Bioenergy

Opportunities and constraints

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*) Based on the report "Uttalande om Bioenergi", 28 November 2007.
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Foreword

In the Spring of 2006, the Royal Swedish Academy of Agriculture and Forestry and the Royal Swedish Academy of Sciences established a working committee comprised of Sven Kullander and Karl Fredga (from the Energy Committee of the Academy of Sciences), Kjell Danell and Dick Hedberg (from the Environmental Committee of the Academy of Sciences), and Göran Hedberg and Erik Herland (from the Academy of Agriculture and Forestry) to compile an overview of current knowledge in the field of bioenergy. The working group met on several occasions and together organized a symposium on 6 November 2006 under the auspices of the Academy of Sciences: "Biofuel – after the Oil Commission". Lectures were held by Stefan Edman, Tage Fredriksson, Sune Linder, Pål Börjesson, Ove Nilsson, Magnus Brandel, Annika Atterwall, Runar Brännlund, Lars Erik Liljelund, Svante Axelsson, Hasse Berglund, Anna Lundborg, Håkan Wirtén, Stefan Wirtén and Carl Wachtmeister.

In conjunction with a symposium of the Royal Swedish Academy of Engineering Sciences, 6 February 2007, Sven Kullander convened a hearing with George Weyerhaeuser, Jr., Geneva, and Prof. Donato Aranda, Rio de Janeiro, about Brazilian production of ethanol and biodiesel.

On 22 February 2007, Sven Kullander called a hearing on the the topic of forests at the Ångström Laboratory in Uppsala, at which Jan Fryk, Peter Hagström, Per Olov Nilsson, Lars Ohlander, Matti Parikka and Lars Tegnér presented compilations of facts about the forest.

The Energy and Environmental Committees also appointed a working group in the Spring of 2007, comprised of Kjell Danell, Carl Folke, Karl Fredga, Dick Hedberg, Sven Kullander and Lars Tegnér, to shed light on the topic of biofuels for the transportation sector. The group arranged a hearing 8 October 2007 at which Runar Brännlund, Nippe Hylander, Francis Johnson and Torbjörn Rydberg gave presentations and responded to questions after an introduction by Lars Tegnér.

The result of the work was published in the report "Uttalande om Bioenergi", endorsed by the Energy Committee and the Environmental Committee and published 28 November 2007. Besides some minor editing and the addition of a section on Waste (6d) this English version contains the same information and the same conclusions and recommendations as the original Swedish report. One or more of the members of the working group participated at the following seminars and symposia:

Skansen, Stockholm, 24-25 April 2006: "What are the implications of a future oil shortage?" Organizers: the Royal Swedish Academy of Agriculture and Forestry and the Swedish University of Agricultural Sciences.

The Swedish University of Agricultural Sciences, Uppsala, 28-29 November 2006: "The forest – against oil dependency, for climate goals." Organizer: the Swedish University of Agricultural Sciences.

The Royal Swedish Academy of Engineering Sciences, Stockholm, 7 February 2007: "The future of forest bioenergy." Organizer: The Royal Swedish Academy of Engineering Sciences.

Bergen, Norway, 22-23 March 2007: "International energy foresight symposium." Organizer: Energy Forum.

The Royal Swedish Academy of Engineering Sciences, Stockholm, 18 April 2007: Symposium in conjunction with presentation of the book "Energy – possibilities and dilemmas." Organizers: The Royal Swedish Academy of Engineering Sciences and the Royal Swedish Academy of Sciences.

Other sources of information are presented in the reference list at the end of this folder.

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Executive Summary

Humankind is currently faced with the huge challenge of securing sustainable supply and use of energy. This is accentuated by increasing oil prices, decreasing oil reserves, growing energy consumption and the threat to the environment and climate. Bioenergy is one component of the energy supply chain and will surely increase in importance. However, bioenergy production will compete for raw materials with the production of food, animal fodder, paper pulp and wood materials for construction. Moreover, decreasing supplies of cheap fossil fuel energy, which is a requisite for today's highly intensive agricultural and forestry industries, will result in lower yields. This can be compensated to a certain extent by improved production methods and by modern plant breeding.

The uncertainties involved in prediction of bioenergy production are considerable. The International Energy Agency (IEA) has recently assessed the potential for generating additional energy from biomass. The estimates range between one tenth and three times the world's current total energy supply, which is currently 130,000 TWh. This illustrates how difficult it is to make reliable predictions regarding the role of biomass in the future. Swedish statistics are also inadequate, as key facts are lacking in certain areas where further research is needed.

The effort to produce ethanol and other automotive fuels from agricultural primary production is questionable for several reasons. The main reason is the considerable amount of energy that is required for the production of liquid fuel. With a growing global population, in the competition between food and fuel, food production must take priority. Producing bioethanol and other liquid fuels from the primary products of the agricultural sector needs to be questioned. One possible exception is in Brazil, where large areas of arable land remain unused. Despite the Brazilian land reserve, extensive deforestation is taking place there, as also in Indonesia and Africa. The exploitation of Indonesian rainforests to make way for production of palm oil for automotive fuel is a terrible example. In Africa, arable land should mainly be used for the production of food, but political and infrastructural obstacles hamper utilization of Africa's considerable potential.

Concerning forest biomass, strong measures need to be taken to immediately stop the ongoing deforestation in Southeast Asia, South America and Africa. In Sweden, the last 100 years have seen an increase of forest biomass which has acted as an important CO_2 sink. With continued capacity for this assimilation of CO_2, and unchanged production of pulp and wood products, it is estimated that the energy production from forestry products can be increased by 20 TWh to the year 2020 through better utilization of logging waste (branches, tops, stumps). In 50-100 years time this figure can be doubled to 40 TWh through a variety of measures to improve forest growth.

A question of particular interest is which plant species for energy production will play a prominent role in Sweden's future agricultural landscape. Salix is efficient but controversial, partly because of the farmers' reluctance to plant this species. Alternative crops and highly efficient grasses which are better suited to the farmers' machinery are currently being developed and tested. It is therefore important to keep all options open concerning what directions energy crops may take in the future. The agricultural fallow land is estimated to have a production potential of 10 TWh.

We estimate that the current contribution of peat (4 TWh) could potentially be doubled. Energy production from organic waste (eg household garbage, slaughterhouse waste, manure) could also be doubled from 8 TWh to 16 TWh by 2020. In a longer time perspective there is considerable potential for growth of forests on bogs and fens, provided they are drained and fertilized. How much additional energy this might provide is difficult to estimate.

If all the above are taken into account, we estimate that the total bioenergy supply in Sweden could increase from 108 TWh in 2004 to 150 TWh by 2020.

In Sweden, ethanol production from agricultural products should be no more than a brief deviation. However, second generation fuels originating from the waste products of forestry and agriculture are of interest. Gasification of these waste materials is an energy-efficient means of fuel production. Ongoing pilot projects in Sweden include gasification of black liquor in Piteå and gasification of biomass in Värnamo. The gasification technique produces "synthesis gas" (syngas) consisting of hydrogen and carbon monoxide which, using well known techniques, can be converted into ethanol, biodiesel and other end products. An alternative and equally attractive use for biomass gas is to produce electricity. Production plants for second generation liquid fuel are planned to be up and running in 10 years. It is estimated that the domestic capacity could cover 10% of Sweden's automotive fuel needs.

Raw biomass materials from fields, forests and waste can be put to optimal use by combined production of a variety of energy carriers such as electricity, liquid fuel, biogas, pellets, heat, cooling, etc, in so-called "cogeneration units". Combined production has already been tested with good results at municipal district heating plants and within the pulp and paper industry, which can already be considered as combination units. New cogeneration units will give synergy effects through more efficient use of resources than is possible when energy carriers are produced separately. The form of energy that is produced can be adapted according to demand.

In comparison to other EU countries Sweden has good potential to further develop bioenergy thanks to its large forests, good agricultural land and relatively high rainfall levels. But bioenergy cannot eliminate more than a fraction of fossil fuel oil; it will be most efficient at providing electricity and heat.

Environmental considerations must be integrated into the production processes in fields and forests from the very beginning. Swedish scientists have made considerable progress in this regard over the last 20 years. It is important to assess environmental impacts and define environmental threats early on. Viewed in the short term, until standing forest biomass has increased to replace harvested biomass, use of biofuels results in carbon emissions just as large as those from fossil fuels. This fact needs to be kept in mind if

there is a major increase in harvest of forests, given that the next 50-100 years will be decisive in the efforts to reduce CO_2 emissions. Biofuel from the agricultural sector also negatively influences the climate through the production of methane and nitrous oxides, which are very strong greenhouse gases. Recent studies suggest that the nitrous oxide generated during production of liquid fuel gives rise to a greenhouse effect that equals or surpasses that of the oil being replaced. The growing demand for bioenergy must also be seen in relation to other assets such as biodiversity, recreation, tourism, pulp and wood products, food, oxygen production and CO_2 assimilation.

The debate about the pros and cons of bioenergy production must be broadened from the pursuit of technically and economically viable methods to decrease emissions from fossil fuels, towards a more comprehensive view that puts bioenergy production into a long term perspective that encompasses ecological, societal and socioeconomic issues. A global demand-driven expansion of biofuels such as ethanol can result in further homogenization of ecosystems and landscapes which will have far-reaching effects on fresh water, coasts and oceans.

1. Definitions

BIOENERGY is energy from biomass.

