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Carbon Dioxide from Integrated Biomass Energy Systems – examples from case studies in USA

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Carbon Dioxide from Integrated Biomass Energy Systems - examples from case studies in USA

Summary

This report is a result of a work by Vattenfall and Electric Power Research Institute (EPRI) to study a number of integrated biomass energy systems. The emphasis of this paper will be on the energy systems of the projects in Minnesota and New York, while the other projects will be dealt with in less detail.

In response to an offer of co-funding from National Renewable Energy Laboratory (NREL) and EPRI, seven case studies were started in 1994 to investigate the feasibility of integrated biomass energy systems, utilizing a dedicated biomass feedstock for energy production. Four of these case studies are mentioned in this paper (the reports from the other three studies were not available at the time of writing this paper):

1. Northern States Power, Minnesota - Alfalfa stems as a biomass feedstock for an IGCC for electricity production.
2. Empire State Power Consortium, New York - Willow hybrids for co-firing with coal.
3. New Bern Advanced Biomass to Energy Project, North Carolina - IGCC integrated with pulpmill, using wood residues. Also an ethanol production option.
4. Kansas Electric Utilities Research Program, Kansas - Fast pyrolysis of different herbaceous and woody crops, for 3-4 MW_e base load production.

The first two studies deal with most aspects of the integrated biomass systems, including energy balances, environmental effects, etc. The other two are less comprehensive.

By introducing the dedicated feedstock supply system (DFSS), the amount of energy spent for production of crops can be reduced, the amount of fertilizers can be decreased,

the soil can be improved, and a significant amount of energy will be produced, compared to an ordinary farm crop.

Although the conversion of biomass to electricity in itself does not emit more CO_2 than is captured by the biomass through photosynthesis, there will be some CO_2-emissions from the DFSS. External energy is required for the production of the biomass feedstock, and this energy is mainly based on fossil fuels. By using this input energy, CO_2 and other greenhouse gases are emitted.

But, by utilizing fossil fuels as external input fuels for production of biomass, we would get about 10-15 times more electric energy per unit fossil fuel, than we would get if the fossil fuel was utilized in a power plant directly!

Compared to traditional coal based electricity production, the CO_2-emissions are in most cases reduced significantly. But the reduction rate is related to the process and the whole integrated system. The reduction could possibly be increased further, by introducing more efficient methods in farming, transportation, and handling, and by selecting the best methods or technologies for conversion of biomass fuel to electricity.

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KOLDIOXID FRÅN INTEGRERADE BIOENERGISYSTEM - EXEMPEL FRÅN FALLSTUDIER I USA

Sammanfattning

Denna rapport är resultatet av ett arbete utfört av Vattenfall och Electric Power Research Institute (EPRI) för att studera ett antal integrerade bioenergisystem. Tyngdpunkten i rapporten ligger på energisystemen i projekt i Minnesota och New York, medan de övriga projekten kommer att behandlas mindre detaljerat.

Ett erbjudande om delfinansiering från National Renewable Energy Laboratory (NREL) och EPRI resulterade i att sju fallstudier påbörjades år 1994 för att undersöka möjligheten att använda ett specifikt biobränsle till energiproduktion i s.k. integrerade bioenergisystem. Fyra av dessa fallstudier behandlas i denna rapport (rapporter från de övriga tre studierna var ej tillgängliga när denna rapport sammanställdes):

1. Northern States Power, Minnesota - Lusern som biobränsle för en IGCC för elproduktion.
2. Empire State Power Consortium, New York - Salix för sameldning med kol.
3. New Bern Advanced Biomass to Energy Project, North Carolina - IGCC integrerad med pappersmassefabrik, med användande av trädavfall. Alternativt också etanolproduktion.
4. Kansas Electric Utilities Research Program, Kansas - Snabb pyrolys av olika gräs- och trädgrödor, för 3-4 MW_e baslastproduktion.

De två förstnämnda studierna behandlar de flesta aspekter av integrerade bioenergisystem, omfattande energibalans, miljöeffekter, etc. De övriga två är mindre utförliga.

Genom att införa ett specifikt biobränslesystem (s.k. Dedicated Feedstock Supply System - DFSS) kan en betydande mängd energi produceras. Jämfört med ordinär jordbruksproduktion minskas behovet av både tillsatsenergi och växtnäring, samtidigt som markens mullhalt ökas.

Även om förvandlingen av biomassa till elektricitet inte leder till utsläpp av mer CO_2 än den mängd som är bunden i biomassan genom fotosyntes, förekommer ett visst utsläpp av CO_2 från systemet. Extern energi är nödvändig för produktion av biobränslet, och denna energi är huvudsakligen baserad på fossilt bränsle. Vid användning av denna energikälla sker utsläpp av CO_2 och andra växthusgaser.

Dock, genom att använda fossilt bränsle som externt bränsle för produktion av biomassa skulle vi kunna få cirka 10-15 gånger mer elkraft per enhet fossilt bränsle än vi skulle få om vi använde fossilt bränsle direkt i en kraftstation!

I jämförelse med traditionellt kolbaserad elproduktion, är CO_2-utsläppen i de flesta fall betydligt mindre. Men minskningstakten står i relation till processen och hela det integrerade systemet. Minskningen skulle möjligen ytterligare kunna förstärkas genom att man inför effektivare metoder i jordbruk, transport och hantering, och genom att man väljer de bästa metoderna eller teknikerna för omvandling av biobränsle till elektricitet.

PREFACE

Since the 1970´s, Vattenfall AB has conducted research and developmental work in bioenergy. In addition, Vattenfall owns and operates plants producing heat and heat/electricity that are powered by biofuel.

Since 1989, Vattenfall´s developmental inputs in the bioenergy sector have been conducted as projects and since 1994 Vattenfall Utveckling AB has had the overall responsibility for the Bioenergy Project. The overall target of the project is to identify possible roles for bioenergy within the future commercial activities of Vattenfall. In order to obtain information necessary to be able to make such an assessment, the entire bioenergy system is analysed, from fuel production to final utilization.

In summary, this implies that Vattenfall´s work in the bioenergy sector includes not only evaluation and adaptation of different conversion techniques but also analyses of competition and market conditions where environmental aspects are assessed to be of increasing importance.

The developmental work is partly conducted by specialists within different companies and also by researchers at universities together with consultants. Degree projects also contribute to the development.

Results from the activities are reported in, for example, reports. This report gives a summary of results from cooperation with Electric Power Research Institute in the USA. The cooperation has concerned integrated bioenergy systems. In particular, emissions of CO_2 have been studied in the entire chain from the growing of biomass through transport to electricity production.

Vattenfall, April 1996

Karin Widegren-Dafgård
Bioenergy Project

Carbon Dioxide from Integrated Biomass Energy Systems- examples from Case Studies in USA

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APPENDICES

1. *BACKGROUND*

Electric Power Research Institute (EPRI) and National Renewable Energy Laboratory (NREL) of the US Department of Energy (DOE) have been funding a number of case studies under the initiative entitled "Economic Development through Biomass Systems Integration". The objective of these case studies is to evaluate the commercial and environmental prospects for integrated biomass power systems, involving the growth of a dedicated feedstock. The feedstock, and the integrated biomass energy system is specific to each location.

The case studies were:
1. Northern States Power, Minnesota - Alfalfa as a biomass feedstock to an IGCC for electricity production.
2. Empire State Power Consortium, New York - Willow hybrids for co-firing with coal.
3. New Bern Advanced Biomass to Energy Project, North Carolina - IGCC integrated with pulpmill, using wood residues. Also an ethanol production option.
4. Kansas Electric Utilities Research Program, Kansas - Fast pyrolysis of different herbaceous and woody crops, for 3-4 MW_e base load production.
5. Pioneer Mill, Maui, Hawaii - Exchange of sugarcane with "energy-cane" and retrofitting of existing steam cycle.
6. Pacific International Center for High Technology Research, Hawaii - Possibilities of liquid fuels and electricity from biomass.
7. Chariton Valley RD&D, Iowa - Gasification and other technologies for production of 20 MW_e from switchgrass.

Biomass is said to have no net emissions of greenhouse gases (GHG), while what is emitted during conversion has been captured by the growing plant. This is true, but also the input of external fuels for production of biomass has to be considered. If significant quantities of this external fuel are fossil fuels, some GHG are emitted also from the biomass energy system.

This paper deals with the full fuel cycle for some of the case studies mentioned above. It tries to answer if and to what extent fossil fuel is used, and how much CO_2 is emitted. Thus, CO_2 is the only greenhouse gas considered here.

Marland and Schlamadinger (1994) and Schlamadinger and Marland (1996) have made detailed studies on the carbon cycle in forest bioenergy. They clearly show the importance of any external energy requirements for the biomass energy system on the amount of GHG emissions. Any byproducts from the biomass system is also of importance to the GHG balance. They have mainly studied forest fuels, but the comprehensive, overall approach used, is valid also for other energy crops. Similar conclusions have been derived at also by others, such as Börjesson (1994; 1996).

1.1. The case studies

The focus of this paper is on the case studies in Minnesota (by Northern States Power, (NSP, 1995 a; b)) and New York (by the Empire States Biopower Consortium, (ESBC, 1995)). Also the North Carolina (New Bern, 1995) and Kansas (Kansas, 1995) case studies will be discussed[1]. Case studies number 5, 6, and 7 above have not been reported, and will thus not be included in this paper.

Northern States Power Company (NSP) has analyzed the technical and economical feasibility of producing 75 MW of baseload electricity, using a BGCC (Biomass Gasification Combined Cycle), located in Granite Falls in south-western Minnesota (NSP 1995 a; b). The feedstock is alfalfa, grown within a 50 miles radius of the power plant.

In the same manner, the Empire States Biopower Consortium (ESBC) has analyzed the feasibility of growing willows and co-firing them in coal-fired boilers in the region (ESBC, 1995). In the long run, the project targets at producing electricity from biomass in an IGCC-plant.

2. *FEEDSTOCK*

2.1. Introduction

In the studies here dealt with, the feedstock is dedicated to a certain plant, and is a biomass crop suitable for the specific region. A dedicated feedstock supply system (DFSS) can be defined as a system where energy crops are grown on agricultural land to be utilized for the production of energy. Either the whole plant is used for energy production, or parts of the plant can be utilized as some co-product. Such a co-product could be put in the market place, contributing to the economic feasibility of the biomass energy system.

2.1.1. Minnesota

In Minnesota alfalfa will be grown in the counties surrounding Granite Falls. The average yield of alfalfa is about 9.5 Mg/ha (4.24 tons/acre[2]) (NSP, 1995 a, Table 4.3-1).

The alfalfa stems will be gasified, producing electricity, while the leaves will be separated and used for leaf meal products. The stems have an energy content of about 16 MJ/kg (6900 Btu/lb), @ 15 % moisture (18.9 MJ/kg dm; 8116 Btu/lb dm) (NSP, 1995 a, Table 10.1-2).

- The case studies are referred to as NSP, ESBC, New Bern, and Kansas respectively. This is only to make the naming of the reports short and simple, although it may not be strictly correct.
- Here, 1 ton = 1 US ton = 0.907 metric ton. 1 metric ton = 1000 kg = 1 Mg. See appendix 1 for units and conversion factors.

The alfalfa will be grown in a seven year rotation cycle, with four years of alfalfa followed by two years of corn and one of soybean (AAAACCS). It is assumed that the requisite amount of alfalfa will be grown via the AAAAC-CS rotation if the farmers producing it can receive a competitive return on their operations compared to the conventional continuous corn and soybean cycle (CSCSCSC).

The average energy input for the AAAACCS system is estimated to be 126 GJ/ha (48.3 MBtu/acre), compared to 190 GJ/ha (72.7 MBtu/acre) for the continuous corn and soybean cycle for a full 14 years cycle (NSP, 1995 a, Table 10.1-1).

2.1.2. New York

In New York, willows will be grown in four regions, surrounding four conversion pants. The willow will be co-fired with coal in these conventional coal-fired, stoker boilers. The expected annual yield of willow is 16.8 dry Mg/ha (7.5 dry tons/acre per year), see ESBC (1995).

Winter harvested and chipped willows would in this case be used as a "cold-season-only fuel", thus avoiding storage costs and problems. Then alternative fuels has to be used during the warm season. In a co-firing situation, this may not cause a problem, since a coal-only fuel can be used then. But in an advanced system, 100 % dependent on biomass, alternative resources may have to be used in addition to the willow DFSS. These could include residues from forests and wood industries, as well as warm season harvested DFSS crops, such as alfalfa.

In both cases, also other alternative fuels have been suggested, but not analyzed in any detail. These alternative fuels may serve as a backup system if the planned DFSS would fail.

2.1.3. North Carolina

In the North Carolina case, the feedstock will be based on wood residues from the forest industry, see New Bern (1995). About 75 % of these residues consist of wood residuals from clear cuts and thinnings, etc., and the rest of residuals from saw mills and pulp mills. The feedstock would then not fall within the definition of a DFSS as stated above. Instead, the feedstock would be a by-product, that otherwise would have to be disposed of.

