The level of coal replacement is a function of wood supply, and this is may be augmented by the establishment of short-rotation energy forests in the future.

Issues

Sustainability

The use of tree plantations for the disposal or re-use of effluent/wastewater has been well established and continues to be investigated, particularly with respect to its sustainability. Here each of the major issues surrounding sustainability of effluent-irrigated plantations is briefly discussed along with implications for management of short-rotation crops.

Nitrogen (N). Generally the major concern is the fate of nitrogen (N) which, if added in excess of plantation requirements, can leach to the often shallow groundwater prevalent throughout much of regional Australia. The potential for nitrogen leaching from effluent-irrigated plantations for a wide range of climatic and soil conditions has been demonstrated (Myers et al. 1999) using a process-based model of N dynamics (Snow et al. 1999), but there are many engineering and silvicultural options available to mitigate this leaching and protect groundwater (Polglase et al. 1994, Myers et al. 1999). These include the use of crops on short rotations to maximise accumulation of nutrients in vegetation.

Phosphorus (P). Phosphorus often is thought of as the element most likely to constrain the longevity of effluent-irrigated plantations as P gradually saturates soil and leaches to groundwater or otherwise is transported to river systems by overland flow. In Australia, build-up of P during summer in the slow moving rivers has caused extensive blooms of toxic *Cyanobacteria*, with consequent loss of stock and of income from reduced recreation. Research from the Wagga Wagga Project (Falkiner and Polglase 1997) has shown that movement of P through the soil profile is not as rapid as predicted from conventional P transport models, and that leaching of P is unlikely to threaten the sustainability of effluent-irrigated plantations before other considerations, particularly N.

Salinity and sodicity. These two related issues are of prime importance for the management of effluent-irrigated plantations. Sodicity refers to the effect of relatively high concentrations of sodium (Na) in effluent gradually displacing the other major cations, leading to dispersion of clay and a reduction in the rate of water infiltration. At Wagga Wagga, very large increases in the exchangeable sodium percentage (the most common index of sodicity) were observed (Falkiner and Smith 1997), but there was no measurable decrease in infiltration rate (Balks et al. 1998). The likely risk of soils becoming sodic therefore depends on site-specific conditions, primarily the relative concentration of Na in effluent, and amounts and types of soil clay. Sodicity is difficult to reverse but may only be a problem when irrigation is terminated and water with a low electrolyte concentration (such as rain) becomes the dominant input.

The negative effects of salinity are manifested through reductions in tree productivity. Should water use also be decreased, this will constrain the volume of effluent that can be applied, and hence not maximise its usage. Tolerance to salinity is highly species dependent. At Wagga Wagga, growth of *E. grandis* was decreased by up to 75% at moderate levels of soil salinity (EC_e about 5 dS/m) whereas growth of *P. radiata* was unaffected (Myers et al. 1998). Interestingly, water use of *E. grandis* was unaffected by salinity despite the large growth reductions. Salinity can be managed by the imposition of leaching fractions, but if a relatively intolerant tree species is irrigated with moderately saline water, the amount of over irrigation required to keep soil salinity within acceptable levels can be large (Polglase and George 1999).

Economics

The relatively low cost of fossil-fuel energy in Australia has and is likely to continue to generally limit the development of biomass energy. The extent to which government policy and regulation on technological development and greenhouse gas emissions and consumer demand for *Green Power* will counteract this cost disincentive is yet to be determined. The greatest prospects in Australia are therefore for crops that yield a commercial product (e.g., eucalypt oil) or provide environmental benefits (beneficial re-use of wastewaters, salinity control in catchments) as well as bioenergy.

Crops solely grown for energy purposes are expected to be a more expensive biomass source than crop-processing residues and cropping-residues and in Australia are yet to be proven commercially viable. Nonetheless, the economics of all biomass energy projects are highly site-specific, and there is potential for energy crops in niche situations. However, the construction of full-scale integrated demonstration plants (growing, harvesting, energy generation) appears to be critical to gaining market confidence.

Acknowledgments

Unless indicated otherwise, many of the statistics stated in this paper are taken from a recent analysis of Australian energy trends (Bush et al. 1999), the Australian Government's National Greenhouse Strategy (AGO 1998), general analyses of the Australian renewable energy sector (REM 1999a, REM 1999b) including specifically the sugar industry (Dixon et al. 1998), the Australian NetEnergy internet site (www.affa.gov.au/netenergy), and the Australian National Plantation Inventory (www.brs.gov.au).

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Report on Bioenergy in Brazil

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Introduction

Biomass for energy generation continues to be a big technological, economical, and ecological challenge. Brazil has achieved great success in the past (27% of total energy consumption) with the reforestation project for pulp, charcoal (siderurgic plan), and sugarcane for alcohol (20% of energy for transportation). However electric energy generation from biomass is presently negligible (sales of 30 MW mainly in the sugarcane and pulp industries). The present situation is characterised by stagnation in both government and private sectors.

The present paper shows a new technology called the BEM (Biomass–Energy–Materials) Programme based on prehydrolysis that generates two products: catalytic cellulignin fuel (CCF) and chemicals of biomass (furfural, alcohol or xylitol). The CCF can be produced in two grades, the first with potable water (0.2% ash, K + Na <100 ppm) and the second with deionised water (0.1% ash, Na + K <25 ppm). These fuels can be used in gas-type turbines with external combustor and cyclone cleaning of the ash and particulates. Capital investment in a combined cycle is lower than U.S. $1,000.00/kW, efficiency is on the order of 45%, and total electricity cost is around U.S. $45.00/MWh when produced from biomass residue, and U.S. $60.00/MWh when produced from dedicated reforestation. These costs compete with hydroelectric and fossil fuel energy. This achievement is mainly due to three factors: (1) A mobile reactor that goes to the biomass source thus eliminating raw biomass transportation cost; (2) a titanium-lined “fail-safe reactor” that allows complete process control thus yielding a CCF powder with a very high internal surface that burns like a gas (<10 ms burning time); and (3) utilisation of advanced coated superalloys in the vanes and blades of gas-type turbine. This new technology forms a basis for the effective implantation of the Clean Development Mechanism (CDM) established in the Kyoto Protocol at a cost range of U.S. $10.00/tC. Market penetration in Brazil is expected to be on the order of 400 MW/year starting in 2001, and the whole development will be made by the private sector.

The Past Biomass Programme

The past Brazilian Biomass Programme was composed of the wood, cellulose, charcoal, and sugar/alcohol industries. Table 1a shows the distribution of productive area supplying forestry products throughout the world. Table 1b shows the Brazilian production per forestry product segment (Dassie 1996). The Brazilian wood industry surpasses only Africa and Oceania, two desert areas, despite the fact that Brazil is the biggest tropical non-desert country on earth. No evolution of the forest products industry has taken place in the last ten years except the replacement of native forest exploration by reforestation. Brazil has 550×10^6 ha of forests, of which 1.5% is planted forest (8.5×10^6 ha). The exploited forest corresponds to 100×10^6 ha. Since there is no management plan for the native forest, the destruction of Amazon forest is a serious threat.

Table 1a. World productive area of forestry products (millions of ha) (Dassie 1996)

Region	Logs	Lumber	Panels	Pulp	Paper	Total
North America	607	172	42	77	86	984
Europe	300	85	34	35	60	514
Asia	257	104	25	14	43	443
Ex-USSR	292	102	14	10	10	428
South America	93	26	04	06	08	137
Brazil	73	18	03	04	05	103
Africa	53	09	02	02	03	69
Oceania	30	06	02	02	02	42
Total	1705	522	126	150	217	2.720

Source: BNDES, 1995, Brazilian National Bank for Social Development.

Table 1b. Brazilian production per forestry product segment (Dassie 1996)

Segment	Quantity	Unit	Data origin	Biomass source
Charcoal[a]	33×10^6	CMC[d]	ABRACAVE[e]	Native + reforestation
Pulp[b]	5.4×10^6	t	ANFPC[f]	Reforestation
Paper	5.70×10^6	t	ANFPC	Reforestation
Plywood	1.90×10^6	m^3	ABIMCI[g]	Native + reforestation
Laminates	510×10^6	m^3	ABIMCI	Native + reforestation
Fiber plates	700×10^3	m^3	SBS[h]	Reforestation
Agglomerate	800×10^3	m^3	ABIPA[i]	Reforestation
Lumber	19×10^6	m^3	FAO	Native + reforestation
Logs	190×10^6	m^3	STCP[j]	Native + reforestation
Logs for all uses[c]	269×10^6	m^3	FAO	Native + reforestation

[a] Equivalent to 66.0×10^6 stereo of wood.
[b] Equivalent to 39.8×10^6 stereo of wood.
[c] Equivalent wood in trunks for all uses.
[d] CMC, cubic meter of charcoal.
[e] ABRACAVE, Brazilian Society of Charcoal.
[f] ANFPC, National Association of Pulp and Paper Factories.
[g] ABIMCI, Brazilian Society of Industries of Industrialised and Playwood Wood.
[h] SBS, Brazilian Society of Silviculture.
[i] ABIPA, Brazilian Society of Panel Industry.
[j] STCP, Project Engineering Ltda., Curitiba, PR, Brazil.

Biomass is the second largest source of energy in Brazil (Freitas and Moreira 1997). Figure 1 shows the primary energy consumption in 1995 (166,400 × 10^3 tOE—tons of Oil Equivalent), where biomass represents 27%, distributed in 14% from wood and 13% from sugarcane (Brazil 1996, IPCC 1995). Worldwide biomass participation in energy consumption is around 12%.

Figure 2 shows the Brazilian wood energy consumption in 1995, where 44% was consumed for charcoal production and the remaining as fuelwood (stoves for rural households), industries (food, pottery and brick kilns, paper and cellulose plants), and for agricultural requirements. Electricity production from wood is negligible. Charcoal produced from native forest is 48% from deforestation and 52% from reforestation. Brazil is responsible for 25% of world charcoal production, totaling 7.8 million metric tons (31 million m^3 of charcoal). Silviculture for charcoal and cellulose in Brazil accounts for 70% of all tree plantations in Latin America. Wood energy plantations and their industrial activities employ 300,000 workers and earn U.S. $5 billions/year. The total Brazilian business derived from wood is U.S. $18 billions/year, the world business is about U.S. $430 billions/year (Table 2), and the international market is in the order of U.S. $120 billions/year (STCP 1997).

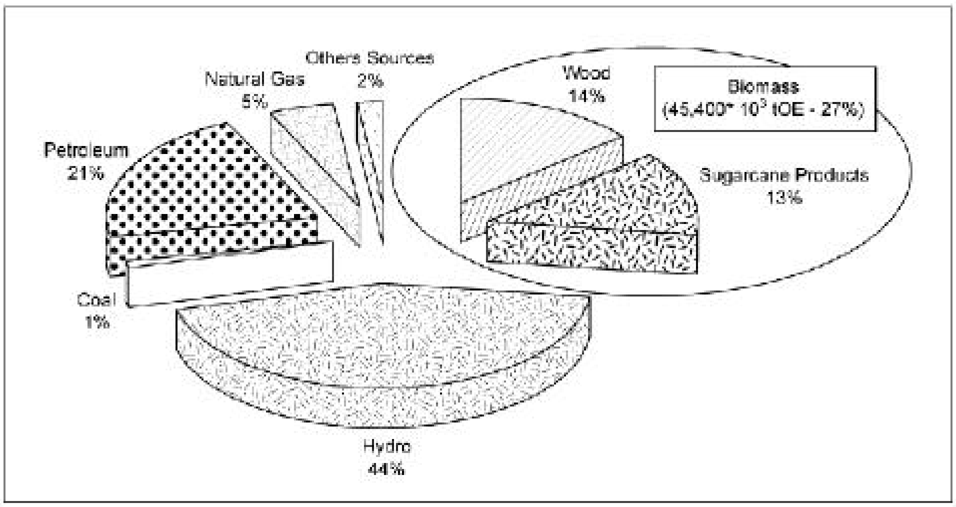


Fig. 1. Brazilian primary energy consumption, 1995 (166,400 * 10^3 tOE).
Source: Brazil 1996.

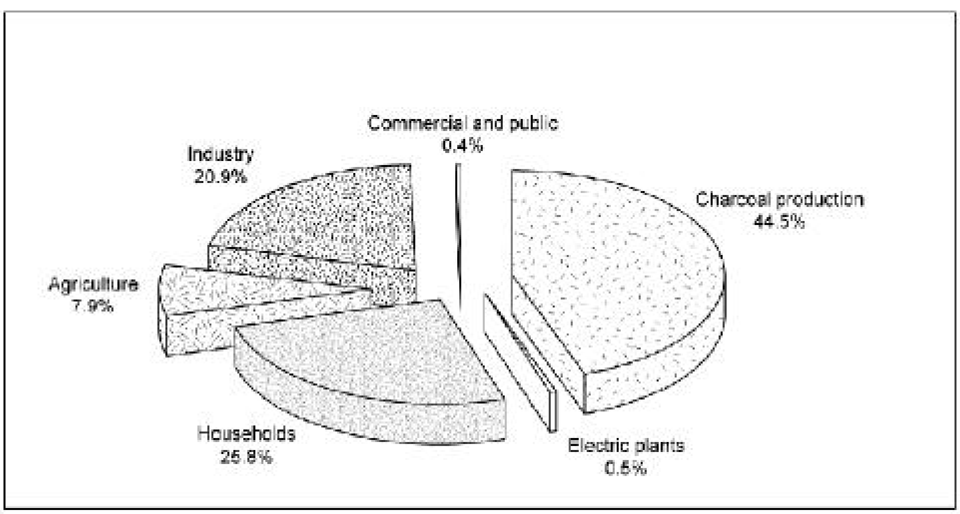


Fig. 2. Brazilian wood energy consumption, 1995 (23,414 * 10^3 tOE).
Source: Brazil 1996.

Table 2. Brazilian and world business of wood segments

Product	Medium price (U.S. $)	Brazilian		World	
		Quantity millions	Value U.S. $ billions	Quantity millions	Value U.S. $ billions
Log	15.00/m^3	190.0 m^3	2.85	1500 m^3	22.5
Charcoal	20.00/m^3	33.0 m^3	0.65	—	—
Lumber	300.00/m^3	19.0 m^3	5.70	500 m^3	150.0
Plywood	500.00/m^3	1.9 m^3	0.95	46 m^3	23.0
Laminates	500.00/m^3	0.5 m^3	0.25	—	—
Agglomerate	300.00/m^3	0.8 m^3	0.24	53 m^3	15.9
Fiber plates	650.00/m^3	0.7 m^3	0.46	12 m^3 (MDF)	7.8
Paper	700.00/t	5.7 t	4.00	280 t	196.0
Pulp	600.00/t	5.4 t	3.25	30 t	18.0
Total			18.35		443.2

MDF = medium density fiber.

Figure 3 shows the Brazilian energy consumption from sugarcane bagasse. Sugarcane covers 43 million ha, 8 to 9% of the total cropland in Brazil (IBGE 1995, FAO 1996), demanding good quality land, high rainfall, and many nutrients. The production of sugarcane is 280 million tons, leading to 13.5 million tons of sugar and 13.7 million m^3 of ethanol. The state of São Paulo has 44% of the sugarcane fields, where 60% is used for alcohol production and the remaining for sugar. Ethanol production consumes 64.4% of the energy, sugar 33.1%, and 2.5% is used for plant and other requirements. Ethanol contributes 20% of the energy consumed for transportation and power and provides 30% of automobile fuel requirements (Brazil 1996), but production of alcohol cars is stagnate. No increase in the Ethanol Programme is expected, and a big effort is needed to maintain the present level. The tendency is to decrease consumption by pure alcohol-powered cars and to increase cars using the 22% gasoline/alcohol mixture. Ethanol production employs 700,000 workers with an income of U.S. $6–7 billion/year.

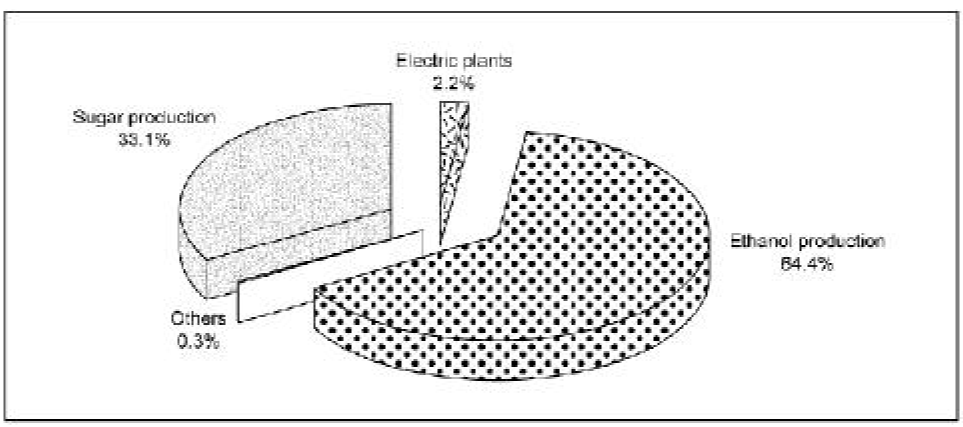


Fig. 3. Brazilian energy consumption from sugarcane products, 1995 (21,987 * 10^3 tOE). *Source:* Brazil 1996.

The Present Biomass Plan—2005 Goals

Three conferences about solar, wind, small hydropower plants and biomass renewable energy development in Brazil were held in Belo Horizonte, Minas Gerais (MG) (1994), Brasília, Federal District (DF) (1995), and São Paulo, São Paulo (SP) (1996) resulting in the Permanent Forum on Renewable Energy sponsered by the Brazilian Science and Technology Ministry. The goals of the plan for 2005 are [CRESESB (The Brazilian Solar and Wind Energy Reference Center), CENBIO (National Reference Centre on Biomass)]:

- Solar Energy—50 MW of photovoltaic cells, 3 million m^2 of thermosolar reception.
- Wind Energy—1000 MW power capacity (10 MW installed—Aquiraz—CE).
- Small Hydropower Plants—2500 MW.
- Biomass Energy
  - — 12 million tons of charcoal/year (the present level is 7.8 million tons).
  - — 18 million m^3 of ethanol (present level is approximately 13 m^3 of ethanol).
  - — 20,000 m^3 combustible vegetables: Oils—6,000 ha of oil-producing forests, 15 MW of power generation from vegetable oil engines (multifuel engine).
  - — 3 million ha of reforestation with exotic and native species for energy, 300 MW from sugarcane bagasse, 100 MW from by-products of the cellulose production.

Although the above goals are the official plans, some of the items will be difficult to achieve for the following reasons: Solar energy is the only one currently in execution, especially with small German funds in the semiarid lands for water desalination and teleschools in small communities. Wind energy and small hydropower plant development is standing still because of the process of privatisation of the state electric energy generation companies. Charcoal production is decreasing instead of increasing because of the competition with imported mineral coal and more profitable utilisation of Eucalyptus wood for cellulose production. The increase of ethanol production is not realistic, and the maintenance of a level of 13 million m^3/year is the maximum possible.

The vegetable oil production goal is realistic and is conducted with coordination of Brasilia University's Energy Planning Group (GPE/UnB) together with many Amazonian institutions (public organisations of research, planning, environmental control and energy generation; private agricultural industries; and civil collective groups, such as extractive and rural associations). The project is called Equinox Project—Sustainable Management Applied Project of the Tropical Forest—and is dedicated to creating a non-timber forest (Freitas et al. 1997). Its aims are (1) to stop deforestation and recover part of the total deforested area of 470,000 km^2 from the total of 3.45×10^6 km^2 tropical rain forest; (2) to exploit the existing 8×10^6 ha of Buriti (*Mauritia flexuosa* Mart) with production of 6,400 ℓ/ha.year of oil and 29 t/ha.year of biomass; and (3) to reforest 20×10^6 ha with oil palm (*Elaesis guineensis*) generating 12,000 ℓ/ha.year of oil and 7 t/ha.year of biomass. The oil will be used for multifuel engines and the biomass for thermoelectric energy. The potential production is 14 times greater than the present consumption in the Amazon Region (Zylbergsztayn et al.1997).

The 100 MW target from by-products of cellulose production is easy to achieve due to the investment of the pulp industry in electricity generation motivated by its cost increase after privatisation.

The 300 MW from sugarcane bagasse represents a considerably more difficult target because the electrical sector and alcohol industries do not agree about sale prices, and a huge potential for electricity generation is being lost. The 280 million tons of sugarcane with 13.5% of fiber (dry matter), 50% moisture content, and 7.7 MJ/kg of heating value [lower heating value (LHV)-basis] result in 580×10^6 GJ. Leaves from sugarcane lost in the field (burned or left over) represent a similar quantity of energy totaling 27.6×10^6 tOE (23.7% of Brazilian primary energy production).* Electricity generation by the sugarcane sector would make alcohol competitive with gasoline, and additionally, it would complement the hydroelectric system because sugarcane harvesting is in the dry season. Table 3 shows electricity cogeneration costs from sugarcane origin. The real cost is U.S. $48.6/MWh, the government offers U.S. $38.0/MWh, and utilities will pay only U.S. $11.00/MWh. The reasons for this stalemate are the hostage situation of the sugarcane industry. Their only possibility is to produce electricity in their site for only one client.

Table 3. Electricity cogeneration costs from sugarcane origin

Size of the sugarcane plant	300 tons of sugarcane/hour
Electricity plant consumption	24 kWh/tc
Steam plant consumption at 1.5 bar, 215°C.	465 kg/tc
Bagasse opportunity price	U.S. $7.50
Operational hours (harvesting season)	3,190 h
Two boilers (80 bar), one considering extraction steam turbines (CEST)	57.7 kWh/tc
Electricity surplus sale cost	U.S. $48.6/MWh
Government price offer	U.S. $38.0/MWh
Electricity private company price offer	U.S. $11.0/MWh
Present sale contract in the state of São Paulo	96 GWh (30 MW)
Total consumption	79,220 GWh

tc = tons of sugarcane.

The utilisation of low-efficiency steam electric generation technology also contributes to the problem.

Bioenergy Future—New Technological Development

The Brazilian BIG-GT Demonstration Project

The Biomass Integrated Gasification-Gas Turbine (BIG-GT) is a project conducted in Brazil by five organisations: MCT (Ministry of Science and Technology), CHESF (Hydroelectric Company of São Francisco River, Eletrobrás), Shell Brazil, CIENTEC (Fundação de Ciência e Tecnologia) (Rio Grande do Sul, specializing in coal), and CVRD (Vale do Rio Doce Company). Presently only the first three remain in the project. Internationally the project is conducted by BIOFLOW (Ahlstrom Corporation of Finland and Sydkraft AB of Sweden), TPS Termiska Processer (Nykoping Energy, Sigtuna Energy AB, Vaxjo Energi AB, Boras Energi, Graningeverkens AB, Sodra Skogsenergi AB, LRF—Federation of Swedish Farmer), GE Gas Turbine, and Jaakko Pöyry Consulting (Engineering in Brazil) (Elliott 1993).

The objective in Brazil is to establish a high-pressure system of 30 MW in the state of Bahia operated by CHESF (WPB/Sigame). The technical details of the project will not be presented here since they are well described in the literature (Larson 1990, Williams 1988). The final commercial phase of the project was supposed to be finished by 1995, but up to now the construction of the demonstration plant (phase II) has been posponed to 2005. The main difficulties for biomass gasification are

- Very high capital cost (U.S. $2,500 to 3,000/kW) supposed to be reduced if ten identical serial plants are manufactured (U.S. $1,300 to 1,500/kW).

*$(2 \times 580 \times 10^6$ GJ $\times 42 \times 10^3$ MJ/tOE$) = 27.6 \times 10^6$ tOE.)

- High cost of raw biomass due to its transportation through medium distance of 85 km from the stationary plant.
- Hostage situation similar that of electricity generation by the sugarcane industry already discussed at the end of the preceding item of this report.

The BEM Programme

The BEM (Biomass—Energy—Materials) Programme was conceived with the objectives of maximizing the recuperation of the energy from biomass, competing economically with hydroelectric and fossil fuel, and respecting all ecological requirements (Pinatti 1997). A critical screening indicates that prehydrolysis of biomassa (digestion of hemicellulose and amorphous cellulose) fullfils all the above items.

Prehydrolysis of biomass. Figure 4 shows a mobile prehydrolysis reactor. It has the following characteristics: (a) The reactor is made of 10-mm high-strength low-alloy carbon steel lined with a 2-mm titanium sheet. Because of its low weight the mobile reactor can go to the source of biomass thus allowing its complete utilisation (trunks and branches) and eliminating cost of transportation through a medium distance (85 km). (b) Table 4 shows the main consumption of energy in the production of short-rotation biomass (David 1981); the BEM Programme eliminates the expenses of fertilisation (by returning the nutrients from the process to the field) and medium distance transportation, thus reducing consumption of energy to only 2.5% of biomass contained energy. (c) A vacuum is maintained between the steel vessel and the titanium (0.1 mm Hg) which avoids implosion and allows sporadic helium leak detection of the lining. Because of this characteristic the technology has been named a “fail-safe reactor.” (d) The feeding device compacts the biomass up to 300 kg/m^3 thus allowing it to work with a liquid/solid (L/S) ratio of 2, decreasing considerably the process energy consumption. (e) Figure 5 shows the flow chart and mass balance of the prehydrolysis; it is a batch process composed of the following steps: feeding (15 min), degassing and flooding (15 min), heating (30 min), prehydrolysis (15 min), discharge of prehydrolysate (10 min), and discharge of cellulignin (5 min). (f) Energy is recovered in the discharge of the prehydrolysate. Appendix 1 shows the process energy consumption on the order of 6% of the biomass compared with the conventional consumption of 30% in tower reactors (L/S = 12) and 50% in percolation reactors(L/S = 12). (g) The crystallinity of cellulose is maintained to allow grinding below 250 :m of particle size and drying with low energy consumption (12 kWh/t from the chimney heat lost at 125°C in the thermoelectric plant).

Two products emerge from the prehydrolysis: catalytic cellulignin and prehydrolysate. The first is used as fuel [catalytic cellulignin fuel (CCF)] and as the energy food component for animal feed. The second is used for production of chemicals from biomass (furfural, ethanol and xylitol).