BIOMASS is organic material that has been through little or no chemical or biological conversion

BIOFUEL is fuel produced from biomass; the fuel can have been subjected to chemical or biological transformation or processing, and the raw materials can have been used previously for some other purpose.

Biofuels can be subdivided into five categories:

FOREST FUELS are based on woody raw materials that have not been through any chemical processing; this includes logging residues, branches and twigs, bark, chips and sawdust, wood pellets and briquettes.

Field fuels are agricultural products. Energy forests, energy grasses, hay, and grain for conversion to ethanol are examples.

BLACK LIQUOR is a byproduct of paper manufacturing formed when wood chips are converted to pulp.

PEAT FUEL is made from peat, a partially decomposed biological material formed in bogs and fens.

BIOFUELS FROM SORTED WASTE are usually burned in special incineration plants; combustible gases from digestion of sludge in wastewater treatment plants and landfills also belong to this category.

Source: Svebio, the Swedish Bioenergy Association

2. Biofuels in a global perspective

According to the United Nations Food and Agricultural Organization (FAO), about 15% of the world's energy in 2004 came from biomass, although in some developing nations nearly all the energy supply comes from biological sources. In Africa, 90% of all harvested forest is used as firewood. Globally, 80% of all renewable energy comes from biofuels, of which 75% comes from the world's forests (4×10^9 hectares; 30% of the world's land surface). More than two billion people are entirely dependent on firewood from forests and 60% of the world's total forest production is used for biofuel. Every year sees the disappearance of 7.3×10^6 hectares of forest land, i.e. 0.2% of the world's total forested area. In South America and Africa, more than 0.5% is cut down per year. The FAO Global Forest Resource assessment from 2005 estimates that

the world's forests contain about 440,000 million m^3 (Mm^3) of standing biomass. Of this total, Brazil and Russia have about 81,000 each, Indonesia has 5,200, and Sweden has 3,100 Mm^3. Unfortunately, the standing forest biomass decreases by 700 Mm^3 per year in Brazil and by 561 Mm^3 in Indonesia. The yearly decrease in Indonesia – 10% – is particularly worrisome. This exploitation of tropical forests is not only an ecological catastrophe, but also contributes to the increase in atmospheric levels of CO_2, owing mainly to an indirect effect: fewer leaves means decreased uptake of CO_2 for photosynthesis. This increase of CO_2 corresponds to the CO_2 emissions of the entire United States, which in turn is twice that of the European Union. One effective way of reducing CO_2 emissions to the atmosphere is thus to halt deforestation. On the bright side, China's standing biomass is increasing yearly by 181, Russia's by 41 and Sweden's by 24 Mm^3. In 2004, the total world harvest of forest biomass was 9,500 Mm^3, i.e. about 2% of the total (FAO 2006).

The potential for energy crops from agriculture is the subject of discussion. Intensive farming requires an ample supply of fossil fuel for machinery, production of fertilizers and transportation. The need for fresh water for production of biofuel is also considerable and may threaten food production, which in 2005 totaled 6,400 million tons, mainly grain, sugar, fruit and vegetables. It is not clear how much biomass agriculture could actually contribute to future energy production. For instance, the International Energy Agency (IEA 2007) has estimated the global potential for energy production from field and forest biomass. The worst case scenario assumes that no extra land is set aside for production of biofuel and that only waste products from agriculture and logging are used. This potential is calculated to 11,000 TWh, which would double the current bioenergy supply. With the best case scenario, which entails intensive farming on high quality soil, the theoretic potential is estimated to a yearly production of 306,000 TWh. For comparison, the world's total energy supply is now 130,000 TWh. According to IEA, a massive expansion of large scale bioenergy production world-wide could enable generation of between 60,000 and 120,000 TWh per year in this century. The report cautions that accessibility of biomass for energy production and other purposes depends on many complex factors, which makes it difficult to assess its future potential. The report particularly emphasizes that the constantly growing need for food must be met and that environmental and ecosystem sustainability must be ensured.

In Southeast Asia – particularly Indonesia and Malaysia – oil palm plantations for production1 of biodiesel constitute a major threat to the rainforests. Devastation of the forests to make room for plantations threatens many

1 The Dutch government, which at first believed that the venture to produce biofuel from oil palms was environmentally sound, has now been forced to reconsider: "… this green fairy tale began to look more like an environmental nightmare" (International Herald Tribune 31 January 2007).

unique species in the rainforests and causes irreparable damage to the entire ecosystem. Forest destruction also makes a significant contribution to the increasing atmospheric carbon dioxide content.

In Brazil, sugar cane for production of ethanol is grown on 5 million hectares of land, corresponding to a mere 0.6% of the country's area. Brazil's ethanol production in 2006 was 16 billion liters – the same amount as in USA, where ethanol is produced from corn. Other major ethanol producers include China, India and France. Sweden produces 0.06 billion liters per year. According to statistics from the Swedish Board of Agriculture, total world production of ethanol was 46 billion liters. Sugar cane yields twice as much ethanol per hectare as corn, and production requires only one sixth as much energy as is needed to convert corn to ethanol.

Reportedly, no land in the Amazonian tropical rainforest has been cleared for production of ethanol. Ninety million hectares of land remain available for agriculture in Brazil![2] Theoretically this means that 18 times the 2006 production of 16 billion liters of ethanol – 288 billion liters – could be produced annually. For comparison, the yearly production of oil for gasoline, diesel and chemical industry totals 4,800 billion liters.

Brazilian ethanol production has been criticized because of the unacceptable living conditions of the sugar cane workers. This criticism applies to all work with sugar cane in Brazil.

Oil crops, mainly soybeans and oil palms, are grown on wide expanses of land in Brazil (soybeans cover 22.2 million hectares). Most of the soybean crop (82%) is used as animal fodder and is exported. A small amount, 500,000 tons per year, is used for production of biodiesel but this figure is constantly growing because the Brazilian government encourages increased use of biodiesel. The goal is to increase current production by a factor of ten.

Cultivation of soybeans is controversial because it is perceived to lead to devastation of the rainforest. Overexploitation of Brazilian rainforests decreased for several years, but this positive trend was broken in 2003. The increased devastation after 2003 is considered to be mainly owing to cultivation of huge monocultures of soybean. Brazil is currently the second largest producer of soybeans, after the United States. Total production in 2004 was 85 million tons in the United States and 53 tons in Brazil. In 2006, Brazilian production had increased to 60 million tons.

2 Information about biofuel production in Brazil was provided by Prof. Donato Aranda at the IVA symposium on bioenergy from forests on 7 February 2007 and a hearing held in conjunction with it on 6 February 2007.

In Europe (EU-25), biofuels contributed only 4.4% of the energy supply in 2005, but nonetheless represented 67% of the renewable energy used. In the United States, only 3% of the energy came from biofuels. The European Union goal is that 20% of the energy supply should come from renewable energy sources by 2020 and that the proportion of biofuels for transportation should increase from 1% to 10%. The proportion of the 2004 energy supply that came from biofuels in Scandinavia was: Sweden 17%, Norway 5%, Finland 20% (peat excluded), Denmark 10% (Fig. 1).

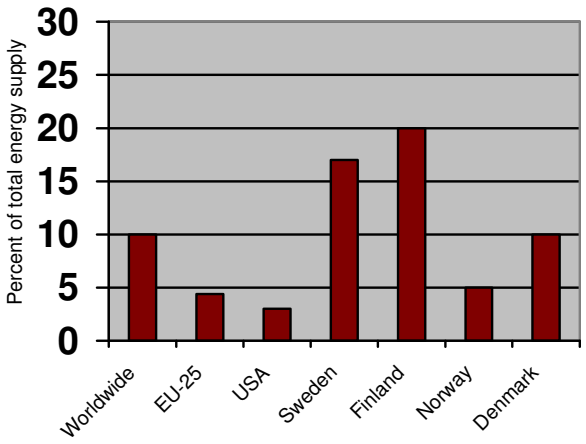

Fig. 1. Proportion of energy supply covered by biofuels in selected countries. Statistics from IEA. (Peat not included.)

3. Energy from biomass

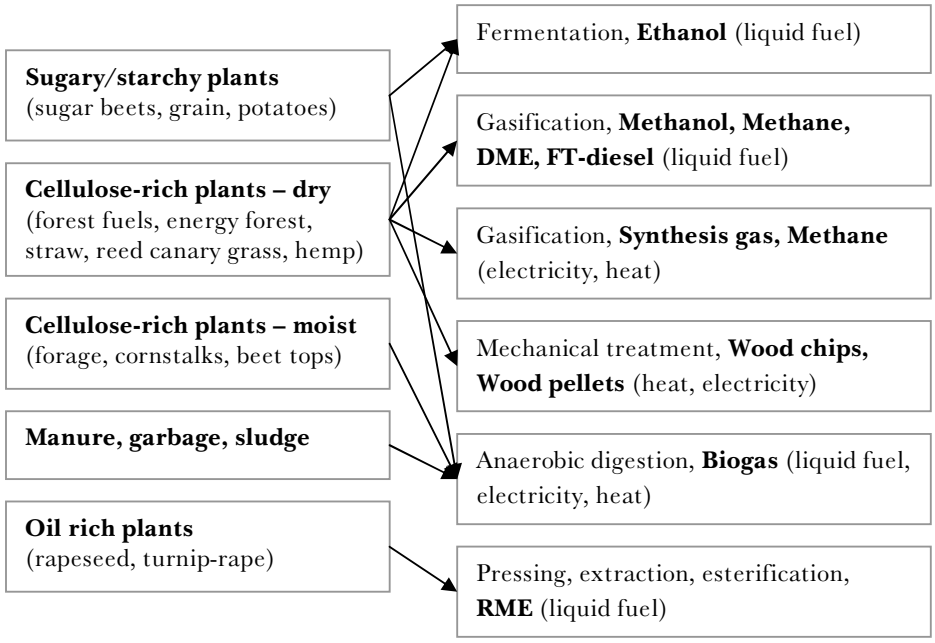

Fig. 2. Energy from biomass in Sweden. Methods for transforming various raw materials into energy carriers which can be used as liquid fuels or for production of heat and electricity.