In the report (New Bern, 1995), it is not clearly stated if these mill residuals also include black liquor, but since the new conversion technology is assumed to be a wood gasification plant, there is no reason to believe that any black liquor is included in the feedstock estimates.

The expected yields of residues within the New Bern, NC, area are estimated to be up to 850 Gg dry matter (d.m.) per year, corresponding to 17500 TJ of energy (based on a HHV of 20.5 MJ/kg). About 30 % of this would come from Weyerhaeuser's own operations, and 70 % from other sources.

This would be more than sufficient to supply a 35-40 MW_e BGCC (biomass gasification combined cycle) that should be integrated with the paper mill.

2.1.4. Kansas

In Kansas, the DFSS is composed of herbaceous and woody sources. The grasses include e.g. switchgrass, sorghums, smooth bromegrass and others. The woody sources consist mainly of waste wood, such as tree and brush trimmings and industrial residues. The crops are produced in a 10-year cycle of establishment, growth and harvest. The annual yields range from 5.4 to 10.8 Mg/ha (2.4 - 4.8 tons/acre), see Kansas (1995).

2.2. Crop/Plant

Both in Minnesota and in New York, the biomass shed is suggested to be within a 80 km (50 miles) radius of the conversion plants.

2.2.1. Minnesota

An increase in regional alfalfa production of about 73,000 ha (0.18 million acres) is anticipated to supply the energy conversion plant. The expected average yield of alfalfa within the shed is estimated to be 8.5 Mg/ha (3.8 tons/acre) (NSP, 1995 a, Table 4.3-1). A cutting schedule with harvests on 25 June and 1 September is suggested to sustain and improve wildlife diversity and abundance. Of the yield, 53 % will be used for energy production. Thus, the yield useful for energy is approximately 4.5 Mg/ha (2.0 tons/acre). With a heating value of 16 MJ/kg (6900 Btu/lb), the energy yield would be 72 GJ/ha (28 MBtu/acre).

2.2.2. New York

In New York, the so called Swedish double-row system of planting will be used. Planting will be done once in spring, and harvesting in every third winter. Approximately 7 three-year coppice harvests are expected following establishment. Machines for planting and harvesting have been developed in Europe, and are commercial available. Willow DFSS commercial productivity is estimated to be 16.8 dry Mg/ha/year (7.5 dry tons/acre/year), which corresponds to 328 GJ/ha/year (based on HHV 19.5 MJ/kg).

The willow system is an agri-forestry system of production, where biomass is produced on agricultural land using agricultural practices. By analogy, the willow is established like a corn crop, but managed like a hay crop with multiple harvests from a single planting (ESBC, 1995).

2.3. Soil

For alfalfa, approximately 70 % of the plant is above ground, and 30 % in the soil (Hatfield, 1995). This relation is similar for other energy crops. When the crop is harvested, the root system starts to decompose, releasing carbon to the soil. This carbon release is depending on the soil type and structure, precipitation, landscape, etc. Still, compared to the conventional commodity crop rotations, more carbon is fixed in the root system, and more organic matter is stored in the soil.

Data to document the level of carbon sequestering in soil and roots are not yet fully available. But some estimates on the changes in soil organic matter has been presented by Graham et al. (1992); Johansson (1994); Ranney and Mann (1994); and Reicosky et al. (1995).

Reicosky et al. (1995) show the importance of tillage practice. With minimized tillage, the soil C content increased significantly, especially for the top 10-15 cm of the soil layer. With perennial crops, such as alfalfa or willows, the effects of C sequestration in the soil would be beneficial. But the effects of crop rotation and tillage on soil organic matter become significant only after several years.

Although some carbon is initially stored when the DFSS rotation is introduced, it is likely that some level of steady state will occur. This assumption is also supported by Graham et al. (1992), and by Ranney and Mann (1994), who state short-rotation plantations may increase carbon inventories (including above-ground wood, soil carbon, litter, and roots) by about 30-40 Mg/ha over a 20-50 year period, when replacing cropland. This increase would cease after some 75-100 years.

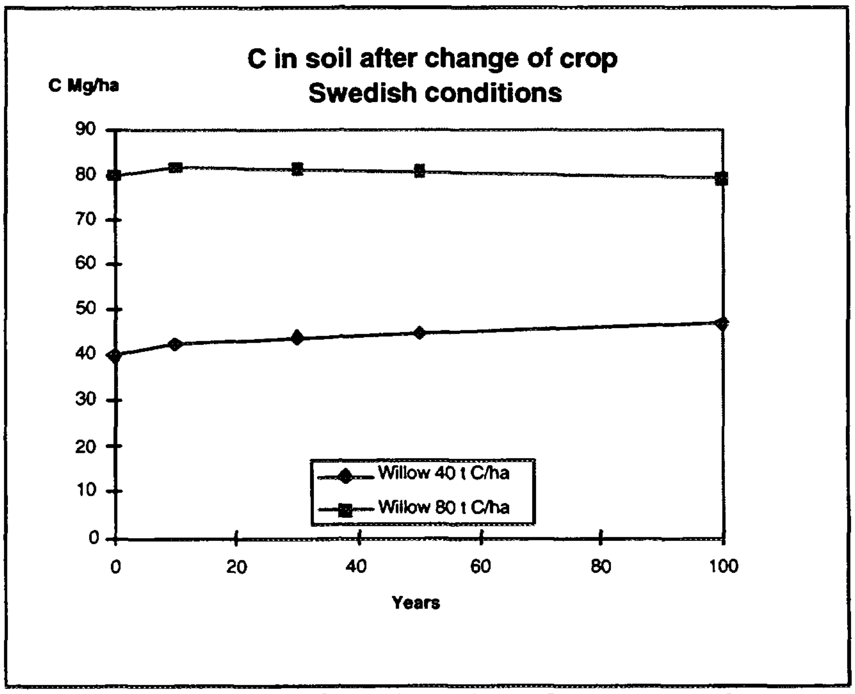

Figure 1. Organic carbon (C) in the soil years after change to willow crops. Initial carbon content 40 and 80 Mg/ha, respectively. Adopted from Johansson (1994)

Also Johansson (1994) has estimated how the soil content of C changes with time, when a land use is changed from traditional crops to willows in Sweden. If the C content in the soil at time of change is 40 Mg/ha, then the C content will increase with time, see figure 1. But if the content initially is 80 Mg/ha, then the C content in the soil eventually will decrease. This supports the assumption that there is some sort of steady state of carbon content which can be reached. The rates of change are small over time.

2.3.1. Minnesota

The biomass shed in Minnesota was originally grassland prairie, now transformed into prime farmland. The soils are generally neutral to alkaline in pH, high in calcium, magnesium, and potassium, medium to high in organic matter, medium in nitrogen supply capacity, and low in phosphorus. Water permeability is often slow in many of the heavier-textured soils and water holding capacity is high.

With the AAAACCS seven year rotation cycle, the needs for external inputs of fertilizers and fossil fuels are reduced. This rotation cycle is, compared to the traditional CS-cycle, environmentally beneficial, due to reduced soil erosion, improved soil tilth, increased soil organic matter levels, and reduced potential for nitrate leaching.

Reduced soil erosion reduces non-point source pollution of lakes and rivers, and alfalfa's deep tap roots remove nitrates from deeper soils. Alfalfa obtains nitrogen through nitrogen fixation from the atmosphere, and reduces needs for nitrogen fertilizers also for the other crops in the rotation cycle. The soil structure is improved by alfalfa, and the soil organic matter levels are increased. This would also mean that the soil acts as a carbon sink and that the soil carbon content will be increased (see e.g. Ranney et al., 1991).

2.3.2. New York

The soil is not described in detail in ESBC's final report (ESBC, 1995). With reference to the National Biofuels Roundtable (1994), it is stated that "the displacement of row or grain crops by woody biomass crops has the potential to improve soil structure, organic matter content, and water quality.... Woody biomass has an extensive and perennial root system which slows erosion when the canopy cover is removed during harvest".

2.3.3. North Carolina

Since the project in North Carolina is somewhat different, inasmuch as there is no dedicated feedstock produced on farmland, there is also no discussion on affects on the soil in the report (New Bern, 1995). The forest plantations are to be continued as wood-suppliers. The energy resources are by-products. But also for a forest managed mainly for wood-products, it is essential to maintain adequate nutrient balance, and to mitigate erosion.

In long-standing forests, erosion is a minor problem. Also, if litter and thinning or cutting residues are left in the forest, the nutrient balance is kept. When removing these residues for energy purposes, the nutrient balance could be disrupted. For nutrients other than nitrogen, this could be counteracted by returning the ashes to the soil[3]. Furthermore, removal of residues from the forest, with ash-return, could reduce an excess of nitrogen, if such exists due to high depositions of N (Lundborg, 1994). On the other hand, if a deficiency of N is at hand, N-fertilizers have to be added to the soil.

2.3.4. Kansas

As for alfalfa in Minnesota, the introduction of perennial grasses in northern Kansas will be beneficial to the soils. Erosion will decrease, and the structure and physical characteristics will improve (Kansas, 1995, section 5).

2.5. Fertilizer

Fertilizers are a major source of external energy input to biomass systems and account for about 1/3 of the energy input for the DFSS. The fertilizer industry has undergone a major technological advancement in the last decade. The energy requirements for production of fertilizers have decreased, and it is likely that this is a lasting trend (Bhat et al., 1994).

Compared to ordinary row crops, the amount of fertilizer is usually decreased for biomass production. Especially for crops like alfalfa, which is a nitrogen-fixing species, the amount of N fertilizer is significantly lower. Since production of N-fertilizers is very energy intensive (reduction from N_2 to NH_4^+ requires a lot of energy), a change in the use of N will strongly affect the energy budget for any DFSS.

Biological nitrogen fixation (fixing nitrogen from the atmosphere) may contribute to tens of kg/ha/year nitrogen to the soil (Ranney and Mann, 1994). This soil N may be taken up by the other crops in the rotation, or by microorganisms. Some of this N can be accumulated as a temporary (long or short term) storage of organic bound nitrogen in the soil (Lundborg, 1995). There is also a possibility of N leakage to the ground water.

2.5.1. Minnesota

The main fertilizers used in the AAAACCS rotation are nitrogen, phosphorus, and potassium. Compared to the traditional CS-rotation, the use of N is decreased, but the use of P and K are increased in the DFSS-rotation. This is shown in table 2. Nitrogen is only applied in the second year of corn.

The total energy requirements for production and transportation of fertilizers are decreased from 5.26 GJ/ha/year to 2.98 GJ/ha/year for the DFSS rotation (from 28.3 MBtu/acre to 16 MBtu/acre for the 14 year rotation). This is due to the very large decrease in use of nitrogen, since alfalfa does not require any N fertilization.

- This is being studied within the "Research Program for recycling of wood ash", financed by NUTEK, Sydkraft, and Vattenfall, s[e]e [Jönsson, 1996 #2[1]7]

2.5.2. New York

Over all, the use of fertilizers will be reduced for the willow DFSS as compared to a traditional row crop.

Fertilizers will be applied only after the crop is capable of utilizing the nutrients, i.e. no application in the year of establishment. Compared to corn, with its significant protein component, willow requires substantially less nitrogen fertilizer. Also the requirements for phosphorus and potassium are lower for willows than for corn, soybeans, or pastureland.

The application of various mulches, sludges, and residues may be possible. This could be beneficial both to the production of biomass, as well as regarding the problem of disposing of residues and waste products. The use of biomass systems for remidation or utilization of wastes is expected to have socioeconomic benefits. This discussion and analysis is however beyond this paper and the final report from ESBC.

2.4. Transportation and Storage of feedstock

Transportation and storage of feedstock will require external energy inputs. Most of the transportation of feedstock to the conversion sites will be by truck. In some cases also transportation by train has been evaluated. The truck transports will involve use of diesel oil, and thereby result in CO_2-emissions.

Most case studies have a transportation range of 80 km (50 miles) or less. Extended distances would lead to increase in costs, as well as in environmental impacts, which might limit the profitability of the systems. Also, normally a sufficient amount of energy crops can be produced within the 80 km radius of the conversion plants. In the North Carolina case, a 160 km radius have been looked upon, while in the Kansas case, the average hauling distance is less than 8 km. This short distance is due to the small conversion plant of less than 5 MW.

By introducing the biomass systems, possibly some other transports could be avoided, but maybe in another part of the state or the country. Thus, the total amount of emissions could be reduced.

The case studies report on production, transportation, and storage of biomass differently. Only Minnesota and Kansas present figures for energy requirements in this area. Estimates have to be made using other sources for the other cases.

2.4.1. Minnesota

The delivery of biomass feedstock to the gasification plant will result in a 7 % increase in total traffic in the rural region, which corresponds to a 37 % increase in total heavy commercial traffic. This increase in traffic is mainly of regional interest, concerning the regional infrastructure.

Transportation from the storage sites to the conversion plant is assumed as 6 days/week, 40 mph average speed, and 16 hours/day on the road (NSP, 1995 a, section 5.2). That would result in about 220 kJ/kg alfalfa, or 138 TJ/year in transportation energy consumption (see appendix 3). This would result in emissions of sulfur, NO_X, and CO_2 and others, see section 5.