Water from cellulignin washing meets potable water specification after conventional simplified water treatment. It is recycled and not discharged to the environment. In fact, the technology of the BEM Programme does not discharge any residues to the environment either solid, liquid, or gaseous.

Catalytic Cellulignin Fuel (CCF). Figure 6 shows the microstructure of cellulignin with the fragile fracture of crystalline cellulose (6.a), the globular-shaped lignin in middle lamella (6.b), and the “volcanoes” in the inner surface of cytoplasm cavity (6.c). These volcanoes are explosions of material caused by formation of liquid and vapor during decomposition of the high concentration of hemicellulose in the inner layer of the secondary wall of the cell (6.d). This conclusion is confirmed by the sudden increase as a function of the heating time in the Brix grade of the prehydrolysate (Fig. 7).

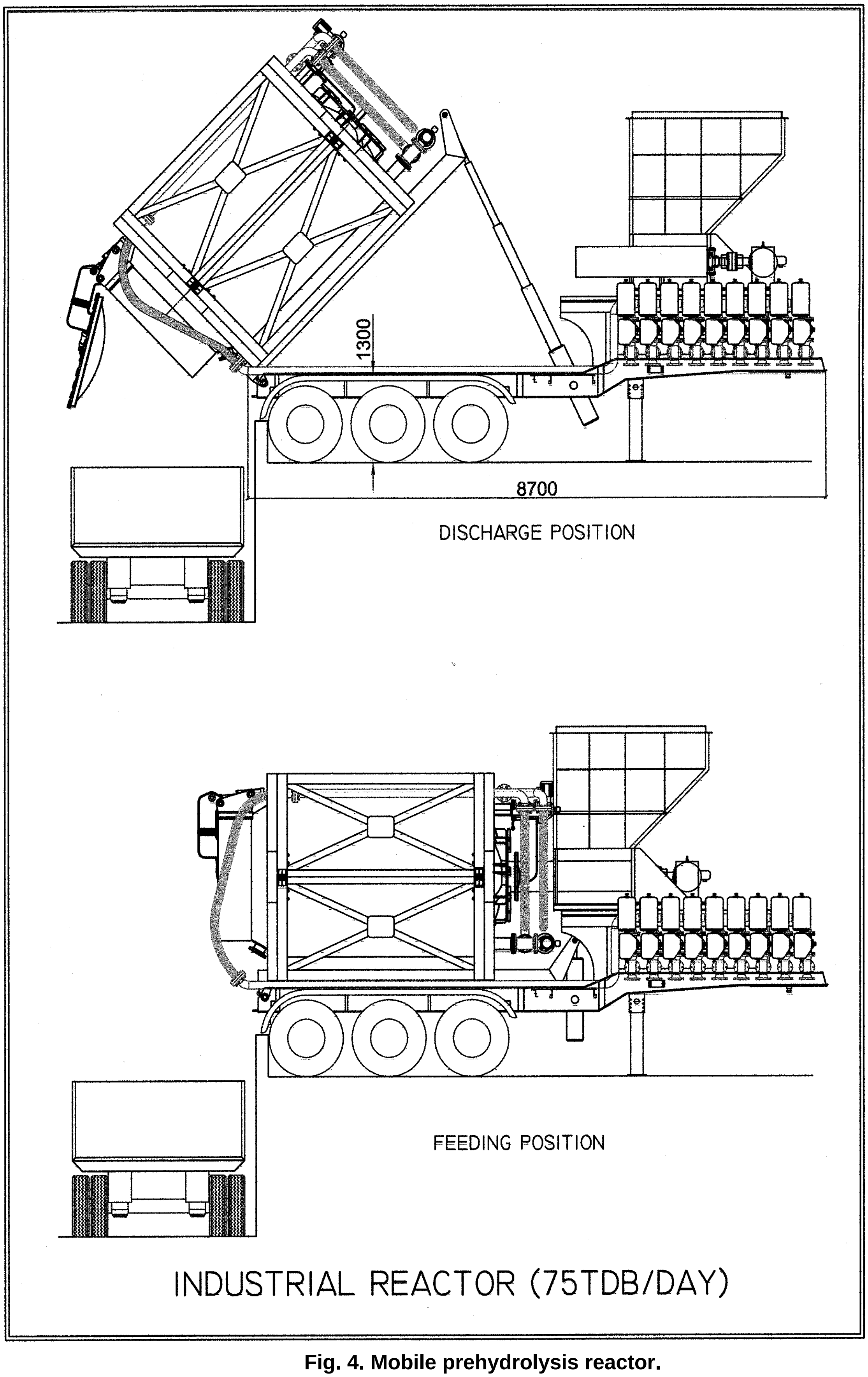


Fig. 4. Mobile prehydrolysis reactor.

Table 4. Energetic analysis of short rotation biomass production

Operation	Consumed energy per ton of dry wood (MJ/t)		Percentage of consumption	
	Conventional	BEM Programme	Conventional	BEM Programme
Production				
• Plantation and culture	9.3	9.3	0.8	3.3
• Fertilisation	804	Null	52.1	—
• Harvest	87	87	7.5	31.0
• Transportation to trucks	115	115	9.9	41.0
• Loading of trucks	55	Null	4.7	—
• Transportation to the user (85 km)	221	Null	19.0	—
• Discharge	Null	Null	—	—
• Auxiliaries	69	69	5.9	24.6
Total	1160	280.3	99.9	99.9
Containing energy in raw biomass (11 MJ/kg)	11000	11000		
• Efficiency in the energy production (%)	89.5	97.5		
• Production ratio to net energy	9.48	39.2		

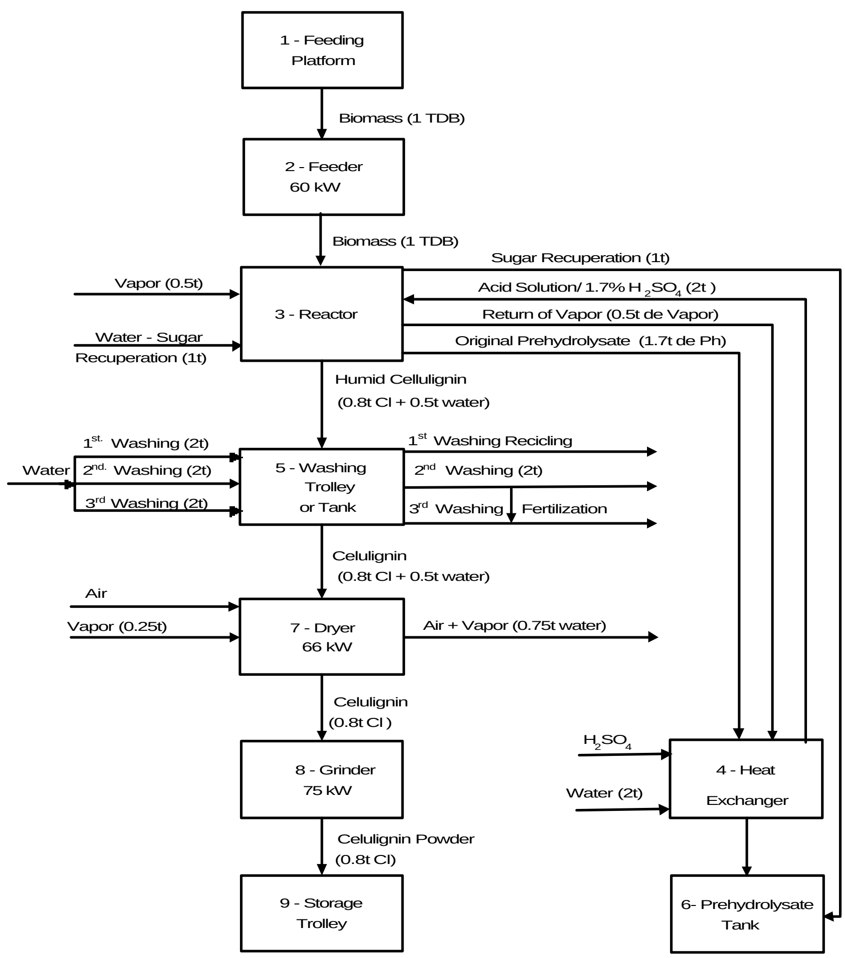
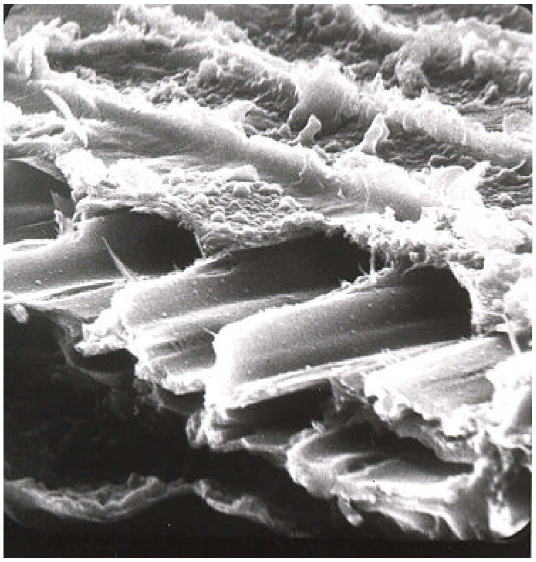
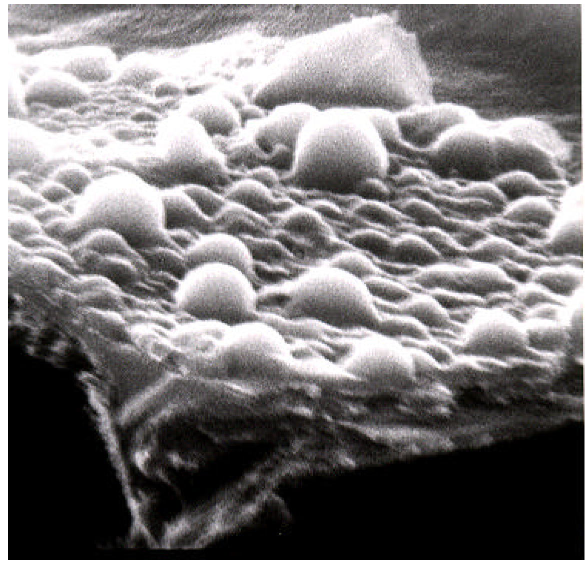


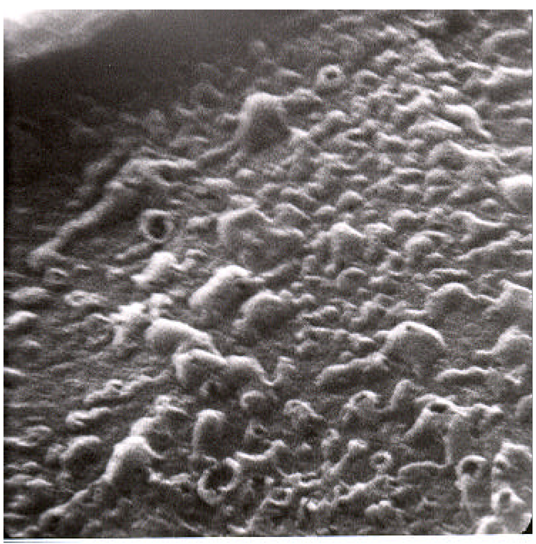
Fig. 5. Flow chart of biomass prehydrolysis with mass balance.
TDB, tons dry biomass. Cl, cellulignin. Ph, prehydrolysate.



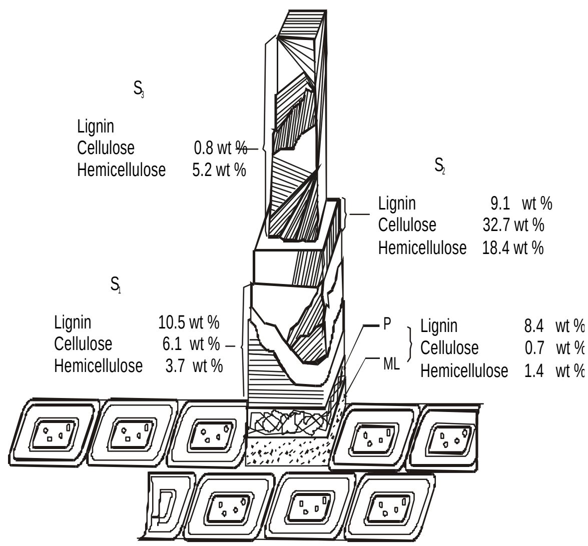
(a) Fragile fracture of the cellulose.



(b) Globular-shaped lignin in the middle lamella of the cell.



(c) “Volcanoes” in the cytoplasm inner wall.



(d) Composition in the cell structure.

Fig. 6. Microstructure of the cellulignin.

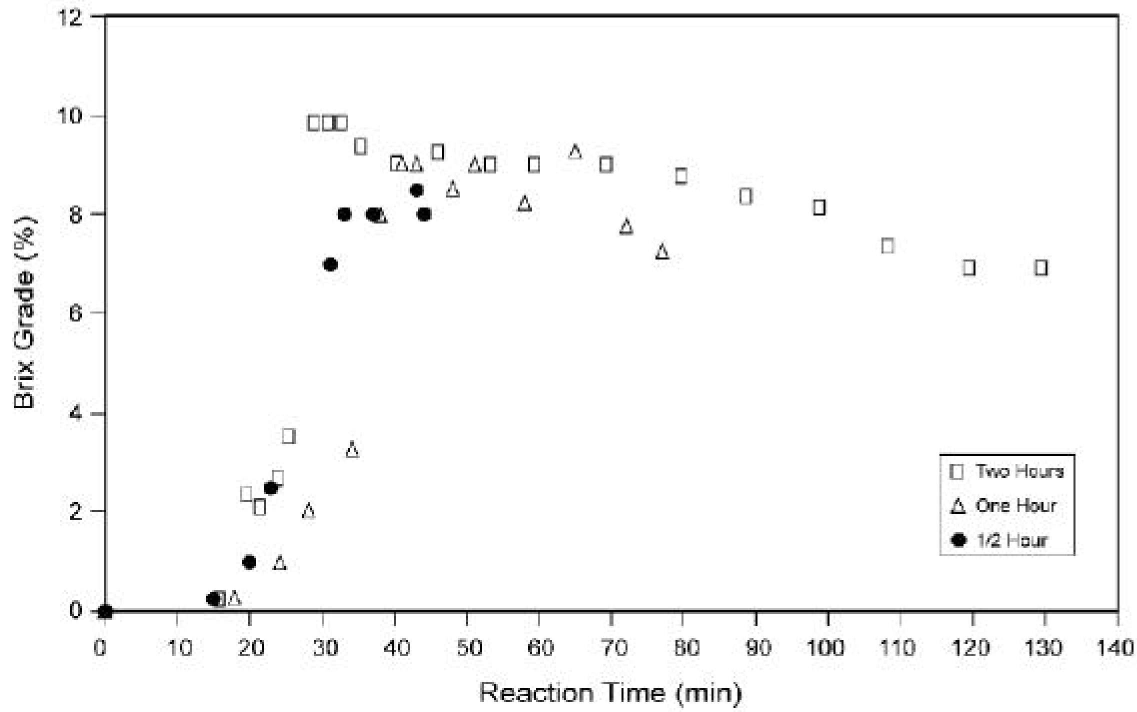


Fig. 7. Acidic prehydrolysis of wood.

A consequence of this process is the increase in the surface porosity from 0.46 m^2/g for wood to 2.2 g/m^2 in microporous surface (porous diameter <2.0 nm—BET absorption of N_2) plus another 2.2 g/m^2 in macroporous surface (porous diameter >50 nm—mercury porosimetry) totaling 4.4 g/m^2 for cellulignin (i.e., 10 times greater than natural wood). Application of Thiele's theory (Essenhigh 1988, 1994; Essenhigh et al.1989) results in catalytic combustion through the inner surface (Boudouard mechanism $C + O_2 \rightarrow 2\ CO$) with ignition time less than 10 ms for a particle diameter less than 250 μm, characteristic of gas combustion, instead of 100 ms for liquid and 300 ms for mineral coal that burns by a much smaller outside surface. Figure 8 shows the specific power irradiated by combustion of one cellulignin particle as a function of its diameter. The conventional combustion (smaller outside surface) takes place for particles with a diameter >250 μm and for particles with a diameter <250 μm catalytic combustion takes place (ten times larger inner surface).

Figure 9 shows the feeding system for CCF to any type of kiln, boiler, or gas-type turbine similar to any type of liquid or gas system. For a gas-type turbine, external combustion is used with cyclone cleaning of the ash and particulates. Figure 10 shows the open-air flame geometry for a 83 kW axial combustor. With an axial swirler, the flame length is reduced to a one-third.

Table 5 shows CCF and its precursor (*Eucalyptus grandis*) composition. Prehydrolysis can be made with potable water, deionised water, non-washed and intensively washed cellulignin. Combination of these process conditions leads to a combustion gas after cyclone cleaning cellulignin with purities ranging from wood grade to natural gas grade.

Economic Analysis

The economic analysis of the BEM Programme is made in four steps: (1) cost of the forests in the field; (2) cost of the cutting, transporting, and chipping; (3) cost of the prehydrolysis; and (4) cost of the electric energy generation.

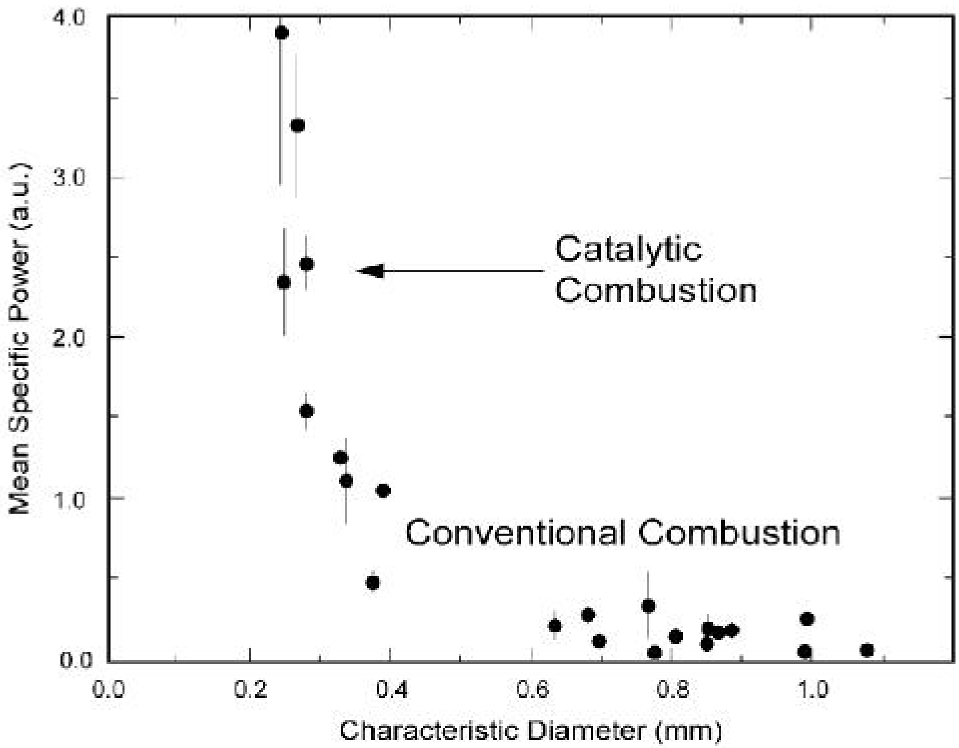


Fig. 8. Mean specific irradiated power in the combustion of a particle of catalytic cellulignin.

- Cost of forests in the field. Five types of forests are considered: cloned Eucalyptus (CE) (40 tons of dry biomass/ha.y-TDB/ha y), seeded forest (SF) (20 TDB/ha y), small forest (SF) (20 TDB/ha y), medium bush (MDB) (5 TDB/ha y), and small bush (SMB) (1 TDB/ha y). The costs for each type of forest, given in Fig. 11 (curve 1), are composed of land, seedling, implantation, and maintenance, applying the same criteria used for pulp reforestation in Brazil. For medium and small bush only the cost of land is considered.
- Cost of cutting, transporting, and chipping. The cost of the cutting is U.S. $7.60/TDB, short distance transportation costs U.S. $6.30/TDB, and chipping costs U.S. $3.30/TDB, giving as a result a total cost of U.S. $17.20/TDB. Notice that long distance transportation, avoided in the BEM Programme, would double this cost. The bagasse/agricultural residue (BG/AR) whose costs are U.S. $7.50/TDB should be added to the list of biomass types for the collected biomass.
- Cost of prehydrolysis. For a plant capacity of 150 TDB/day, working 330 days per year, the costs of obtaining cellulignin and prehydrolysate include capital investment (U.S. $3.58/TDB), labor cost (U.S. $4.12/TDB), consumables (U.S. $3.20/TDB), and steam (U.S. $0.85/TDB). The processing cost totals U.S. $11.75/TDB (see Appendix 2 for expanded calculations).

Addition of all the above costs gives, for each type of forest, the industrial costs shown in Fig. 11 (curve 3).

The final processing cost of the cellulignin and prehydrolysate includes 20% of administrative costs, 20% profit, and 4% taxes after profit (2.3% for the Rural Fund + 1.5% for the Social Funds, social integration program (PIS)/social security financing (FINS) as shown in Fig. 11 (curve 4). These costs should be split between the cellulignin and the prehydrolysate. We propose 70% of the total cost for the cellulignin (80% of the biomass) and 30% for

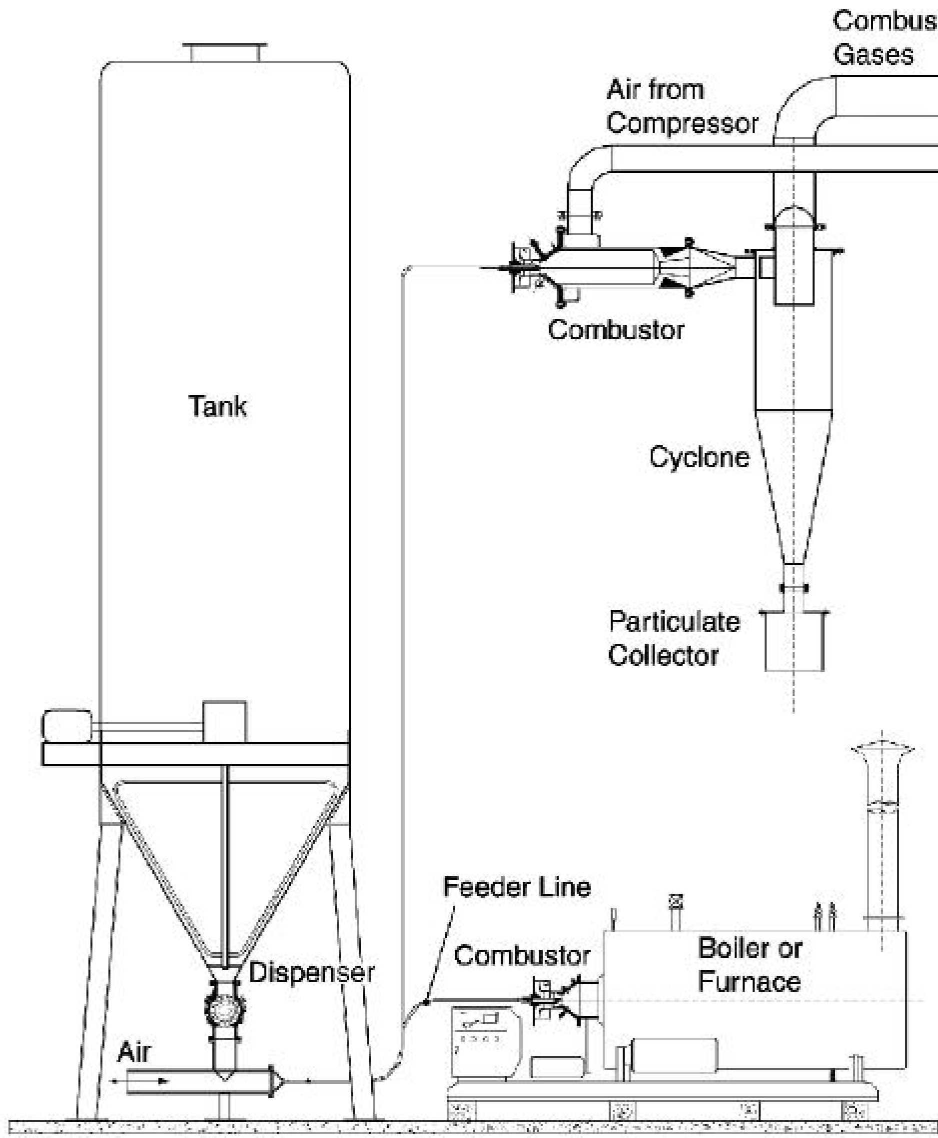


Fig. 9. Feeding system for catalytic cellulignin for boiler/furnace or gas-type turbine.

prehydrolysate (20% of the biomass) because the liquid portion of the processing requires a slightly higher operation cost. For the three main types of biomass (bagasse/agricultural residue, cloned Eucalyptus, and seeded forest), the cellulignin has a smaller cost than natural gas and fuel oil (Fig.12).