Sugary and starchy plants such as sugar beets, grains (mainly wheat) and potatoes can be fermented to produce ethanol (C_2H_5OH) or digested to produce biogas, composed of about 60% methane (CH_4) and 40% carbon dioxid (CO_2). Worldwide, sugar cane and corn are the most important raw materials for ethanol production.

Dry plant material rich in cellulose – forest products, energy crops (*Salix*), reed canary grass, hemp and straw – can be converted to ethanol through fermentation and hydrolysis, or be gasified to methanol (CH_3OH), DME (dimethylether, $(CH_3)_2O$), Fischer-Tropsch diesel, biomethane or syngas. It can also be "refined" to chips and pellets. There is an urgent need for new strains of yeast with better efficiency for various energy substrates. At present, dry plants are mainly used for production of heat and electricity.

Moist cellulose-rich plants such as forage (grasses and legumes such as clover), cornstalks and beet tops can be digested to produce biogas (digestion gases). Manure, garbage and sludge can also be digested to produce biogas. Oil rich plants such as rapeseed and turnip-rape can be pressed, extracted and the oil esterified to produce the biodiesel RME (rapeseed methylester). In a global perspective, palm oil and soybean are the most important raw materials for biodiesel.

Ethanol, methanol, DME, RME and biogas are used as automotive fuels. Biogas can also provide heat and electricity. DME is gaseous, whereas RME is viscous, and addition of diesel oil is recommended when RME is to be used at temperatures below -15°C. Wood chips and pellets are burned to produce heat or electricity.

4. Bioenergy in Sweden

Biofuels contributed 108-110 TWh of Sweden's total energy supply in 2004, corresponding to 17% of the primary energy (Energimyndigheten, The Swedish Energy Agency). Of this total, forest fuels provide 92 TWh (85%), agricultural fuels and peat each provide 4 TWh (3.7%) and residential and slaughterhouse waste provide 8 TWh (7.4%). Sweden imports forest fuel corresponding to 12 TWh. Biofuels go mainly towards production of heat, but also electricity. The ethanol shown in the figure is imported. Biofuels give 90 TWh as heat, 6 TWh as electricity and 10 TWh is lost in conversion.

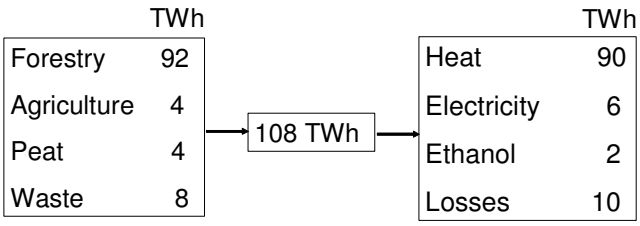

Fig. 3. Bioenergy in Sweden in 2004[3]; source and energy carrier. Note that Swedish forests provide 80 TWh and remaining 12 TWh are from import. (Swedish Energy Agency statistics elaborated by Harry Frank.)

5. A comparison of energy sources in Sweden and Finland

Sweden and Finland are the two countries within the European Union that have the largest forest area per capita and the smallest amount of agricultural land per area of forest. It can therefore be of interest to compare various energy sources in these countries. One important difference between Sweden and Finland is that the Finnish forestry industry is proportionally larger.

Primary energy use in 2004 in Sweden was 647 TWh (including overseas shipping) and the corresponding figure for Finland was 413 TWh. The proportion from biomass was 17 and 27%, respectively. The greatest difference between the two countries is that peat is used much more in Finland, where it provides 24 TWh (6%) versus 4 TWh (0.6%) in Sweden. Comparison between other energy sources in Sweden and Finland shows: fossil fuel 38 versus 50%; nuclear power 35 versus 16% and hydroelectric power 9 versus 4%. The figure for nuclear power can be misleading because two-thirds is losses. Heat exchangers and imported electricity contribute 3% in Finland. In 2004, windmills provided 0.1% of Sweden's energy, but this figure has increased slightly since then. Of the fossil fuel used in Sweden, a larger proportion comes from oil (32 versus 24%) whereas coal and gas use is proportionately larger in Finland (15 versus 5% for coal and 11 versus 1% for gas).

[3] In 2005 biofuels contributed 112 TWh and in 2006 115 TWh.
In 2020 biofuels are expected to contribute 154 TWh.

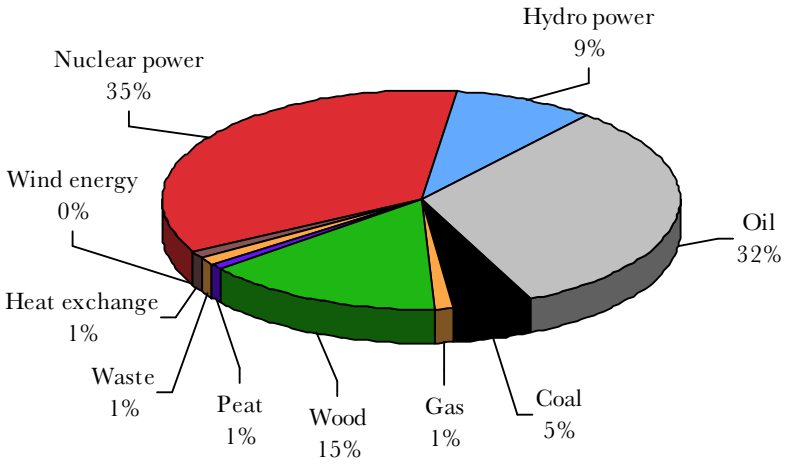

Fig. 4. Primary energy in Sweden in 2004, 647 TWh, subdivided according to energy sources. Note that the gas shown in figures 4 and 5 is of fossil origin.

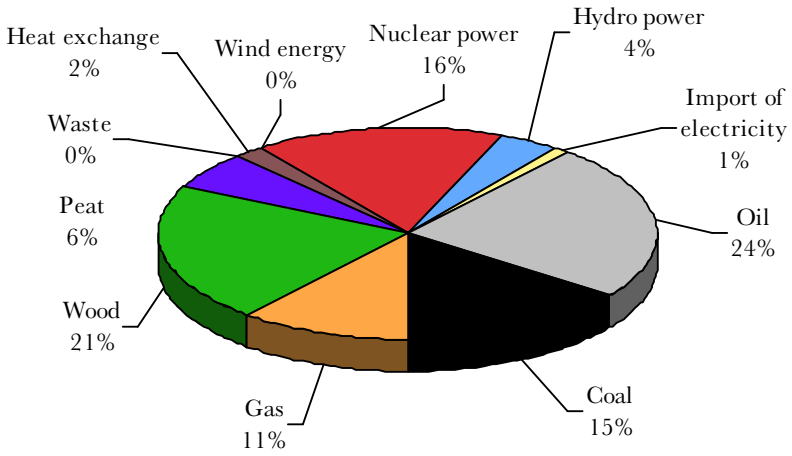

Fig. 5. Primary energy in Finland in 2004, 413 TWh, subdivided according to energy sources.

6. Possibilities for increased production of biofuel from forests, farmlands, peat bogs and waste

As is clear from Figure 3, forests are the predominant source of biofuel, despite the fact that energy forest is considered an agricultural biofuel. Energy forest consists mainly of *Salix* grown on farmland or fields that have lain fallow. In Sweden, the total area involved is 23 million hectares of forest, 2.7 million hectares of farmland, and 0.5 million hectares of pasture land. The

corresponding figures for EU-25 are 146 million hectares of forest and 103 million hectares of farmland.

6a. Forestry

With the exception of a few years in the 1970s, the growth of Swedish forests has exceeded felling for the past 50 years. The standing stock has therefore increased substantially, making Swedish forests a sizeable CO_2 sink. Figure 6 shows total forest stock, growth and felling in 2002.

The report "Biomass Flows in Swedish Forest Industry 2004" compiled by Per Olov Nilsson (Swedish Forest Agency report 23/2006) shows the flow of wood biomass from all Sweden's productive forests, from forest growth to final product within industry or other end user. All flows are expressed in megatons of dry matter (Mt_{dm}).