2.4.2. Kansas

To supply the conversion plant with 100 Mg/day (110 tons/day) of herbaceous and woody crops, a weighted loaded distance of 7 km (4.21 miles) is required. With a diesel fuel consumption of about 0.6 l/km, the energy consumption would be 17.5 MJ for transportation of 1 Mg hay and 14.5 MJ/Mg for wood chips transportation.

2.4.3. New York and N. Carolina

The transportation systems are not well documented in the New York and N. Carolina cases. Estimates for these types of systems could be found e.g. in Brännström-Norberg et al. (1994) for willows and forest fuels, in Turhollow and Perlack (1991) for hybrid poplar a.o., and in Börjesson (1996). These estimates show no great difference in transport energy requirements for biomass or coal.

Table 1 shows the estimated values for transportation of willows and forest residues, based on Brännström-Norberg et al. (1994). The assumptions made here, is an average traveling distance of 50 km (31 miles), and that the ashes amount to 1.5 % for willows and 2 % for forest residues. The ashes too, are transported an average distance of 50 km. Further it is assumed that each truck has to travel this distance twice.

Table 1. Estimated transport energy requirements for New York and N. Carolina (based on Brännström-Norberg et al., 1994)

	Transported Biomass	*Transport Fuel per year and per unit biomass*			*CO2-emissions per unit biomass*	
	Mg/y d.m.[4]	*GJ/y*	*kJ/kg*	*kJ/MJ*	*kg/Mg*	*kg/GJ*
New York: 10% Willows	40606	5414	133	6.7	10	0.5
N. Carolina, Forest residues	285656	31740	111	5.6	8.3	0.4

As can be seen in table 1, the energy requirements for transportation of willows and forest residues amount to only about 0.6 % (6 kJ/MJ) of the energy content of the biomass.

- d.m. = dry matter

3. *ENERGY INPUT*

For the production of electricity, both fuel and external energy is required. The fuel is used in the conversion process (combustion, gasification, etc.) at the conversion plant. The external energy is the energy required for processing, handling, and transportation of the fuel to get it to the conversion plant. This energy consists mainly of fossil fuel.

3.1. External energy input

All production of biomass is dependent on external energy. This energy is in general some sort of liquid fossil fuel. Especially for farming, diesel fuel is used for running machines. For the production of additives, such as fertilizers, both fossil and non-fossil fuel is used, such as electricity (which of course may be produced from fossil fuels). Figure 2 shows some estimates for the energy requirements according to different sources. Since different sources allocate the energy differently, the allocation to fuel, seed, etc. in Figure 2 is somewhat arbitrary. The sums are in accordance with the sources.

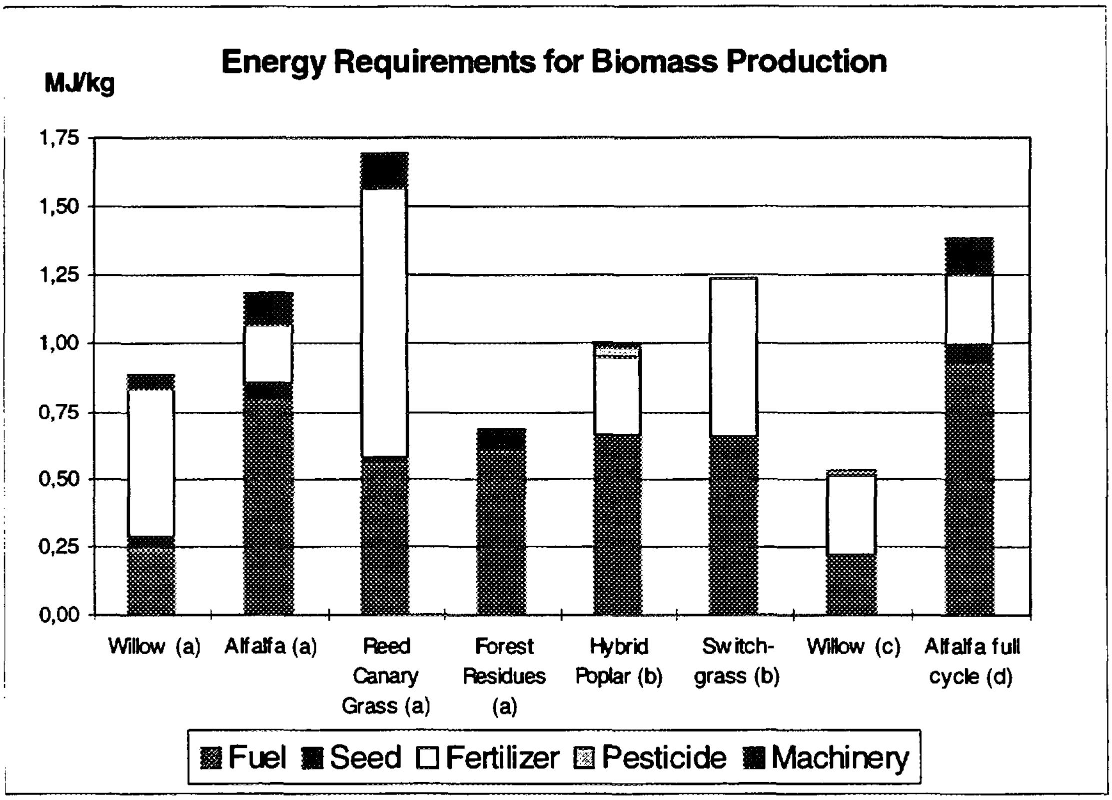

Figure 2 Energy requirements for production of some biomass, according to:
(a) Börjesson (1994)
(b) Turhollow and Perlack (1991)
(c) Brännström-Norberg et al. (1994)
(d) NSP (1995 a) (sum of all parts for production)
See Appendix 4 *for assumptions*

Of the case studies, only the Minnesota study is represented in figure 2. The energy requirements for the other studies have to be based on figure 2.

The assumptions made in the sources for figure 2 are of course somewhat different, which makes a straight forward comparison between the different references impossible. The assumptions are presented in Appendix 4.

What can be seen though, in this comparison, is that the energy requirements for biomass production is in the order of 1 MJ/kg (430 Btu/lb) (ranging from 0.6 to 1.7 MJ/kg). On an energy to energy basis, this would correspond to input energies in the range of 30 to 90 kJ/MJ biomass.

Electricity will be produced from the biomass. Therefore it is of interest to see how much electricity can be produced compared to external energy input. In figure 3 the relation between external energy input and electricity production is presented. The figure is based on the same sources as figure 2, assuming a net conversion efficiency of 40 % (8530 Btu/kWh) can be achieved both for biomass and coal.

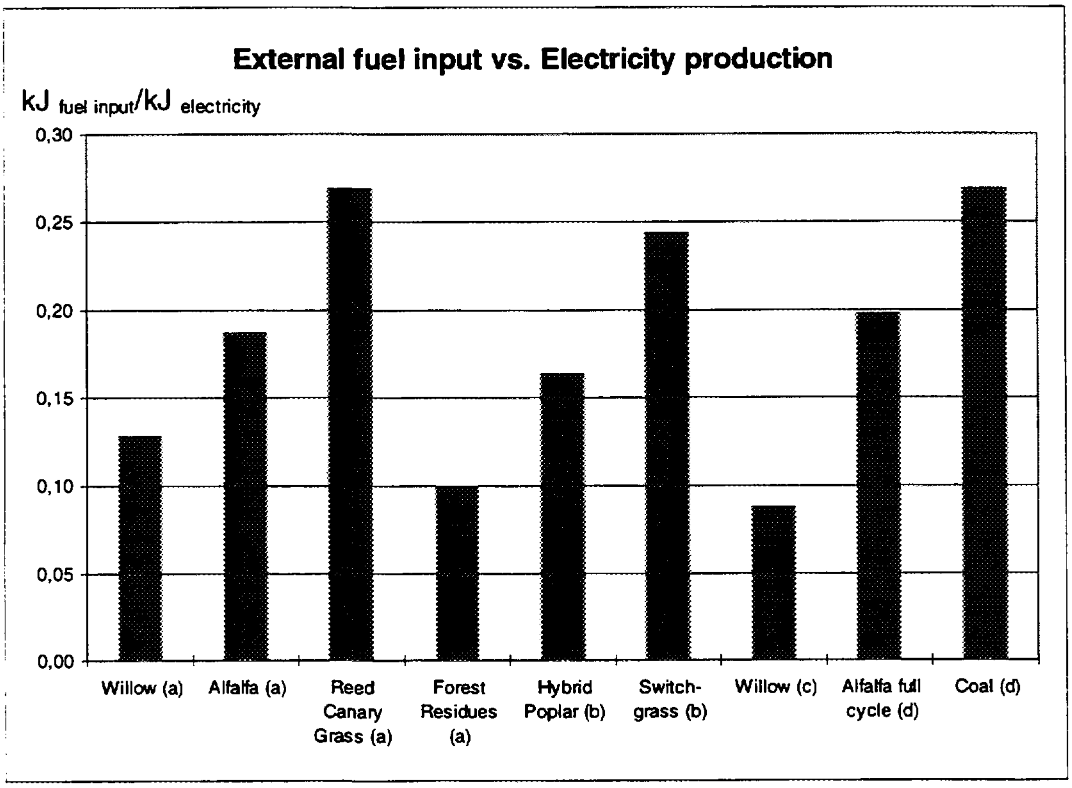

Figure 3 External energy input vs. Electricity production, η_{el}=40 %, incl. transportation. See Appendix 4.
(a) Börjesson (1994)
(b) Turhollow and Perlack (1991)
(c) Brännström-Norberg et al. (1994)
(d) NSP (1995 a)

Again, it is hard to make straight comparisons between the different biomass systems, since the underlying assumptions are different for different sources (see appendix 4). But the figures 2 and 3 also reflect some of the differences between different biomass systems. Between the best and the worst case, there is a ratio of about 2.5, providing the same conversion technology is used. With other, less efficient, conversion technologies, these differences would be much greater.

Table 2 shows the energy balances for alfalfa and coal (based on NSP, 1995 a) and the energy ratios (the table is shown in more detail in appendix 2). Both figures 3 and 4 show the energy ratios (i.e. external energy input compared to electrical energy output).

Figure 4 is a special case of figure 3, showing specifically the energy ratios for alfalfa, based on NSP (1995 a) and using their conversion efficiencies of 37.9 % for alfalfa and 42.6 % for coal (9005 and 8011 Btu/kWh, respectively). Also, in figure 4 and in "Alfalfa, full cycle" in figure 3, all the external energy input presented in table 2 is accounted for, while in figure 3 also the case ("Alfalfa") where only the farming and transportation parts are included. The reason for this being that drying and fractionate are not included or specified in any of the other cases presented in figures 2 and 3.

Table 2. Energy balance for alfalfa and coal (NSP, 1995 a)

		Assumed fuel	Alfalfa stems		Coal	
			kJ/kg	Btu/lb	kJ/kg	Btu/lb
A	Farming	oil	663	285		
B	Transportation	oil	219	94		
C	Drying from 15 to 10 %	biomass	263	113		
D	Fractionate [a]	electricity	237	102		
E	Total handling	oil			1924	827
F	**Sum ext. energy input, total**		**1382**	594	**1924**	827
G	Sum ext. energy input, oil (A+B)		882	379	1924	827
H	Heat content, HHV		16000	6900	19800	8500
I	Electric output [b]		6064	2615	8423	3621
J	Energy ratio - input:output (1:I/F)		1:4.39		1:4.38	

a 0.03 hp/lb, motor efficiency =75 %

b Conversion efficiency (HHV): η_{el}=37.9 % for alfalfa; η_{el}=42.6 % for coal

As can be seen in table 2 and figure 4, the energy ratios are almost equal for alfalfa and coal. But what is also shown, is that part of the energy input for alfalfa is from renewable sources, which in turn leads to less emissions of CO_2.