- Cost of the electric energy. Considering the steam injected gas turbine (STIGT) cycle with an efficiency 0 = 45% and the combustion heat (P) of the cellulignin = 20 MJ/kg, the cellulignin incidence fuel cost in the energy, according to the type of biomass, is given in Fig. 13 (curve 1). Capital investment depreciation gives U.S. $13.70/MWh. Labor cost is U.S. $1.70/MWh for a 12 MWe power plant operation. At a rate of 3% of the capital cost, consumable cost is U.S. $0.40/MWh (for expanded calculations, see Appendix 2). Industrial costs include the cost of the cellulignin as fuel, capital depreciation, labor costs, and the cost of consumables. Figure 13 (curve 2) gives the industrial costs for each type of biomass. The final cost of the electric energy is obtained by taking into account 20% of administrative

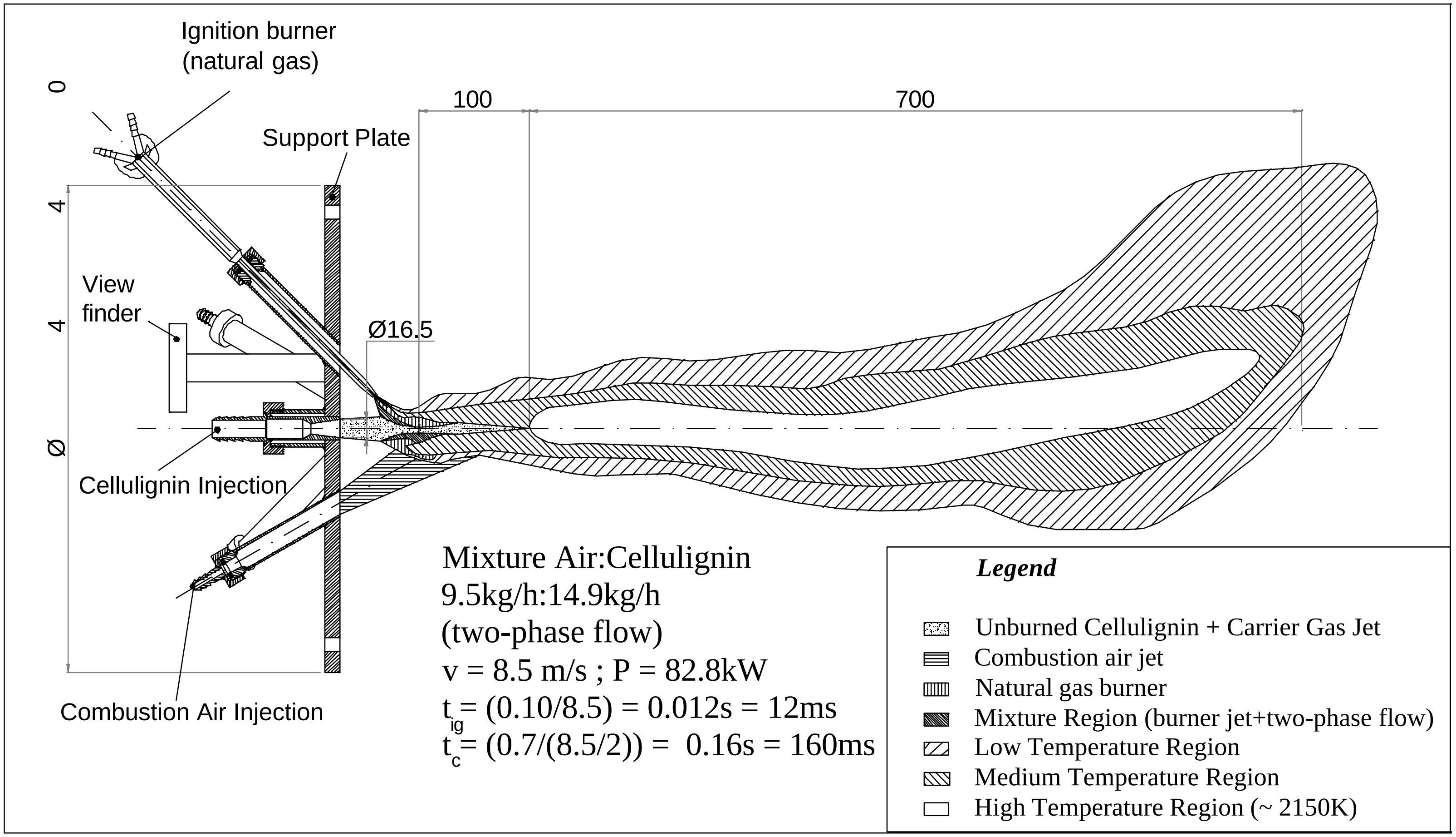


Fig. 10. Axial combustor with cellulignin flame in open air (dimensions in mm).

Table 5a. Biomass fuel analysis

Composition	Alder fir (USA)	Eucalyptus grandis	Cellulignin fuel: Potable water (PW)	Cellulignin fuel: Deionised water (DW)	
			Washed cellulignin	Non-washed cellulignin	Washed cellulignin
Proximate analysis					
Fixed carbon	19.31	27.23	31.42	31.42	31.42
Volatile matter	75.56	72.38	68.41	68.37	68.50
Ash	4.13	0.39	0.17	0.21	0.08
Moisture	Oven dry	Oven dry	Oven dry	Oven dry	Oven dry
Ultimate analysis					
Carbon	51.02	—	66.23	66.21	66.30
Hydrogen	5.8	—	4.27	4.26	4.27
Oxygen	38.54	—	29.32	29.32	29.36
Nitrogen	0.46	—	—	—	—
Sulfur	0.05	0.014	0.008	0.02	0.008
Ash	4.13	0.39	0.17	0.21	<0.08
Moisture	Oven dry	Oven dry	Oven dry	Oven dry	Oven dry
LHV, BTU/#	7415	4729	8599	8599	8599
Chlorine %	<0.01	—	—	—	—
Water soluble alkalis	ppm	ppm	ppm	ppm	ppm
Na_2O	<10	<190	<190	74	<1
K_2O	600	<482	<73	42	<6
CaO	170	<784	<700	168	<74
Elemental composition	%	%	%	%	%
SiO_2	35.4	<6.6	<15.6	32.76	<33.5
Al_2O_3	11.5	2.44	<4.6	19.90	<9.9
TiO_2	0.9	—	—	—	—
Fe_2O_3	7.6	0.37	<0.87	1.03	<1.3
CaO	24.9	20.20	42.43	8.04	<9.7
MgO	3.8	6.85	<4.0	2.38	<13.0
Na_2O	1.7	4.87	<11.5	3.55	<0.13
K_2O	5.8	12.43	<4.4	2.02	<0.78
SO_3	0.8	10.82	(SO_4^{2-}) <14.5	(SO_4^{2-}) 28.67	(SO_4^{2-}) <31.3
P_2O_5	1.9	10.05	1.39	1.65	<0.6
Cl_2/other	1.9	—	—	—	—
Undetermined	3.9	24.68	0.71	—	—
Total	100	100	100	100	100

Table 5b. Minor constituents in Eucalyptus grandis and cellulignin (mg/kg)

Biomass fuel	Ca	K	Na	Mg	P	Al	Si	Mn	Fe	Zn	S
Eucalyptus grandis	510	635	100	255	120	240	135	25	40	10	140
Washed cellulignin (PW)[a]	500	<60	<140	<40	10	<40	<120	<4	<10	<4	<80
Non-washed cellulignin (DW)[b]	120	35	55	30	<15	220	320	1	15	8	200
Washed cellulignin (DW)[c]	<53	<5	<1	<60	<2	<40	<120	<2	<7	<4	<80

[a]Semiquantitative XRF analysis.
[b]Quantitative ICP-OES analysis.
[c]Semiquantitative XRF analysis, except for Na (AAS-flame) and K (ICP-OES), both referring to detection limits.

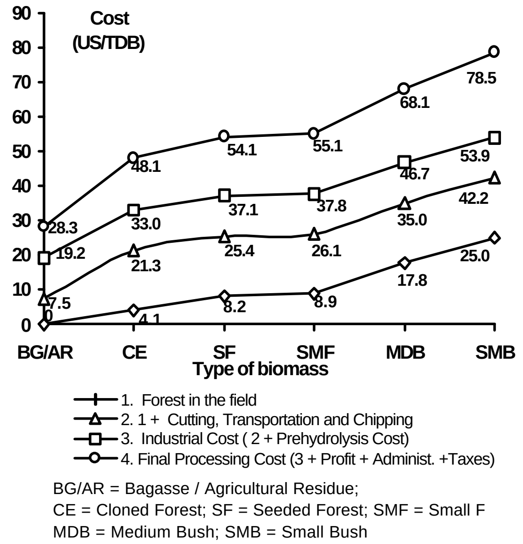


Fig. 11. Prehydrolysis processing costs.

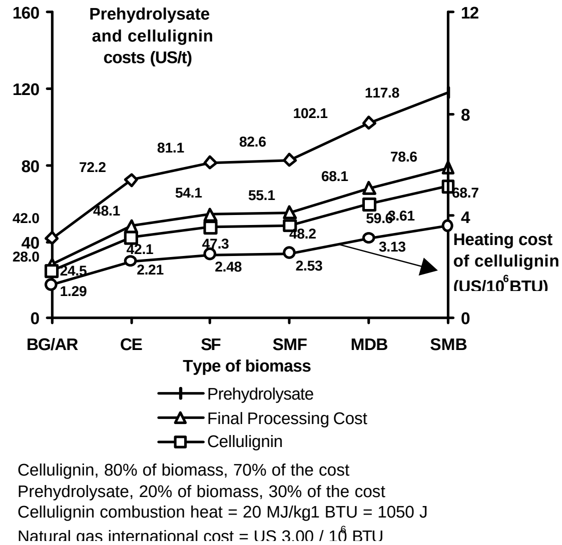


Fig. 12. Splitting of final processing costs into prehydrolysate and cellulignin.

costs, 20% profit, and in addition 19.5% of taxes [1.5% (PIS)/(FINS) and 18% sales tax/services tax, Imposto sobre Circulação de Mercadorias e Serviços (ICMS)]. Values are shown in Fig.13 (curve 3). Except for the last two types of biomass (medium bush and small bush), the cost of the electricity from the burning of the cellulignin is lower than the medium cost of hydraulic energy in Brazil (U.S. $62.00/MWh).

Application and Market Strategies

Table 6 shows the biomass generation, biomass production, and potential and effective electric energy generation for the three areas of BEM technology: short-rotation forest, sugarcane, and municipal solid waste. The current effective capacity of electric generation is only 10% of national consumption, therefore there is no risk of competition and market is guaranteed. Application of reforestation (Eucalyptus and Pine) is immediate, because these companies generate a high volume of biomass residue and environmental laws are pressing them to find a technical-economic solution. In the future, dedicated energy forests will be established. In the sugarcane application, progress is slow because of the conservative attitude of this sector, although they are also under pressure of environmental laws. Demand to solve the problems of municipal solid waste is very strong. The main holdup is the political resistance. There is no economic limitation since prehydrolysis investment represents only one-third of the one-year expenditure with garbage collection.

The thermoelectric plant investment is expected to be made by the private sector. Market penetration is expected to be around 400 MW/year with plant sizes from 12 MW up to 200 MW. Because CCF can be easily transported, there is no difficulty with establishment of base-load plants (1000 MW to 2000 MW). Figure 14 shows a typical layout of a 150 TDB/day BEM industrial plant and a 12 MWe thermoelectric plant.

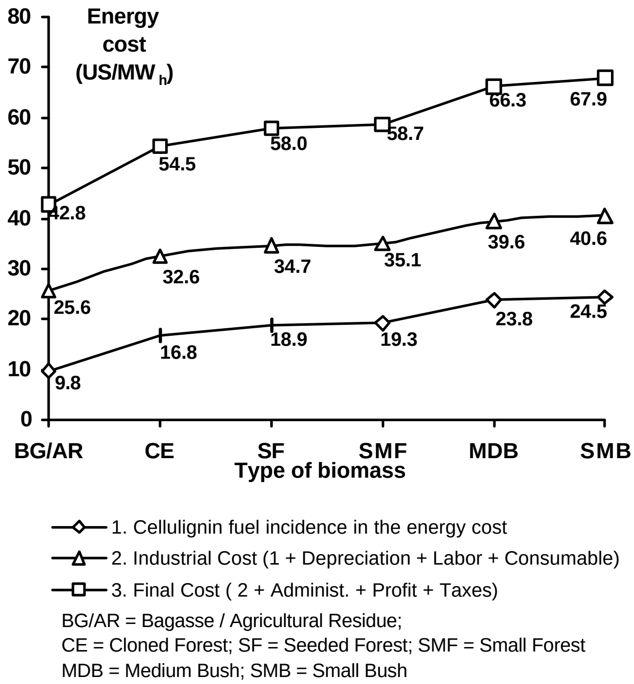


Fig. 13. Electric energy cost based on cellulignin fuel.

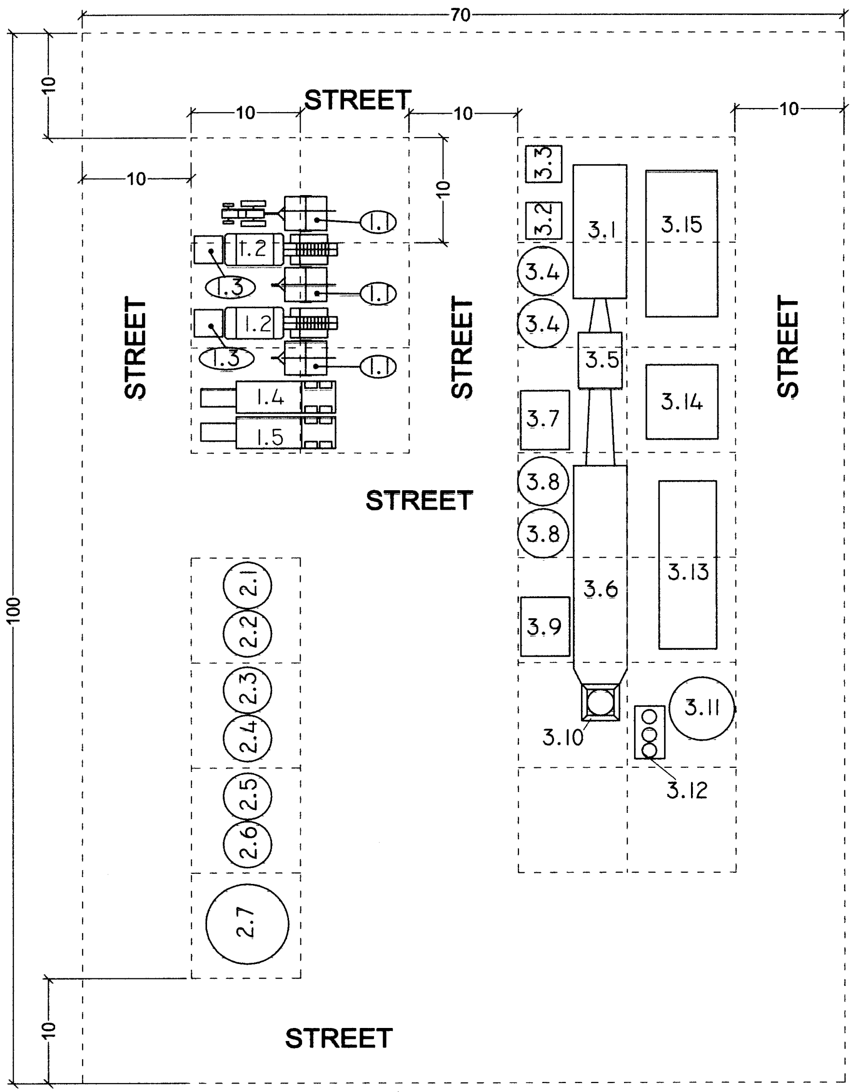
Table 6. Applications and market strategies

BEM Programme application	Biomass generation	Biomass production, TDB/year	Processed biomass, TDB/year	Number of BEM plants[a]	Potential energy generation,[b] MW	Effective market, MW
Short rotation forest	8.5×10^6 ha reforested	212×10^6 [c]	21×10^6 (10% residue)	420	5,040	5,050 (100%)
Sugarcane	4.5×10^6 ha planted	300×10^6 (sugarcane) 36×10^6 (bagasse) 36×10^6 (leaves)	72×10^6 (bagasse + leaves)	1440	17,280	3,450 (20%)
Municipal solid waste	160×10^6 hab.[d]	19×10^6 (organic matter[e])	19×10^6	380	2,280	1,140 (50%)
Total				2,240	24,600	9,630

[a]50,000 TDB/year/plant.
[b]12 MW/plant.
[c]25 TDB/ha.year.
[d]0.4 kg/day.hab., 365 days/year.
[e]80% of municipal solid waste.

Conclusions

The Brazilian biomass programme has experienced three phases. The first (past phase) from 1965 to 1985 was based on conventional technology of wood for pulp and charcoal (siderurgic sector) and sugarcane (alcohol sector). In this phase, the country reached the position of the largest biomass producer for energy in the world. The programme was strongly supported by the Government. The second (present phase) from 1985 to 2000 is characterised by the complete



Layout of BEM Industrial Plant
Legend of Machinery

Area 1 Prehydrolysis

1.1 – Biomass transfer lory
1.2 – Reactor
1.3 – Cellulignin discharge box
1.4 – Acid solution tank
1.5 – Prehydrolysate tank

Area 2 Furfural Processing

2.1 – Furfural reactor
2.2 – Flash, condenser and condensing tank
2.3 – Distillation column
2.4 – Refrigerator, decanter and raw furfural tank
2.5 – Depuration column (distillation of light compounds, methanol, etc.)
2.6 – Vacuum rectification column
2.7 – Commercial furfural tank

Area 3 Thermoelectric Plant

3.1 – Gas turbine
3.2 – External combustor
3.3 – Natural gas, LPG or diesel oil supplier system
3.4 – Wood cellulignin container
3.5 – Diverter valve
3.6 – Boiler
3.7 – External combustor (MSW cellulignin)
3.8 – MSW cellulignin container
3.9 – Supply pump
3.10 – Chimney
3.11 – Condensing tank
3.12 – Steam collector
3.13 – Steam turbine/Electric generator
3.14 – Electric room
3.15 – Control room

Fig. 14. Lay out of a 150 TDB/day BEM industrial plant and 12 MWe thermoelectric plant.

stagnation of biomass development. Government support is negligible and official plans have not been accomplished. The third phase (future phase) starting in the year 2000 will be completely supported by the private sector. It is mainly based on prehydrolysis of biomass, producing two products: catalytic cellulignin fuel for electric energy generation through combined cycle gas-type turbine/steam turbine and prehydrolysate for biomass chemicals (furfural, alcohol, xylitol). The new technology processes any kind of biomass (wood, sugarcane, agricultural residue, and organic matter of municipal solid waste), is fully ecological, has no market limitations, and can compete economically with hydroelectric and fossil fuel energy and hydrocarbon products. The new technology is based on the application of advanced materials in the biomass processing reactor (steel lined with titanium) and in the gas-type turbine (superalloy and its coating in the vanes and blades). The technology of the BEM Programme forms a technical-economic basis for the Clean Development Mechanism established by the Kyoto Protocol with the cost in the range of U.S. $10.00/tC compared with a cost of U.S. $580.00/tC in Japan, U.S. $180.00/tC in the United States, and U.S. $270.00/tC in Europe using other technologies than reforestation.

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Information on the World Wide Web

CENBIO. National Reference Center in Biomass. e-mail: cenbio@lee.usp.br, http://www.iee.usp.br/energia/cenbio/cenbio.html.

CRESESB—Reference Center for Solar and Eolic Energy Sergio de Salvo Brito. http://www.cresesb.cepel.br, e-mail: cresce@cepe.br.

Appendix 1 Energy Consumption per ton of dry biomass (TDB)

Biomass heating

(35% humidity, specific heat
C = 2,345 MJ/TDB °C

MC) T = 1 × 2,345 × (160-20)
= 328,50 MJ/TDB

Heating of 2 t of water (L/S = 2)

h^a_{20} = 83.96 KJ/kg (water)

h^a_{80} = 334.91 KJ/kg (water)

h^a_{100} = 418.94 KJ/kg

h^a_{160} = 675.55 KJ/kg (water)

h^a_{160} = 2,758.10 KJ/kg (vapor)

H_{CL} = 20 MJ/kg (heat of combustion of cellulignin)

CL / cellulignin

- Starting water at 20°C

$m\left(h^a_{160} - h^a_{20}\right) = 2 \times 10^{+3}\,(675.55 - 8.96)$
= 1,183.18 MJ/TDB

Percentage of energy consumption in the cellulignin

$$\frac{328.30 + 1{,}193.18}{10^3 \times 0.8 \times 20} = 0.0945 = 9.45\%$$

- Starting with water at 80°C

Percentage of energy contained in the cellulignin

$m\left(h^a_{160} - h^a_{80}\right) = 2 \times 10^{3}\,(675.55 - 334.91)$
= 681.28 MJ/TDB

Vapor consumption

$$\frac{(328.50 + 681.28)\ \text{MJ/TDB}}{(2{,}758.10 - 418.94)\ \text{KJ/kg}} = 431.68\ \text{kg of vapor/TDB}$$

Boiler efficiency = 90%

Cellulignin consumption for vapor production

$$\frac{487.9\,(2{,}758.10 - 418.94)\ \text{KJ/TDB}}{0.9 \times 0.8 \times 2\ \text{MJ/kg}} = 70\ \text{kg CL/TDB}$$

Appendix 2

Expanded calculations for the prehydrolysis process

Item of cost	Calculations
Capital investment	$\frac{Ci(1+i)^n}{(1+i)^n - 1} = 0.177\ C$ C = U.S. $\$10^6$; i = 12% per year; n = 10 years
Labor cost	Salary + social cost = U.S. $1,000.00/month 17 workers, 12 months
Consumable	H_2SO_4: 1% of TDB 0.01 t × U.S. $320.00/t H_2SO_4 = U.S. $3.20/TDB
Steam	4% of the Biomass Cost: Cloned Eucalyptus = U.S. $21.30/TDB

Expanded calculations for the electric energy costs

Item of cost	Calculations
Cellulignin as a fuel, according to the type of biomass	$\frac{\text{Cellulignin cost (U.S./kg)} \times 3600\ \text{s}}{P = 20\ \text{MJ/kg} \times 1\ \text{h} \times 0.45}$ $\frac{Ci(1+i)^n}{(1+i)^n - 1} = 0.128\ C$
Capital investment depreciation	C = U.S. $750,000/MWe; i = 12% per year; n = 25 years; 80% of availability $\frac{0.128 \times \text{U.S. } 750{,}000}{1\ \text{MWe} \times 24\ \text{h/d} \times 365\ \text{d/y} \times 0.8} = \text{U.S. } 13.70/\text{MWh}$
Labor cost	Salary + social cost = U.S. $1,000.00/month 12 workers, 12 months $\frac{12 \times \text{U.S. } 1{,}000.00 \times 12\ \text{months}}{12\ \text{MWe} \times 24\ \text{h} \times 365\ \text{d/y} \times 0.80} = \text{U.S. } 1.70/\text{MWh}$
Consumable	3% of the capital investment

Country Report for Denmark
IEA Bioenergy Task 17

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Background

With the reform of the Common Agricultural Policy (CAP) in Europe in 1992 and its demand for setting aside land from food and feed production, a high interest in non-food crops appeared in Denmark. Several new initiatives were undertaken. With the lowering of the set-aside and the often low production economy in non-food cropping, this interest decreased in the period 1996–98. As grain prices have decreased recently, the set-aside percentage increased, and Agenda 2000 has indicated that set-asides will be possible in the long term, interest seems to be increasing slightly again.

The area of non-food rape (which is not used for energy nationally, however) has been proportional to the set-aside percentage. The area of energy grain has been linked to demonstration projects and has been decreasing since 1994. The area of willow increases very slowly, while the area of *Miscanthus* is almost stable.

Projects on energy crops cover both basic aspects of crop breeding and more applied projects. However, the initiation of more or less commercial demonstration projects was stopped in the period of low interest, although recently such projects are being discussed again. In the governmental demonstration and development project “The Energy Crops Program,” the whole energy crop chain, including environmental aspects, is addressed, and this reflects the holistic approach that is emphasized in Danish energy policy. What is currently lacking is more focus on aspects of commercialisation. The few commercial actors on energy crops in Denmark have heavily criticised this and the lack of an implementation policy.

Energy 21

In April 1996, the Danish Government launched its Action Plan “Energy 21.” The following is from chapter 2.3 “Renewable Energy.”

> The long-term perspective over a period of 30 years is the development of an energy system in which an increasing proportion of the energy consumption is covered by renewable energy. The assumption is that there will be a gradual phasing in of renewable energy as technological and economic conditions make the various renewable energy solutions commercially viable.
>
> On the basis of the initiatives that have been launched, it is estimated that domestic renewable sources of energy will contribute some 12-14% of the total gross energy consumption by 2005. The Government intends to continue the development of renewable energy at an average annual rate of 1%. This entails renewable energy increasing its share of the energy supply to about 35%, a development which will also be necessary if it is decided to halve CO_2 emissions by 2030 relative to 1988.
>
> The implementation of the biomass agreement of 1993 means that the use of biomass for energy purposes will be increased from 50 PJ to some 75 PJ a year before the end of 2000. Biomass will then comprise almost 10% of the total consumption of fuel in the year 2000. The biggest expansion will be caused by the power plants’ increasing use of straw and wood chips. In

> addition the use of biogas and landfill gas will increase following the Government's initiatives in the autumn of 1995.
>
> The main part of the present exploitation of biomass takes place in plants which only produce heat. The objective of the development in the coming years is to increase the use of biomass in power producing plants. This will partly be achieved by increasing the use of straw and chips in power plants, partly through the ongoing conversion of waste heating installations to power production, and partly by further development of combined heat and power technologies for smaller district heating plants.
>
> The Government intends this development to be continued.
>
> Residual and waste products from agriculture and forestry will remain the basis for some years of the utilisation of biomass. At the end of 2000 there will still be large, unexploited quantities of raw material for use in plants using biogas, landfill gas, and straw. The main part of the present wood resources will be exhausted, but it has been decided to increase Danish wood resources by afforestation. In addition increased production of bioenergy, including energy crops, will be required to meet the demand for biomass after 2005. In the long term, stable supplies of biomass will depend on land use. If, for example, the agricultural policy of the EU were to be changed, the shortage of land might mean that the production of biomass for energy purposes would take place as a byproduct of more valuable main crops. After use, the main crop itself may be used in the supply of energy. The use of land for energy crops should not, however, take place before the possibilities of using residual products for energy purposes have been exhausted.
>
> Initiatives in the field of biomass are directed, firstly, towards conversion from heat production plants only to combined heat and power units, secondly towards increased exploitation of straw, biogas, and landfill gas, and thirdly towards reduction of the costs of producing biomass for energy purposes.

The conclusion is that the government wants all available residual products (mainly straw and wood chips) used before energy crops are to be considered.

Part of the Action Plan was to implement a demonstration and development program for energy crops, "The Energy Crops Program." This was started in 1997 and runs until 2000. Unfortunately, seen from a "Short Rotation Crops view," most effort is put into annual crops such as Energy Grain.

So, while we are waiting for 2005, what happens in Denmark in the SRC (short rotation crop) field?