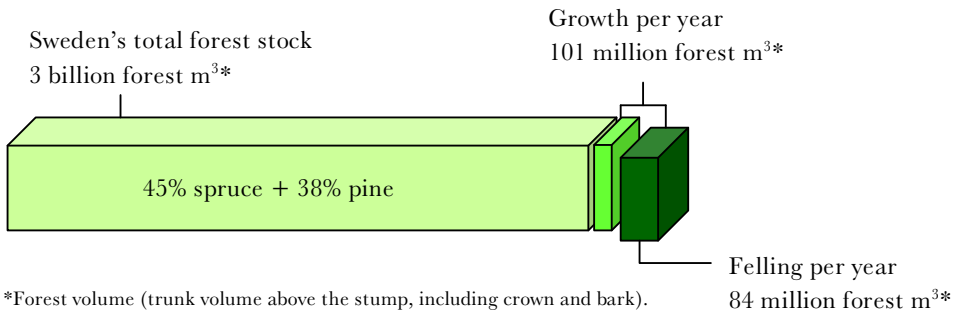

Fig. 6. Swedish forest stock, growth and felling in 2002. Note that growth exceeds felling. (Source: National Forest inventory, The Swedish Forest Agency)

Figures 7 and 8 show growth, felling and removal of wood biomass subdivided according to ultimate use, from 2004. It should be noted that the total standing biomass increased by about 15 Mt_{dm} since only about 80% of the annual growth was felled. This increase corresponds to about 75 TWh. Over half of the felled wood biomass was removed from the forest that year, mainly in the form of trunks, along with a smaller amount, mainly in the form of branches and tops from clear-cut areas. The remainder, somewhat less than half, was left in the forest – tops, stumps and roots. This unused biomass could theoretically provide 137 TWh. We consider it realistic to salvage 20 TWh every year from these logging residues for energy use.

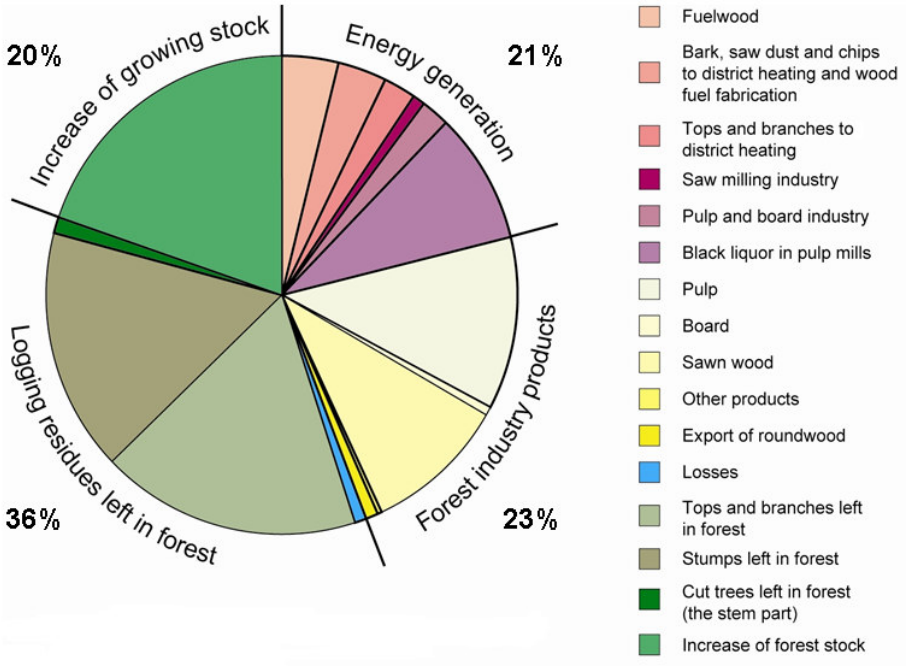

Fig. 7. Growth, felling and harvest of forest biomass subdivided according to end product in 2004. The growth was 75.9 megatons of dry matter (Mt_{dm}) and the felling 61.0 Mt_{dm}. (After Per Olov Nilsson).

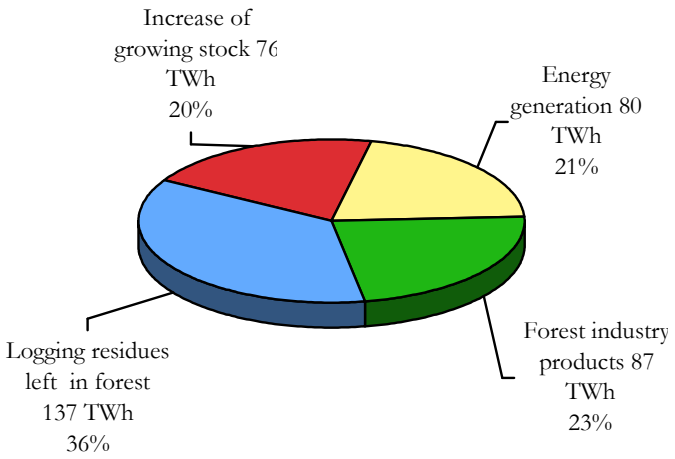

Fig. 8. Growth, felling and harvest of forest biomass in 2004 presented as energy units and subdivided according to major end products. 75.9 Mt_{dm} is equivalent to 380 TWh. (Adapted from Per Olov Nilsson).

About half the wood harvest was used for forest industry products and the other half for some kind of energy production. Among Sweden's forestry products, paper pulp and sawn wood have the lion's share. Fiberboard is scarcely produced at all in Sweden today. Of the wood biomass used for energy

generation, spent liquor (black liquor) dominates completely. Black liquor is a byproduct of chemical pulping in the paper industry. A major constituent of black liquor is lignin that is released from the wood during the pulping process and ends up in the boiling liquid. Black liquor is then burned in special furnaces where the chemicals used in pulp production are recovered and the heat generated is used within the factory for production and generation of electricity. Black liquor is often mentioned as a "raw material" for production of various automotive fuels. But if black liquor is to be used outside the pulping industry, paper mills will have to cover their energy needs some other way, which is likely to be uneconomical in the factories currently in use. There is disagreement on this point, however, because new techniques are coming onto the market. One is a separation technique that extracts lignin from black liquor; another is a gasification technique. The former technique produces a fuel that can be used in traditional furnaces and the latter yields syngas that can either be used for electricity or heat production in combined heat and power plants or for production of methanol/DME or FT diesel. The rate of introduction of these new techniques is determined by the age and condition of equipment currently in use, by market demand for new products, and by the economic feasibility of the new processes. It is likely that booster techniques would be put to use if the pulping industry expands.

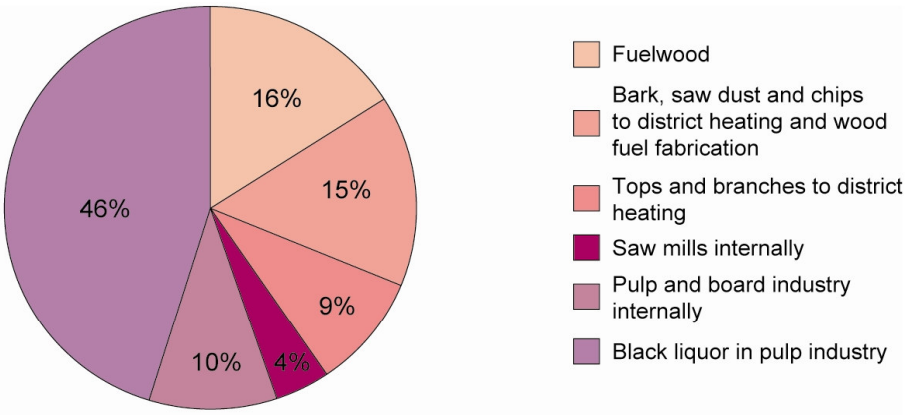

Fig. 9. Biomass for energy generation in 2004. 15.9 megatons (dry matter) are of Swedish origin and 2 megatons are of foreign origin. (After Per Olov Nilsson).

Tops and branches should be exploited much more than they are today. So as not to upset the ecological cycle, removal of biofuels from the forest should be done in a way that does not threaten or weaken soil productivity. Wood ash would probably need to be recycled if large amounts of wood are harvested from the forest (Ågren and Hyvönen-Olsson, 2006).

The Forestry Research Institute of Sweden (Skogforsk) has estimated the potential for increased harvest of biomass from Swedish forests. A 20% increase from the current 90 Mm^3/year to 108 Mm^3/year by 2060 is considered realistic. This corresponds to an additional energy supply of 36 TWh. Realization of such an increase would above all require improvement of established cultivation techniques: better silviculture, genetically improved plant materials, increased use of contorta pine and fertilization (Table 1).

By adapting fertilization to suit the need, it is possible to make spruce forests in Västerbotten as productive as stands in Skåne without nutrient leakage into groundwater (Linder et al. 2007). It has been asserted that modern plant breeding (GMO) and fertilization of seedlings with specific amino acids (L-arginine) will make it possible to achieve considerably increased growth rates in the future, without harming the environment (Ove Nilsson). Further research and better documentation – particularly on economic and ecological aspects – will be required for a more detailed assessment of these possibilities.

In the report "Biofuel from the forest. Supply and demand" from 2006, **the Swedish Forest Industries Federation** (Skogsindustrierna) wrote that the felling residues, branches and tops currently used for biofuel production correspond to 7 TWh of fuel per year. The Federation estimates that this harvest could be more than doubled to 15 TWh per year. If other felling and thinning residues were also exploited, it would be possible to extract a further 12 TWh of fuel. All in all it would be possible to increase the harvest of biofuel by 20 TWh per year. Potential feedstocks are as follows (in TWh): tops and branches 8, long tops 0.8, thin trees 3.0, other clearing residues 3.0, stumps 5.1, and rotten wood 0.4, giving a total of 20.3 TWh.