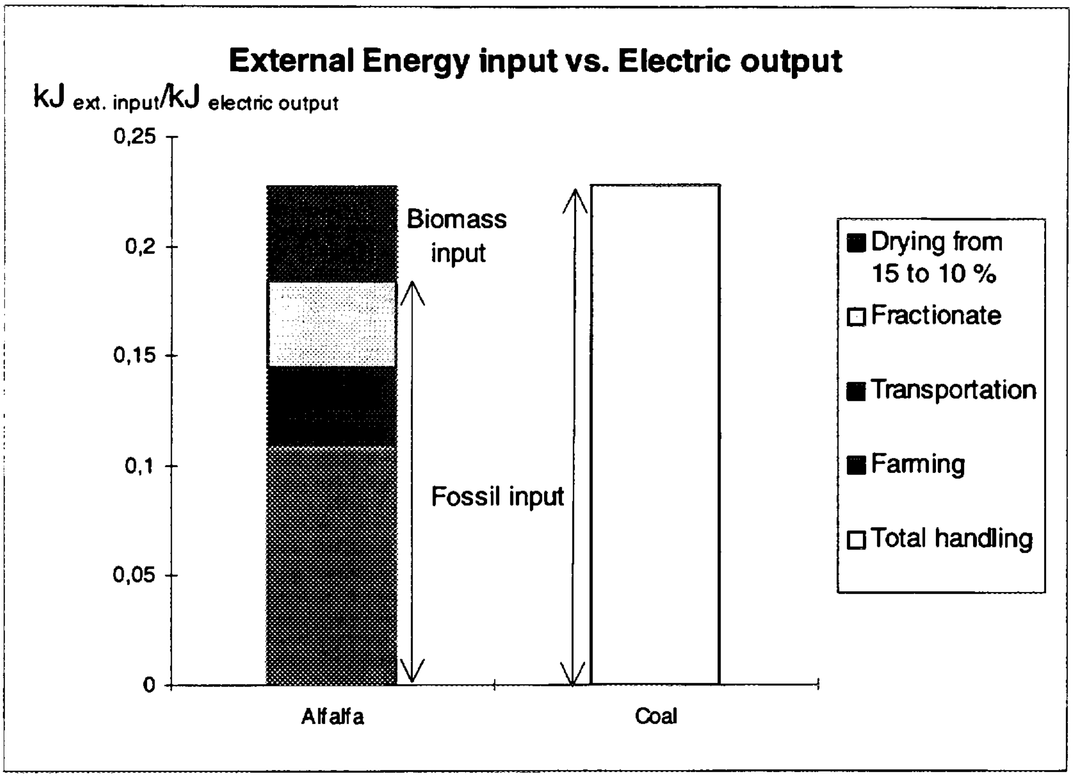

Figure 4 External energy input vs. Electric output for alfalfa and coal (NSP, 1995 a)

According to Brännström-Norberg et al. (1994), the external energy input per unit produced fuel energy to a CHP-plant are 5.8 % for coal, 3.7 % for willows, and 2.6 % for forest felling residues. With an electric efficiency of 30% (11400 Btu/kWh), this would give a energy ratios of external energy input to electric energy output of 1:5.2 for coal, 1:8.1 for willows, and 1:11.6 for forest residues. These numbers are in the same order of magnitude as for coal in the Minnesota case, and somewhat better compared to the fossil energy input to the alfalfa system.

3.2. *Fossil energy input*

When comparing a biomass DFSS with a coal system, it can also be of interest to compare *total fossil fuel* energy input to electric energy output.

For the integrated biomass systems, the only fossil fuel used is of course for external energy input (except for the New York case, where the biomass is co-fired with coal). At the conversion plant, the electricity is generated from biomass (biomass and coal in the co-firing situation).

In the Minnesota system, about 19 % of the energy input is biomass (see table 2). Thus, we will have a non-biomass energy input of 1119 kJ/kg alfalfa. This results in an energy balance of non-biomass energy input to electric output of 1:5.4 (this ratio is dependent on how the electricity for fractionating is produced. A coal based system would give a reduced ratio, while a hydro power system would give an improved ratio. For simplicity, the electricity is here calculated for on a one-to-one basis. See also Appendix 4).

For the coal fuel cycle, not only the external energy is fossil, but also the fuel for the production of electricity. Thus, all energy is fossil in such a system. The fossil energy input is then 19800+1924=21724 kJ/kg (8500 + 827 = 9327 Btu/lb), and the electric output is still 8423 kJ/kg (3621 Btu/lb), see table 2. This gives an energy balance (non-biomass energy input to electric output) of 1:0.39.

Thus, by utilizing fossil fuels (as external input fuels) in the alfalfa DFSS, we would get almost 14 (5.4/0.39) times more electric energy per unit fossil fuel!

4. CONVERSION TECHNOLOGY

Both in the Minnesota and the North Carolina case studies, the proposed conversion technologies are based on gasification of biomass, so called Biomass Gasification Combined Cycle (BGCC). The concepts are pretty much the same, but of course for different fuels. In New York, a traditional pulverized coal steam boiler will be used for co-firing. In Kansas, a fast pyrolysis process converts biomass into a biocrude oil, which can be used for electricity production or as a feedstock for chemicals.

4.1. Minnesota

The gasification process chosen is the IGT Renugas™ technology (see NSP, 1995 b, for details). This technology will be used together with a Westinghouse designed power island consisting of hot-gas-cleanup (HGCU), low-Btu gas combustion, and combined cycle.

The plant is to be a base load electric generation facility, with a total electric output of 75 MW_e. The system efficiency will be about 38.3 % (8910 Btu/kWh), which would require some 705 GJ/h of fuel (669 MBtu/h). The capacity factor is designed to be 80 %.

4.2. New York

The biomass is to be co-fired with coal in conventional pulverized coal steam boilers, at the four sites Dunkirk, Kintigh, Greenidge, and Milliken. These power plants are existing plants, today burning pure coal. Advanced conversion systems such as IGCC (BGCC) are considered as an attractive option with respect to future increases in electricity demand and production capacity.

For the purpose of this study, the NYSEG Greenidge Station has been evaluated for retrofitting for co-firing wood and coal. The plant is a 108 MW pulverized coal unit, built in 1953, and it is NYSEG's third most efficient unit, with an efficiency of 34.2 % (9963 Btu/kWh), see table 3.

Table 3. Greenidge station performance (HHV) (ESBC, 1995)

	Unit	*100 % coal*	*10 % bio, 90 % coal*
Net power	MW_e	108	108
Boiler efficiency	%	88.3	88.1
System Efficiency	%	34.5	34.4
Heat rate	Btu/kWh	9818	9917

For a unit this size, efficiencies above 42 % (less than 8100 Btu/kWh) could be expected for supercritical coal-fired plants, (Kjear, 1994). For non supercritical plants, efficiencies of 38-40 % could be expected. Recent experiences also indicate that there should be no significant difference in efficiency when burning wood compared to burning coal (see e.g. Rasmussen, 1994 or Graham et al., 1992).

4.3. North Carolina

Both a gasification system and an ethanol system have been considered (New Bern, 1995). In this report though, only the gasification system is dealt with.

A BGCC (biomass gasification combined cycle) with feedstock flexibility that can be integrated with pulp mill thermal requirements is proposed. Both the Tampella pressurized and the TPS atmospheric gasifiers are considered. The BGCC is based on a GE Frame 6B gas turbine.

The existing pulp mill power complex includes a black liquor recovery boiler and a bark boiler which supply steam to a backpressure steam turbine. The BGCC will replace the bark boiler. Eventually, the black liquor boiler may be replaced by a black liquor gasifier.

Two cases each for the TPS and Tampella gasifiers are considered. All of them are designed to meet the plants requirements for electricity and process heat, and will also export electricity to the regional grid. The performances of the four cases are summarized in table 4.

Table 4. BGCC performance for the New Bern plant (New Bern, 1995)

Case	*Biomass consumption/year*			*Net output*	*Power sales*	*Efficiency*	*Heat rate*
	kBDT	*Gg d.m.*	*PJ*	MW_{el}	MW_{el}	*%*	*Btu/kWh*
TPS Flue Gas Dryer	261	237	4.9	33.8	28.2	31.4	10 885
TPS No Air Extr.	273	248	5.1	36	30.4	31.0	11 000
Tampella Flue Gas Dryer	283	248	5.1	39	33.4	31.7	10 764
Tampella Steam Dryer	308	280	5.7	38.9	33.3	27.7	12 319

4.4. Kansas

A fast pyrolysis process is proposed. This process converts 70 % (by wet weight) of the biomass into a biocrude oil. This oil is to be used as a fuel oil replacement. The co-products are 15 % charcoal and 15 % noncondensable, medium heating value gas burned to provide process heat.

There is no information on electricity production systems or efficiencies in the report (Kansas, 1995).

5. EMISSIONS

Emissions of pollutants will occur at production of feedstock, transportation, and at the conversion sites. In addition to this, there will be emissions due to the production of fertilizers, herbicides, and other materials needed for the energy crop production.

5.1. Carbon dioxide emissions from energy crop production and transportation

As has been shown in sections 2 and 3, energy is required to produce biomass energy crops. Since only the Minnesota case has reported on these energy requirements, the estimates of Börjesson (1994) will be used for willows (New York) and forest residues (N. Carolina), while the estimates of Turhollow and Perlack (1991) will be used for switchgrass (Kansas).

As can be seen in figure 5, the production of these biomass fuels result in some emissions of CO_2 (here shown as kg carbon per GJ biomass energy). For further details on assumptions, see Appendix 4.

The energy requirements and due carbon dioxide emissions related to transportation have been estimated (see appendix 4). As can be seen in figure 5, the transportation makes up for about 15 % of the CO_2-emissions. In the Kansas case it is less, due to the very short hauling distance (6.8 km).

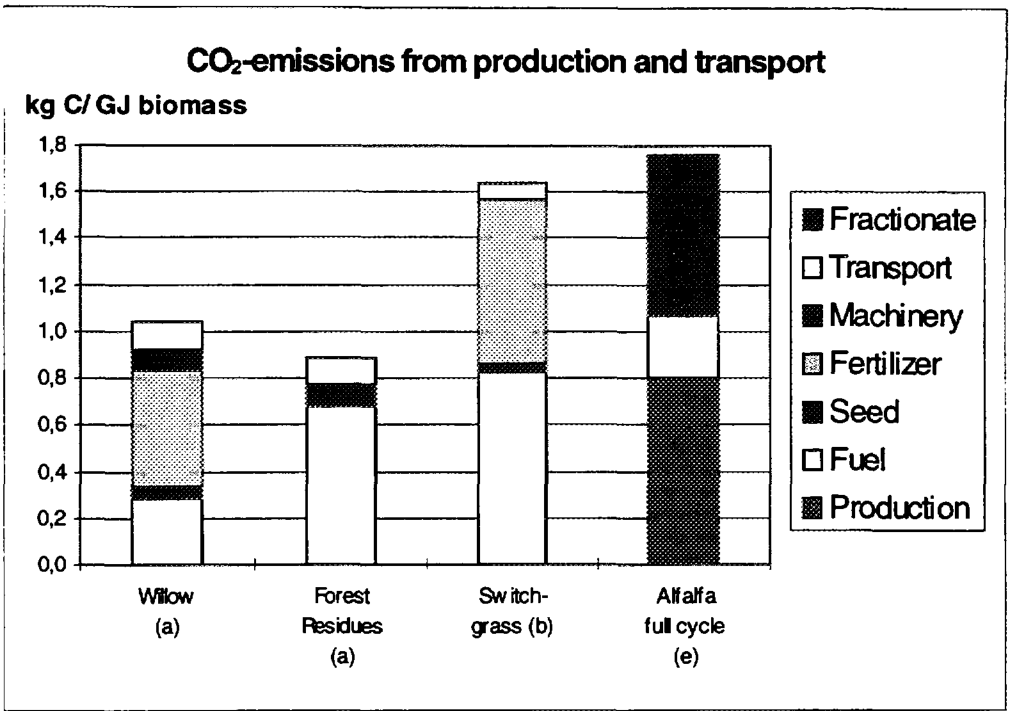

Figure 5 *CO_2 emissions from production and transportation of biofuels*
(a) Börjesson (1994; 1996), 80 km
(b) Turhollow and Perlack (1991), 6.8 km
(e) NSP (1995 a), 80 km

5.2. Emissions at conversion site

For the cases where the fuel is 100 % biomass, no net CO_2-emissions will occur. In the New York case, though, where willows are co-fired at 10 % with coal, also CO_2-emissions will occur.

5.2.1. Minnesota

The IGCC will emit some gaseous and solid wastes at full load, according to table 5.

Table 5. Total IGCC emissions at full load on biogas

	kg/h	*mg/MJ* [a]	*lb/h*	*lb/MBtu* [a]	*ppm* [b]
SO_x (as SO_2)	57.6	82	127	0.190	40 (vw)
NO_x (as NO_2)	44.9	64	99	0.148	40 (vd) [c]
CO	14.5	21	32	0.048	22 (vd)
PM (10) [d]	2.7	3.8	6	0.009	4 (w)
UHC [e]	6.8	9.6	15	0.022	20 (vd)

[a] HHV
[b] vw = volume wet basis; vd = volume dry basis; w = weight
[c] @ 15% O_2
[d] particulate matters
[e] Unburned hydro carbons

The biomass feedstock sulfur content is low (S content as % weight of fuel is reported to be 0.12 (NSP, 1995 a, table 7.3-2), 0.08 (NSP, 1995 b, table 2-1), and 0.07 (NSP, 1995 b, table 5-2)), and "SO_x emissions are not an environmental concern" in Minnesota (NSP, 1995 b, p. 5-8). Sulfur reduction is thus not provided for by the gasification plant.

The expected NO_x emission rate is 45 kg/h (as NO_2), and it is controlled to 40 ppmvd at 15 % O_2 by a combination of fuel-bound nitrogen-to-ammonia reduction by the gasifier system and by the use of special low-Btu fuel combustors.

5.2.2. New York

The performance and emissions of the proposed Greenidge station in New York are shown in table 6.