A number of research projects are being run, but at the commercial scale there is little activity. Two commercial operators (mainly in *Salix*) have been doing most of their work in the United Kingdom in 1999. A few fields of *Salix* have been planted in Denmark, more for wildlife than for energy!

The following is a list of current projects in Denmark. In projects that our institute (Danish Institute of Agricultural Sciences) is not directly involved in, I have included the contact persons.

Production Projects of the Energy Crops Program

Objectives

The demonstration and development program for energy crops is designed to contribute to the evaluation of the long-term consequences of increasing the Danish biomass resources by energy crop production, in terms of finance, energy and environment, nature and landscape, and commerce.

Table 1 shows sub-projects and crops included in a research and demonstration program, 1997–2000. The project contains three main parts: a demonstration part, a research part, and a development part, together with an overall assessment part.

Table 1. Overview of activities in the energy crop program

	Forest	Willow coppice	*Miscanthus*	Reed Canary Grass	Hemp	Rye	Triticale
Demonstration part							
Establishment/growing	+	–	–	–	–	+	+
Harvest/storage and transport	+	–	–	–	–	+	+
Research and development part							
The influence of variety on fuel quality and yield	–	–	+	+	+	+	+
Fuel characteristics of potential biofuels	–	–	+	+	+	+	+
Fuel analysis and burning tests	–	–	+	+	+	+	+
The effects on surface and ground water from growing energy crops			+	–	–	+	+
The effects on surface and ground water from energy forestry	+	–					
Harvest, pelletizing and storage of *Miscanthus*			+				
The effects of perennial energy crops on flora and fauna		+	+				
Visualisation of the influence of energy crops in landscape	+	– +					
Carbon balances in energy forestry	+						
Co-ordination and assessment							
Planning and co-ordinating fuel deliveries and end use	– +	– +	– +	– +	– +	– +	– +
Technical and fuel related follow up	+	+	+	+	+	+	+
Assessment and economic evaluation of annual and perennial energy crops	– +	– +	– +	– +	– +	– +	– +

– = Information is gathered from literature and experiments outside this program.
\+ = Information is gathered from experiments in this program.
– + = Information is gathered from experiments in this program, experiments outside this program and literature.

When the proposal was made, the budget was approximately 6 million $. This budget was later reduced to approximately 1,5 million $. Because of this cut in the budget, it is doubtful if the objectives can be fulfilled.

The effects on surface and ground water from growing energy crops

This is an example of activity in the energy crops program. *Miscanthus* and *Salix* sewage sludge and cattle slurry is used as fertiliser. Because of the budget cut *Salix* was removed from this activity, but the Danish Institute of Agricultural Sciences (DIAS) has, with its own financing, done the same experiments in *Salix* as in *Miscanthus*. The impact on water quality in relation to nitrate and water use is being monitored.

Figure 1 shows the results from 1997–98 for *Salix* using sludge on coarse sand.

The reason for the high level in Sludge 1 in 1997 compared with Sludge 2 is probably that Sludge 1 was used on a lower yielding clone (defoliated in August by rust).

Figure 2 shows the results from 1997 to 1998 in *Salix* using slurry on a sandy loam.

European *Miscanthus* improvement (EMI) [EU project (FAIR3 CT-96 – 1392)]

The general objectives of this project are to improve the methods and the genetic base needed for the future development of *Miscanthus* as a non-food crop for combustion and fibre

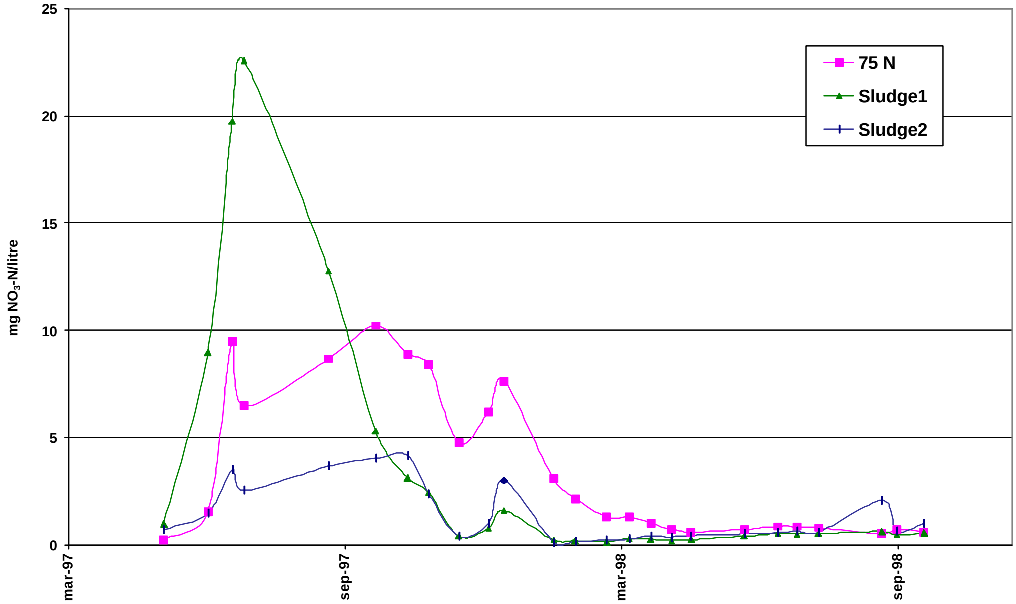

Fig. 1. *Salix viminalis* on coarse sand in Denmark. 75 N: (75 kg N, 19 kg P, 56 kg K)/ha annually. Sludge 1: 140 kg N/ha and 120 kg P/ha applied every third year [maximal amount of sludge that may be applied for a three-year period. The limiting factor is P (max. 40 kg P/ha and year)]. Sludge 2: Double amount of sludge 1 (twice as much as the legislation allows!).

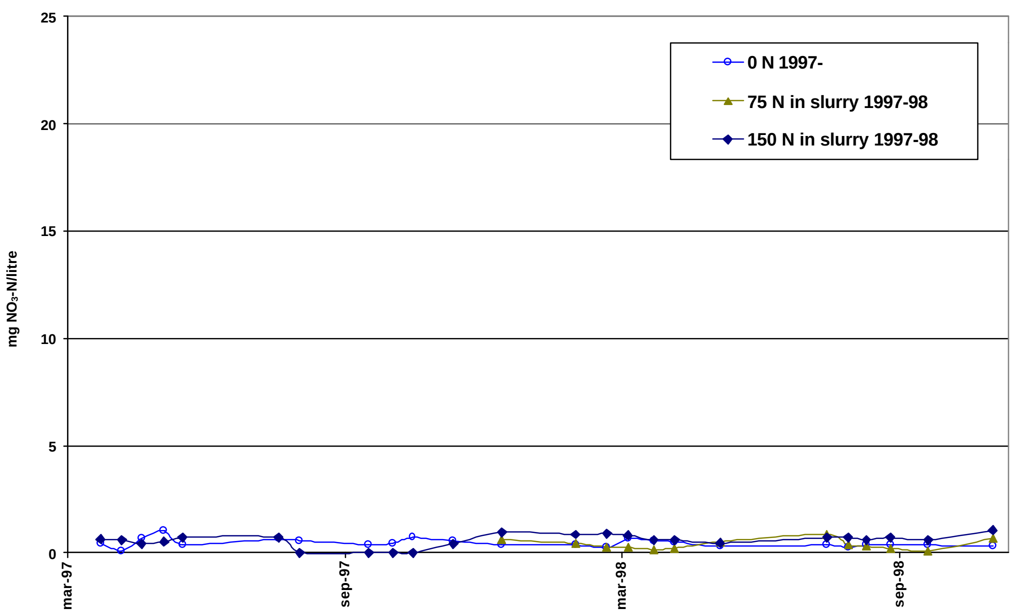

Fig. 2. *Salix viminalis* on sandy loam in Denmark. 0 N 1997–98: No fertiliser. 75 N in slurry 1997–98: 75 kg ammonium-N/ha in slurry 1997 and 1998; no fertiliser in 1999 and 2000. 150 N in slurry 1997–98: 150 kg ammonium-N/ha in slurry 1997 and 1998; no fertiliser in 1999 and 2000.

uses and to maximise the productivity, quality, and adaptive range of the crop. Fifteen different genotypes of *Miscanthus* are being compared on sites in Germany, England, Sweden, Portugal, and Denmark.

Reduction of fouling, slagging, and corrosion characteristics of *Miscanthus* for power and heat generation using biotechnology (BIOMIS) [EU project (FAIR-CT98-3571)]

The objectives of this project are (1) to achieve significant cost reductions in cleaning, maintenance, and replacement costs of expensive heat exchangers (piping) in thermal conversion processes (combustion, gasification, and pyrolysis) by reduction of the fouling, slagging, and corrosion characteristics of *Miscanthus* for power and heat generation using biotechnology; (2) to further integrate the expertise from the agricultural and energy sector into an R&D project covering the whole bioenergy chain; and (3) to demonstrate the usefulness and perspective of biotechnology for structural and cost-effective improvement of biomass fuel characteristics.

The project started in 1999, and experimental plots are planted in Spain and Denmark.

Heavy Metal Removal from Lake Sediments by Phytoremediation

A research project on a method for removing heavy metal from sediments has been conducted. The main idea of the method is to make use of the high concentration of nutrients as means of soil improvement for energy forestry. The trees will absorb the nutrients and the heavy metals, after which the trees can be cut down. Thereby the heavy metals will be removed from the environment. With this method in mind, the purpose of the project has been to examine if heavy metals can be removed from soil that has been treated with lake sediment by means of phytoremediation. Furthermore the purpose has been to examine the possibility of removing heavy metals from the lake sediment and at the same time producing biomass for energy. This method has been used in two pilot experiments at the two Danish lakes, Arresø Lake and Bygholm Lake.

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Evaluation of Combined Food and Energy systems for more efficient land use and environmentally benign sustainable production (CFE) [EU project (FAIR3-PL96-No. 1449)]

The objectives of this project are (1) to evaluate the potential for developing farming systems that provide nutritious food in conjunction with valuable non-food renewable energy biomass crops, as a financially viable alternative to the set-aside option; (2) to examine the feasibility, environmental benefits, and economic viability of alternative arable systems of production that integrate renewable energy (biomass) crops with food crops and perennial vegetation; (3) to produce and evaluate combined, less-intensive food and renewable energy crop production systems compatible with environmental protection for a more sustainable European agriculture; (4) to examine and model modified land use and management techniques to enhance landscape, biodiversity, and biological control by providing ecological reservoirs to exploit natural regulation within adjacently grown food crops; (5) to build upon and improve existing principles for lower-input integrated crop production and to extend these in the direction of energy neutral agricultural production; and (6) to provide the agricultural industry with effective integrated packages of land use and crop management for energy neutral alternative production systems that are less reliant upon external inputs.

At the Danish Royal Agricultural and Veterinary University, the Combined Feed/Fodder and Energy (CFE) system consists of short rotation coppice (SRC) biofuel belts separating fields used for crop production, similar to agroforestry systems that have been proposed for the tropics. The biofuel belts consist of three 0.7-metre-wide double rows with a distance of 1.3 metres between each double row.

Three cultivars of willow (*Salix* spp.) are grown in the rows. At the edges of the fields one row of hazel (*Corylus avellana*) and one of alder (*Alnus glutinosa*) act as nutrient (nuts) source, biodiversity reservoirs, and nitrogen cycle modifiers. This gives a total design width of the biofuel hedges of 10.7 meters.

The Danish fields were planted in 1995. The EU project is running from 1997–2000.

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Biomass for energy: Effects on the soil carbon balance in agriculture and forestry

This project analyses the soil carbon balance in agriculture and forestry under different management strategies and describes the consequences of removing biomass for energy purposes. The project is based on the existing soil databases, on analyses of soil samples retrieved from long-term experiments, and on pair-wise sampling of soil profiles under arable use and forestry. Data on management history and results of soil analysis are coupled with climatic data, and different scenarios are modelled with the soil-plant-atmosphere model DAISY.

The results of the project will add to the knowledge-base upon which future political and administrative decisions can be established, in particular, decisions related to the relationship between reductions in CO^2 emissions, biomass for energy, and sustainability of agricultural and forest soils.

The project started in 1999 and runs until 2001.

Utilisation Projects of the Energy Crops Program

Most of the utilisation in this program is focused on annual crops (energy grain). In April 1999, two combustion tests were carried out at the Masnedø combined heating/power (CHP) plant. The first test included a mixture of straw and chopped *Miscanthus* (about 40 tonnes of *Miscanthus*) harvested on 16 March, and the second one included 29 Hesston *Miscanthus* bales harvested on 19 April.

The purpose of the Masnedø plant combustion tests was to test the combustion abilities of other biofuels than the conventional ones (straw and wood chips). The biofuels may be used as solitary fuels or as an admixture to straw for combustion.

The tests results indicate that the existing combustion plant and stoking system may be used for combustion of *Miscanthus*, both in the form of additive fuel and as whole bales.

The described combustion tests show that *Miscanthus* may be a potential alternative bio-fuel for combustion in CHP plants. Further analyses of the fuel should, however, be made, as well as more combustion tests of longer duration.

More details at: www.eeci.net: “Combustion test with *Miscanthus* in CHP-plant”

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Combustion of energy crops

The Danish Technological Institute has carried out a number of combustion tests which show that many small boilers have serious problems when burning different kinds of energy crops. There are problems especially with large amounts of slag, heavy dust generation, and combustion chamber and fire tube fouling.

From 1997 to 1999, the Danish Energy Agency financed a project to improve knowledge of different energy crops in small automatic boilers from 20 to 250 kW. Eight different energy crops were tested in five different boilers. Each crop was tested in two boilers with approximately three days of continuous operation at nominal load and partial load, respectively.

The following conclusions were drawn from these tests:

- The best biofuel for small boilers is still wood pellets.
- It is difficult to point out unambiguous parameters characterising a biofuel.
- Small boilers are not always able to burn a dry, pelletised biofuel satisfactorily.
- Pelletised or shredded biofuels (except wood pellets and grain) are less suitable for the available biofuel boilers under 250 kW.
- Boilers with a step grate are able to burn more types of fuel than boilers with a fixed grate or boilers in which the combustion takes place in a tube.

Further information. The report “Alternative biobrændslers anvendelighed i små fyringsanlæg fra 20 til 250 kW” is available from the Danish Technological Institute, tel.: 8943 8556. The price is DKK 300 exclusive of VAT. The report is written in Danish, but an English summary is being planned.

See also the European Energy Crop Internetwork (EECI) at www.eeci.net: “Combustion of Energy Crops.”

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Demonstration: The Energy Crops Program

The demonstration part of this program is mainly focused on forest and annual crops.

Samsø renewable energy island

In 1997 the island “Samsø” was appointed as a demonstration area for the conversion to 100% renewable energy. The project is running until 2008. Samsø is a part of “European Island Projects.”

Beginning in 1999 a co-operation will commence between Samsø, El Hierro (Spain), La Madalena (Italy), and Aran Islands (Eire). The aim of the project is development and implementation of organisational and financial tools in network collaboration on renewable energy systems. The project is supported by the ALTENER (Alternative Energy) agreement of the EEC, and Samsø will be project co-ordinator in co-operation with Green Globe International.

On Samsø, items that will be specifically dealt with are (1) thrusts for solar energy in open areas, (2) the new district heating systems, (3) flake- and wood pellet production, (4) wind energy, and (5) electric vehicles.

Biomass is expected to cover 36% of the total energy consumption. An assessment of biomass resources was carried out in 1999. It showed that there is not enough biomass available at the moment (straw, wood chips, and other residuals). The best solution is to grow energy crops. The annual rainfall on Samsø is relatively low, and utilising wastewater from municipal waste treatment for irrigation of energy crops is being considered. Which energy crops are to be planted is not yet decided.

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Langholt potato processing plant

A project on willow planted 23 ha at the potato processing plant 'Langholt,' but it has not yet been harvested. Fifteen different clones were planted. The area is used for spreading sediments from the lagoons of potato processing water in high amounts (no figures available), which often have caused leaf scorching and may also be the cause of several instances of plant death. This spreading during the first year especially should be avoided. The sediments contain high amounts of organic material and most likely potassium, sodium, and chlorine. No data on environmental balance are available. Crop production has been rather limited, probably because of the adverse effects of the processing water. The clones 'Gustav' and 'Stefan' were the most tolerant. The company is considering planting a larger area where the spreading of processing water may also be tested.

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Potential projects

Two demonstration project ideas are currently being investigated. One focuses on willow in a large scale (c. 1600 ha) around 'Nordjyllandsværket' near Ålborg, where construction of a new biomass-fired block to supplement the current coal-fired units is planned. Another potential project focuses on the production of *Miscanthus* to be delivered to the Masnedø 8.3 MWe CHP biomass plant where the successful combustion test on *Miscanthus* was recently conducted. The aim is to harvest *Miscanthus* during winter for direct delivery to the plant. Another aim is to produce *Miscanthus* on nitrate sensitive areas where research results have demonstrated that nitrate leaching from perennial energy crops is very low.

Outlook for Energy Crops in Denmark

Whether the Energy 21 scenario for significant increases in the Danish energy crop areas after the year 2005 will be fulfilled is still an open question. Even though many technical bottlenecks are being addressed and some seem to have been solved, the initiation of a major development in energy crops is mainly a political question as the main barriers are still non-technical. If energy crops gain political support and an implementation policy is developed, there seem to be no remaining significant technical barriers. Key issues that will govern the political decision are the most likely environmental externalities of energy crop production compared with those of other renewable energy resources, the general development of biomass conversion technologies, and discussion of land use for food, energy, or nature and recreation. The cost-benefit of energy from crops compared with, for example, energy from wind will, of course, also influence the policies, but this analysis is heavily influenced by the development in European agricultural policy and how energy crops are situated in the agri-environmental support scheme.

Additional Information on the World Wide Web

EECI:	www.eeci.net
Samsø–Renewable Energy Island:	www.samso.com/ve/uk/
Energy 21:	www.ens.dk/e21/e21uk/index.htm
CFE (Denmark):	www.agsci.kvl.dk/~bek/cfehtml.htm

Developing a Willow Biomass Crop Enterprise in the United States

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Abstract

More than two decades of research on woody crops, combined with growing concern about environmental issues, prompted the formation of the Salix Consortium in 1994. Over 20 organisations have pooled their resources and talents to facilitate the development of willow biomass crops as a locally grown source of renewable energy and cellulose feedstock that produces multiple benefits for the northeastern and midwestern regions of the United States. State University of New York College of Environmental Science and Forestry (SUNY-ESF), and other Salix Consortium partners, continue to develop and expand a strong applied research program, which underpins the commercialisation effort. Research focuses on both optimizing the production system and quantifying environmental benefits associated with willow biomass crops.

In 1998 and 1999 over 120 ha of willow biomass crops were established in western New York in close proximity to a coal-fired power plant. The power plant is being retrofit for co-firing wood biomass with coal, with initial tests scheduled for the spring of 2000. Continuing research gains in crop yields and reductions in costs, and supportive state and national policies that value the environmental and rural development benefits, will be essential to making a commercial willow biomass enterprise successful.

Background

The development of a willow biomass production system for the northeastern and midwestern United States is based on almost two decades of research at the State University of New York College of Environmental Science and Forestry (SUNY-ESF). Research has ranged from trials with hybrid poplar at relatively wide spacing and anticipated 10- to 12-year rotations (Abrahamson et al. 1990) to willow trials at extremely high densities and 1-year rotations (Kopp et al. 1993). As this research began to yield encouraging results, and concern about environmental issues grew, interest developed in the concept of a rural-based enterprise centered on willow biomass as a renewable source of energy and cellulose feedstock for bioproducts. In 1993 SUNY-ESF, in conjunction with Niagara Mohawk Power Corporation (NMPC), New York State Electric and Gas (NYSEG), and the New York State Research and Development Authority (NYSERDA), formed the Salix Consortium (originally called the Empire Power Consortium). In 1995, the Salix Consortium conducted and submitted a feasibility study on the development of a willow biomass crop enterprise in New York state (Neuhauser et al. 1995). The project was one of three competitively bid, national projects selected to demonstrate the development of a dedicated feedstock energy project under the United States Departments of Energy and Agriculture Biomass Power for Rural Development program. Support has been received from a variety of additional sources including NYSERDA, Electric Power Research Institute (EPRI), the U.S. Forest Service, Oak Ridge National Laboratory, and others. During this program, the Consortium will investigate and assess critical aspects and questions concerning the commercial development of willow biomass for power generation and the multiple benefits to the environment and local economy.

The Salix Consortium

The goal of the Salix Consortium is to facilitate the development of willow biomass crops as a locally grown source of renewable energy and feedstock for bioproducts that produces multiple benefits for the northeastern and midwestern regions of the United States. The Salix Consortium currently pools the research and investment interests of over 20 corporations, associations, universities, conservation groups, environmental organisations, and regional and national government agencies to develop this crop to a pre-commercial demonstration and commercial production stage (White et al. 1999). Participation in the Consortium has shifted since its inception, particularly as the energy industry in New York and other states undergoes restructuring.

The challenge facing the Salix Consortium is to simultaneously optimise production and utilisation technology, develop farmer interest, increase crop acreage, and add a new fuel to the power supply providing long-term markets for producers. The scenario is challenging because currently there is not enough willow biomass established to fulfill a power producer's needs, while at the same time there are no long-term agreements/commitments that will assure producers of a stable market in the future for their crop. In order to be successful, the participation of farmers and landowners, businesses, and local and regional governments is essential. The Consortium has designed and implemented a three-phased approach to elicit this participation (Volk et al. 1999). The avenues include a focused outreach and education effort, the active involvement of potential producers of willow biomass crops, and the development of an economic and business opportunity model for willow biomass crops.

The willow biomass production system being developed is based on SUNY-ESF's years of research, as well as extensive work in Sweden (Larsson et al.1998), the United Kingdom (Armstrong et al. 1999), and Canada (Kenney et al. 1996). Its basic characteristics are double row mechanical planting of 15,300 plants/ha and mechanical harvests on three- to four-year cycles (Volk et al. 1999). Willows were selected for the northeastern and Great Lakes regions of the United States over other woody species because of their rapid juvenile growth rates, vigorous coppicing ability, ease of establishment from unrooted cuttings, and high potential for rapid genetic improvement. Yields of fertilised and irrigated willow grown for three years have exceeded 23 odt ha^{-1} yr^{-1} (Kopp et al. 1997). First rotation, unirrigated trials in central New York have produced yields of 8.4 to 11.6 odt ha^{-1} yr^{-1} (Adegbidi 1999). It is anticipated that second rotation yields will increase, while commercial yields will be slightly lower due to variability in field conditions. Yields of the first large-scale trials will be available in the winter of 2000/01. Improved willow clones that will increase yields will be available soon from ongoing breeding efforts at SUNY-ESF. Additional improvements in yields should be realised by optimizing the production system in terms of weed control, clone-site interactions, fertilisation, and integrated pest management.

The near-term energy market strategy that the Salix Consortium is focusing on for willow biomass is co-firing at pulverised coal power plants. The 104 MW Greenidge pulverised coal power plant in central New York was retrofit and has demonstrated continuous co-firing of wood at 10% by heat input for over three years now. A successful test firing of willow biomass at Greenidge has been performed. This experience has provided insight into the remaining issues to be addressed in order to assure efficient use of the willow energy crop. As a part of utility restructuring in the state, NYSEG sold the Greenidge power plant to Atlantic Electric Service (AES). While this plant remains a potential market for willow biomass, the future participation of the new owners is still being defined. NMPC successfully completed wood co-firing tests at the 400 MW Dunkirk power station in western New York state. The station's new owner, NRG Energy Inc., will continue with the retrofit of one 96 MW boiler at the station. Test burns using willow and other wood biomass are planned for the spring of 2000. The immediate fuel for co-firing will be wood residues from the forest products industry, with willow biomass becoming a part of the mix in 2001 when the first large area of willow biomass crops are harvested.

A major benefit of the willow biomass cropping system is that environmental and social benefits, in addition to the renewable energy and bioproducts, can be produced simultaneously. The production, quantification, and valuation of these benefits is essential in order to make the system economically viable under the current electric energy industry structure in the northeastern United States. SUNY-ESF is actively pursuing and researching some of these additional benefits including

- Quantification of changes in soil carbon under willow biomass crops over time,
- Phytoremediaiton of contaminated sites with willow biomass crops,
- The use of willows as nutrient filters in riparian zones and as part of on-farm manure management systems,
- The use of willow and poplar as an alternative cover for landfills,
- The application of biosolids on willow biomass crops, and
- The development of living willow snow fences.

Efforts are under way to assess the rural development benefits in terms of job creation and new tax revenue that will accrue from the development of a willow biomass enterprise (Proakis et al. 1999).

A major task for the Salix Consortium during the Biomass Power for Rural Development demonstration project will be to show that willow energy crops can compete as a fuel in a restructured industry where emphasis is placed on obtaining the lowest energy production cost. The key to accomplishing this will be translating as many of the environmental and social benefits of a willow biomass enterprise into measurable items that can contribute to the bottom line. For example, the Consortium's objective of demonstrating a delivered fuel cost of under $2.00/MMBtu for willow (White et al. 1995) would be a major step forward for energy crop development. However, on average, that price is still $0.50 to 0.60/MMBtu more expensive than coal under long-term contracts in New York state. To compete in the current energy and bioproducts market, policy makers must be convinced that tax incentives, emission credits, and other approaches to valuing environmental and social benefits associated with a willow biomass are necessary to develop the enterprise.

Recent Program Developments

Research Program

Since the inception of the Biomass Power for Rural Development program, significant progress has been made at both the production and energy conversion use ends of the enterprise. SUNY-ESF and other Salix Consortium partners continue to develop and expand a strong applied research program, which underpins the commercialisation effort. Research focuses on both optimizing the production system and quantifying environmental benefits associated with willow biomass crops (Table 1). Results to date have been translated into initial recommendations for scale-up activities.