In summary, we can harvest another 20 TWh per year for energy purposes without reducing the standing forest capital. On the contrary: Swedish forest biomass is currently increasing by 0.5-0.7% per year.

Table 1. Potential for increased growth or harvest in 50 to 100 years through implementation of various growth-enhancing measures. (Adapted from O. Rosvall 2007 by The Forestry Research Institute of Sweden.)

Measure	Possible increase (forest Mm^3)	Plausible increase (forest Mm^3)
Rejuvenation approved - intensive	2.7-6.2	3.5
Plant breeding, seed plantations - vegetative	8.3-12.6	8.0
Contorta pine 15,000-30,000 hectares/year	2.0-3.5	2.0
Fertilization 60,000-220,000 hectares/year	1.0-3.5	1.5
Subtotal established methods	14.0-25.8	15
Clone forestry using somatic embryogenesis	1.3	0.5
Intensive fertilization of spruce	4.0	?
Planting spruce/hybrid aspen 50/50 on farmland	4.4	1.5
Trench clearing	0.9	0.5
Ash fertilization	1.0	0.5
Subtotal intensive methods	11.6	3.0
Total increase in forest Mm^3 (%)	37.4 (%)	18.0 (%)
Drainage of bog and marsh forests	6.1 (%)	?

6b. Agriculture

This summary is based mainly on the Swedish Board of Agriculture report "Bioenergy from agriculture – a growing resource" (SOU 2007:36) with appendix, and on information presented by Pål Börjesson at the symposium arranged by the Royal Swedish Academy of Sciences, 6 November 2006.

Sweden's farmland covers a total of 3.2 million hectares, of which 2.7 million hectares arable fields and the rest grazing land. Fodder and grain are the most common crops (ca 42% and 37% of the fields in 2006). There is a clear ongoing trend toward decreasing cultivation of grain. Since 1990 the area planted in grain has decreased about 25%. Another clear trend is that the proportion of land lying fallow has increased, although it is likely to decrease in the future. Scarcely 3% of Sweden's arable land is currently used for cultivation of energy crops. Grain prices have increased considerably in 2007, which will probably stimulate cultivation of grain.

Growing conditions for various crops differ substantially in different parts of the country. Based on such factors as climate and soil, the country can be

divided into eight regional production areas within which harvests and growing conditions are comparable.

On the plains of Götaland, for example, the net harvest of bioenergy (i.e. gross harvest minus the energy required for cultivation) is currently about 50 MWh per hectare per year for high-energy crops such as sugar beets and *Salix* (energy forest). On Svealand's plains, the net yield of bioenergy is at best about 35 MWh for energy forest. The net energy yield from grain and particularly from oil plants is considerably lower than from energy forest.

Energy crops can be divided into the following categories: (i) traditional food and fodder crops (grain, sugar beets, forage, corn, oil seeds, etc.); (ii) new energy crops (*Salix*, reed canary grass, hemp, poplar, hybrid aspen); (iii) cultivation byproducts (straw, manure-based biogas production, byproducts from animals). Second-generation fuels are also mentioned in this context, as they are mainly produced through gasification of cellulose.

The three production systems with the best economic potential are cultivation of wheat to make ethanol, cultivation of rapeseed for production of RME, and cultivation of *Salix* (energy forest) for heat, electricity and automotive fuel. Farmers are also advised to invest in manure-based biogas production.

Salix has several positive characteristics for a crop. It is efficient in terms of resources, energy and cost, is environmentally advantageous and

- selectively takes up cadmium from the soil
- is perennial, giving a lower risk of nutrient leakage, erosion, etc. than annual crops
- can contribute to increasing carbon assimilation and mulch in soil
- can be used to clean soil after application of waste products such as sludge and wastewater
- can be of benefit to wildlife, provided the field is placed correctly within the landscape, surrounded by open farmland.

Today, *Salix* is grown on 14,000 hectares. With suitable subsidies and other support measures, it is believed that the area could increase to 50,000 hectares in 2013 and then expand further to 200,000-300,000 hectares "once economy of scale has been attained and a well-functioning market established". Current harvests total about 7-10 tons per hectare, but the report takes it for granted that the yield will be 20 tons per hectare for the first harvest (four years after planting) and 25 tons per hectare for the second harvest (after eight years). The approximate yield of bioenergy from 50,000 hectares of energy forest is estimated at 1.25 TWh (p 187) and approximately 2 TWh (p 189). In 2006, 0.2 TWh *Salix* fuel was produced. The report discusses many reasons why the area planted with energy forest was not as large as anticipated. Measures to encourage farmers to grow more *Salix* are also proposed. The most important

of these is to introduce a new government subsidy, a contract premium, that is given to industries (district heating plant or combined heat and power plants) that sign contracts to purchase newly planted *Salix*.

Skeptics may ask whether the suggestions and cost estimates in the SOU 2007:36 report are realistic. The area newly planted with *Salix* has decreased from 2,000 hectares in the mid 1990s to 300 hectares in 2007 (Swedish Radio Channel 1, 2 August 2007; Svenska Dagbladet, 4 August 2007). The bioenergy researcher Susanne Paulrud at the Swedish Environmental Research Institute has interviewed 2000 Swedish farmers and concludes that *Salix* is not well liked (Swedish Radio Channel 1, 3 August 2007).

The reasons farmers are reluctant to plant energy forest include the following factors:

- Energy forest is said to remain productive for twenty years, but in reality the trees are no longer viable after the second harvest, that is after eight years, because of bacteria and pests (gall gnats).
- Small harvests. The economic predictions on which the decisions were based were inaccurate.
- Farmers are unwilling to take risks. Multi-year crops with long production cycles are riskier than annual grain crops. Assets are bound and liquidity can be a problem.
- Land ownership. Forty-five percent of all farmland is on leasehold and the leases usually run for 1-5 years.
- Uncertainty about how *Salix* will be handled in national agricultural policy in the future.
- Uglification of the landscape. Some farmers feel that *Salix* detracts from the beauty of the landscape. One study has shown that a height of 4-8 m is viewed as negative compared to a height under 2 m.
- Complicated legislation.
- Seeds are easier to handle than cuttings.
- Transition to new production requires expensive investments (farm equipment, tools, etc.). After a *Salix* plantation, the field may be difficult to prepare for other uses.
- The tree roots invade and clog drainage systems.

In a fifty-year perspective, *Salix* may become a valuable crop if (i) the price of *Salix* chips is high relative to other crops, (ii) young farmers who own their own land take up *Salix* production, (iii) the land is within 50 km of a power plant, and (iv) varieties more resistant to bacteria and pests are developed.

We believe there is reason to maintain flexibility for the future. For example, reed canary grass is a perennial crop admirably suited for cultivation in central and northern Sweden, on land where other energy crops (e.g. *Salix*) cannot be

grown because of the climate. Another example is szarvasi-1, a new perennial supergrass from Hungary, which is currently being grown experimentally in Skåne. It can be planted on fallow ground and is expected to give a first harvest of 12 tons per hectare in Sweden. The energy content is 4.7 MWh per ton, as compared to 4.85 in wood pellets (Jan Vainult 2007).

Production of energy crops can be increased by opening up fields currently lying fallow (12% of the arable land) and by switching from cultivation of grain for export to cultivation of energy crops (6%). If potential improvements through plant breeding are taken into consideration, perhaps even more arable land (9%) could be used for energy production in 2020. Agricultural production of biomass for energy could then increase to around 27 kWh by 2020 (Pål Börjesson, Academy of Sciences Symposium, 6 November 2006). However, we feel that it is only the arable land presently lying fallow that should be used for energy crops. These are estimated to provide an additional 10 TWh.

In round figures, energy forest provides thirty times as much energy as is invested, grain provides ten times and oil crops five times as much as is invested (Börjesson, response to query, 6 November 2006). Some other scientists present emergy analyses showing considerably lower energy returns.

6c. Peat and peat forests

Should peat be considered a renewable or a fossil fuel? Conventional peat has so far been classed as a fossil fuel and has therefore lacked the economic incentives that would be required to make it interesting for production of heat and electricity (Oil Commission Report: On the road to an oil-free Sweden, p 46). However, in the report summary (p 45), peat is included among "other biofuels, waste, etc". Peat forms relatively slowly and therefore falls somewhere between renewable and fossil fuel (The Swedish Energy Agency). EU has included peat in its system for emission quotas (CO_2) and thus considers peat as a fossil fuel in this context. This leads to a 10-15% price increase which makes peat less competitive. Whether peat is to be classed as a biofuel or a fossil fuel can depend on the situation, but we include peat among the biofuels in order to fascilitate comparisons with other reports (see Fig. 3).

At present peat is harvested from about 15,000 hectares, i.e. less than 0.2% of Sweden's peat-covered land (Björn Hånell, 2006). Finland uses six times as much peat, which implies that peat in an unexploited resource in Sweden. The proportion of peat used in the district heating sector could increase from 7% to 15% (Magnus Brandel, Academy of Sciences Symposium, 6 November 2006). Research has shown that peat bogs with drainage ditches leak carbon dioxide, methane and nitrogen oxides, all of which are significant greenhouse gases. Peat extraction from this type of land would therefore mitigate the greenhouse effect. We consider it realistic that peat should supply twice the

current amount of 4 TWh, that is, should provide an additional 4 TWh in the future. Exploitation of wetlands is a sensitive and controversial topic, however. We are confident that the environmental problems associated with peat extraction can be solved satisfactorily; among other things we will need a discussion about how best to use peatlands after they have been fully harvested.