Table 6. Greenidge station emissions (ESBC, 1995)

	Unit	*100 % coal*	*10 % bio, 90 % coal*
SO_2	g/MJ	1.30	1.19
	lb/MBtu	3.02	2.77
NO_2	mg/MJ	258	215
	lb/MBtu	0.6	0.5
CO_2	g/MJ	85	76.5
	lb/MBtu	198	178

As can be seen in table 6, the emissions of SO_2, NO_2, and CO_2 are reduced by about 10 % when cofiring 10 % biomass. The NO_2-emissions decrease even more, about 16 %, which could be due to lowered combustion temperature.

5.2.3. North Carolina and Kansas

The information in New Bern (1995) and Kansas (1995) on emissions are too brief to draw any conclusions from.

5.3. Total CO_2-emissions

The CO_2 emissions from the conversion plant are considered to be zero, as long as only biomass is fed into the system. In section 3, it is shown that the biomass system requires some external energy input for production and transportation. In section 5.1, the carbon emissions from the production and transportation of biomass fuels were discussed.

In figure 6, a comparison is made between carbon emissions from the alfalfa and the coal system, as they are presented in NSP (1995 a).

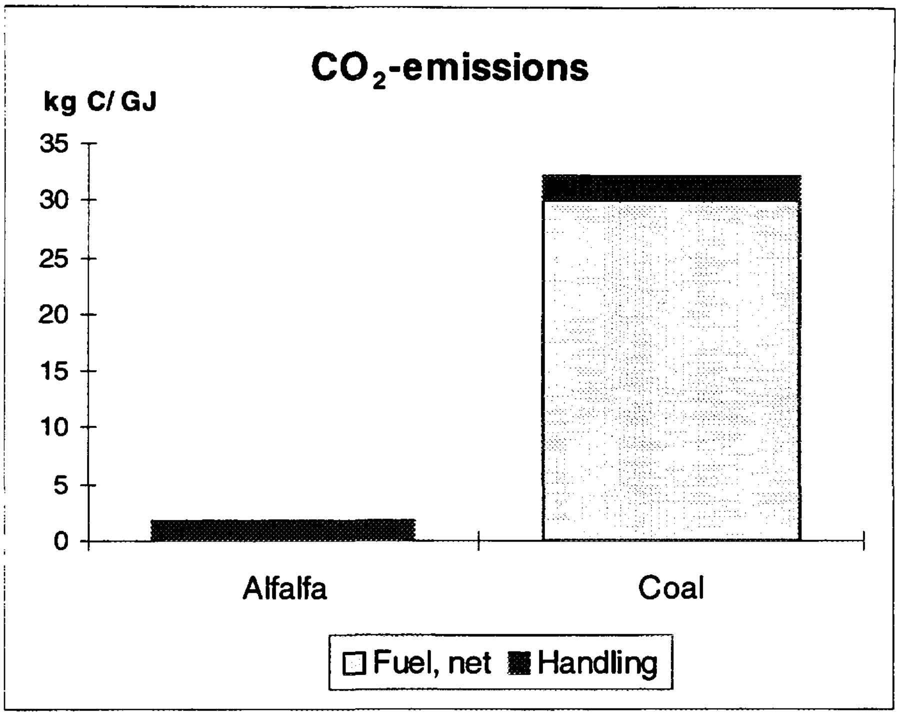

Figure 6. Total CO_2-emissions (expressed as kg C/GJ fuel) from alfalfa and coal

As could be expected, the emissions from the biomass system is substantially lower than from the coal system. This relation is representative for the other biomass systems also, except for the co-firing in New York. Figure 7 is presented as a comparison between different fuels used in the Swedish energy system.

The discharge of CO_2-equivalents is almost negligible for biomass, compared to fossil fuels, see figure 7. The emissions of CO_2-equivalents from biomass are related to the requirements of external energy to produce and transport the biomass. The external energy inputs for production and transportation of fossil fuels are significant, see figure 7.

The big differences for the two types of ethanol in figure 7, are related to the production methods. Ethanol 1 is produced from grain, using fossil fuels for destillation. Ethanol 2 is derived from forest residues, using waste heat for the destillation process. Waste heat is regarded as CO_2-free.

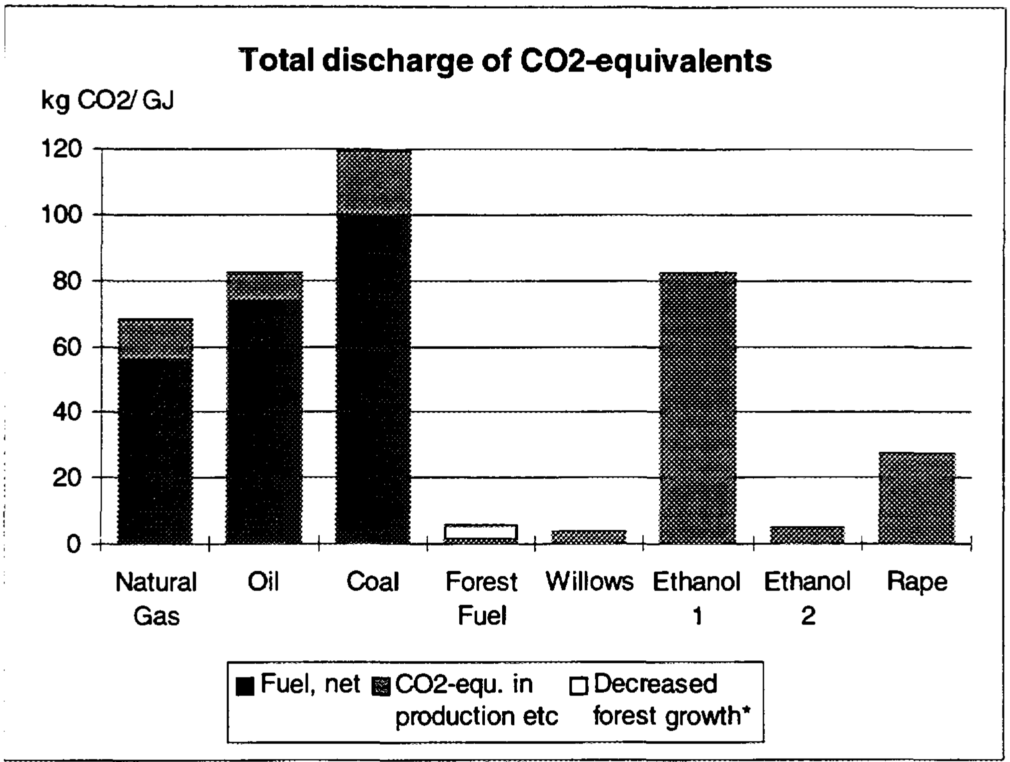

Figure 7. Total discharge CO_2-equivalents from some fuels (adopted from Lundborg (1994), citing a governmental report)
Ethanol 1 is produced from grain, with fossil fuel input, see text.
Ethanol 2 is produced from forest residues, with waste heat input.
** Decreased forest growth can be counteracted by fertilization. Return of ashes is also recommended*

5.4. Other GHG emissions

Other greenhouse gases that should be considered are mainly methane and nitrous oxide (as mentioned above). The CO_2-equivalents in figure 7 include also methane and N_2O. At this point, the information on the emissions of these gases is scarce. There is reason to believe that some methane could be released from the farm land, but that these emissions would not be greater than for the system with traditional CS rotation.

The emissions of methane are a great part of the emissions of CO_2-equivalents from production of fossil fuels. The emissions of methane and nitrous oxide will not be dealt with further in this report.

6. CARBON OFFSET AND SEQUESTRATION

By introducing DFSS, a significant amount of carbon can be sequestrated. There are basically two ways this is done:

- Most important is the replacement of fossil fuels with renewable, biomass energy, see e.g. figures 6, 7 and 8.

- Changed agricultural practices can result in carbon sequestration in soils, i.e. organic matter is added to the soils, which then act as carbon sinks.

In addition to this, there is also a role of by-products[5]. These could either be long-lasting (wood) products, that replace other, energy intensive materials (see e.g.Marland and Schlamadinger, 1994; Schlamadinger and Marland, 1996), or they can be short-lived products like animal feed. This is the case in the Minnesota case study, where a certain amount of protein rich feed is produced as a by-product to renewable energy, thus offsetting fossil fuels that would otherwise have been used in the production of these feeds. The long-lasting wood products are to be considered as carbon sinks.

6.1. Coal fuel replacement

As mentioned above, CO_2-emissions can be reduced by replacing fossil fuel with renewable energy. Based on the previous sections, the carbon emission reductions for the DFSS in New York, North Carolina, Kansas, and Minnesota have been calculated, see figure 8. The carbon reductions are per GJ of electricity (i.e. per 278 kWh of electricity).

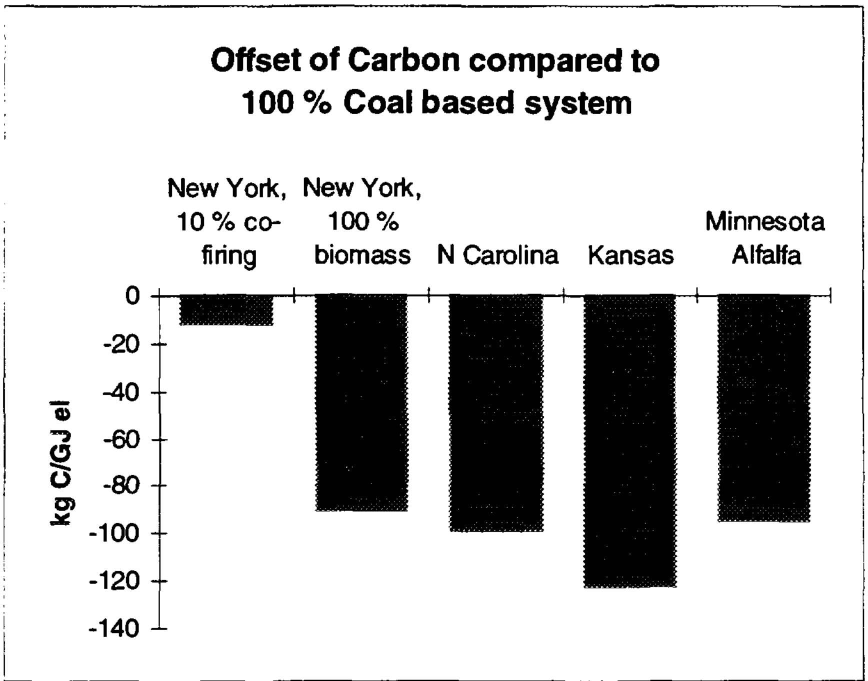

Figure 8. Reduced carbon dioxide emissions compared to a coal based system. kg C per GJ of electricity.

The carbon reductions in figure 8 are based on how much carbon would have been emitted if the system had been utilizing coal only. In the New York case, only 10 % of the fuel is replaced with biomass, whereby the reduction is rather low. Had it been 100 % biomass, the reduction would be 8 times greater. In the Kansas case on the other hand, a low conversion efficiency

- Here: by-products to energy production, although it is clear that in many cases the biofuel is a by-product in the forest industry.

(25 %) is assumed, so by replacing coal with biomass would decrease the amount of carbon significantly (but of course one immediate step could be to increase the efficiency!).

In addition to what is shown in figure 8, there is a possible reduction of methane-emissions from the coal mines. This would give an even more favorable situation for the biomass, since methane is a strong greenhouse gas.

6.2. Changed agriculture

As has been discussed in section 2, the changes in agricultural practices may significantly affect the carbon sequestration. If farmland, growing traditional commodities such as corn or wheat, are converted into energy crop production, there could be significant improvements in carbon sequestration. If, on the other hand, forests are changed into SRWC or herbaceous crops, there will be a reduction in soil carbon content.

Ranney et al. (1991) have made estimates on how the (hypothetical) carbon levels may vary among land uses, see table 7.

Table 7. Comparison of hypothetical average[6] carbon levels (Mg/ha) (Ranney et al., 1991)

Carbon components	*Cropland*	*Six-year rotation plantations*	*Managed forests*
Leaves	4.0	2.5	2.5
Stems	-	21	70.0
Weeds	0.5	1.0	2.0
Litter	0.5	5.0	15.0
Roots	2.0	5.0	10.0
Soil	25.0	35.0	45.0
Total	32.0	69.5	144.5

If the land use is changed from cropland to SRWC on a 6-year rotation, the soil carbon level may increase with 10 Mg/ha. This is more than Johansson (1994) has estimated, see figure 1. This increase in carbon level is to be regarded as a one-time carbon sink.

6.2.1. North Carolina

For the North Carolina case, there will be no great changes i soil carbon content due to biomass energy production; the main product being wood for pulp and paper. The changes in silviculture will mainly be to improve pulp wood quality (Campell, 1995). These improvements will also be beneficial to energy biomass, but the effects on the carbon balance in soil and biomass will be small if any.

- Average here means the time-average state from the time of plantation/sowing to harvest.

6.2.2. New York

In the New York case, there should be some improvements in soil carbon. If we assume that the average soil carbon content increases with 3 Mg/ha (conservative estimation from table 7) former cropland is changed to SRWC, we could get a carbon offset by about 9 kg C/GJ willows (the range would be 0-30 kg C/GJ).