Planting Stock Production

Planting stock production for willow biomass crops currently occurs at two facilities in New York state: The New York State Department of Environmental Conservation's Saratoga Tree

Table 1. Research under way by SUNY-ESF and other Salix Consortium partners

Study title currently	Willow Production system benefit	Issue addressed
	Production system research	
Genetic Improvement of Willows via Interspecific Hybrids and Intraspecific Crosses	A strong clonal improvement program will help ensure increases in productivity and clone survivability. This will have a positive impact on production costs.	Inheritance patterns of traits important to biomass production. Molecular markers will be identified to ultimately serve to accelerate genetic improvements.
Integrated Pest Management in Willow Biomass Crops	Pest management ensures high willow survivability and productivity.	Identification of pests and diseases impacting various willow clones and designing control strategies to minimise impacts.
Effect of Slow-Release Nitrogen Fertilisation on Aboveground Biomass Production	Slow-release nitrogen will improve yields and be less environmentally detrimental than other types of N fertiliser.	Recommended rates of nitrogen fertiliser application to optimise biomass production rates of willow.
Use of Biosolids as Organic Soil Amendment in Willow Bioenergy Plantations	Lower production costs by replacing commercial nitrogen fertilisers and provide a productive use for biosolids.	Mineralisation rates of nitrogen from biosolids, heavy metal and nutrient movement, and willow growth response.
Alternative Methods of Site Preparation	Minimise soil erosion and reduce site preparation costs.	Aboveground biomass production of different site preparation methods.
Cutback After First Year Growth	Reduce operational costs and potential compaction of wet soils during the fall.	Impact of cutback versus no cutback treatment on survival and biomass production of five willow clones.
Clone-Site Testing and Selections for Scale-up Plantings	Establishing parameters for clone to planting site relationships will enhance yields and reduce production costs.	Survivability and yields of various clones over wide range of climate and soil conditions.
Clonal Selection Trial and Studying the Ecophysiological Basis for Relative Productivity	Understanding factors affecting yield will improve selection of new clones and help modify management practices to improve yield.	Seasonal variations in physiological and environmental parameters will be characterised.
Aboveground Biomass Equation Development for Five Salix Clones and One Populus Clone	Accurate estimation of biomass yields before harvesting will be important in establishing contracts and economic modeling.	Design protocols and develop equations for non-destructive estimation of biomass yields.
Field Production Equipment Improvement (Cornell University)[a]	Optimise planting and harvesting rates while minimizing impact on fields and willow crop.	Increased productivity, lower final product costs, long-term sustainability.
Effect of Storage Conditions on the Survival and Growth of Willow Cuttings	Vigorous and viable cuttings for planting stock are critical to the commercial success of willow production.	Length of time cuttings can be left out of storage during planting season without losing viability.
Effectiveness of Different Weed Control Practices in Willow Biomass Crops	Optimised weed control practices will ensure crop survival, higher yields, and lower production costs.	Effectiveness of different mechanical and chemical weed control practices.

Table 1 (continued)

Study title currently	Willow Production system benefit	Issue addressed
	Environmental studies	
Impact of Willow/Poplar Biomass Crops on Diversity of Soil Microarthropods	Quantification of the sustainability of willow biomass systems.	Belowground biodiversity impact of sustained willow production.
A Study of Avian Biodiversity in Short Rotation Intensive Culture Willow Plots (Cornell University)	Address concerns raised about the impact of willow crops on avian biodiversity.	Impact of sustained willow production on bird populations and diversity.
Soil Sustainability and Productivity in Willow and Poplar Biomass Crops	Address concerns raised about sustainability and quantify soil carbon sequestration.	Evaluate the impact of willow on soil carbon and sustainability over time.
Root Dynamics in Willow Biomass Crops	Will assist in valuing carbon sequestration benefits of willow and assist in optimizing management practices.	Improve understanding of fine root longevity, distribution, biomass, and turnover.

[a]Studies listed are being lead by SUNY-ESF unless other institutions are noted.

Nursery (STN) and the SUNY-ESF's Tully research station. Cutting orchards, irrigation systems, and cold storage facilities have been developed at both locations to support these operations. In the winter of 1998/99 almost 1.5 million cuttings (records are kept on the number of 25-cm long cuttings or the equivalent in rods or whips) were produced at the two locations (Table 2). This represents an increase of 85% from 1997/98. Increases were due to maturing of cutting beds established in 1996, partial production from beds established in 1997, and irrigation system improvements at STN. Cuttings made from first-year coppice material in central and western New York added another 110,000 cuttings to the supply. The implications for producing cuttings from dedicated beds is that a two- to three-year lead time is required to bring the beds into full production. However, the higher density (30,000 to 35,000 plants ha^{-1}) and concentration of effort at central locations, compared with the commercial planting density of about 15,300 plants ha^{-1} at scattered locations, increases the efficiency of the operation. Initial assessments indicate that the cost per cutting is reduced by 10 to 17% when whips rather then cuttings are produced. Production costs for material from cutback operations is up to 100% greater than material from cutting orchards due to increased labor and transportation costs.

Table 2. Cutting and whip production in 1998 and 1999 at SUNY-ESF and the Saratoga Tree Nursery in New York state

	SUNY-ESF		Saratoga tree nursery (STN)		Total
	1998	1999	1998	1999	1999
Cuttings[a]	257,000	225,000	375,000	446,000	671,000
Whips/rods[a]		300,000	175,000	528,000	828,000
Total	257,000	525,000	550,000	974,000	1,499,000

[a]Data presented are for 25-cm-long cuttings or the equivalent number in whip sizes.

Demonstration Areas in Western New York

In 1998 the Salix Consortium planted over 45 ha of willow biomass crops with modified Froebbesta planters in western New York. In 1999 an additional 80 ha of land was planted to willow biomass crops using a newly acquired Step planter and the older, modified Froebbesta planters. Field assessments indicate that the Step planter operated at a rate of 1.0 ha hr^{-1}, including time for reloading and turning around at the end of the fields. The rate for the modified Froebbesta planters was 0.25 ha hr^{-1}(R. Pellerin, personal communication).

All the areas planted in 1998 and 1999 were within a 60-km radius of the power plant where the biomass will be utilised. All of the sites were in a hay crop the previous year or had been fallow for one to five years. This type of land is common across New York because the agriculture industry, and in particular the dairy industry, has been in decline over the past decade. The 125 ha was spread over seven landowners, with field sizes ranging from 2 to 40 ha. Smaller fields were immediately adjacent to one another. No collection of fields was smaller than 8 ha in size. Four to six different willow clones were planted in each set of fields. One clone of hybrid poplar is being planted and assessed for use in the high-density, double-row system.

Regional Expansion

Interest in willow biomass crops continues to grow across the northeastern and midwestern regions of the United States. Over the past six years, 18 willow clone-site and genetic selection trials have been established in New York, six other states, and the province of Quebec in Canada (Fig. 1). Trials were conducted previously in southern Ontario by the University of Toronto (Kenney et al. 1996). The current clone-site trials range in size from 0.5 to 1.0 ha in size. At each site between 6 and 40 different clones of willow and poplar are being screened for their suitability to different soils and climate conditions.

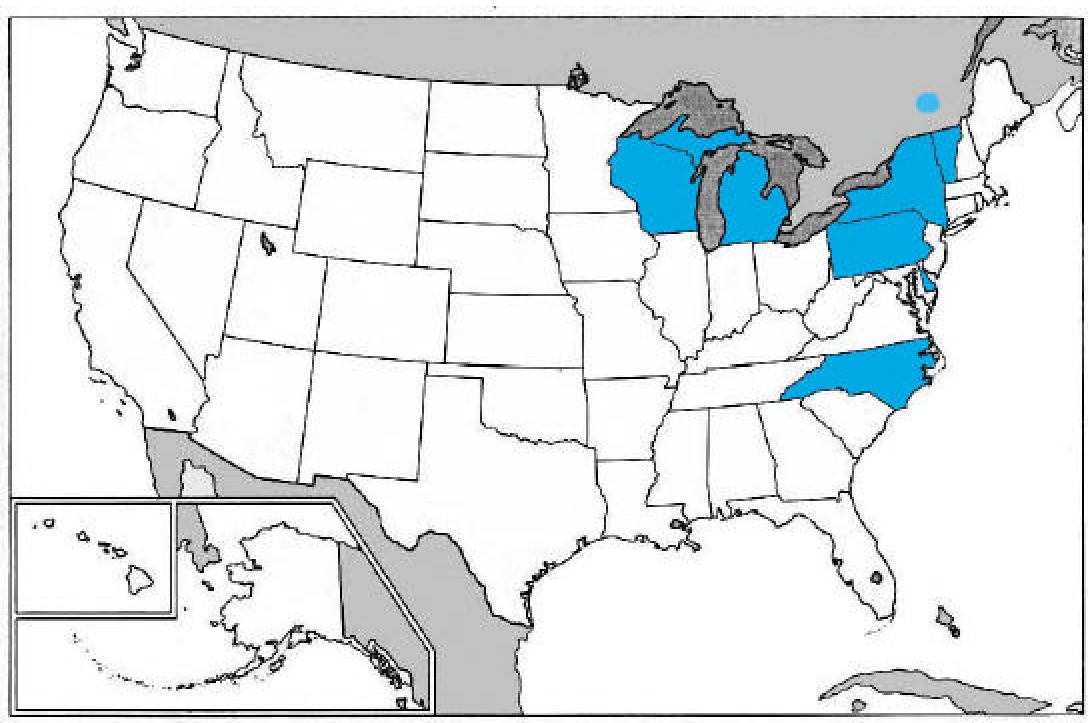

Fig. 1. Locations in the United States and Canada where the SUNY-ESF is participating in willow biomass trials.

Future Plans

Over 130 ha of land have been selected and prepared for planting in the spring of 2000. By 2001 the target under the Biomass Power for Rural Development of over 320 ha of willow biomass crops should be reached. Plans are under way to initiate small trials in two additional states in 2000. Decisions on the harvesting system for use in the demonstration areas will be made by the end of 1999. Machinery will be available for small-scale trials on 3 to 4 ha, in the winter of 2000/01. Harvest of the first 40 ha under the Biomass Power for Rural Development Program will occur in the winter of 2001/02.

The Salix Consortium has made significant progress in developing a willow biomass enterprise. These efforts have received renewed interest with President Clinton's Executive Order of August 1999, which ordered a threefold increase in the use of bioenergy and bioproducts in the United States by 2010. However there are still challenges that need to be overcome, including the stability of energy markets because of the sale of power plants under restructuring. In addition to energy products, the Consortium will continue to quantify and promote the valuation of environmental and rural development benefits associated with the system. Using willow biomass as a feedstock for bioproducts will provide another set of markets. Technological progress and research on cellulosic conversion of willow biomass to high-value chemicals will be helpful in addressing barriers to successful commercialisation utilizing these wood-based renewable resources. However, science alone will not overcome all of the barriers limiting the development of a willow biomass enterprise. Strong federal and state government visions and supportive policies and regulations are necessary to make renewable biomass a viable market competitor to a barrel of oil or a ton of coal.

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Bioenergy Status and Expansion in the United States

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Abstract

The United States is a large consumer and producer of energy. Current energy consumption is about 100 EJ with bioenergy providing 3% of the total. The U.S. President has charged the Departments of Energy and Agriculture and the Environmental Protection Agency to modify and coordinate their programs to promote an increase by 3 times the amount of biobased products and bioenergy produced in 2010. Legislative actions also support increased bioenergy research and modification of tax incentives to encourage increased bioenergy commercialization. Development of biomass power production technologies and biomass liquid fuels production is being pursued through separate programs with the U.S. Department of Energy. Each program has differing needs and expectations for biomass feedstock research. The Bioenergy Feedstock Development Program juggles and integrates the feedstock needs of both programs. Research is addressing near-term, midterm, and long-term goals simultaneously. Development of new crops and cropping technology comprises the largest component of the current program. More emphasis is being placed on residues, both agricultural and urban, to meet near-term bioenergy goals.

U.S. Energy Production and Consumption

The United States' production and consumption of petroleum, coal, and natural gas are among the highest in the world (EIA 1999). In 1998, the United States consumed 100.0 EJ compared with 73.3 EJ consumed by Western Europe (Fig. 1). U.S. consumption included 18.9 million barrels per day of petroleum, almost 26% of world consumption, as well as 21.3 trillion cubic feet of dry natural gas and 1.04 billion short tons of coal. China was the largest consumer of coal at 1.31 billion short tons. While U.S. consumption is exceptionally high, energy consumption per dollar of gross domestic product is moving downward, suggesting a continuing trend toward better energy efficiency.

In 1998, the United States, Russia, China, Saudi Arabia, and Canada produced 48.4% of the world's total energy (Fig. 2). The United States supplied 76.8 EJ of primary energy, followed by 43.3 EJ by Russia and 35.0 EJ produced by China. Petroleum was the world's single most important primary energy source, accounting for 39.8% or 160.4 EJ (1 exajoule = 10^{18} Joules) of world primary energy production (EIA 1999).

The largest primary energy source in the United States is coal. Of the 76.3 EJ of total primary energy produced within the United States, biomass accounts for 3.16 EJ (Fig. 3). More than half of the biomass energy produced in the United States is associated with the wood products industry where bark, sawdust, and spent pulp liquors are used to produce heat and electricity for internal use. A total of about 0.58 EJ of electricity is produced from biomass in the United States, but most is not connected to the electric grid.

Electricity generation from biomass residues and ethanol production from corn are both largely subsidized by some form of tax incentive or localized price supports. The only conditions under which biomass energy is economically competitive (without subsidy) in the United States at present is where it provides a waste disposal service for biomass wastes and residues that

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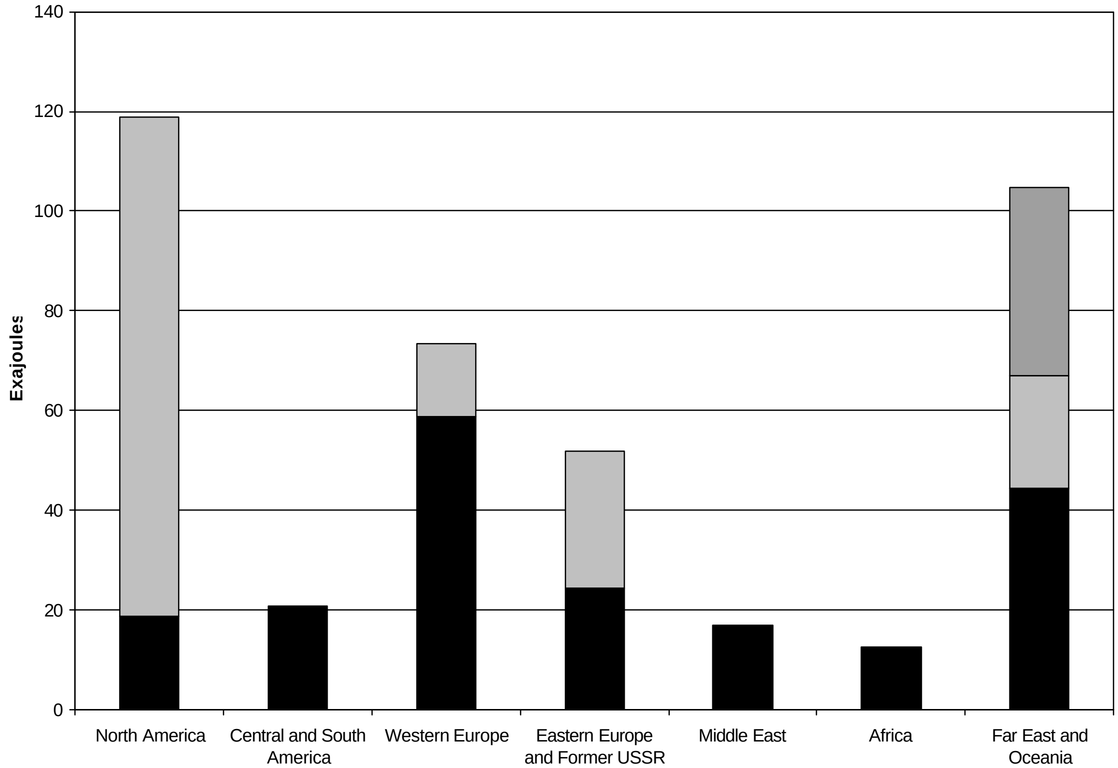

Fig. 1. Consumption of primary energy in 1998 (EIA 1999). Major consumers shown individually: North America (gray = U.S., black = other); Western Europe (gray = Germany, black = other); Eastern Europe (gray = Russia, black = other); Far East (stripes = China, gray = Japan, black = other).

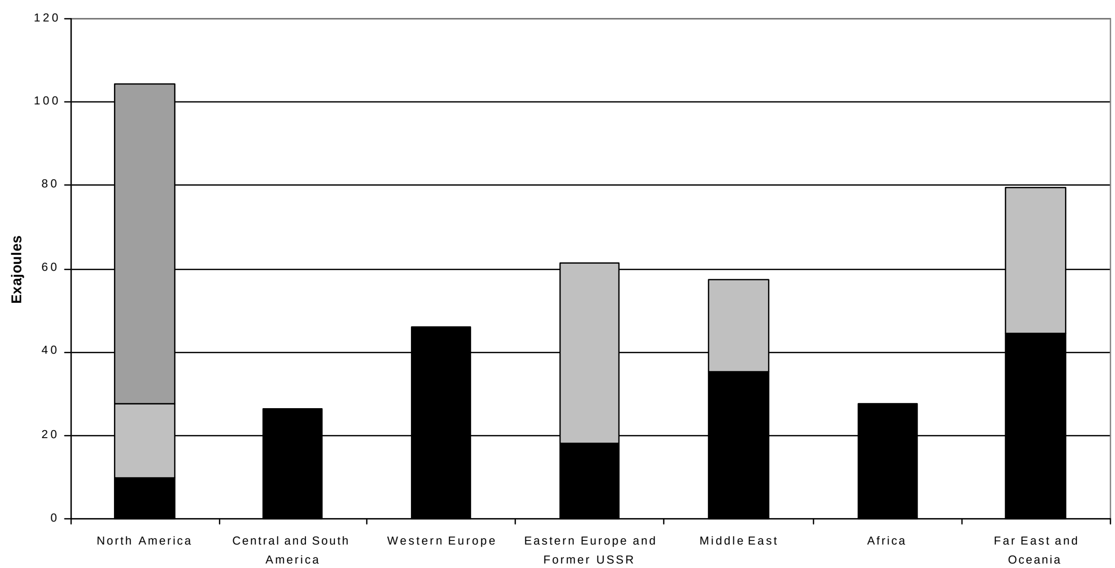

Fig. 2. Production of primary energy in 1998 (EIA 1999). Large producers shown individually: North America (stripes = U.S., gray = Canada, black = other); Eastern Europe (gray = Russia, black = other); Middle East (gray = Saudi Arabia, black = other); Far East (gray = China, black = other).

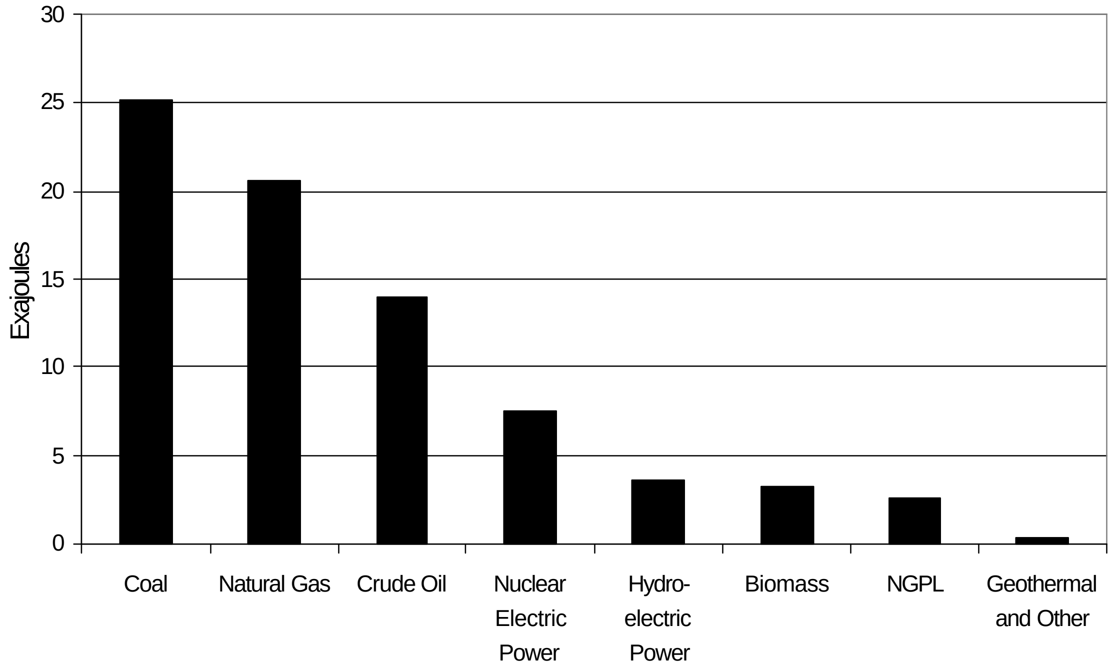

Fig. 3. Energy production by source in 1998 (EIA 1999). Crude oil includes lease condensate, hydo-ele includes conventional and pumped-storage, biomass includes wood, wood waste, peat, wood liquors, railraod wood sludge, municipal solid waste, agricultural waste, straw, tires, landfill gases, fish oil and/or other wastes

otherwise would be hauled to landfills. States or cities with tipping fees for landfill waste disposal clearly create the best opportunities for economically competitive biomass energy. This picture is expected to change if the current bioenergy initiatives being supported by the President and Congress are successful.

Bioenergy Initiatives in the United States

The development of alternatives to traditional, fossil-based fuels for power and transportation as well as development of biobased products has received an unprecedented level of attention in the executive and legislative branches of the United States government.

Actions in the Executive Branch of the U.S. Government

On August 12, 1999, President Clinton signed Executive Order 13134 *Developing and Promoting Biobased Products and Bioenergy.* Executive orders are official documents, through which the President of the United States manages the operations of the Federal Government. The order outlines the administration’s means to achieve a goal of tripling the use of biobased products and bioenergy in the United States by 2010. As stated in a memorandum from President Clinton to the Secretaries of Agriculture, Energy, and the Treasury and the Administrator of the Environmental Protection Agency, reaching that goal will require that the United States further the development of a comprehensive national strategy that includes research, development, and private sector incentives to stimulate the creation and early adoption of technologies needed to make biobased products and bioenergy cost-competitive in national and international markets.

The Executive Order establishes three entities: (1) an Interagency Council, (2) an Advisory Committee, and (3) a National Coordination Office. The Council is asked to develop an annual strategic plan that defines national goals in the development and use of biobased products and bioenergy, promotes national economic growth (especially rural), provides energy security, is sustainable, and provides for environmental protection. It does not provide for additional Federal programs or offices, rather it requires that the goals be achieved through existing Federal programs. The first plan is due April 2000.

President Clinton's FY 2001 Budget includes $976 million in tax incentives over 5 years and $2.1 billion over 10 years to accelerate the development and use of biobased technologies. This package of credits would:

- Extend current "closed-loop" biomass credit. This proposal, which includes plants and trees specifically grown for use as biomass, extends for 2.5 years the current 1.5 cent per kilowatt hour tax credit (adjusted for inflation after 1992), which covers facilities placed in service before January 1, 2002.
- Provide credits for "open-loop" biomass facilities. This proposal expands the definition of biomass eligible for the 1.5 cent tax credit to include certain forest-related resources and agricultural and other sources for facilities placed in service from 2001 through 2005 and provides a 1.0 cent credit for electricity produced from 2001 through 2003 from facilities placed in service prior to July 1, 1999.
- Provide a credit for co-firing biomass and coal. This proposal adds a 0.5 cent per kilowatt hour tax credit for electricity produced by co-firing biomass in coal plants from 2001 through 2005.
- Provide credit for methane from landfills. This proposal adds a 1.5 cent per kilowatt hour credit for electricity produced from landfills not subject to EPA's 1996 New Source Performance Standards/Emissions Guidelines (NSPS/EG) and 1.0 cent per kilowatt hour for landfills subject to NSPS/EG. Qualified facilities would be facilities placed in service after December 31, 2000, and before January 1, 2006.

Actions in the Legislative Branch of U.S. Government

Because an executive order is non-binding on the legislative branch of the U.S. government, senators (members of the U.S. Senate) and representatives (members of the U.S. House of Representatives) must introduce bills, which if approved could result in the appropriation of U.S. funds for initiatives such as the one outlined in the executive order. In addition, incentives (tax savings or credits) to produce and use biomass or biofuels take the form of introduced bills. The passage of such bills is vital for increasing the ability of biomass/biofuels to compete in the near term with sources of power or fuel such as coal and petroleum.

During 1999, approximately 26 bills related to bioenergy were introduced during the 106th Congress. Only one of the bills has been acted upon. This bill is the National Sustainable Fuels and Chemicals Act of 1999 introduced by Senator Richard Lugar (Indiana) and cosponsored by thirteen additional senators. Two similar bills were introduced in the House of Representatives. The Senate bill and the two House bills include provisions for increased funding for biomass conversion research and development (R&D) and biobased industrial product technology. The bills also direct the Secretaries of Energy and Agriculture to cooperate in promoting biomass research, development and demonstration and to authorize additional funding for biomass.

Numerous bills have also been introduced in the House and Senate that provide for tax incentives related to bioenergy, affect agricultural or forestry policies that relate to bioenergy, contain provisions for ensuring that renewable energy is part of the electric power restructuring that is ongoing in the United States, and contain proposals that provide for credit for early actions or voluntary reductions in greenhouse gases. Subcommittee hearings were held on a tax credit bill (S1429), one proposal impacting carbon sequestration (S1457), and one concerning electric power restructuring (S1047). Of these, the tax credit bill is the only one that has been acted upon.

The tax credit of 1.5 cent per kilowatt hour for electricity produced from qualifying wind and biomass facilities was extended to cover facilities placed in service by December 31, 2001. The only change was that poultry waste was added as a form of qualifying biomass. Otherwise the biomass facilities must be supplied with "closed-loop" biomass, which is defined to include only dedicated energy crops grown exclusively to generate power. It had been hoped that qualifying biomass would be expanded to include crop residues, mill residues, and other forms of clean, segregated biomass residues. Although the tax credit has been available for a number of years, no biomass facilities have managed to qualify.