Peatland forests are a partially unexploited resource. Improved drainage of already trenched forests and fertilization with phosphorous and potassium will allow peatland forests to flourish. This could be one way to reduce dependence on oil and move towards the climate goals (Björn Hånell, 2006). New drainage of marsh forests and bogs could theoretically provide 6.1 Mm^3, corresponding to about 12 TWh (Table 1). Recent findings show that bogs are stable carbon sinks even in a changed climate (Svenska Dagbladet, 13 May 2007).

6d. Waste

The waste dealt with in this context comes mainly from agriculture, industries, and households in Sweden. Waste from forest industries (bark, chips, logging residue and black liquor) is discussed in section 6a.

Agricultural waste includes straw, stalks, tops and animal and vegetable leavings from the food industry (slaughterhouses, industrial kitchens) as well as sludge from municipal wastewater treatment plants. Animal byproducts (ABP) include unwanted material from slaughterhouses, animals that have died spontaneously or been put down because of injury or illness, and food that has passed its "best before" date. These waste products can be gasified (see Rensfelt 2007) or digested (see Nordberg 2007). Digestion yields biogas, which can be used for automotive fuel or for production of heat and electricity.

Manure plays an important role in agriculture. The report by Andersson (SOU 2007:36) suggests that techniques for production of biogas from manure should be developed. Its potential amounts to at least 4 TWh.

Waste has been used for heat production in district heating plants since the nineteen seventies and increased between 1990 and 2005 from close to 4 TWh to fully 8 TWh and is expected to continue to increase (The Energy Situation 2006).

Household waste – over 4.7 million tons of it in 2007 – goes to recycling (47%) and energy production through incineration in district heating plants (47%); 5% ends up in landfills, and 1% is hazardous waste, which is taken care of in special ways. About 20% of the energy produced in district heating plants comes from household waste (Swedish Waste Management).

It is estimated that the current energy production from waste, 8 TWh, may be doubled by 2020. This is based on the assumption that heat production in district heating plants increases at the same rate as before and that the potential of manure is exploited.

Sweden imports a substantial amount of refuse, scrap wood from demolition and similar fuels. In 2005, Sweden imported 450,000 tons of waste material for energy production from eleven different countries! Sometimes the importer is paid to take care of the refuse; sometimes it costs something. In terms of sheer weight, scrap wood from building and demolition dominates completely. After that, in decreasing order of importance, come wood residues, energy pellets, creosote, household waste, slaughterhouse waste and finally sludge and oil sludge (Swedish Environmental Protection Agency). In 2006 the waste import totaled nearly 600,000 tons (TT, The Swedish News Agency).

This trade is considered environmentally friendly, but one rarely sees figures on the cost in terms of the fossil fuel consumed for transport. For example, 30 tons of household waste is hauled several times every day from Oslo to Uppsala, each time at a cost of 300 liters of diesel fuel! This aspect of waste management should come under closer scrutiny.

7. What is economically and ethically acceptable?

Economic and ethical questions, not least questions of equity, are complex and often elicit different answers depending on whether they are asked at a regional, national or global level.

What is the "best" way to use a forest? Boil it, fell it, burn it, distill it, or hike in it? The question is not easy to answer because the qualities attributed to forests change with time and are determined by the value society and individuals place on the natural environment relative to the material well-being the forest provides us (Runar Brännlund, The Forest Conference 2006, abstracts, p 12). One million cubic meters of wood can currently generate either 3,000 million SEK in profits if exported as paper, or save Sweden 100 million SEK in costs for imported energy (Linda Eriksson, The Forest Conference 2006, abstracts, p 9). The individual forest owner rarely thinks in these terms; he or she usually sells to whoever pays best. Many factors must be included in a conscientious overall analysis, for example the intrinsic value of the natural environment, the forest's role as a carbon sink and its other contributions to the ecosystem, in addition to providing wood and fiber. The interests of the individual, industry and society as a whole must all be given due consideration.

Should farmland be used to grow food or fuel? It takes 2.65 kg of wheat to produce one liter of ethanol; this simultaneously yields 0.85 kg of animal fodder (Matti Parikka 2006). About twenty years ago there was a heated debate about whether it was ethical to burn food. This debate may be resurrected in a situation where energy crops supplant food crops on our farmland and domestic food production sinks to unacceptable levels (Annika Atterwall, Academy of Sciences Symposium, 6 November 2006). In the past year, grain prices have doubled in Sweden, and wheat prices are now so high that it is no longer profitable to make ethanol from wheat (Upsala Nya Tidning, 29 August 2007). Another observation is that when wheat prices increase, it may be economically feasible to start using suboptimal farmland. It is all a matter of supply and demand. If import tariffs on ethanol are removed, the economic conditions for domestic ethanol production will become less favorable. If more grain is used for energy production, the price of fodder will increase for the pig farmers and pork will become more expensive.

In the United States, the price of corn has increased substantially since corn began to be used for ethanol production, and this has led to higher food prices in Mexico. In 2006, for the first time, more American corn went into ethanol production than was exported, and after President Bush spoke in support of ethanol the price of corn skyrocketed. One week earlier, hungry Mexicans had marched on Mexico City and President Calderón to protest at the price of corn tortillas, which had doubled in one year (Svenska Dagbladet, 26 February 2007).

When analyzing energy issues it is important to adopt a perspective that encompasses an entire system – and the system should not be too narrowly defined. The risks inherent in choosing too narrow a system can be illustrated by the following examples:

- Large scale production of biofuels from forests might decrease the availability of raw materials for Swedish forest industries. This would probably lead to increased prices for wood, which also implies both that biofuels would become more expensive and that the costs for exported Swedish forest industry products would rise, with potential consequences for the balance of trade. Similar arguments could be voiced about what would happen if arable land was used for cultivation of energy crops. Then one would expect decreased production of traditional farm crops, with consequent increases in food prices and increased food import. If the shift towards use of biofuels is modest these indirect effects are probably negligible, but in the case of large-scale ventures, they will need to be reckoned with.

- A major expansion of Brazilian ethanol production might lead to land use changes. Even if this does not lead to exploitation of land currently

covered with rain forest, the changes in land use might indirectly lead to exploitation if farmers are displaced from their lands in favor of ethanol crops, and are forced to open up new farmland in previously forested areas. Increased ethanol production might thus exacerbate the pressure on the rain forest and pose potentially devastating threats to biodiversity and the living conditions of indigenous peoples.

Given that energy is of fundamental importance for every society, indirect effects of the type described above will probably have a very great impact. Economists analyze this by using what are called general equilibrium models. Sweden has pioneered the use of this type of analysis and several different models are available. It would be desirable to start studies using such tools to pinpoint general system-wide effects that might be overlooked in more narrow analyses.

8. Environmental aspects

Solving one environmental problem can cause another. Environmental impacts must be assessed meticulously at an early stage and environmental problems clearly delineated. Perhaps one should also assess the environmental consequences of doing nothing.

Environmental aspects should be integrated into production processes in field and forest right from the start. This would increase the likelihood that problems are detected early on so that adjustments can be made. A new way of thinking will be needed at many levels. We must be aware of the threats, but also grasp the opportunities. For instance, biomass production and removal of nutrients in the outflow from farmland and residential areas should be possible to integrate into the production of biofuels. *Salix* fields are controversial in the environmental debate, but the government report SOU 2007:36 maintains that energy forests can have beneficial effects on the environment provided they are placed in suitable locations in the landscape (see above under section 6b). It should also be possible to make them look less monotonous.

Will Sweden's sixteen environmental objectives (see www.miljomal.nu) be affected if the Oil Commission's objectives are achieved? There is fairly detailed knowledge about what happens within small areas – e.g. a stand of trees – when cultivation is changed or intensified. Far less is known about what happens within an entire county or region – particularly when cultivation of forest and farmland increases both in scale and intensity. More extensive and comprehensive planning will be required if the the Oil Commission's goals are to be realized without having too great a negative impact on the environment.

The issue of the positive and negative effects of bioenergy must also be broadened from the search for technically and economically viable methods to reduce emissions from fossil fuel, to a more all-encompassing view of bioenergy production in a long-term perspective, including both ecological aspects and societal and socioeconomic ones. Healthy ecosystems constitute the basic foundation for sustainable development of society. Large-scale monocultures, exotic species and homogeneous landscapes increase society's vulnerability in a time of climate change.

Emergence of biofuels such as ethanol, driven by global demand, can lead to even greater uniformity of ecosystems and landscapes and may have widespread side-effects on air, fresh water, coasts and seas. The increasingly interdependent global economy will demand quick solutions to the challenges of global environmental changes (including climate change) and create globally perceptible trends. The search for biofuels to reduce emission of greenhouse gases is one such trend. One of the central challenges for civilization is to create incentives that will steer development in a sustainable direction.

9. Biofuels for transportation

Renewable automotive fuels are generally divided into first, second and third generation biofuels.

THE FIRST GENERATION is today's fuels based on agricultural products. These include ethanol produced by fermentation of sugar and starch from sugar beets, grain (mainly wheat) and potatoes, RME (rapeseed methyl ester) which is made from rapeseed and turnip-rape by pressing, extraction and esterification, and biogas produced from digestion of manure, garbage and sludge.