6.2.3. Minnesota and Kansas

As in the New York case, a change from traditional row crops to perennial biomass crops would increase the soil carbon content.

In Minnesota case, the difference would be smaller, since the rotation time is shorter, and that in the rotation also corn and soybean are included. In the Kansas case, there could possibly be an offset of a few Mg C/ha, but information is not sufficient.

Thus, it is not possible to make any clear estimates at this time for the Minnesota and Kansas cases.

7. WASTE PRODUCTS AND TREATMENT

7.1. Ash

The focus of waste products would be on ash handling and treatment, since ashes will or can be used as fertilizers if returned properly to the crop land. If the biomass is cofired with a fossil fuel, special precautions have to be made.

The IGCC process in the Minnesota case will produce some amounts of ash, see table 8. The ash is expected to be returnable to the land and may have value as a soil amendment or fertilizer (but not as a nitrogen fertilizer).

Table 8. Total IGCC ash at full load on biogas (NSP, 1995 b)

	kg/h	lb/h
Bottom ash	2130	4700
Fly ash	820	1800

Before land application of the ash can be made, physical and chemical properties of the ash need to be known. No information related to ash that has been generated from gasification was available at the time of publication of the Minnesota report (NSP, 1995 a). After that, Jönsson and Nilsson (1996) have published results showing that ashes from gasification seem suitable for recycling to the soil. They seem to have somewhat lower content of phosphorus and potassium, compared to combustion ashes. The fly-ash have high content of PAH.

Also in the other cases, it is discussed what to do with the ashes. In North Carolina, it is anticipated to use the wood-ash as a fertilizer, to maintain nutrient balances when biomass fuel is removed.

No further estimates will be done here though, on whether the utilization of ashes could affect the carbon balance.

7.2. Others

In some cases, it could be possible to utilize municipal waste sludges (e.g. Campell, 1995). This could improve yields with as much as 50 % in forest plantations in North Carolina, since the sludge would provide both nutrients and irrigation.

A significant increase in biomass production (yield), would of course be a very substantial contribution to the offsetting of carbon, both by direct sequestration, and by increase in coal fuel displacement.

8. *CONCLUSIONS*

The main and important conclusions regarding the integrated biomass energy systems described in this report are

- that biomass systems do not require more external energy input than coal based systems. On the contrary, the biomass systems often require less external energy.
- there is a great potential of reducing greenhouse gas emissions through the offset of coal by biomass.

The systems have been shown to be energy efficient and to have positive energy balances. The systems may also be beneficial from other environmental points of view.

A major benefit is of course that the net CO_2-emissions are significantly reduced, compared to a coal based system. The CO_2-emissions for the full fuel cycles are decreased by about 95 %, from more than 100 kg C/GJ of electricity to less than 10 (indicated in figure 8).

Compared to a traditional agricultural systems, these systems also reduce the needs for external energy and for fertilizers. By reducing the amount of fertilizers, also the non-point sources of emissions into the rivers and water system could be reduced. Also the DFSS reduce the need for tillage, which is beneficial to the soil.

The biomass DFSS are not totally free from the use of fossil fuels and thus related GHG-emissions. But, by utilizing fossil fuels (as external input fuels for biomass production) we would get about 10-15 times more electric energy per unit fossil fuel!

By improving methods for production of the crop, it would probably be possible to further decrease the amount of external energy requirements, and thus decrease the GHG-emissions. However, major changes in production methods are not anticipated in the near future.

9. *ACKNOWLEDGMENT*

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10. REFERENCES

Bhat, M. G., English, B. C., Turhollow, A. T., and Nyangito, H. O. 1994. *"Energy in synthetic fertilizers and pesticides: Revisited."* ORNL/Sub/90-99732/2, Oak Ridge National Lab.

Brännström-Norberg, B.-M., Rosén-Lidholm, S., and Ternström, C. 1994. *"Analysis of environmental consequences for a co-generation power station burning willows - comparison with forest fuel and coal."* R&D Report no UB 94/3, Vattenfall, Stockholm, Sweden.(in Swedish, abstract in English)

Börjesson, P. 1994. *"Energy analysis of biomass production in Swedish agriculture and forestry - Today and around 2015."* IMES/EESS Report No 17, Lund University, Lund, Sweden.(in Swedish)

Börjesson, P. 1996. *"Emissions of CO_2 from biomass production and transportation in agriculture and forestry."* Energy Conversion and Management, Vol 37 (6-8), pp. 1235-1240.Paper presented at the "Greenhouse Gases: Mitigation Options" Conference of the IEA GHG R&D Programme, 22-25 Aug. 1995, London, UK

Campell, B., 1995: Weyerhaeuser Inc., New Bern, N. Carolina, Personal communication.

ESBC. 1995. *"Economic development through biomass systems integration."* Final report, Empire States Biopower Consortium, Syracuse, NY, USA

Graham, R. L., Wright, L. L., and Turhollow, A. F. 1992. *"The potential for short-rotation woody crops to reduce U.S. CO_2 emissions."* Climate Change, Vol 22 , pp. 223-338

Hatfield, J., 1995: National Soil and Tilth Lab, Personal communication.

Johansson, W. 1994. *"Sequestration and flows of C in soils (Kolbindning och kolflöden vid odling)."* PM, SLU, Uppsala, Sweden.(in Swedish)

Jönsson, O., and Nilsson, C. 1996. *"Characterisation of wood ash from gasification."* , Research Programme for recycling of wood ash, NUTEK, Sydkraft, Vattenfall.(in Swedish)

Kansas. 1995. *"Economic development through biomass systems integration in Northeast Kansas."* , The Kansas Electric Utilities Research Program, Topeka, KS, USA

Kjear, S. 1994. *"Advanced steam cycles."* IFRF Advanced Power Generation, TOTeM10, Velhoven, The Netherlands

Lundborg, A. 1994. *"Forest fuel and carbon balances."* R&D Report No UB 94/11, Vattenfall.(in Swedish, summary in English)

Lundborg, A., 1995: Vattenfall Utveckling AB, Personal communication.

Marland, G., and Schlamadinger, B. 1994. *"Biomass fuels and forest management strategies: How do we calculate the greenhouse gas emissions benefits?"* Energy, Vol 20 (11), pp. 1131-1140

National Biofuels Roundtable. 1994. *"Principles and guidelines for the development of biomass energy systems."* Draft final report

New Bern. 1995. *"New Bern biomass to energy project."* Phase 1 Feasibility Study, Weyerhaeuser, New Bern, NC, USA

NSP. 1995 a. *"Sustainable Biomass Energy Production."* Volume 1: Final report to NSP, Northern States Power, Minneapolis, MN, USA

NSP. 1995 b. *"Sustainable Biomass Energy Production."* Volume 2: Final report to NSP, Northern States Power, Minneapolis, MN, USA

Ranney, J. W., and Mann, L. K. 1994. *"Environmental considerations in energy crop production."* Biomass and Bioenergy, Vol 6 (3), pp. 211-228

Ranney, J. W., Wright, L. L., and Mitchell, C. P., 1991: *"Carbon storage and recycling in short-rotation energy crops."* in *Bioenergy and the greenhouse effect*, (C. P. Mitchell, ed.). Vol. B 1991:1. NUTEK: Stockholm, Sweden.

Rasmussen, I. 1994. *"Atmospheric pressure combustion of coal and biomass."* IFRF Advanced Power Generation, TOTeM10, Velhoven, The Netherlands

Reicosky, D. C., Kemper, W. D., Langdale, G. W., Douglas Jr, C. L., and Rasmussen, P. E. 1995. *"Soil organic matter changes resulting from tillage and biomass production."* Journal of Soil and Water Conservation, Vol 50 (May-June), pp. 253-261

Schlamadinger, B., and Marland, G. 1996. *"Full fuel cycle carbon balances of bioenergy and forestry options."* Energy Conversion and Management, Vol 37 (6-8), pp. 813-818

Turhollow, A. F., and Perlack, R. D. 1991. *"Emissions of CO_2 from energy crop production."* Biomass and Bioenergy, Vol 1 (3), pp. 129-135

APPENDIX 1: CONVERSION FACTORS

	From	multiply by	to get
Area	1 m^2 =	10.764	ft^2
	1 ha =	2.471	acres
	=		
Energy	1 kJ =	0.948	Btu
	1 kWh =	3.6	MJ
	1 MWh =	3.413	MBtu
Heating value	1 MJ/kg =	429.9	Btu/lb
Length	1 m =	3.281	ft
	1 km =	0.62137	miles
Mass	1 kg =	2.205	lb
	1 Mg = ton =	1.103	US ton
Power	1 W =	3.413	Btu/h
Pressure	1 kPa =	0.145	psi
	1 bar =	14.5	psi
Volume	1 l =	0.26418	gal
Temp	t °C =	1.8*t+32	°F

Prefixes

Name	Symbol	Factor
milli	m	$0.001 = 10^{-3}$
kilo	k	$1000 = 10^3$
mega	M	10^6
giga	G	10^9
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}

Efficiency (η) and heat rate:

Efficiency: $\eta = \dfrac{\text{output energy}}{\text{input energy}}$; consistent units.

$$\text{Heat rate} = \frac{\text{fuel input in Btu}}{\text{electric output in kWh}}$$

Example:

We use 36 GJ=10 MWh=34.13 MBtu fuel
to produce 14.4 GJ=4 MWh=4000 kWh electricity.
This gives:

$$\text{Efficiency: } \eta = \frac{14.4}{36} = \frac{4}{10} = 0.4 \text{ or } 40\ \%$$

$$\text{Heat rate} = \frac{34.13 \cdot 10^6}{4000} = 8532 \text{ Btu / kWh}$$

APPENDIX 2: ENERGY BALANCES FOR ALFALFA AND COAL

Table 1:1. Energy balance for alfalfa (NSP, 1995 a)

INPUT for	kJ/kg	Btu/lb	Assumed fuel	CO_2 emissions[e] kg CO_2/GJ alfalfa
Farming[a]	663	285	oil	3.19
Transportation[b]	219	94	oil	1.05
Drying from 15 to 10 %[c]	263	113	biomass	1.27
Fractionate[d]	237	102	electricity	1.14[f]
Total	1382	594		6.65
OUTPUT			45 % leaves, 28 % crude protein 55 % stems, 16 MJ/kg @ 15% moist	
Feed (kg/kg; lbs/lbs)	0.11 kg	0.11 lbs	crude protein	
Electricity (kJ/kg; Btu/lb)	3345	1438	η_{el}=37.9 % HHV	

a Alfalfa only
b 3.35 Btu/lb/mile; 40 mile aver
c 3 % stems used for drying
d 0.03 hp/lb; motor η=75 %
e 0.077 g CO_2/kJ oil
f Assumed electricity produced from oil with η=33 %

Table 1:2. Energy balance for coal (NSP, 1995 a)

INPUT for	kJ/kg	Btu/lb	Assumed fuel	CO_2 emissions[a] kg CO_2/GJ coal
Mining, transport, breaking, sizing, washing, distribution	1 924	827	oil	7,48
Coal: HHV and CO_2-emiss.	19 800	8 500		100
OUTPUT				
Electricity	8 423	3 621	η_{el}=42,6 % HHV	

a 0.077 g CO_2/kJ oil

APPENDIX 3: TRANSPORTATION ENERGY FOR ALFALFA

Transportation from the storage sites to the conversion plant is assumed as 6 days/week, 40 mph average speed, and 16 hours/day on the road (NSP, 1995 a, section 5.2). That would result in 3840 miles/week (6*40*16), i.e. 6180 km/week, or about 320,000 km/year (200,000 miles/year). A diesel fuel consumption of 0.48 l/km (Brännström-Norberg et al., 1994) (0.2 gallons/mile) would give a total fuel consumption of 154 m^3/year (41,000 gal/year). If the energy content is 38.7 MJ/l, we would get 6 TJ/year/truck energy consumption.

The conversion plant requires 1 Mg (2200 lb) per day of alfalfa, which would require about 23 trucks/day. Thus, the total energy consumption for transportation would be 23*6=138 TJ/year.

This would result in emissions of sulfur and CO_2 and others. If the CO_2 emissions are 2700 kg/m^3 diesel (Brännström-Norberg et al., 1994) (22.5 lb/gal), the total CO_2 emissions would be 9,600 Mg/year (10,500 US ton/year).

APPENDIX 4: ASSUMPTIONS FOR INPUT ENERGY FOR BIOMASS PRODUCTION

Assumptions for figures 2, 3 and 5: Energy requirements for biomass production and External energy input vs. electricity production, respectively.

Figure 2 does not include energy for transportation from farm to conversion site. On the other hand, figure 3 does include this.

(a) Börjesson (1994) includes diesel fuel for operating farm machinery, energy for the production and handling of seeds, fertilizers, and pesticides, energy for the production of machinery, and for the transportation of machines to and from the biomass production site. He does not include the transportation of biomass from the production site (farm) to the conversion plant. The assumed annual yields are 10 Mg/ha for willows, 8.2 Mg/ha for alfalfa, and 7 Mg/ha for reed canary grass. Any possible byproducts are not mentioned.