Actions at the U.S. Department of Energy

In 1998, independent of the actions in the legislative branch, the U.S. Department of Energy (DOE) initiated a focused national effort to (1) boost economic opportunities in rural America; (2) provide new revenue streams for foresters, farmers, and other agricultural producers; (3) expand possibilities for sustainable energy use in power production, transportation, and manufacturing processes; and (4) lead to less dependence by U.S. consumers on foreign energy sources. The Bioenergy Initiative builds upon DOE's Office of Energy Efficiency and Renewable Energy's nearly 20 years of conducting programs aimed at increasing the development and deployment of biomass energy resources and technologies. The primary goal of the initiative is to accelerate the use of bioenergy technologies, fuels, energy crops, and feedstocks in power generation, industrial processing, and manufacturing and transportation applications. This is to be accomplished through partnerships with industry, national laboratories, and universities. DOE has developed a ten-point action plan which includes (1) establishing a partnership vision, (2) developing roadmaps, (3) creating an effective policy framework, (4) expanding biomass markets, (5) conducting supporting analysis, (6) promoting advanced technologies, (7) expanding federal–state coordination, (8) pursuing outreach and showcasing successes, (9) holding quarterly progress meetings, and (10) maintaining effective partnerships. DOE has held several meetings with industry, national laboratories, and other government agencies to develop an integrated vision for the national bioenergy initiative. The vision document is close to being released for public review and comment.

Bioenergy Program Goals in the United States

Bioenergy R&D in the United States is following two separate pathways as led by two separate programs within the U.S. Department of Energy. While the programs may combine in the near future as a result of the Bioenergy Initiative, the program managers of the Biomass Power Program and the Alternative Fuels Program are currently expressing needs for different biomass feedstock research. Oak Ridge National Laboratory manages the feedstock research for both of these programs. The following sections describe stated goals and metrics and feedstock research needs of both programs followed by a brief description of the feedstock research approach of the Bioenergy Feedstock Development Program.

Biomass Power Program Goals and Feedstock Needs

The mission of the U.S. DOE Biomass Power Systems Program is to develop and validate clean, efficient, renewable, biomass-based electricity generation technologies and operational systems with sustainable biomass supplies. Cost-competitive feedstock development and resource assessment are seen as indispensable components of an integrated biomass strategy.

Near Term (2000–2005). The near-term goal of the Biomass Power Systems Program is to facilitate increased use of biomass power primarily by collaborating with utilities, independent power producers, and small power users, such as schools and hospitals, to encourage co-firing of biomass with coal, oil, or natural gas.

Wood wastes and residues, including urban wood wastes, wood products wastes (from sawdust to furniture manufacturing wastes), and limited amounts of forestry residues (bark, tops, and limbs), are the most likely feedstocks to be economically available in the near term. However, policy changes appear to be needed for biomass power expansion using these resources. Feedstock R&D activities needed to support near-term biomass power generation include:

1. Analysis to better define location, cost, and availability of biomass resources;
2. Analysis of supply logistics to better define complete systems costs;
3. Improvement of residue collection, handling, storage, and feeding technologies to improve system economics;
4. Analysis of environmental effects of wood waste and residue use;
5. Analysis to support evaluation of policy options and regulations;
6. Outreach activities to all types of stakeholders of biomass power systems; and
7. Improvement of information on feedstock characteristics relevant to biomass power.

Midterm (2005–2010). The Biomass Power Systems Program metric for 2010 (published prior to the summer 1999 Executive Order) is to displace as much as 0.42 Quadrillion Btu (Quads) or 0.44 EJ of fossil energy. This goal will likely be expanded as a result of the Executive Order. The best alternative for meeting the expanded goal is to obtain a significant increase in co-firing and some use of small modular systems.

Biomass power demonstration projects already under way in the United States are designed to demonstrate that a combination of residue and crop resources can provide reliable, year-round supplies for biomass power production. The projects in progress include the following. In New York, utilities are testing co-firing of forestry residues with coal, and farmers are being recruited to grow willows for future supplies. Projects in Iowa and Alabama are evaluating the potential of switchgrass as a reliable feedstock supply system for co-firing with coal. A new 25 MW biomass power facility project in Minnesota is planning to supply the plant with hybrid poplars. An alfalfa residue supply system was recently also under investigation for supplying a gasifer, but the project was discontinued for several non-technical reasons. The hybrid poplar, willow, and switchgrass supply system demonstrations provide an opportunity to test concepts and technologies under development by energy crop researchers and to provide feedback to the core crop development activities. They also provide the opportunity to investigate environmental effects under operational conditions.

Feedstock R&D needs for meeting midterm objectives include those described above for near-term and additional activities associated with the ongoing demonstration projects such as:

1. Technical support and monitoring of the ongoing projects;
2. Evaluation of the environmental and economic effects of the projects;
3. Communication of the environmental and economic benefits to stakeholders and decision makers who can affect the rate of commercialization of biomass power;
4. Improvement in collection, harvesting, handling, storage, and feeding technologies for switchgrass, woody crops, and a variety of wood and agricultural residues; and
5. Additional yield improvement of biomass crops through breeding, species/site matching, and optimization of management approaches.

Long Term (2020). The Biomass Power Systems Program metric for 2020 (published prior to the summer 1999 Executive Order) is to supply as much as 0.53 Quads/yr (0.56 EJ/yr) of power. This metric will likely be significantly increased in FY 2000. It is anticipated that gasification and advanced direct combustion technologies that operate most efficiently at scales of 50 MW or larger will be major contributors to biomass power production by 2020 in addition to maximal use of co-firing opportunities.

Production of significant amounts of new biomass power by these relatively large-scale facilities will require widely available, abundant, competitively priced, sustainable, dedicated feedstock supply systems. Additionally, it would be desirable to develop biomass power crops that contain low levels of ash and alkali and high Btu values. There is public concern that unsustainable harvesting of natural forest stands will occur to supply feedstocks to bioenergy systems. Thus it may be necessary for utilities or power producers to collaborate with the wood products industry in the establishment and harvesting of farm-grown trees to supply both fiber and power needs.

Feedstock R&D activities needed to support the long-term goals of the Biomass Power industry include the following:

1. Genetic improvement of model fast growing species to further improve yields in order to reduce production costs and improve reliability of feedstock supplies;
2. Selection and development of new species to increase diversity in feedstock supply systems and optimize use of the available landscape;
3. Improvement of feedstock characteristics through either genetic modification of existing fast growing species or selection of new species with preferable characteristics;
4. Development of the basic understanding and tools needed to allow environmentally acceptable modification of the traits and characteristics of desirable species;
5. Improvement in our understanding of the environmental effects of deployment of new crops in the landscape at large scales of operation;
6. Improvement in management approaches for optimizing growth, disease resistance, ease of harvest, feedstock characteristics, and environmental benefits from energy crop production; and
7. Further improvement in harvesting, handling, storage, and transportation technologies.

Alternative Fuels Program Goals and Feedstock Needs

Ethanol is the primary alternative fuel being developed by the Alternative Fuels Program of the U.S. Department of Energy. The DOE goal for ethanol research is to facilitate the development of a robust biomass ethanol fuel market, thereby helping to meet the Nation’s energy policy goals.

Near Term (2000–2005). The near-term objective is to demonstrate commercial-scale production of ethanol from cellulosic material using one or more low-value waste feedstocks. A few projects are already under way that expect to be commercial and cost-competitive by 2005 under current policy conditions. These projects propose to use rice straw, sugarcane bagasse, and selected portions of municipal solid waste. Little to no feedstock research is needed to assist these near-term projects.

Midterm (2005–2010). The midterm (2005–2010) objective is to facilitate achievement of industry-scale ethanol production using a variety of cellulosic materials generated by U.S. farmers. Feedstocks are anticipated to be agricultural residues, such as corn stover and wheat stover, supplemented with dedicated crops, such as switchgrass. The 2010 metric published in early 1999 by the Alternative Fuels Program is to displace 0.36 Quads (0.38 EJ) of imported oil, equivalent to four billion gallons of ethanol.

Feedstock R&D needed to support the midterm ethanol goals are as follows:

1. Identification of environmental concerns of the public and policy makers relative to use of agriculture residues and switchgrass and research to address those issues;
2. Definition of conditions under which agricultural residues can be removed without negative environmental effects;
3. Improvement of collection, handling, and storage methods for agricultural residues and switchgrass;
4. Additional yield improvement of switchgrass through breeding, species/site matching, and optimization of management approaches; and
5. Outreach and communication with key ethanol stakeholders.

Long Term (2015–2020). The long-term objective is to demonstrate that ethanol production from dedicated energy crops is cost-competitive with gasoline and to facilitate the development of a significant cellulosic industry. The metric of the Alternative Fuels Program published in early 1999 is to displace 1.0 Quads (1.1 EJ) of imported oil, equivalent to 11 billion gallons/year (41.6 billion liters) of ethanol.

Feedstock R&D needed to support the long-term ethanol goals are essentially the same as those needed for Biomass Power, but there are some major differences. Optimization of feedstocks for ethanol conversion includes modifying the cellulose-to-lignin ratios to favor higher cellulose levels. This is likely to also reduce the Btu value, losing some of the value on a per ton basis for biomass power conversion. Characteristics such as low ash content and low levels of alkalies should benefit both technology pathways. Another research approach that is unique to ethanol is to optimize crop genetic characteristics for production of a suite of higher value co-products along with ethanol. In either case, advancement of basic plant science is needed to provide capability for tailoring plant characteristics for single or multiple end-products while continuing to increase the yield and reduce crop risks.

Biomass Feedstock Research in the United States

The Bioenergy Feedstock Development Program (BFDP) defines a mission to accomplish, through partnerships, the research, analysis, demonstrations, and infrastructure development needed to establish environmentally sustainable and economically competitive biomass supply systems with widespread availability at scales capable of supporting multiple bioenergy and bio-products industries. This mission statement encompasses long-term crop development activities, together with short-term and midterm activities that involve much more than crop development.

The crop development activities aim to develop new plant materials and the basic plant science information needed to achieve yield increases, reduce the risk of crop loss from biological and climate factors, and genetically modify plants for specific end-uses. Since its initiation in 1978, crop development research has evolved from evaluation of many species and production methods to a focused effort on improvement of poplars and switchgrass as model crops that are broadly adaptable to many regions of the United States. Hybrid poplars serve as a vehicle for basic research on molecular genetics because of their ease of clonal propagation and the relatively large amount known about their genomics and physiology (compared with other energy crops).

Regional crop development “centers” exist as groups of interacting researchers in the North Central region, Pacific Northwest, and South for poplars; in the Northeast for willows; and in the North Central region, South Central region, and East for switchgrass. Hybrid poplars are most likely to be used as a source of energy by fiber companies that are primarily growing the crop for fiber but use the tops and limbs, bark and lignin to produce heat and electricity. Willows are being developed as a dedicated crop for biomass power. Switchgrass is of interest as a dedicated crop for both biomass power and ethanol.

The focal point of the crop development centers for each species is the crop-breeding effort. Breeding incorporates both traditional and molecular genetics approaches and is linked to research on optimization of management approaches. Management research includes evaluating the lowest cost, most environmentally sound methods for obtaining high yields and increasing carbon sequestration. Several institutions may be involved in these virtual crop development centers within a region, but information and plant material exchanges are encouraged and facilitated. Research projects range from bench-scale to near-operational field-scale trials. The small-scale regional field trials are an extremely important interim step for making the connection between the breeding and the selection of the most appropriate genotypes for the region. It is also at this stage that several academic institutions and the private sector are brought in as collaborators in a regional crop development center.

In order to meet the long-term (2015–2020) objectives of both the Ethanol and Biomass Power Programs, the long-term crop development efforts on poplars, willows, and switchgrass must continue and be expanded through the addition of new species. Success would be best ensured if government funding could be leveraged through partnerships and industry cost-share to amount to at least $1 million/year per crop for at least the next 5 to 10 years. The testing and plant material scale-up phase of crop development requires a minimum of 10 to 12 years. Thus, for either wood or grass crops, new but fully tested materials suitable for commercial establishment by 2015 must be identified in breeding and research nurseries by no later than 2005. While funding appears to be increasing, it is not yet at the level needed to ensure meeting 2015 to 2020 goals, much less the 2010 goals. To adequately develop crops for all crop growing regions in the United States, a program supported by government funding at the level of at least 20 million annually is needed together with strong partnerships with the private sector.

The short-term and midterm activities of the BFDP include analysis, demonstration, evaluation, environmental research, and infrastructure development activities. All activities are aimed at facilitating the success of the first few integrated commercial projects for both biomass power and ethanol production. Research on agricultural residues is determining how much residue can be removed without affecting the sustainability of the agricultural crop production systems. The primary effort on urban and mill wastes is to determine how much may be available under various price conditions. Near-term project development efforts require facilitation of infrastructure development for more efficient collection, delivery, handling, storage, and processing of feedstocks. The U.S. Bioenergy Feedstock Development Program is adding staff and developing proposals to expand to cover that area while maintaining the long-term crop development effort.

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Status Report on Energy Crops in The Netherlands in 1999

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Abstract

First of all, the contribution of bioenergy is put into a Dutch perspective. Then some exciting new ideas are presented which have the potential to place energy crops high on the political agenda by trying to enhance the social acceptance of a whole new land use concept. Finally, the preliminary results of a European experiment with switchgrass and of a clonal test of willow on contaminated dredging sludge are given. In addition, a new biomass database on the Internet is presented.

Renewables in Perspective

The renewable energy targets of the Dutch government aim at 1000 MW installed by the year 2000. So far, 390 MW of renewable power from solar, wind, and heat pumps has been realised. Bioenergy from waste and biomass contributes an additional 518 MWe and 18,665 MWth, thereby substituting 38,3 PJ of fossil fuels and avoiding an annual carbon dioxide emission of 2,450 kton. Table 1 summarises the contribution of various sources of bioenergy that are in operation at present.

Table 1. Bioenergy from waste and biomass in the Netherlands in 1998 (PJ)

Waste incineration with E-recovery	23.3
Wood combustion	9.3
Landfill gas	2.1
Anaerobe digestion	3.6
Total bioenergy	38.3 PJ

Waste Incineration

The main activity of waste incineration plants is to dispose of waste. Electricity or heat is a by-product. Existing Dutch plants with inclined grate furnaces have an electrical efficiency of about 23%. There is one waste incinerator (at Moerdijk) with an efficiency of 38%, due to a combined-cycle gas turbine unit. New technologies, such as fluidised bed gasifiers, promise higher grades than the traditional furnaces. Table 2 gives an overview of power plants in operation or in their planning stage in The Netherlands. The existing waste incineration plants have a total capacity of 5,000 ktons of waste, which produce 400 MWe and 344 MWth. This corresponds with savings of 23 PJ of primary energy from fossil sources and a carbon dioxide

Table 2. Power plants fueled by waste and biomass in operation or under construction in 1999

Project	Type	Size	Stage of realisation
EPON, Nijmegen	Co-firing of waste wood	18 MWe	In operation since 1996
HIS, Schijndel	Combustion of wood residues	1.1 MWe	In operation since 1997
De Lange, de Lier	Combustion of wood residues	0.7 MWe	In operation since 1998
Couterman, Best	Combustion of wood residues	2.5 MWth	In operation
Komeco, Dronten	Combustion of waste wood	3.9 MWth	In operation
Hoegst, Weert	Combustion of waste	3.2 MWth	In operation
Parenco, Renkum	Combustion of paper pulp and sludge	15 MWth	In operation
Biomass Nederland Maasvlakte	Co-firing of biomass pellets	150,000 tons of pellets	In operation
Labee groep, Moerdijk	Pellets from wood residues	80,000 tons of pellets	In operation
EPZ, Borsele	Co-firing of dried sludge	15 MWe	In operation
EPZ, Geertruidenberg	Co-firing of dried paper sludge	19 MWe	In operation
UNA, Amsterdam	CHP pilot plant on shredder waste	8 MWe +10 MWth	In operation
PNEM, Cuijk	Fluidised bed combustion of forestry thinnings and wood residues	24.6 MWe	Built, now testing
EZH, Maasvlakte	Co-firing biomass pellets from paper pulp and sludge	15 MWe	Built, now testing
NUON, Lelystad	Stand-alone CHP plant on 100% biomass	1.5 MWe + 6.5 MWth	Under construction
Ekoblok, Almelo	Briquetes from saw dust for co-firing	30,000 tons of briquetes	Under construction
Afvalzorg, Halfweg	Wood chips shredder	60,000 tons of wood chips	Under construction
UNA, Amsterdam	Co-firing of dried sludge	19 MWe	Under construction
Amergas, Geertruidenberg	Gasification of waste wood	30 MWe + 83 MWth	Under construction

emission reduction of 1000 kton. Energy from waste is eligible for government grants up to 50%, whereas bioenergy from biomass is fully supported.

Present Status of Wood Combustion

Bioenergy from wood combustion at present saves about 9.3 PJ of fossil fuels, excluding traditional household wood stoves. Conversion routes include co-firing in existing coal plants, industrial waste wood combustion, gasification of waste wood, and dedicated biomass plants, totaling a capacity of 83.7 MWe and 124 MWth (Table 2). At present two stand-alone biomass plants are under construction: a 24.6 MWe power plant in Cuijk, based on fluidised bed combustion, and a 1.3 MWe and 6.5 MWth combined heat and power plant in Lelystad.

The Cuijk plant is now being test-fired and contracts have been signed for the wood fuel supply (250,000 tonnes annually). Because of the existing pressure on the Dutch market for

Stand-Alone Options for Green Electricity

The electricity requirement of 1000 households amounts approximately to 3 million kWh, which, in case of green electricity, can be supplied either by:

- 2 windmills of 750 kW, or
- 40,000 m^2 of solar panels (1500 roofs), or
- 0.5 MWe biomass plant, which needs 190 ha of dedicated energy crops to produce 2100 odt of biomass per annum.

waste wood, assignments have been made to procure at least some of the biomass needed from suppliers in Belgium and Germany.

For the fuel supply of the Lelystad plant, 200 ha of dedicated energy crops are to be included, which are to produce 2000 odt of biomass annually (which is about 10% of the total fuel supply). The business plan and layout for the plantation area have been approved, and the first plantings were carried out in the spring of 1999 (15 ha). For 2000 the second planting stage includes an additional 35 ha of willow and poplar coppice stands. In this project the short-rotation crops (SRC) will be combined with other forms of land use to create an attractive landscape, both in a profitable and socially acceptable way.

Landscape Design Contest

As in most other countries, dedicated energy crops in The Netherlands lack support and are not viable to farmers in an economic sense. Alternative land uses simply have a higher priority. In order to stimulate the introduction of energy crops into the Dutch landscape, The Netherlands Organisation for Energy and the Environment (Novem) last year came up with a design contest on ‘Living energy’. The project area was 2000 ha and all contestants had to follow a multi-functional approach. In this way, the concept of ‘combi-farming’ was extended to include landscape issues as well. Twenty designs were submitted, and a professional jury judged the poster presentations and essays. This created a lot of new ideas on how energy crops can be combined with other forms of land use. The prize-winning design is being implemented as a demonstration project that is now in its feasibility stage.

Combi-Farming

In 1999 a large survey was carried out that included almost everyone in the Dutch biomass scene (over 300 people and organisations have been interviewed). Twenty different concepts of combi-farming were presented in an attempt to find out which ideas were the most appealing. Over 50% of the inquiry forms were returned (which was considered a fairly good response) and a clear ranking resulted. Ninety additional suggestions for other combinations of energy crops were given. For the top five combi-options a SWOT (strengths and weaknesses; opportunities and threads) analysis was carried out. This opened up a whole range of potential demonstration projects, some of which already have been proposed for funding. Such a survey proved to be an effective way of getting a quick scan of the types of projects that appeal to representatives of the various strata of society (i.e., politicians, decision makers, consultants, scientists and workers of energy companies, forestry exploitation, municipal solid waste (MSW), and farmers associations). The top 10 combi’s are given in Table 3.

Table 3. Ranking of the most appealing combi-farming ideas

1	Energy crops in buffer zones
2	On set-aside land put into fallow
3	Co-production of fibrewood
4	Visual screens along motor- and railways
5	Part of recreational areas
6	SRC on dredging sludge lagoons
7	Planted strategically to improve water retention areas
8	As a Joint Implementation measure abroad
9	Bio-filter for affluent water
10	Plantations designed for maximum CO_2-reduction

European Switchgrass Project

The first pan-European switchgrass project, sponsored by the EU FAIR programme, started in April 1998 and continued until July 2000. Partners are ATO-DLO (Agrotechnological Research Institute) and BTG (Biomass Technology Group) (Netherlands), Rothamsted Experiment Station (UK), FAL (Federal Agricultural Research Centre) Braunschweig (Germany), ENEA (Ente per le Nuove Tecnologie, l'Energia e l'Ambiente) (Italy), and CRES (Centre for Renewable Energy Sources) (Greece). Twenty different varieties of switchgrasses are being tested at six sites throughout Europe. So far (1999), 3 ha have been established successfully. Objectives are the identification of adapted varieties, determination of the potential dry matter production, and fertiliser requirement and thermal conversion quality. An economic and environmental assessment is also planned. In the first year weed control was the main problem. First-year yields ranged from 2 odt/ha on the northern sites up to 15 odt/ha on irrigated land in southern Europe. First-year observations suggest that switchgrass has a somewhat better drought resistance than, for example, *Miscanthus*, and that lodging may be a problem in some of the northern varieties. For more information: Contact Dr. H. Elberson at the Agrotechnological Research Institute in Wageningen, The Netherlands (h.w. elbersen@ato.dlo.nl).

Willows on Dredging Sludge

The disposal of large quantities of dredging sludge, which otherwise would fill up numerous rivers, canals, and lakes in The Netherlands, is a big environmental problem. Basically, Holland is a lowland estuary. Hence a lot of sedimentation takes place. About 25 million m^3 of sludge needs to be dredged urgently, some of which is heavily contaminated. The current policy, however, is to dredge the most critical waterways only. Initially, dredging sludge is a very wet substrate on which few plant species will thrive. But willow is a lucky exception (i.e., at least some varieties are). In 1999 a clonal test was carried out with 16 varieties of willow, 3 types of sludge, 3 reps in plastic 150-litre containers, and 6 cuttings per container. The sludge was characterised as clay loam, slightly brackish, pH 7.7, and in general low on heavy metals. However, these sludges had (extremely) high contents of poly aromatic carbohydrates (PACs) and some mineral oil contamination. Willow varieties included 11 clones from local origin and 4

Swedish clones commonly used in SRC. Preliminary results suggest that the following willow clones perform best under these rather extreme conditions:

- *Salix alba* ‘Het Goor’
- *Salix alba* ‘Lievelde’
- *Salix alba* ‘Belders’
- *Salix triandra* ‘Black hollander’
- *Salix triandra* ‘Zwarte driebast’
- *Salix fragilis* ‘Deventer rood’
- *Salix dascyclados* ‘Loden’

With the top five clones in 2000, a field experiment will be done to test clonal performance and the purification potential in situ on a 2 ha experimental plot in Slootdorp. Willows tend to quickly aerate the soil, which is an important prerequisite for the natural reduction of PACs in the substrate by microbial activity. Energy crops may thus help solve environmental problems. At the same time biomass is being produced on land unsuitable for other uses: a win-win situation.

Database on Characterisation of Biomass

Now available on the Internet is an extensive database with over 1200 records of various types of biomass, including proximate and ultimate analysis, biochemical composition, calorific value, ash composition, etc. It offers everything you have always wanted to know about biomass and the possibility of mixing your own ‘blend’ of biomass. The Internet site is www.ecn.nl/phyllis.

The Energy Crops Inter Network, co-ordinated by the Biomass Technology Group, is an extensive energy crops database that contains 75 contributions from 14 different EU countries. The EECI Network will be operational on the Internet for at least another year. The address is www.eeci.net

The Swedish Carbon Dioxide Tax 1990–95: Implications for Biofuel Use and Carbon Dioxide Emissions[1,2]

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Abstract

The Swedish carbon dioxide tax was introduced in 1991, by adjusting the existing energy taxation to consider the carbon load of fuels. The tax was initially set at a general level of U.S. $133 per ton carbon (tc). It was differentiated in 1993, with the result that industry paid U.S. $43/tc, while nonindustrial consumers paid U.S. $160/tc.

This paper presents an *ex post* evaluation of the tax, using the criteria developed by the Organisation for Economic Co-operation and Development (OECD) in 1997. The period under consideration is from 1990 to 1995. The effects of the tax must be seen in relation to other policy measures introduced.

The effects of the tax vary across sectors. Biofuel use in the *district heating sector* increased from 36.7 PJ to 73.4 PJ, replacing primarily coal, thus leading to great carbon dioxide savings. Dynamic effects of the tax include development of new industry for refined wood fuels and extraction machinery. *Transports* have not been affected. *Industry* pays lower taxes on fossil fuels with the differentiated tax than it did before the tax was introduced, leading to increased fossil fuel use. While potential cost-effective measures in industry have thus been lost, international competitiveness has not been affected. The effect of the carbon dioxide tax on emissions depends on system assumptions; estimated abatement ranges from 0,5 to 1,5 million tons CO_2 on a yearly basis.

Key words: bioenergy, wood fuels, ex post evaluation, carbon dioxide, economic policy instruments.

1. Introduction

Although a carbon dioxide tax was introduced in Sweden in 1991, national carbon dioxide emissions have grown from 55.4 million tons in 1990 to 58.1 million ton in 1995 (Regeringskansliet 1997), an increase of 5%. An *ex post* evaluation of the effects of the carbon dioxide tax is therefore called for both as a national concern and in a wider international context. Carbon dioxide taxes have also been introduced in Denmark, Finland, The Netherlands, and Norway, though on a much smaller scale than the Swedish tax (OECD 1994). There is an increasing interest and a growing demand for *ex post* evaluations of economic instruments to regulate environmental pollution, particularly carbon dioxide, as evidenced by, for example, IEA (OECD 1996) and OECD (OECD 1997). This paper examines the effects of the Swedish carbon dioxide tax, focusing mainly on the substitution of fossil fuels by solid biofuels in the district heating sector.

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[1]For a full account see "Folke Bohlin. The Swedish carbon dioxide tax—effects on biofuel use and carbon dioxide emissions. Biomass and Bioenergy, 15 (4/5): 283–293.