Production of automotive biofuels in Sweden is currently done only on a small scale. However, there is potential to increase the efficiency of first generation production systems, for instance by developing cogeneration systems where electricity, heat cooling, steam, pellets, automotive fuels, chemicals, fodder and biogas can be produced in different combinations. The production of automotive fuels from biomass may be justified from the point of preparedness. However, the Royal Swedish Academy of Sciences is of the opinion that agricultural products in principle should be used as food.

Ethanol is produced in Norrköping from wheat and the production is being expanded to have greater capacity in 2008. In the new plant protein fodder, heat and electricity are produced in addition to ethanol. The energy profit is 1:5 (Lantmännen Energi, February 2008). 2.6 kg wheat gives 1 liter of ethanol and 0.85 kg fodder pellets for cattle. As of October 2008 550 000 tons of grain

will give about 210 000 m^3 ethanol. That is a great part of the ethanol regularly added to petrol. 5.5 millions m^3 of petrol was in 2005 consumed in Sweden and addition of 5.5 % ethanol means 275 000 m^3 (Lantmännen Agroetanol, www.agroetanol.se). The production of ethanol from cereal crops amounted to 0.3 TWh in 2005 and will increase to 1.2 TWh in 2008 (ER 2008:04). Ethanol is also produced from sugar in spent liquors from pulp mills where the sulfite process is used.

RME is made from rapeseed in Knislinge, Karlshamn, Kungsör and Stenungsund. The Swedish RME production in 2005 amounted to 1.1 TWh, 0.6 of which was produced from imported rapeseed oil (ER 2008:04). Expanded facilities for production of biodiesel are being built in Stenungsund and Karlshamn.

Biogas is produced from wastewater sludge, manure and other types of organic waste in many towns, particularly Stockholm, Göteborg and Linköping.

THE SECOND GENERATION of biofuels for transport can come into production within the next decade. They are based on lignocellulose from forests and farms. This group includes ethanol produced from forest biomass using improved techniques and various automotive fuels that can be produced through gasification of biomass to syngas. Syngas can be converted to methanol, DME (dimethyl ether), synthetic diesel (Fischer-Tropsch diesel) and biomethane.

Experimental facilities for production of ethanol from cellulose are planned or already running in Umeå, Skellefteå, Örnsköldsvik and Sveg. In view of the dominant role of forest biomass as biofuel in Sweden, it is imperative to develop new and improved production methods. (This information comes from appendix 5 of SOU 2007:36.)

Second generation liquid fuels from forest feedstock offer interesting possibilities. Ongoing projects in Örnsköldsvik aim to establish processes that can be used on an industrial scale to break down cellulose and produce ethanol through fermentation of the resulting hexoses and ultimately also pentoses. Experiments are being done in Piteå aimed at producing syngas through gasification of black liquor for production of both methanol and DME to replace gasoline and diesel fuel. Similar experiments on forest biomass are being initiated in Värnamo at the gasification facility built by Sydkraft in the early 1990s. It is hoped that production of second generation automotive fuel can reach full industrial scale within ten years' time. Cautious estimates suggest that 10 TWh of domestic automotive fuel from forest biomass could be produced around 2020. From an international perspective, there is great promise for production of second generation liquid fuel from field and forest waste, according to a recent IEA prognosis. It appears realistic to achieve the

goal set by EU, namely that 10% of all automotive fuel should originate from biofuels by 2020.

But several factors may limit future production of biofuel for transportation. One such factor is the amount of energy required to produce biofuels. In most cases it is better to use the energy directly than to take the long route via cultivation of energy crops. This view is held by emergy experts, Sergio Ulgiati and Torbjörn Rydberg among them. Their opinion is supported by Johan Falk in an article in the weekly science magazine Forskning & Framsteg, where he expresses strong reservations about ethanol production, particularly from American corn.

The climate effects of biofuels are also being called into doubt. In a recent study, a research team headed by Nobel Laureate Paul Crutzen showed that the crops most commonly grown for use as biofuels (corn, rapeseed, sugar cane) release twice as much greenhouse gases as assumed in IPCC calculations (Crutzen et al. 2007). Microorganisms transform the nitrogen in fertilizers into nitrogen oxides. The crops included in the study thus have a climate impact equal to or larger than that of fossil fuels.

THE THIRD GENERATION fuels can be anticipated in about fifty years. Among this group the most important is hydrogen for fuel cells. Hydrogen gas can be produced through electrolysis of water, but this requires a lot of electricity which must be produced from renewable energy sources. At high temperatures, exceeding 900°C, water also decomposes into hydrogen and oxygen.

10. Oil Commission proposals

The Commission Against Oil Dependency was established by the previous government, with Prime Minister Göran Persson as Chairman. The current government has not altered the ambitious goals; the commission report has been sent out for consideration and the government is awaiting the outcome. The Commission proposes several specific measures to reduce Sweden's dependency on oil. Among other things, this will be achieved by improved energy efficiency and substantially increased production of biofuels. The targets for 2020 are, in brief:

- Sweden will improve its energy efficiency by at least 20%
- the amount of gasoline and diesel used for road transportation will decrease by 40-50%
- homes and commercial buildings will be heated essentially without use of oil
- industries will reduce their use of oil by 25-40%

In section 6 we showed that the forestry sector has potential to provide an additional 20 TWh, agriculture at least an additional 10 TWh, peat and peatlands at least 4 TWh, and waste an additional 8 TWh. There is good agreement between the estimates of the Royal Swedish Academy of Sciences and the Oil Commission (p 45 in the Oil Commission's report).

The Royal Swedish Academy of Sciences' comment on the Oil Commission's report (Öquist and Hedberg, 2007), contains an illustrative example. If use of electricity from climate-neutral sources (water, wind and nuclear power) increases by 12 TWh, and use of electricity from biofuels increases by 16 TWh, this would allow reduced oil import corresponding to 75 TWh. Provided that the development of electrically fueled plug-in cars continues and nuclear power is not phased out, the Oil Commission's proposals should be feasible. It is worth noting that transition from oil to electricity automatically entails a considerable efficiency increase.

11. Terminology, definitions and abbreviations

(See also Definitions on p 1)

BIODIESEL: usually RME or FAME

BIOGAS: gaseous biofuel consisting of about 60% methane (CH4) and 40% carbon dioxide (CO_2)

BLACK LIQUOR: byproduct of paper production; contains lignin; is burned in special furnaces to permit recovery of chemicals used in paper production; the resulting heat is used locally in production processes at the paper mill or for generation of electricity

BOOSTER TECHNIQUE: supplementary facility for soda recovery furnaces

CARBON SINK: a process that binds carbon and removes it from the atmosphere; for example, forests take up carbon dioxide during photosynthesis

COGENERATION FACILITY: facility where more than one type of energy carrier is produced simultaneously, e.g. electricity, heat, liquid fuel

DDGS: distiller's dried grains, byproduct of ethanol production that can be used as fodder

DIESEL: fuel for diesel engines; synonyms include diesel oil, diesel fuel, diesel fuel oil

DIGESTION: anaerobic (without oxygen) biological breakdown of biomass

DME: Dimethyl ether. The lightest ether, used in modified diesel engines

E85: automotive fuel containing 85% ethanol and 15% gasoline (volume %)

EMERGY: the sum of all energy of a specific type required to produce a commodity, service or fuel

EMERGY ANALYSIS: includes all energy flows, both from renewable sources (solar, wind and water power) and non-renewable sources (diesel, phosphorous and machines) and human labor

ENERGY CONTENT: different fuels contain different amounts of energy relative to gasoline. Ethanol, for instance, has a 25-35% lower energy content than gasoline

ENERGY QUALITY: different types of energy differ in their ability to produce goods and services. Electric energy has quality factor 1

EXERGY: a measure of utilizable energy, that is, the amount that can be put to work

FAME: fatty acid methyl ester

FERMENTATION: in this context, fermentation to alcohol; yeast and bacteria convert sugar and starch to ethanol and carbon dioxide

FT METHOD: developed by the German chemists Fischer and Tropsch during World War II. A catalytic chemical process in which carbon monoxide and hydrogen are transformed into various types of liquid hydrocarbons

FTD: Fischer-Tropsch diesel. Produced from synthesis gas through the FT method from coal, natural gas or biomass

FTG: Fischer-Tropsch gasoline. Synthetic gasoline produced in the same way as FTD.

GASIFICATION: decomposition of plant material with the aid of heat (pyrolysis)

GEOTHERMAL ENERGY: energy extracted from the Earth's core

GTL: gas-to-liquid; production of liquid fuels from natural gas

HYDROLYSIS: chemical process in which a chemical bond is broken through a reaction with water

IEA: International Energy Agency

LCA: life cycle analysis

LIGNIN: organic compound in the cell wall of plants; is found in black liquor and has a high energy content

LPG: liquid petroleum gas; propane, butane or a mixture of the two, which is liquid at relatively low pressure

NATURAL GAS: a fossil fuel consisting of about 90% methane. Manufactured coal gas, "town gas", is also a fossil fuel. (Natural gas must not be confused with biogas.)