In figures 3 and 5, the energy for transportation has been added. The assumption is that the biomass is transported 80 km by truck. The truck uses 1.3 MJ/Mg per km fossil fuel, according to Börjesson (1996).

(b) Turhollow and Perlack (1991) include energy requirements for establishment of crops, fertilizers, herbicides, harvesting, and hauling (average hauling distance of 40 km (25 miles)). They also divide the input energies into diesel, natural gas, and electricity. The annual net yields are assumed as 11.3 Mg/ha for hybrid poplar and 9 Mg/ha for switchgrass.

(c) Brännström-Norberg et al. (1994) have evaluated full fuel cycles of willows, forest residues, and coal to a Swedish CHP-plant. In figure 2, only the willows results are presented. Included in their estimates are crop establishment and management, fertilizer production, harvest and chipping, and transportation to conversion plant, (average hauling distance of 21 km (13 miles)). Their annual yields of willow are assumed to be 12 Mg dm/ha, which is a rather high number for Sweden.

(d) NSP (1995 a) give estimates on farming, transportation, drying, and fractionate, see table 2. In figure 2 though, only farming is included, since neither drying nor fractionate are included in the other references. In figure 3, also the transportation is included. The annual yields are set to 8.5 Mg/ha,. Of this yield, 55 % consists of stems used for energy production, and 45 % are leaves used for animal feed.

In figure 5, the CO_2-emissions from fractionating is based on an electric driven machine, with electricity produced from coal, with an efficiency of 33 %. Thus, the electricity emits 55 kg C/GJ.

3 maj 1996

Tidigare utgivna rapporter inom
Vattenfall - projekt Bioenergi

Titel	:	**Trädbränsle och skogsekologi**		
	:	**Projekt skogskraft rapport nr 1**		
Förf.	:	Lundborg A		
FUD-nr	:	U(B) 1990/38	Datum: 90-10-16	Sidantal: 33

Titel	:	**Kolbalansberäkningar för bränsleuttag i skogsbruk**		
		Projekt skogskraft rapport nr 3		
Förf.	:	Ågren G		
FUD-nr	:	U(B) 1990/39	Datum: 90-10-19	Sidantal: 14

Titel	:	**Inventeringsstudie biobränslepotential i södra Sverige**		
		Projekt skogskraft rapport nr 2		
Förf.	:	Danielsson B-O, Eriksson H, Eriksson M m fl		
FUD-nr	:	U(B) 1990/40	Datum: 90-10-18	Sidantal: 193

Titel	:	**Förstudie av trädbränsleeldade demonstrationsanläggningar**		
		Projekt skogskraft rapport nr 4		
Förf.	:	Westermark M		
FUD-nr	:	U(B) 1990/43	Datum: 90-10-19	Sidantal: 118

Titel	:	**Tillvaratagande av skogsbränsle som träddelar och slutavverkningsrester - system, maskiner, metoder och kostnader**		
Förf.	:	Brunberg B		
FUD-nr	:	U(B) 1991/17	Datum: 91-02-25	Sidantal: 56

Titel	:	**Bränsle från skogen**		
Förf.	:	Andersson B		
FUD-nr	:	U(B) 1991/18	Datum: 91-02-25	Sidantal: 41

Titel	:	**Ny avverkningsteknik för lägre skogsbränslekostnader**		
		Projekt skogskraft nr 5		
Förf.	:	Jörgenson K G		
FUD-nr	:	U(B) 1991/21	Datum: 91-03-06	Sidantal: 67

Titel : **Trädbränsle till Nässjö KVV (Kraftvärmeverk)**
Förf. : Johansson R, Lindblom A
FUD-nr : U(B) 1991/24 Datum: 91-03-26 Sidantal: 55

Titel : **Biobränslen i det svenska energisystemet, en modellstudie**
Förf. : Boman U
FUD-nr : U(B) 1991/33 Datum: 91-05-22 Sidantal: 47

Titel : **Odling av lövträd på åkermark för energiändamål**
Förf. : Johansson T
FUD-nr : U(B) 1991/36 Datum: 91-05-25 Sidantal: 30

Titel : **Atmosfärisk förgasning - diesel**
Förf. : Ekström C
FUD-nr : U(B) 1991/37 Datum: 91-06-13 Sidantal: 23

Titel : **Bränslekarakterisering - Kväveföreningar Samarbete med LRF/SLR.**
Förf. : Johansson J
FUD-nr : U(B) 1991/39 Datum: 91-06-04 Sidantal: 34

Titel : **Alkali och klor i biomassa - ett problem vid elgenering Samarbete med LRF/SLR.**
Förf. : Gärdenäs S
FUD-nr : U(B) 1991/40 Datum: 91-06-04 Sidantal: 43

Titel : **Halm som bränsle för framtida elproduktion - en sammanfattning av dagsläget. Samarbete med LRF/SLR.**
Förf. : Axenbom Å, Kristensen D, Praks O
FUD-nr : U(B) 1991/44 Datum: 91-08-01 Sidantal: 84

Titel : **Kraftvärme från energigrödor. Samarbete med LRF/SLR.**
Förf. : Sieurin J, Augustinsson H
FUD-nr : U(B) 1991/45 Datum: 91-05-30 Sidantal: 45

Titel : **Vedaska i skogen.**
Förf. : Eriksson J, Börjesson
FUD-nr : U(B) 1991/46 Datum: 91-08-29 Sidantal: 77

Titel : **Trädbränsle från sågverk. Projekt Skogskraft rapport nr 6.**
Förf. : Thörnqvist T, Kyrkjeeide A
FUD-nr : U(B) 1991/52 Datum: 91-08-23 Sidantal: 18

Titel : **Transportsystem för biobränslen. Samarbete med LRF/SLR.**
Förf. : Staland P, Westerberg D
FUD-nr : U(B) 1991/53 Datum: 91-09-04 Sidantal: 85

Titel : **Fjärrvärme i Fellingsbro. Samarbete med LRF/SLR.**
Förf : Alsén L, Swahn H
FUD-nr : U(B) 1991/54 Datum: 91-06-07 Sidantal: 33

Titel : **Ekonomi och projektredovisning Projekt Skogskraft rapport nr 7.**
Förf : Olsson A
FUD-nr : U(B) 1991/55 Datum: 91-09-12 Sidantal: 67

Titel : **Biobränsleaskans sintringsegenskaper, bedömning med hjälp av tillståndsdiagram.**
Förf : Ryding B
FUD-nr : U(B) 1991/57 Datum: 91-08-14 Sidantal: 47

Titel : **Produktion och förädling av bränslen vid skogsindustrin - möjligheter och förutsättningar.**
Förf : Magnusson L
FUD-nr : U(B) 1991/58 Datum: 91-08-23 Sidantal: 50

Titel : **Biogas för värme, el-, och drivmedelsproduktion.**
Förf : Ström E, Ekeborg T
FUD-nr : U(B) 1991/59 Datum: 91-09-23 Sidantal:110

Titel : **Vegaprojektet**
Förf : Aronsson I
FUD-nr : U(B) 1991/62 Datum: 91-10-25 Sidantal: 27

Titel : **Resultatrapport december 1991**
Förf : UB
FUD-nr : U(B) 1991/64 Datum: 91-12-31 Sidantal: 50

Titel	:	**Biobränslebaserad metanol och etanol som bränsle.**		
Förf	:	Ekström C, Ström E, Bengtsson A, Brandberg Å		
FUD-nr	:	U(B) 1991/66	Datum: 91-11-25	Sidantal: 59

Titel	:	**Teknik för gröndelsavskiljning samt näringsinnehållet i gröndelarna. Projekt skogskraft rapport nr 8**		
Förf	:	Hedman G, Westerberg I, Lindquist H		
FUD-nr	:	U(B) 1991/69	Datum: 91-12-15	Sidantal: 30

Titel	:	**Närvärme från energiskog - En affärsidé för lantbruksföretaget. Samarbete med LRF/SLR.**		
Förf	:	Rosenkvist H, Uhlin H E		
FUD-nr	:	U(B) 1992/2	Datum: 92-01-07	Sidantal: 116

Titel	:	**Gränsdiameterns inverkan på skogsbränsletillgången. Projekt Skogskraft rapport nr 9.**		
Förf	:	Danielsson B-O		
FUD-nr	:	U (B) 1992/5	Datum: 92-02-26	Sidantal: 19

Titel	:	**Avverkning i lövbestånd anlagda på jordbruksmark.**		
Förf	:	Björheden R		
FUD-nr	:	U(B) 1992/6	Datum: 92-02-22	Sidantal: 30

Titel	:	**Plantöverlevnad och tillväxt efter helträdsutnyttjande - sammanställning av fältförsök.**		
Förf	:	Sinclair E, Leijon B, Albrektson A		
FUD-nr	:	U(B) 1992/7	Datum: 92-02-28	Sidantal: 113

Titel	:	**Råvarubalans och logistik för kraftvärmeverk i Skövde.**		
Förf	:	Eriksson Ola		
FUD-nr	:	U(B) 1992/11	Datum: 92-05-04	Sidantal: 56

Titel	:	**Slam och aska i energiodlingar.**		
Förf	:	Diedrich Helena Samarbete med LRF/SLR		
FUD-nr	:	U(B) 1992/12	Datum: 92-04-08	Sidantal: 77

Titel	:	**Beräkningar av näringsbalanser och kväveförluster vid helträdsutnyttjande.**		
Förf	:	Wikström Fredrik		
FUD-nr	:	U(B) 1992/16	Datum: 92-05-18	Sidantal: 19

Titel	:	**Granulerade vedaskors upplösning i skogsmark.**		
Förf	:	Börjesson Pål		
FUD-nr	:	U(B) 1992/17	Datum: 92-06-26	Sidantal: 30

Titel	:	**Biobränslens roll i Skaraborgs energisystem.**		
Förf	:	Boman Ulf, Rosell Maria		
FUD-nr	:	U(B) 1992/18	Datum: 92-04-30	Sidantal: 53

Titel	:	**Förbränningsanläggningar för trädbränsle - en databas.**		
Förf	:	Gustafsson Bernt		
FUD-nr	:	U(B) 1992/19	Datum: 92-06-17	Sidantal: 34

Titel	:	**Odling av lövträd på åkermark för energiändamål - del 2. Torrsubstansproduktion hos 10-120 mm grova träd av al, asp och björk.**		
Förf	:	Johansson Tord		
FUD-nr	:	U(B) 1992/21	Datum: 1992-06-23	Sidantal: 25

Titel	:	**Bioflex. Ett geografiskt informationssystem för analys av regional biobränslemarknader. Exempel Västerbotten.**		
Förf	:	Nordlander S, Staffansson H, Westholm E		
FUD-nr	:	U(B) 1992/22	Datum: 1992-06-09	Sidantal: 57

Titel	:	**Från åkermark till elektricitet.**		
Förf	:	Sundell P, Ekeborg T		
FUD-nr	:	U(B) 1992/23	Datum: 1992-06-03	Sidantal: 126

Titel	:	**Tekniker och metoder att i fält mäta fukthalt i bränsleflis. Projekt Skogskraft rapport nr 10**		
Förf	:	Andersson C, Yngvesson M		
FUD-nr	:	U(B) 1992/26	Datum: 1992-09-15	Sidantal: 28

Titel	:	**INGA-projektet**		
Förf	:	Bergman J		
FUD-nr	:	U(B) 1992/27	Datum: 1992-09-16	Sidantal: 20

Titel : **Skogsenergins konsekvenser för floran.**
Förf : Kruuse A
FUD-nr : U(B) 1992/29 Datum: 1992-09-24 Sidantal: 37

Titel : **Biobränslebaserat metanol-/elkombinat - översiktlig studie**
Förf : Ekström C, Kopp F
FUD-nr : U(B) 1992/30 Datum: 1992-08-31 Sidantal: 29

Titel : **Trädjordbruk**
Samarbete med LRF/SLR
Förf : Falk B
FUD-nr : U(B) 1992/31 Datum: 1992-07-13 Sidantal: 41

Titel : **Trädbränslen i Sverige 1800-1990 - användning och prisutveckling.**
Förf : Schön L
FUD-nr : U(B) 1992/32 Datum: 1992-09-30 Sidantal: 41

Titel : **Miljöeffekter vid biobränsletorkning**
Förf : Nyrén C
FUD-nr : U(B) 1992/33 Datum: 1992-09-30 Sidantal: 81

Titel : **Teknik för tillvaratagande av röjningsvirke**
Projekt Skogskraft nr 11
Förf : Jonsson M, Kjellberg M, Lindholm D
FUD-nr : U(B) 1992/34 Datum: 1992-09-30 Sidantal: 162

Titel : **Bränsletorkning eller rökgaskondensering vid kraftvärmeproduktion?**
Förf : Odeberg J
FUD-nr : U(B) 1992/35 Datum: 1992-10-01 Sidantal: 79

Titel : **ADA-projektet**
Förf : Bergman J, Petsén O
FUD-nr : U(B) 1992/42 Datum: 1992-10-07 Sidantal: 13