[2]The exchange rate used in this paper is U.S. $1=7.5 SEK (Swedish krona).

2. Methodology

2.1 Economic policy measures

Economic policy measures are advocated precisely on the grounds of cost-effectiveness: The measures with the lowest abatement costs will be the ones which are carried out first. Economic instruments also provide an incentive for continued abatement as long as a tax makes it profitable.

2.2 Methodology for *ex-post* evaluation

Seven criteria have been defined by the OECD (OECD 1997) which will be used to examine the effectiveness of the tax.

1. Environmental efficiency. To what extent has the tax had the intended environmental effect?
2. Cost-effectiveness. Has the tax met its environmental objective at a competitive cost?
3. Administrative and compliance costs. How large are these transaction costs to the governmental authority and the tax-paying agent, do they influence the effectiveness of the tax?
4. Revenues. Are they important and how are they used?
5. Wider economic effects. To what extent has the tax influenced price levels, competitiveness, employment?
6. Dynamic effects and innovation. To what extent has the tax stimulated innovation and other dynamic effects?
7. What would have happened without the tax?

3. Policy Prior to the Introduction of the CO_2 Tax

3.1 General policy

Support for the expansion of the district heating grid and investment support in the form of grants and loans for the replacement of oil furnaces by solid fuel furnaces have also been advantageous for biofuels, whether these measures were taken to propagate energy efficiency or to facilitate coal or peat introduction.

3.2 Direct investment support (NUTEK 1994a)

Two programmes for direct investment support that create definite advantages for wood fuels have been initiated. In 1981–1986 a programme for the introduction of peat furnaces was carried out with a total budget of U.S. $66 million in grants and U.S. $32 million in the form of loans; the programme covered 78 plants. In 1991–1996 a programme to stimulate the introduction of Combined Heat and Power (CHP) was carried out with a total budget of U.S. $150 million covering 45 plants.

4. The Carbon Dioxide Tax

4.1 General description (NUTEK 1994b, FINANSDEPARTEMENTET 1997)

The carbon dioxide tax was introduced in 1991 by halving the existing energy tax on fossil fuels to make room for a differentiation according to the carbon load of the fuel. The main purpose of the carbon dioxide tax was, according to the government directives, to diminish carbon dioxide emissions resulting from combustion of fossil fuels. However, this steering effect was considered from a long-term perspective, and the tax also had a strong short-term fiscal profile. The income from the tax enters the governmental budget and is used as any other tax without recycling of revenues.

The level of the carbon dioxide tax is set in relation to the average carbon content of the fuel. In this way the level of the taxation reflects the damage costs of global warming. The carbon dioxide tax is not levied for biofuels, and peat is also exempt from taxation. Further exemptions are made for fuels which are used for the generation of electricity, since electricity is taxed at the consumption stage.

In combined heat and electricity production that part of the fuel which is used for heat production is charged full carbon taxes and half energy taxes, while no taxes are applied to electricity generation.

4.2 Development and effects of the carbon dioxide tax and other energy taxation

The effects of the new taxation from 1990 to 1991 were a doubling of the total taxes for natural gas, an 80% increase of the total tax for coal, and a less than 20% increase in the total tax levied on oil (Table 1).

In 1993 the tax was amended, and subsequently industry as a whole pays no general energy tax and only 1.1 c/kg CO_2 in carbon dioxide tax. The general level of the carbon dioxide tax, which applies to private consumption, was raised to 4.2 c/kg CO_2. The total effect of these changes is that industry pays five to six times lower taxes for fossil fuels than other energy consumers do (Table 2).

The combined effect of taxes and prices is shown in Fig. 1. Basically, industrial consumers will buy at prices close to the price without taxes, while all other consumers, including district heating, pay the price quoted with taxes.

Table 1. Tax rates for coal, oil, and natural gas divided into general energy tax (GET) and carbon dioxide (CO_2) tax before and after the introduction of the CO_2 tax

Taxes in U.S. $				
	1990	1991–92		
Fuel	GET	GET	CO_2	Total
Coal, ton	61	31	83	114
Oil, m^3	144	72	96	168
Gas, km^3	47	23	71	94

Adapted from Ministry of the Environmental and Natural Resources, 1994 (NUTEK 1996). Special reductions of taxes apply to larger parts of industry.

Table 2. Tax rates for coal, oil, and natural gas divided into general energy tax (GET) and carbon dioxide (CO_2) tax, before and after the tax reform in 1993

Taxes in U.S. $.						
	Industry			Other consumption		
Fuel	GET	CO_2	Total	GET	CO_2	Total
Coal, ton	0	27	27	31	107	138
Oil, m^3	0	31	31	72	123	195
Gas, km^3	0	23	23	23	91	114

Adapted from Ministry of the Environmental and Natural Resources, 1994. Special reductions of taxes apply only to marginal parts of industry from 1993 onwards.

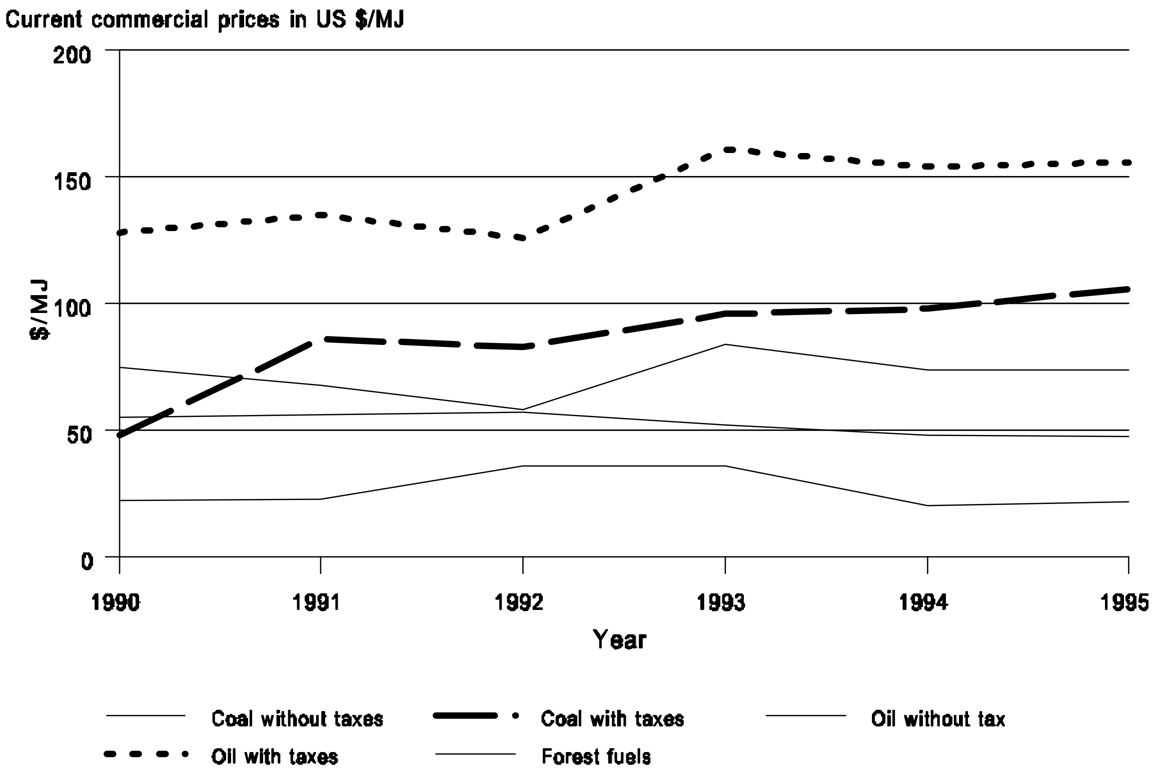

Fig. 1. Swedish energy prices 1990–95, with and without taxes. Based on NUTEK 1996.

For district heating purposes the tax on oil is on the same order of magnitude as the price of the untaxed product. The tax on coal represents roughly 80% of the total price of the product, which raises the coal price above that of forest fuels.[1] Counting the whole period, the price of forest fuels has fallen by some 10% in current commercial prices, indicating an even greater fall in real price.

[1]Wood fuels comprise: (a) forest fuels, primarily from clear-cuts; (b) different qualities of wood residues from forest industry; and (c) refined wood fuels, mainly pellets and briquettes. These fuel qualities sell at different prices; in this paper forest fuels have been selected to represent the price of wood fuels as a whole since it is the dominant fuel.

4.3 Effects on the district heating sector

The most striking effects of the carbon dioxide tax can be found in the district heating sector. As Fig. 2 shows, the total use of biofuel (including peat) within the sector has doubled, from 36.7 PJ in 1990 to 73.4 PJ in 1995. Increased woodfuel use, which trebled during the period, from 13 to 37 PJ, accounts for a major part of this development.

The energy supply from the district heating sector has increased from 146.5 PJ in 1991 to 173.5 PJ in 1995. Electricity use has diminished by 10 PJ. Natural gas and oil show a slight increase, while the use of coal in the system has been roughly halved.

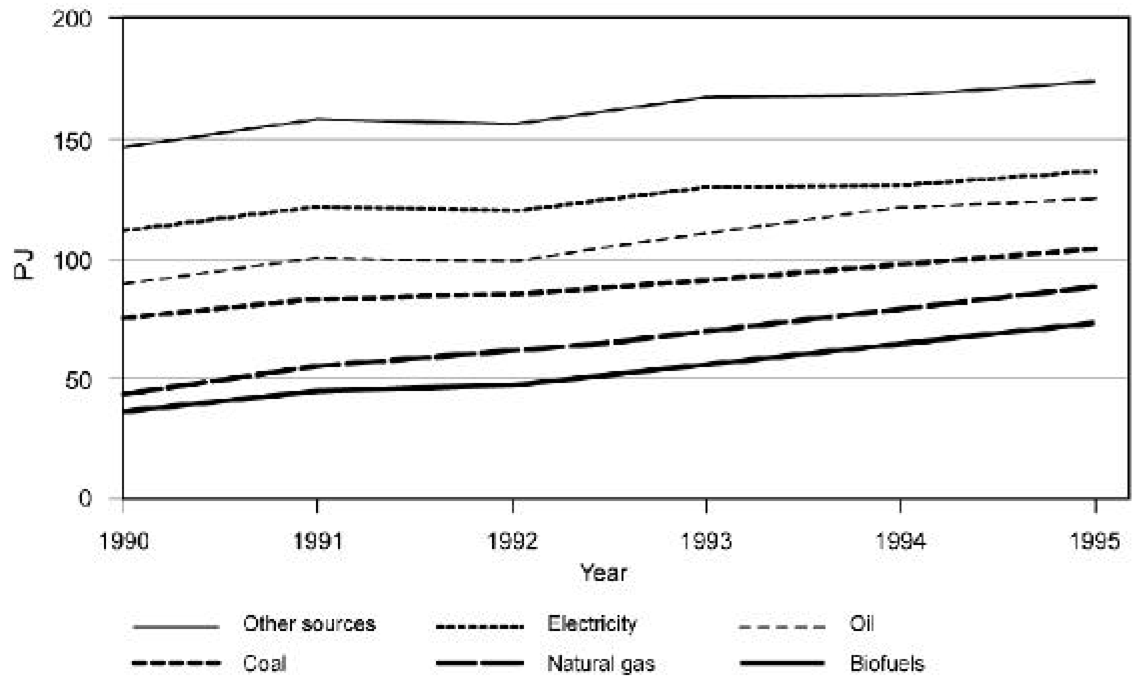

Fig. 2. Supply of district heating 1990–95, PJ. Based on NUTEK 1996.

4.4 Carbon accounting

Table 3 illustrates this method showing the emissions in 1990 and 1995, arriving at a total mitigation effect of 0,5 million tons.

This case is oversimplified, partly underestimating the mitigation effect, because during the five-year period covered, the district heating supply has increased (from 146.5 PJ to 173.5 PJ), correspondingly increasing its use of energy and the resulting emissions. To avoid this problem of expanding volumes, the 18% increase of the system may be multiplied by the CO_2 savings already calculated, thus arriving at 630 000 ton CO_2 gained.

Energy carriers may be differentiated according to base-load and peak-load demand, where base-load fuels are those with high fixed costs and low variable costs, and peak-load fuels are those with low fixed costs and high variable costs. Hence, coal and biofuels are substitutable for base loads (and frequently also from a technical point of view). We may therefore contend that the coal which has been replaced by biofuels results in a carbon dioxide gain of 1.5 million ton. The CO_2 tax, by making coal more expensive than forest fuels, has been instrumental in this switch.

Table 3. Supply of district heating based on fossil fuel and resulting CO_2 emissions in 1990 and 1995

	1990, PJ	1995, PJ	Difference, PJ	Ton CO_2/PJ	CO_2 change, tons
Coal	31.7	15.8	–15.9	95 000	–1 510 500
Oil	14	20.9	6.9	77 000	531 300
Natural gas	6.8	14.8	8	56 000	448 000
Total					–531 200

Energy data according to NUTEK 1996. Emissions according to IEA/OECD 1991.

Different weather conditions in 1990 and 1995 also affected outcomes. Since 1990 was an unusually warm year with high precipitation (Regeringskansliet 1997), there was more electricity in the system and the need for peak load capacity was not as strong as in 1995. In 1995, natural gas and oil were used for peak loads, leading to an extra CO_2 load of ca 1 million tons.

If, to compensate for these peak-load biases, the fuel mix of 1990 were used in a baseline, the result would be a net gain of 1.5 million tons of carbon dioxide. However, the fuel mix *was* changed, and we can conclude by saying that the tax was not a strong enough incentive to handle peak-load situations.

5. Discussion and Conclusions

5.1 Environmental effectiveness

The effects of the tax on CO_2 emissions are different according to which sector we study. Within the *transports, private housing, and service sectors*, other costs are so dominant that the CO_2 tax has not induced a noticeable result of its own (NUTEK 1994a).

The most pronounced effects are to be found within the *district heating sector* where the use of bioenergy has doubled, replacing primarily coal. The tax has not effectively halted peak-load use of oil and natural gas, however, so CO_2 emissions from these sources have increased.

5.2 Government revenues

Energy and environmental taxes yield a total national revenue of U.S. $6 billion or 3% of the gross national product in 1995. Energy taxes, which are levied strictly for fiscal reasons, yielded U.S. $3.8 billion. The carbon dioxide tax accounted for the most important governmental environmental revenue, U.S. $1.6 billion, leaving U.S. $ 0,6 billion for other environmental taxes (Finansdepartementet 1997).

Hence, the carbon dioxide tax is an important source of revenue for the government. The low price elasticity of fossil fuels also means that fuel substitution is slow and the revenue will remain largely intact for a longer period. The taxes are not recycled (i.e., exchanged for other taxes) but enter the general budget.

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Current Status of Short-Rotation Forestry in Sweden

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Willow short-rotation coppice (willow SRC) in Sweden today covers about 16.000 ha. Because of European Union (EU)-driven changes in the subsidies for alternative crops, hardly any new energy forestry plantations were established during 1999. However, because of an adaptation in the national agricultural policy, willow SRC establishment is expected to increase again during the years to come, with an expected planting of ca 800 ha during 2000.

Due to initial commercialisation in the late eighties, a number of farms are gaining experience with a third-rotation cycle. In general, we see a continuously increasing pressure of pests and diseases on our willow SRC systems. Current experience focuses research on site fertility–spacing–rotation length interactions and addresses questions about system sustainability and long-term system performance. Management practices should be developed to make plants less susceptible to fluctuating pest and disease pressure and site conditions. Our current understanding of willow production during a first rotation period is satisfactory, although implementation of knowledge falls short. Actual weeding practices do not conform to recommendations at all and lead to large production losses. The production biology during later rotations, however, involves a number of interactions of re-sprouting with environmental factors that at present are not well understood and consequently can not be managed yet.

The opportunities for delivering willow chips to the terminal are very sensitive to winter conditions. Because only a small fraction of the fuel in most heating plants consists of willow chips, the low energy consumption (and low willow chip consumption) during warm winters may limit the system. Willow supply logistics, including fuel storage methods, urgently needs further development.

While all commercial short-rotation forestry is based on willow cultivation, a number of trials with other species have been initiated. Trials with *Alnus* confirm that nitrogen fixation is working in practice to make yield entirely independent of nitrogen fertilisation regime. Production in young *Alnus* systems is much higher than in conventional forestry, but still lags behind willow performance. Because propagation has to be performed by means of seedlings, establishment costs are higher than for willow. Trials with dense hybrid aspen and hybrid polar stands are under evaluation, and preliminary results indicate that under Swedish conditions yields can be obtained which are at least as high as willow yields under comparable environmental conditions.

Among the different primary forestry goals (see Fig. 1) biomass production for energy purposes has been and still is the major goal of willow SRC. During the past few years, public opinion and an active government policy have stressed the importance of the environmental goals that can be reached by means of applied forestry practices. The problems related to eutrophication of surface water and groundwater caused by agricultural practices or by malfunctioning sewage treatment systems especially have been an incentive for the implementation of willow SRC as a vegetation filter system.

This development encourages new and extended co-operations between municipalities, entrepreneurs, research groups, and stakeholders. Because willow SRC essentially is developing as a functional core in a ‘recycling society,’ knowledge of the system must be transferred at

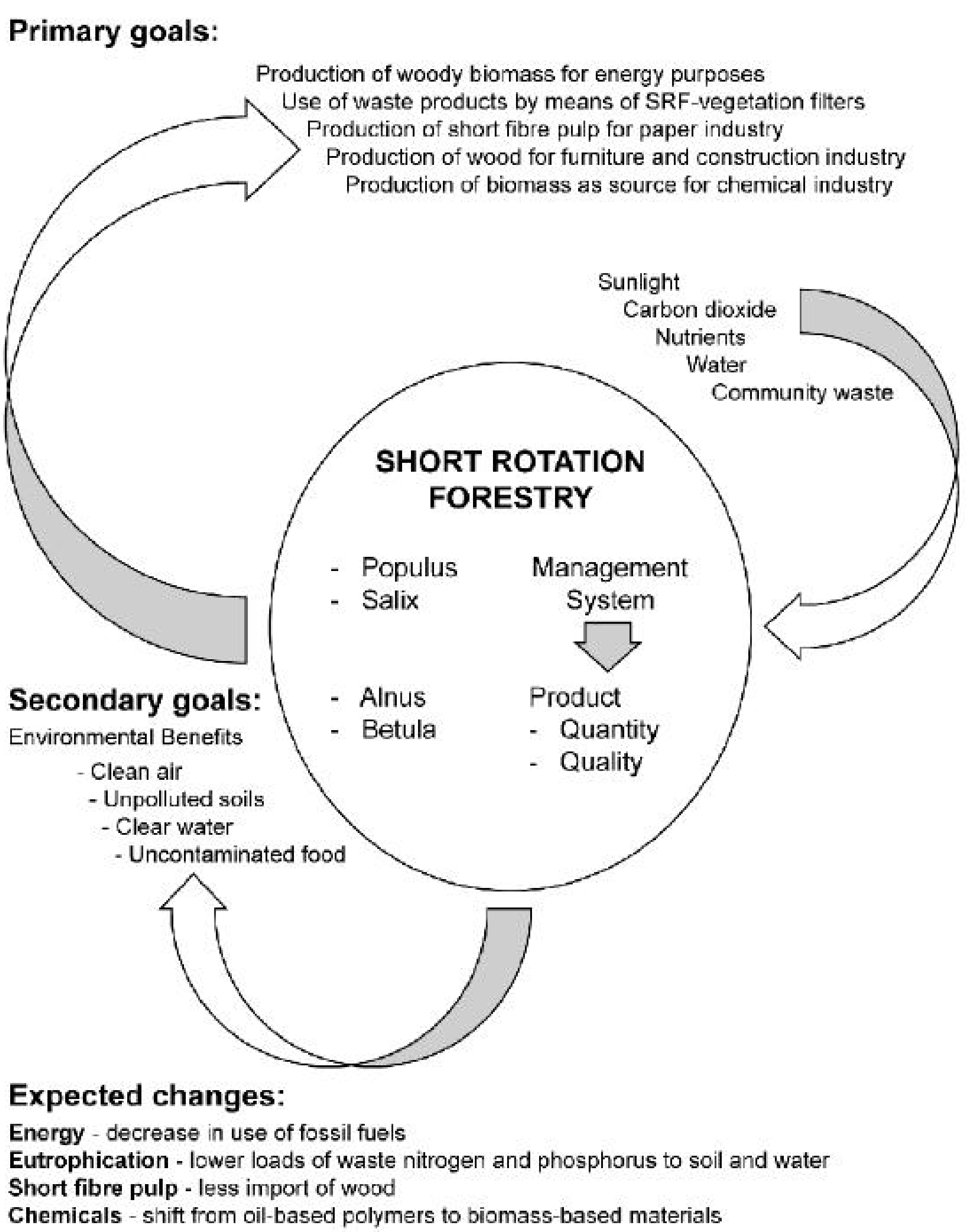

Fig. 1. Production goals in combination with environmental goals provide a wide range of possibilities for optimisation of sustainable production systems for fast growing deciduous forest stands.

many different levels to interested groups of the society. The information task associated with this extended working scope of Swedish willow SRC is huge and should be developed rapidly, because funding for information and extension work has been fading during the last five years. The rapid developments abroad in the field of phyto-remediation also justify increased information exchange and renewed international collaboration.

Reed Canarygrass Development in Sweden

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Abstract

Reed canarygrass (RCG), *Phalaris arundinaceae*, a naturally occurring plant in temperate regions, was first identified as a crop with high biomass production capacity 1987 in the national Swedish bioenergy programme. The search for a suitable production method started 1988 in the project Norrfiber, and the idea about delayed harvest (spring harvest) was first presented in 1990. Evaluation of the new method started in 1991 with an integrated chain approach covering all aspects from plant breeding, crop production, harvesting and handling, and quality measurements as well as end use for industrial purposes and energy use. In 1991, a new Swedish agricultural policy created great interest in the crop from farmers and led to the establishment of over 4000 ha of RCG. The new method with delayed harvest was used by most of the farmers parallel to the research and has provided full-scale experiences of the new method. Commercial production failed because the end use technology was undeveloped, and the Danish straw firing technology use of RCG was not competitive with the forest residues used in most biomass boilers. Ongoing research has identified that the best development lines for RCG are as chemical pulp for replacing the insufficient hardwood pulp and in the energy sector in upgraded fuels as pellets and briquettes as well as biofuel powder. Promising results were also obtained in co-combustion tests with fuels rich in sulfur and chlorine. Good potential for craft pulp production on the mill scale was demonstrated in a sawdust digester in 1999. A research and demonstration plant for fuel upgrading and local heating is under construction and will be ready in November 1999. The plant will also produce the heat for the research buildings of the university in Röbäcksdalen Umeå and replace the previous consumption of about 300 m^3 oil.

Introduction

The potential for Reed canarygrass (RCG) production under Swedish conditions was first identified by the Swedish scientist Carl von Linne, and his student Hesselgren presented the potential for forage use of the grass in 1749 in his doctoral thesis. The high biomass production capacity of RCG was first identified in a national Swedish bioenergy programme in 1987. The conclusion was that production costs with conventional harvesting technology including a needed post-harvest drying were too high and all interest was later focused on willow (Westermark and Hansson 1987). Research specific for RCG started 1988 with an integrated chain approach with special emphasis on developing a production system suitable for use in northern Sweden, and a new harvesting system, the delayed harvesting system, was presented in 1990.

Evaluation of the new method all over Sweden began in 1991, and later evaluations have shown that the method can be used all over Sweden.

In 1995, evaluations of the new method were expanded to larger parts of Europe, including Finland, Germany, Denmark, Ireland, England, Wales, and Scotland. The commercial production of RCG is still of limited size. In 1991, when the new Swedish agricultural policy was established, farmers showed a great interest in RCG and about 4000 ha were established. A few demonstration projects for heat production were also established that used Danish straw firing technology.

Results from the Swedish Research and Development Programme

The research, which was initiated by a programme financed by the Swedish Farmers Association, The Swedish Energy Authority, and the Vattenfall company, has been performed with an integrated chain approach, but crop production studies, especially evaluation of the agronomic potential for the delayed harvesting system, have dominated the programme.

Plant breeding

The programme, with the company Svalöf-Weibull AB as the responsible party, started with an evaluation of materials from gene banks all over the temperate region. This study revealed a high potential for breeding of energy and industrial varieties, that is, changing breeding direction from leafy varieties to stem-rich (internode) varieties. During the whole programme the commercially available variety Palaton has been used for comparisons and also in crop production studies. The breeding research continued with collections of wild populations from places all over Sweden. Sixteen collected populations were used in a screening trial located in seven different places all over Sweden. The commercially available varieties Palaton and Venture were used as standard varieties. The mean, range, and significance for dry matter (DM) yield and important quality characteristics are shown in Table 1. Eight populations had yields higher than the standard varieties with the highest yields about 20% higher (Lindvall 1997).

Table 1. Screening trial with wild collected populations

Character	Mean	Range	Sign.am.populations	Sign.am.locations
DM-yield, kg/ha	9670	6410–12500	*a, b*	*c*
Ash, % of DM	3,6	2,85–5,26	*b*	*c*
Si, g/kg of DM	1,32	2,85–5,26	*b*	*c*
K, g/kg DM	1,08	0,73–1.95	*a*	*b*

^{a}p <0.05.
^{b}p <0,005.
^{c}p <0,001.

A number of new experimental varieties been developed as a result of the first selections from these screening trials and crossings, and one variety, “Bamse”, has also been registered for commercial use and is suited for southern Sweden and many northern European countries. A number of experimental varieties suitable for northern Sweden are also in progress, and the first commercially available variety is expected within a few years.

Crop production

Crop production studies have focused on evaluating the possibilities of the new delayed harvesting system in different parts of Sweden and examined yield, quality for pulp and fuel use, and need of fertilisers as well as plant protection. More basic studies have also been performed [e.g., concerning nutrient allocation (N^{15} studies) as well as life cycle] for a recently identified new gall midge which seems to be favoured by the delayed harvesting system.