POWER PLANTS: there are three types. Condensation power plants produce electricity exclusively; heat that is simultaneously generated is not put to use. Combined heat and condensation power plants produce both electricity and heat; the condensed steam is used for district heating. District heating plants produce only hot water for district heating

RENEWABLE ENERGY: originates from biomass, solar radiation, wind or water

RME: rapeseed methyl ester. Is re-esterified with methanol. For diesel engines

SALIX: genus of plants of which about 30 species grow in Sweden. The species most commonly used for plant breeding are basket willow (*Salix viminalis*) and thick-branched willow (*Salix dasyclados*). Hybrids are used for energy forests

SYNTHESIS GAS (SYNGAS): gas consisting of hydrogen and carbon monoxide, which is made from natural gas or through gasification of coal or biomass

12. Reference literature, sources

12a. Hearings and symposia

Skansen, Stockholm, 24-25 April 2006: "What are the implications of a future oil shortage?" Organizers: the Royal Swedish Academy of Agriculture and Forestry and the Swedish University of Agricultural Sciences. Report: Helmfrid, H. and Haden A. 2006. After the oil peak. How can we establish preparedness when visions of the future diverge? [In Swedish]

The Royal Swedish Academy of Sciences, Stockholm, 6 November 2006: Symposium "Biofuels – After the Oil Commission." Organizers: Energy Committee and Environmental Committee of the Royal Swedish Academy of Sciences, and the Royal Swedish Academy of Agriculture and Forestry. [In Swedish]

The Swedish University of Agricultural Sciences, Uppsala, 28-29 November 2006: "The forest – against oil dependency, for climate goals." Organizers: the Swedish University of Agricultural Sciences, Faculty of Natural Resources and Agricultural Sciences, and Faculty of Forest Sciences. [In Swedish]

Royal Swedish Academy of Engineering Sciences, Stockholm, 6 February 2007. Hearing with George Weyerhaeuser, Jr., Senior Fellow, World Business Council for Sustainable Development, Geneva, Switzerland; Prof. Donato Aranda, Federal University of Rio de Janeiro, Brazil. Organizer: Sven Kullander.

Royal Swedish Academy of Engineering Sciences, Stockholm, 7 February 2007. Symposium "The Future of Forest Bioenergy". Organizer: the Royal Swedish Academy of Engineering Sciences.

Ångström Laboratory, Uppsala, 22 February 2007. Hearing with Jan Fryk, Peter Hagström, Per Olov Nilsson, Lars Ohlander, Matti Parikka and Lars Tegnér. Organizer: Sven Kullander. [In Swedish]

Royal Swedish Academy of Engineering Sciences, Stockholm, 18 April 2007. Symposium in conjunction with presentation of the book "Energy – possibilities and dilemmas", emanating from the Royal Swedish Academy of Engineering Sciences and Royal Swedish Academy of Sciences project "Science and Everyday Life – Energy Aspects"; chairperson Bengt Kasemo. Book project manager Eva Stattin. [In Swedish]

12b. Reports, investigations, compilations

On the road to an oil-free Sweden. Commission Against Oil Dependency. Göran Persson, chairperson; Stefan Edman and Anders Nylander, secretaries. The Prime Minister's Office, June 2006, 67 pages, 3 appendices. [In Swedish]

Bioenergy from agriculture – a growing resource SOU 2007:36. Lars Andersson, expert consultant, Anders Lundin, executive secretary, May 2007, 496 pages, 5 appendices. (Also known as "The Andersson Report") Stockholm 2007. [In Swedish]

Bioenergy from agriculture – a growing resource SOU 2007:36, appendices. Two reports published in 2005 by Pål Börjesson: *Premises for production of biofuels in Swedish agriculture*, pp 5-126, and *Breeding and marketing of agricultural biofuels*, pp 127-278. Stockholm 2007. [In Swedish]

Bioenergy – for what and how much? Formas Fokuserar. Editor Birgitta Johansson, Swedish Research Council Formas. Stockholm 2008. 403 pages.

The Energy Situation 2006. Report from the Swedish Energy Agency. 66 pages. [In Swedish]

ER 2008:04. Potential market of biomass for the production of electricity, heat and automotive fuel. Report from the Swedish Energy Agency by Karin Ericsson and Pål Börjesson. 77 pages, 6 appendices. [In Swedish with English summary]

Biomass flows in Swedish forestry 2004. Report 23/2006, Swedish Forest Agency. Author Per Olov Nilsson. 13 pages. [In Swedish]

Biofuels from the forest. Supply and demand. Report from the Swedish Forest Industries Federation, 2006. 7 pages. [In Swedish]

Automotive fuel from forest materials – techniques, development status, costs and need for forest materials. Report from ÅF-Process AB, 2006. 54 pages. A brochure with the same title, based on the ÅF report, has been published by the Swedish Forest Industries Federation, 2006, 11 pages. [In Swedish]

Costs for and availability of forest fuels in the medium-range perspective. SIMS report no. 51, Swedish University of Agricultural Sciences 1998. Authors: Göran Lönner, Bengt-Olof Danielsson, Björn Vikinge, Matti Parikka, Bo Hektor, Per Olov Nilsson. 116 pages. 14 appendices. [In Swedish]

Food and Agricultural Statistics Global Outlook, World Profile. Food and Agriculture Organization of the United Nations, FAO 2006.

http://faostat.fao.org/default.aspx

Forest Bioenergy 2004. United Nations Food and Agriculture Organization, FAO. www.fao.org/forestry/site/28679/en

United Nations Global Forest Resource Assessment 2005, Global Tables. United Nations Food and Agriculture Organization, FAO. www.fao.org/forestry/site/32178/en

Potential Contribution of Bioenergy to the World's Future Energy Demand. International Energy Agency, IEA Bioenergy: ExCo: 2007: 02. http://www.idahoforests.org/img/pdf/PotentialContribution.pdf

Market survey: Ethanol, an agricultural and industrial product. Swedish Board of Agriculture, Report 2006:11. http://www2.sjv.se/webdav/files/SJV/trycksaker/Pdf_rapporter/ra06_11.pdf [In Swedish]

Millennium Ecosystem Assessment, Living beyond our means: Natural assets and human well-being, Statement from the Board, 2005.

Well-to-wheels analysis of future automotive fuels and future drivelines in a European context. A summary compiled by the Swedish Petroleum Institute, 2006. 22 pages. [In Swedish]

Additional information may be obtained from the following links:

Swedish Waste Management, www.avfallsverige.se

Swedish Environmental Protection Agency, www.naturvardsverket.se

12c. Articles, book chapters, lectures

Börjesson, Pål. 2008. "Bioenergy systems – which are the most efficient?" *Bioenergy – for what and how much?*: 133-148.

Crutzen, P.J. et al. 2007. "N_2O release from agro-bio-fuel production negates global warming reduction by replacing fossil fuels." *Atmos. Chem. Phys. Discuss.*, 2007(7): 11191-11205.

Falk, Johan. 2007. "Ethanol – a waste of resources and energy." *Forskning & Framsteg* Issue 7, October-November 2007: 12-14. [In Swedish]

Fryk, Jan. 2007. "Forest biomass production in Sweden – Future potentials." Lecture at the Royal Swedish Academy of Engineering Sciences Symposium *The future of forest bioenergy*, Stockholm, 7 February 2007.

Hagström, Peter. 2006. "How big is Sweden's bioenergy potential?" *Fakta skog* 1, 2006. About research at the Swedish University of Agricultural Sciences. 4 pages. [In Swedish]

Hånell, Björn. 2006. "Treat peat forests the right way and they will grow like crazy. The forest – against oil dependency, for climate goals" pp 14-15 (abstract). *The Forest Conference*, 28-29 November 2006. [In Swedish]

Linder, Sune; Bergh, Johan; Lundmark, Tomas. 2008. "Fertilization for more raw material from the forest! *Bioenergy – for what and how much?*: 215-228.

Nordberg, Åke. 2008. "Biogas - can a little become a lot?" *Bioenergy – for what and how much?*: 201-214.

Olsson, Olle. 2006. *The Swedish biofuel market – studies of Swedish foreign biofuel trade and of the consequences of hurricane Gudrun*. Degree project, May 2006, 59 pages excluding appendices.

Parikka, Matti. 2006. Biomass and bioenergy in Sweden. Powerpoint presentation. 32 pages.

Rensfelt, Erik. 2008. "Gasification of biomass - from producer gas to synthesis gas." *Bioenergy – for what and how much?*: 183-200.

Rosvall, Ola. 2007. *Production potential far exceeds current growth* – background material for a lecture on the theme: *Forestry for the future*. The Royal Swedish Academy of Agriculture and Forestry. 8 February 2007. 16 pages. [In Swedish]

Rydberg, Torbjörn. 2008. "Today's analysis methods create overconfidence in bioenergy." *Bioenergy – for what and how much?*: 149-166.

Tegnér, Lars. 2007. Two summaries prepared for the Automotive Fuel Group of the Energy Committee 11 June 2007: *Biomass into automotive fuel* (16 pages) and *Black liquor gasification* (8 pages). [In Swedish]

Ulgiati, Sergio. 2001. "A comprehensive energy and economic assessment of biofuels: When "green" is not enough." *Critical Reviews in Plant Sciences*, 20(1): 71-106.

Vainult, Jan. 2007. "Supergrass gives record yields." ATL 31 August 2007 (Article in *Lantbrukets affärstidning*). [In Swedish]

Ågren, Göran; Hyvönen-Olsson, Riitta. 2006. "Will biogeochemical cycles work if we use more biofuel?" *Fakta skog* 3, 2006. About research at the Swedish University of Agricultural Sciences. 4 pages. [In Swedish]

Öquist, Gunnar; Hedberg, Dick. 2007. Comment on the report "*On the road to an oil-free Sweden".* [In Swedish]

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