Titel : **HYDRA-projektet**
Förf : Bergman J
FUD-nr : U(B) 1992/43 Datum: 1992-10-07 Sidantal: 18

Titel : **Svavel- och koldioxidrening**
Förf : Lindberg A
FUD-nr : U(B) 1992 /44 Datum: 1992-11-23 Sidantal: 77

Titel : **Komprimering av trädrester vid transport**
Projekt Skogskraft rapport nr 12
Förf : Nordén B, Jonsson T
FUD-nr : U(B) 1992/45 Datum: 1992-11-27 Sidantal:38

Titel : **Långväga transport av biobränsle till VEGA**
Förf : Brunberg B
FUD-nr : U(B) 1992/46 Datum: 1992-12-01 Sidantal: 61

Titel : **Förädlade biobränslen - En inventering av den svenska marknaden**
Samarbete med LRF/SLR
Förf : Sieurin J
FUD-nr : U(B) 1992/47 Datum: 1992-11-06 Sidantal: 26

Titel : **Karakterisering av vedaska**
Förf : Eriksson J
FUD-nr : U(B) 1992/48 Datum: 1992-12-21 Sidantal: 38

Titel : **Prisbildning på biobränslen - förstudie**
Förf : Hedman J
FUD-nr : U(B) 1992/50 Datum: 1992-12-22 Sidantal: 35

Titel : **Energigrödor för biogas**
Förf : Thyselius L, Johansson W, Mattsson L, Wallgren B
Samarbete med LRF/SLR
FUD-nr : U(B) 1992/51 Datum: 1992-11-23 Sidantal:63

Titel : **Bioenergins miljö- och hälsoeffekter.**
Förf : Rosén-Lidholm S, Sundell P, Dahlberg H
Welander L, Miljökonsulterna
FUD-nr : U(B) 1992/52 Datum: 1992-06-30 Sidantal: 141

Titel : **Prisbildning på biobränslen i Västsverige**
Förf : Åstrand Å
FUD-nr : U(B) 1993/1 Datum: 1993-01-12 Sidantal: 18

Titel : **Fallförna samt mängd organiskt material i skogsmark**
Förf : Reurslag A, Berg B
FUD-nr : U(B) 1993/2 Datum: 1993-01-20 Sidantal: 116

Titel : **Biobränsleeldad kraftvärme i ett stort fjärrvärmesystem - systemstudier med energisystemmodellen Martes**
Förf : Ryding B
FUD-nr : U(B) 1993/3 Datum: 1993-01-25 Sidantal: 41

Titel : **Salixflis- eller oljeenergisystem - en samhällsekonomisk jämförelse.**
Förf : Olandersson B
FUD-nr : U(B) 1993/6 Datum: 1993-01-29 Sidantal: 70

Titel : **Konkurrenssituationer för biobränsle i USA**
Förf : Järmyr A-K
FUD-nr : U(B) 1993/7 Datum: 1993-03-01 Sidantal: 34

Titel : **Arbetsmiljön vid uttag, hantering och förbränning av biobränslen**
Förf : Dahlberg H
FUD-nr : U(B) 1993/8 Datum: 1993-03-11 Sidantal: 59

Titel : **Poppelplantager som biomassaproducenter**
Förf : Telenius B, Elowson S, Christersson L
FUD-nr : U(B) 1993/9 Datum: 1993-03-12 Sidantal: 20

Titel : **Skogsbränsle minskar kvävebelastningen**
Förf : Lundborg A
FUD-nr : U(B) 1993/10 Datum: 1993-03-12 Sidantal: 76

Titel : **Modifierad totalstegskalkyl**
Samarbete med LRF/SLR
Förf : Rosenkvist H
FUD-nr : U(B) 1993/11 Datum: 1993-03-12 Sidantal: 138

Titel : **Beräknad betalförmåga för förädlade fasta bränslen från jordbruket.**
Samarbete med LRF/SLR
Förf : Hadders G, Ekeborg T, Sieurin J
FUD-nr : U(B) 1993/12 Datum: 1993-03-04 Sidantal: 77

Titel : **Kadmium i biobränslesystemet**
Samarbete med LRF/SLR
Förf : Åbyhammar T, Fahlin M, Holmroos S
FUD-nr : U(B) 1993/13 Datum: 1993-03-22 Sidantal: 106

Titel : **Regional energisystemstudie i Mälardalen**
Samarbete med LRF/SLR
Förf : Rosell M
FUD-nr : U(B) 1993/14 Datum: 1993-03-25 Sidantal: 90

Titel : **Vågutrustning på flisare**
Projekt Skogskraft rapport nr 13
Förf. : Nordén B
FUD-nr : U(B) 1993/15 Datum: 1993-05-07 Sidantal: 31

Titel : **Statliga styrmedel på marknader för biobränslen i ett historiskt perspektiv**
Förf. : Schön L
FUD-nr : U(B) 1993/16 Datum: 1993-05-13 Sidantal: 43

Titel : **Skogsbränsleuttag vid gallring**
Projekt Skogskraft rapport nr 14
Förf. : Brunberg B, Persson J
FUD-nr : U(B) 1993/17 Datum: 1993-06-16 Sidantal: 75

Titel : **Miljökonsekvensbeskrivning: "Från vaggan till graven - fallstudie VEGA"**
Förf. : Setzman E, Brännström-Norberg B M, Rosén-Lidholm S
FUD-nr : U(B) 1993/18 Datum: 1993-06-09 Sidantal: 120

Titel: : **Import av biobränslen och torv.**
Projekt Skogskraft rapport nr 15
Förf. : Albertsson N
FUD-nr : U(B) 1993/19 Datum: 1993-06-30 Sidantal: 50

Titel : **Resultatrapport 1992**
Förf. : Projekt Bioenergi
FUD-nr : U(B) 1993/20 Datum: 1993-06-30 Sidantal: 90

Titel : **Terminallagring av bränsleflis**
Projekt Skogskraft rapport nr 16
Förf. : Jiris R, Lehtikangas P, Oskarsson R
FUD-nr : U(B) 1993/21 Datum: 1993-06-30 Sidantal: 45

Titel : **Lagring av buntade hyggesrester av barrträd**
Projekt Skogskraft rapport nr 17
Förf. : Lehtikangas P, Jirjis R
FUD-nr : U(B) 1993/22 Datum: 1993-08-31 Sidantal: 23

Titel : **Småträdsbränsle i sydsvensk slutavverkning**
Projekt Skogskraft rapport nr 18
Förf. : Laestadius L
FUD-nr : U(B) 1993/23 Datum: 1993-09-15 Sidantal: 65

Titel : **Fukthaltsbestämning i avverkningsrester**
Projekt Skogskraft rapport nr 19
Förf. : Yngvesson M
FUD-nr : U(B) 1993/24 Datum: 1993-10-20 Sidantal: 53

Titel : **Lagerstudier med Salixbränsle - Kraftvärmeverk som kund.**
Samarbete med LRF/SLR
Förf. : Gärdenäs S
FUD-nr : U(B) 1993/25 Datum: 1993-10-26 Sidantal: 56

Titel : **Tungmetallanalyser av mossor och bäckvattenväxter i norra Estland.**
Förf. : Wikberger C, Palm H
FUD-nr : U(B) 1993/26 Datum: 93-11-08 Sidantal: 37

Titel : **Biobränslebaserade bränsleceller**
Förf. : Ramsköld A
FUD-nr : U(B) 1993/27 Datum: 93-07-05 Sidantal: 57

Titel : **Mängd trädrester efter trädbränslesköird**
Projekt Skogskraft rapport nr 20
Förf. : Lars-Göran Eriksson
FUD-nr : U(B) 1993/28 Datum: 94-08-22 Sidantal: 27

Titel : **Regional försörjning av flis från åker och skog - En systemanalys**
Förf. : Hans Erik Uhlin, Dan Westerberg, Bertil Johansson, Birgitta Olandersson
FUD-nr : U(B) 1993-29 Datum: 94-03-08 Sidantal: 39

Titel : **Metanol och etanol ur träråvara - Huvudrapport**
Samarbete med LRF/SLR
Förf. : Nils Elam, Clas Ekström, Anders Östman, Erik Rensfelt
FUD-nr : 1994/1 Datum: 94-06-02 Sidantal: 80

Titel	:	**Metanol och etanol ur träråvara - Bilagor** **Samarbete med LRF/SLR**		
Förf.	:	Nils Elam, Clas Ekström, Anders Östman, Erik Rensfelt		
FUD-nr	:	1994/2	Datum: 94-06-02	Sidantal: 128
Titel	:	**Analys av miljökonsekvenser för ett kraftvärmeverk eldat med Salix** **- Jämförelse med miljökonsekvenserna för kol och skogsbränsle** **Samarbete med LRF/SLR**		
Förf.	:	Britt-Marie Brännström-Norberg, Susanne Rosén-Lidholm, Cecilia Tärnström		
FUD-nr	:	1994/3	Datum: 94-06-06	Sidantal: 93
Titel	:	**Biobränsle från skog till panna**		
Förf.	:	Sebastian Örjenfelt		
FUD-nr	:	1994/4	Datum: 94-06-07	Sidantal: 48
Titel	:	**Kadmium i Salix**		
Förf.	:	Gölin Östman		
FUD-nr	:	1994/5	Datum: 94-06-16	Sidantal: 22
Titel	:	**Skogsbränsle, aska och ekologi** **Projekt Skogskraft nr 21**		
Förf.	:	Anna Lundborg		
FUD-nr	:	1994/6	Datum: 94-06-20	Sidantal: 49
Titel	:	**Externbuller vid biobränsleanvändning**		
Förf.	:	Jonce Kotaleski		
FUD-nr	:	1994/7	Datum: 94-08-15	Sidantal: 96
Titel	:	**Skogsbränsleanvändningens konsekvenser för ryggradslösa djur.** **Projekt Skogskraft nr 22**		
Förf.	:	Jan Weslien		
FUD-nr	:	1994/8	Datum: 94-10-06	Sidantal: 27
Titel	:	**Uppskattning av biobränsletillgången inom upptagningsområden till kraft-värmeverk. - En studie där Landsat TM-data kombineras med fältdata.**		
Förf.	:	Mats Nilsson, Anders Lundström		
FUD-nr	:	1994/9	Datum: 94-10-06	Sidantal: 31

Titel : **Skogsbränsle och Svavel**
Förf. : Anna Lundborg
FUD-nr : 1994/10 Datum: 94-10-10 Sidantal: 52

Titel : **Skogsbränsle och kolbalanser**
Förf. : Anna Lundborg
FUD-nr : 1994/11 Datum: 94-10-11 Sidantal: 43

Titel : **VEGA Test & Verifikation - Trycksatt förgasning av biobränslen**
Förf. : Leif Liinanki
FUD-nr : 1994/12 Datum: 94-11-17 Sidantal: 44

Titel : **Logistik vid direktskörd av Salix**
Samarbete med LRF/SLR
Förf. : Birger Danfors, Berndt Nordén
FUD-nr : 1994/13 Datum: 94-12-27 Sidantal: 37

Titel : **Kadmium i Salixodlingar efter behandling med kommunala restprodukter**
Samarbete med LRF/SLR
Förf. : Kenth Hasselgren
FUD-nr : 1995/1 Datum: 95-07-14 Sidantal: 28

Titel : **Spridningstekniker för slam i Salixodlingar**
Samarbete med LRF/SLR
Förf. : Lars Sjösvärd
FUD-nr : 1995/2 Datum: 95-09-22 Sidantal: 20

Titel : **Skogsbränsle minskar kvävebelastningen - Beräkningar av kväveflöden**
Förf. : Fredrik Burström, Jan Johansson
FUD-nr : 1995/3 Datum: 95-12-04 Sidantal: 22

Titel : **Kommunalt slam som gödsel i Salixodlingar**
Samarbete med LRF/SLR
Förf. : Helena Diedrichs, Torleif Bramryd
FUD-nr : 1995/4 Datum: 1995-11-15 Sidantal: 42

Titel : **Tungmetaller i träd och energigrödor - en litteraturstudie**
Förf. : Lars Johnsson
FUD-nr : 1995/5 Datum: 95-12-04 Sidantal: 30

Titel	:	**Effekter av långvarig Salixodling på kadmiuminnehållet i jorden - en pilotstudie** **Samarbete med LRF/SLR**		
Förf.	:	Jan Eriksson, Stig Ledin		
FUD-nr	:	1995/6	Datum: 96-02-22	Sidantal: 21

Titel	:	**Småskalig värme och kraftvärme från biobränslen - nischer** **Samarbete med LRF/SLR**		
Förf.	:	Åsa Granqvist, Pelle Sundell, Bengt Lindgren		
FUD-nr	:	1995/7	Datum: 96-04-15	Sidantal: 20

Titel	:	**Småskalig värme och kraftvärme från biobränslen - tekniksammanställning** **Samarbete med LRF/SLR**		
Förf.	:	Åsa Granqvist, Pelle Sundell, Bengt Lindgren		
FUD-nr	:	1995/8	Datum: 96-04-15	Sidantal: 91