The evaluations show that the delayed harvesting method can be used all over Sweden and northern Europe, although new varieties suitable for maritime climates will be needed for such areas as Wales and southern England. In areas without a protecting snow cover during winter, the yields are lower, but ongoing analysis shows that winter losses as a result of rain storms are mainly due to losses of leaves that contribute to a minor extent to the value of the crop. The delayed harvest method gives a lower total yield than conventional harvests in young leys. This disadvantage decreases in older leys because delayed harvesting results in a more sustainable crop with a higher yield of fertile shoots (Fig. 1).

The ash content of RCG is on average high in comparison with forest trees and is strongly correlated to soil type. Sandy soils as well as organic soils have low ash content and clay soils high (Fig. 2). There is also a strong correlation between ash and silica content, and the SiO_2 content of ash can be as high as 85% (Fig. 3) (Burvall and Hedman 1998).

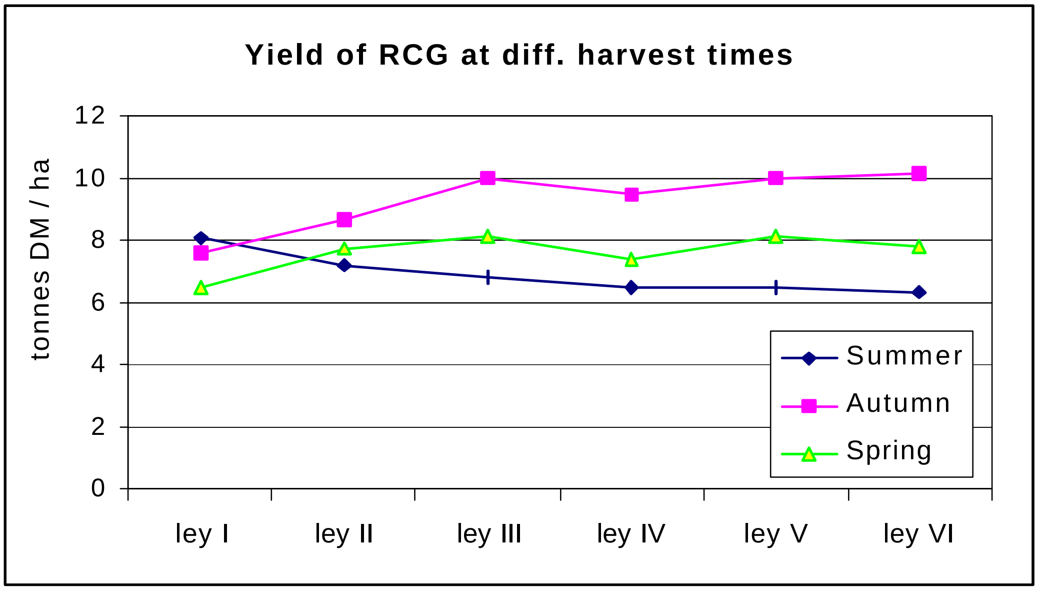

Fig. 1. Yields of reed canarygrass in relation to harvest time and age of ley.

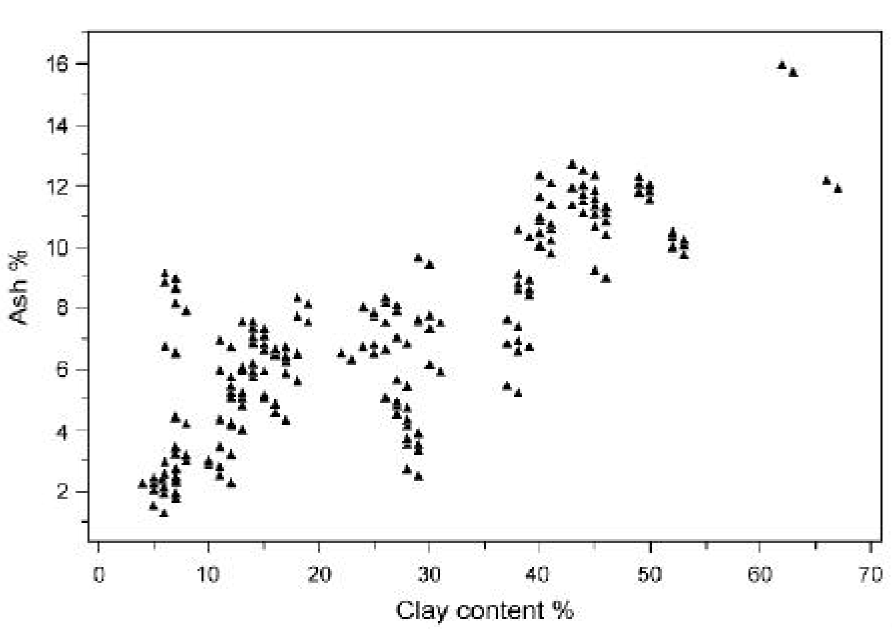

Fig. 2. The ash content in RCG in relation to the clay content in soil.

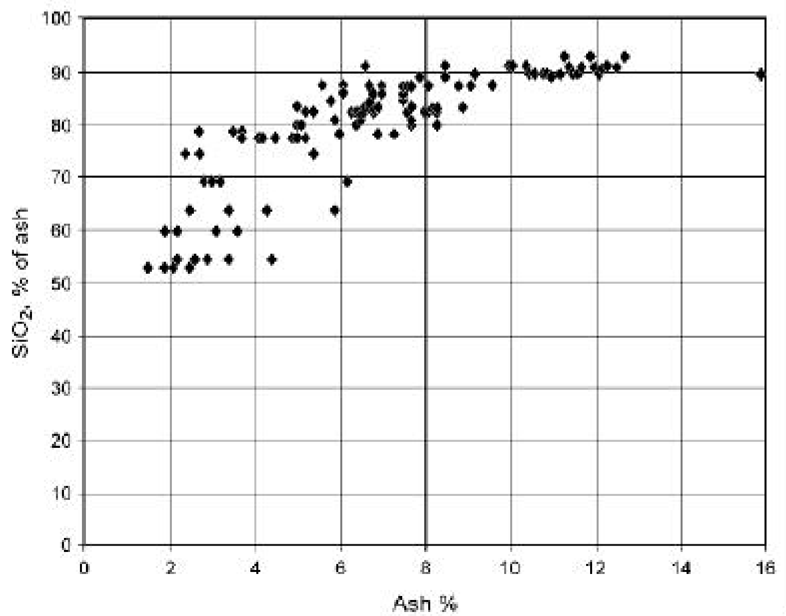

Fig. 3. The silica content in RCG in relation to the ash content.

The results of trials of RCG with the delayed harvesting method can be summarised as follows:

Advantages

- High dry matter content at harvest (DM >85%)
- Sustainable production for many years (10 years or more)
- Nutrient recycling (low production costs and improved quality as fuel or pulp raw material)
- Increased number of fertile shoots (higher stem-internode yield)

Disadvantages

- Lower yields (during the first years) compared with conventional harvesting
- Lower resistance to attacks from insects (new gall midges are favoured)
- Needs a climate with frosty conditions in autumn?

Harvesting and handling

Conventional forage harvesting and baling technology can be used for RCG harvested with the new method. The capacity of many of these machine systems is low, and the losses during harvest and storing can be high. In many aspects, the existing technologies are “farm scale” technology and thus not competitive with existing technology in, for example, the forest sector. Ongoing studies show that this part of the production chain corresponds to about 70% of the total costs at the mill gate. Production steps that provide a densification of the material as near the production fields as possible are under investigation.

Combustion of reed canarygrass

The low moisture content and high ash and silica content of RCG means that many boilers developed for forest fuels will not work satisfactorily with this fuel. The low energy density will also strongly influence combustion. The Danish straw combustion technology was first analysed both in our research as well as in a few demonstration plants owned by farmers. Experience shows the high particle emissions in this technology and thus high smoke gas cleaning costs make this technology not competitive under Swedish conditions.

The best development strategies for RCG include densification of the fuel by fuel upgrading to powder, pellets, and briquettes as well as a new combustion technology developed for ash-rich fuels.

RCGs are highly competitive as raw material for upgraded fuels, because no drying of the fuel is needed. The high ash content (alkali metals and silica) can also be used in cocombustion with other fuels rich in sulphur and chlorine and decrease the emissions and investment costs for smoke gas cleaning. Successful trials have been performed also in small-scale, low-investment boilers including cocombustion with peat and household wastes. RCG powder combustion seems to be competitive in boilers larger than 10 MW.

Pulp and paper making from reed canarygrass

The delayed harvesting method has many advantages for pulp processing of RCG. In chemical sulfate pulping, the pulp yield increases about 20% compared with raw material harvested in summer. The content of extractives also decreases from 10 to 1%, and the content of alkali metals such as potassium decreases about 80%. Still there will be many process-disturbing elements, such as a lot of thin cells (parenchyma cells) that produce “fines” which influence the dewatering of pulp, silica which influences the chemical recovery system, and metals which influence the whole process line including the bleaching of pulp.

An intermediate processing step is needed before cooking. In our research, a Danish technology developed by the Danish company United Milling A/S been used. The scheme used is described in Fig. 4 (Finell et al. 1998). The quality improvement by intermediate processing is described in Tables 2 and 3.

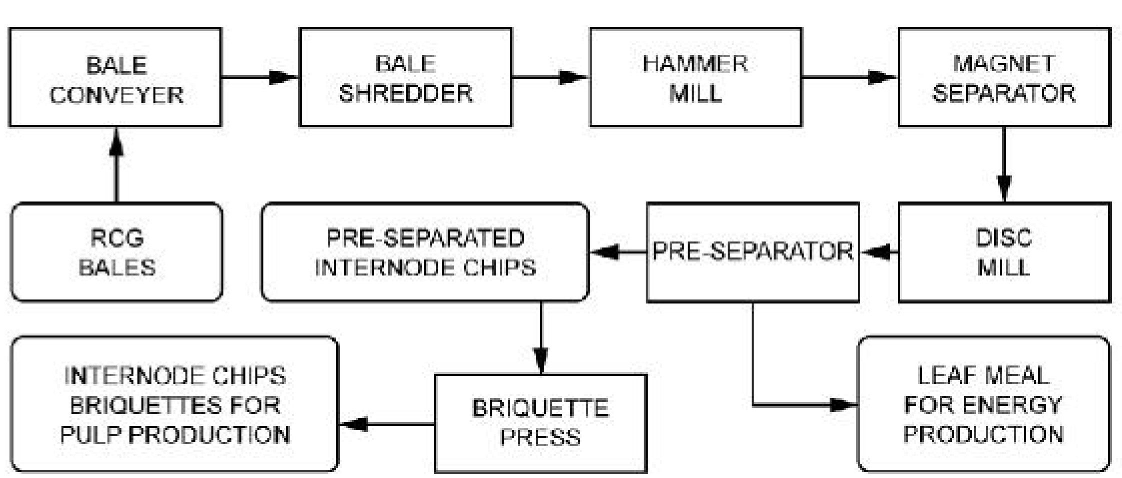

Fig. 4. Scheme of the fractionation process, including briquetting of the chip fraction.

Table 2. The influence of intermediate processing on content of ash and silica

RCG properties	Separated by hand	Separated on 1st separator + 3 mm screen	Separated on 1st separator only	Whole plant, not separated
Accept, %	N/A	39	56	100
Ash, %	N/A	3.43	3.70	5.40
Si, %	N/A	1.38	1.60	2.30

Table 3. The influence of intermediate processing on pulp characteristics

Pulp properties	Separated by hand	Separated on 1st separator + 3 mm screen	Separated on 1st separator only	Whole plant, not separated	Birch, reference (90 min)
Kappa no.	9.7	11.0	12.0	15.9	18.0
Scr. pulp yield, %	54.5	54.5	50.8	47.5	53.2
Reject # 0.15 mm, %	<0.5	<0.5	<0.5	<0.5	<0.5
Dewatering, °SR	23.0	24.0	28.0	33.5	14.0
Coarseness, mg/m	0.074	0.062	0.076	0.078	0.077
A fibre length, mm	0.40	0.36	0.36	0.33	0.85
W fibre length, mm	0.85	0.79	0.77	0.72	1.00
Fines <0.20 mm, %	33.6	38.5	38.7	43.3	6.8

The intermediate processing will in many aspects improve the raw material quality and will in some cases even give a better raw material than birch. There are still a need to modify the pulp mill construction in comparison with wood pulping, because the silica content as well as the content of fines still are too high. The silica must be taken away in a desilicification unit, and the washing units must be larger.

Mill trials with reed canarygrass pulping

In June 1999, the first pulp production trial on mill scale was done. The trial was done by the Swedish University of Agricultural Sciences (SLU) in cooperation with the ASSIDomän company and Jaakko Poyry Oy. The trial was done in a Tampella-type sawdust digester at the Karlsborg mill owned by ASSIDomän AB. The mill trial was successful, and a pulp of very high quality was produced. The pulp is under investigation for use in white top liner and fine paper production.

The design and costs for RCG modifications in existing digesters is very low.

The yield of pulp raw material in the intermediate processing depends on the actual raw material. In our mill test, 60–70% of total raw material was used for pulping and the rest as a biofuel powder. The quality of the fuel powder is quite similar to commercially available wood fuel powder except for the ash content which is much higher. Large coal powder burning units or smaller boilers built for ash-rich fuels must be used.

Biofuel technology center of Umeå

A research, demonstration, and education plant specially designed for RCG development for energy use is under construction at the research station of SLU in Umeå and will be in operation in November 1999. The plant has one unit for research on fuel upgrading to briquettes, pellets, and powder as well as for fuel mixing and one unit for heat production. The heat production unit will have three boilers. Two boilers, 600 and 150 KW, are German boilers from Öko-Therm Fellner, which are designed for burning *Miscanthus* and thus developed to handle ash-rich fuels well with a low level of particle emissions because of a good afterburner.

The heat production unit will also be responsible for production of hot water for the research station. This will provide good opportunities for long-term burning trials and evaluations as well as good possibilities for logistic studies of the RCG production chain, because about 80 ha will be contracted for the need of fuel which will be upgraded in the plant. The fuel will yearly replace 300 m^3 oil.

Research and development needs for the scaling up of RCG production and utilisation

RCG is today near the stage of commercial introduction in Sweden. Research, basic as well as applied, is still needed as well as demonstration projects. The important areas to investigate are summarised here:

Plant breeding

- New varieties with more fertile shoots
- Internode yield
- Straw stiffness
- Resistance to gall midges

Crop production

- Sustainability in production
- Nutrient balance in different soils
- Fertilisation with ash and municipal sludge
- Water requirement
- New screening trials

Harvesting and handling

- Harvesting time, time available, time for harvest
- Optimal water content at harvest
- Logistics of the bale harvesting line
- New bale-free technology
- Mobile equipment for upgrading (terminal operation)

Energy production

- Fuel upgrading technology
- Mixed fuels
- Small-scale combustion technology
- Powder burning technology
- Gasification
- Cocombustion with sulphur- and chlorine-containing fuels

Integrated chains—scaling up and demonstration

- Energy Farmer (crop production, briquetting, and combustion of 50 to 500 KW)
- Environmental Farmer (sludge, ash, new waste handling systems with cocombustion with RCG)
- Large-scale production and upgrading to pellets (5000 ha)
- RCG powder production integrated with heat and electricity production
- Crop production at industrial scale for energy, pulp and paper, and particleboard production

Acknowledgments

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Minutes from the Business Meeting of IEA Bioenergy Task 17, Short-Rotation Crops, at Auburn, Alabama, September 9, 1999

Chair: Lars Christersson
Secretary: Stig Ledin

Participants of the Business Meeting: Tom Baker, Australia; David Bransby, United States; Laercio Couto, Brasil; Bob Harris, United States; Gunnar Johansson, Sweden; Jens Bonderup Kjeldsen, Denmark; Leen Kuiper, The Netherlands; Sandy McLaughlin, United States; Wilma McNabb, United States; Rolf Olsson, Sweden; Paltro Garcia Pinatti, Brasil; Håkan Rosenqvist, Sweden; Roger Samson, Canada; Theo Verwijst, Sweden; Mats Wilstrand, Sweden; Ed Woolsey, United States; Lynn Wright, United States.

Lars Christersson opened the Business Meeting.

The following meeting agenda was presented:

A. Objectives of Task 17—changes?
B. Country reports
C. Priorities of Task 17 and state-of-the-art report
D. New tasks
E. Executive committee—co-operation
F. Next meetings
G. Other issues

Decision: The agenda was approved.

A. Objectives of Task 17—Changes?

Lars Christersson presented the objectives of the Task as follows:

- to stimulate the full-scale implementation of energy crops in the participating countries
- to strengthen the contacts and co-operation between participating countries, scientists, biomass producers, machine developers, entrepreneurs, and end users
- to select most urgent research and development areas and suggest projects of co-operation
- to inform Ex-Co-members
- to deliver proceedings from the meetings

Decision after discussion: No changes.

B. Country Report

Proceedings from this meeting will be published by Oak Ridge National Laboratory and edited by Lars Christersson and Stig Ledin. Costs related to the printing will be paid by Task 17, Short-Rotation Crops. Everybody who has given talks during the meeting in Auburn should deliver a paper for the proceedings. All papers should include an abstract. Also country reports should be published in the proceedings. The absolute last date for sending manuscripts to the editors is November 9th.

Decision: The proceedings should be published by the Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Responsible: Lynn Wright and Lars Christersson

C. Priorities of the Task 17 and State-of-the-Art Report

The Chairman presented the following list of the "high priority areas" that were decided at the Uppsala meeting and that shall be dealt with in Task 17:

1. Sustainability:
   production, economy, ecology, and sociology.

2. Implementation in Large Scale:
   politics and subsidies.

3. Water and Nutrients:
   water use efficiency (WUE) and nutrient use efficiency (NUE)

4. Pests and Diseases:
   frost, leaf rust, insects, bacteria, and virus.

5. Courses:
   university and technical.

C.1 Sustainability

First the concept, "sustainability," was discussed and also other aspects were touched upon. The question was raised whether farmers should take part in meetings like the one we just held in Auburn. It was stated that before we invite farmers we need to be able to demonstrate a business where biomass-for-energy (biomass from short-rotation crops) is proved to be successful from an economic point of view. The farmers need to see that they get a profit from growing biomass for energy. If we have no good stories to tell to farmers, it may well turn them negative to the concept.

When dealing with sustainability, one should take the opportunity to characterise the benefits, target the successful components of a sustainable system, and quantify them.

It was discussed whether farmers organisations should take part in our meeting. At the meeting in Auburn, one person from the industry of short-rotation crops for energy took part (Mats Wilstrand). Most of these people are home doing industry.

As the discussion went on, it was stated that income from the growing of short-rotation crops for energy was the number one question for the farmers. However, the level of income is not necessarily very high. An income of $50 per acre has been reported as sufficient to create interest from farmers in Alabama (switchgrass).

Certification of the biomass product produced by farmers was discussed.

The question was raised regarding who is the customer in the biomass-for-energy business. In one case the municipality was the customer; in another case a car company (fuel from biomass). So it was suggested that, while it is important to invite farmers to future meetings, it is just as important to invite big companies.

A wide spectrum of "customers" should be invited. For example in Europe, Volvo and BASF were mentioned. There are, on the production side, experts regarding production of a new raw material for fuels and chemicals, etc. The production chain is related to effects that add value (e.g., purification of water). So, people like decision-makers and politicians should be invited to our meetings or to our group.

Also, the question was raised regarding the connection between companies and other Tasks.

At this point in the discussion, a “one liner” was introduced by Mats Wilstrand. We have had the dream: “to drive on pure water, now we can drive on dirty water.”

The chairman asked the question regarding what we can do during the remaining time of the Task 17 period. Can we write a “state-of-the-art” report covering the different issues treated in the Task?

It was suggested—since the issues are so broad—that we should focus on highlights with examples and in the process define gaps in our knowledge.

The following is a quotation from Mats Wilstrand’s contribution.

“Replacing fossil fuels with biomass leads to global benefits, such as reduced emissions of greenhouse gases; this is a well-known fact. Biomass has another, *unique* characteristic: when a plantation is applied to the solution of water or soil-related environmental problems it generates added value that *no other energy source* can achieve.”

The most important environmental improvements can be achieved when energy crops are used as vegetation filters for the treatment of municipal wastewater, as buffer strips for the interception of fertiliser run-off from food crops to watercourses, and as plantations for the recirculation of sewage sludge.

With environmental values higher than production costs, the competitiveness of biofuels against fossil fuels increases dramatically.

The take-off of the short-rotation coppice-based energy sector can take place, even in countries exempted from eco-taxation on fossil fuels, namely the vast majority of countries in the world.

Dr. Laercio Couto offered a PhD Thesis on sustainability (written in the Portuguese language) as a contribution to our Task and the state-of-art-report. The study deals with 600 000 hectare of eucalyptus. (We would like Laercio to send the thesis to SLU, LTO, Box 7016, 750 07 Uppsala, Sweden, where translation is available.)

In the discussion we tried to come up with a solution to concentrate a very vast topic, such as sustainability, into something that has an informative impact. We tried one-liners like: “Drive a car on dirty water.”

We agreed that each country should try to pull together in creating an outline defining sustainability. Each country should give an example. A group of people should be responsible for this effort: Lynn Wright, Virginia Tolbert, Sandy MacLaughlin, Tom Baker, Mats Wilstrand, Theo Verwijst, Jens Bonderup Kjeldsen, and Rolf Olsson. The first draft should be sent to Lynn Wright no later than 2 months from now.

Decision: Task 17 should write a paper concerning sustainability with the above-mentioned persons as responsible and Lynn Wright as chairperson.

C.2 Implementation on large scale

The debate regarding implementation on a large scale showed that the situation is so different in different countries that a common paper would be of little use. A better idea would be that every country should write a page on this topic that responds to the following questions: What are the barriers regarding different crops? What are the problems today? What problems can be foreseen for tomorrow? The report should be sent to the chairman no later than two months from now.

Decision: Each country representative should write a page about problems in his or her country regarding large-scale implementation of biomass cultivations.

C.3 Water and nutrients

Regarding water and nutrients, Jens Bonderup Kjeldsen volunteered to cover this topic at the next meeting. In the discussion that followed, an American delegate described the problem with the gasoline additive MTBE (methyl tertiary butyl ether) and pollution of water. The chairman indicated that water use efficiency (WUE) and nutrient use efficiency (NUE) also should be treated in this area of concern.

Decision: Jens Bonderup Kjeldsen should write a state-of-the-art report on water use efficiency and nutrient use efficiency of short-rotation energy crops for the next meeting.

C.4 Pest and diseases

Pests and diseases were discussed. It was concluded that these problems are so big that they should have a Task of their own. Leen Kuipers and Lynn Wright (together with Gerry Tuskan) are prepared to go on with this and write a new Task proposal.

Decision: Leen Kuiper and Lynn Wright should write a new proposal concerning Pest and Diseases in Short-Rotation Energy Crops.

Responsible: Leen Kuiper.

C.5 Courses

Courses on short-rotation crops for energy were treated next. University courses as well as technical courses for farmers, politicians, and decision-makers were discussed. Participants were very positive toward courses. We were informed that El Bassam in Braunschweig, Germany, has put together courses on biomass for energy. We need to know what exists today. Everyone should collect information about courses until the next meeting.

It was suggested that aspects of biomass be integrated into existing courses rather than giving courses exclusively on biomass for energy. Teaching should be done on several levels.

We could ask El Bassam to provide information on the situation of biomass for energy courses at the next meeting.

Further it was suggested that we ask the Executive Committee to provide their opinion regarding courses. Maybe a new Task should be created that deals with courses.

Decision: Task 17 should suggest that ExCo consider the possibilities for creating and developing courses and pedagogic materials for university and technical courses.

Responsible: Lars Christersson.

D. New Tasks

Prof. Pinatti suggested International Bioenergy Commercialisation as a new task. There were many different opinions about this idea.

For a new Task of its own on Courses, the following was felt by the participants. Positive: U.S.A., Australia, Sweden, Canada, Denmark. Hesitant: The Netherlands. We should ask the ExCo for advice.

Another new Task was suggested by the Swedish delegation: Design and Implementation of Short-Rotation Energy Crop Systems for Sustainable Urban and Rural Environments. The suggested Task would include “Sustainability,” “Full-Scale Implementation,” and also Alastair

Hunter's suggestions about "Combifarming" and Thord Olsson's suggestions about "The Double Loop."

The participants of the meeting supported the idea of sending in a Task proposal with the above-mentioned preliminary title.

It was also suggested that "Biomass fuel homogeneity" should be treated within that new task, if approved.

Another new Task: "Pests and Disease" was discussed. Leen Kuipers and Lynn Wright (together with Gerry Tuskan) are prepared to go on with this Task proposal (see C.4).

Decision: The following new Tasks should be suggested to the ExCo in Japan:

Design and Implementation of Short-Rotation Energy Crop Systems for Sustainable Urban and Rural Environment. Responsible: Theo Verwijst and Stig Ledin.

Pests and Diseases. Responsible: Leen Kuiper and Lynn Wright.

Suggestion to ExCo to discuss possibilities of developing teaching materials for universities and technical high schools and perhaps also creating courses of their own (e.g., similar to distance learning on the Internet).

Responsible: Lars Christersson (see C.5)

E. Executive Committee Co-operation

Task: ExCo relations were discussed. The chairman has support from the group for sending a letter to the Executive Committee and suggests that all Task leaders meet once a year together with ExCo members.

F. Next Meeting

The possibility of holding the next meeting in Australia in February 2000 will be explored. Melbourne and Sydney were mentioned as possible meeting places.

The Chairman provided information on an International Union of Forestry Research Organisations (IUFRO) meeting in Kuala Lumpur, Malaysia, 7–12 August 2000.

At the end of 2000 (November) a meeting of Task 17 may be held in Denmark or in The Netherlands or in both.

G. Other Issues

The meeting participants supported the "double loop system" application to the EU. It was stated: The meeting concluded that "the innovative model for double loop recycling of nutrients in sustainable non-food and food crop systems" presented by Mr. Thord Ohlsson, from Edafos Ltd in Sweden, can be used to further the large-scale implementation of energy crops.

A European project on this theme is planned. It is recommended that this project work be done in close contact with Task 17 of IEA-Bioenergy.

H. Final

Lars Christersson finished the meeting by thanking Lynn Wright, Wilma McNabb, and David Bransby and presented the ladies with two Dala Horses from Sweden.

Stig Ledin	Lars Christersson
secretary	chairman