The future of bioenergy in Sweden

– Background and summary of outstanding issues

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The future of bioenergy in Sweden
– Background and summary of outstanding issues

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Preface

This report is intended to give a background to discussions about the future of bioenergy in Sweden. It deals with possible future domestic supply of biomass, and possible future demands. Conflicts of interest and other potential uses of biomass are discussed. A global perspective is also given, as well as a discussion of outstanding issues and proposals for further studies.

The report should be of interest to all involved in planning for future bioenergy related activities. Authors are Göran Berndes, Department of Energy and Environment, Physical Resource Theory, Chalmers University of Technology and Leif Magnusson, EnerGia Konsulterande Ingenjörer AB.

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Content

1 Summary

This report is intended to give a background to discussions about the future of bioenergy in Sweden, to be used by the Swedish Energy Agency in the planning of future efforts in the biofuel supply chain.

An overview of the present supply and use of biomass in Sweden is given, and trends and prospects for increased use of bioenergy in Sweden are assessed. Both sources of increased bioenergy demand and possibilities for increased domestic supply are treated. Biomass contributes about 110 TWh, or one fifth of the Swedish energy supply. Biomass is mainly used for energy within the forest industry, in district heating plants, in the residential sector and for electricity production. More than 50% of the heat comes from biomass today. Based on a number of studies it is concluded that there is a potential for a substantial increase in the Swedish biofuel use, by introduction of new forest management practices and a re-orientation of agriculture.

Calculations indicate that there is scope for a substantial increase in bioenergy use in Sweden and that the Swedish bioenergy potential is large enough to accommodate such an increase. However, related to the aspirations in the EC biofuel directive and the hopes that Sweden by taking early steps could become a major supplier of liquid biofuels in EU, it is also shown that Sweden to a significant extent would need to rely on imported bioenergy (biomass feedstock at the magnitude 100 TWh) in order to supply a biofuels industry capable of providing for the domestic market and also exporting substantial volumes of liquid biofuels to Europe.

The prospects for a large-scale import of biofuels are discussed based on an analysis of the potential global biomass production and use in forestry and agriculture. A number of issues of great importance for increased biomass use are discussed – competitive land uses, availability of water, international trade rules, and international politics.

The report also discusses additional and new uses of biomass as raw material for the production of renewable materials and chemicals in addition to the established uses in for instance the forest and wood material industries. Europe and the US are promoting biomaterials in agricultural and energy policy measures, and high oil prices have increased their competitiveness. A large interest is addressed to “biorefineries” as an efficient component in the production of both biofuels and materials.

The report is concluded with a discussion of outstanding issues and proposals for further studies.

2 Summary in Swedish

Denna rapport syftar till att ge underlag för diskussioner om biomassans framtida roll i Sverige, som industriell råvara och för produktion av värme, el och drivmedel.

Inledningsvis ges en redogörelse för nuvarande situation och trender.

Biomassa står i dag för ungefär 110 TWh, motsvarande en femtedel av den svenska energitillförseln. Råvarubasen består huvudsakligen av skoglig biomassa och en stor del av den svenska bioenergianvändningen sker inom skogsindustrin. Jordbrukets bidrag till den svenska bioenergitillförseln är liten: omkring 1 TWh tillförs huvudsakligen i form av strå, energispannmål och lignocellulosaväxter (främst Salix).

Betydande mängder biomassa används inom fjärrvärmeproduktionen, i form av småskalig eldning för uppvärmningsändamål samt för elgenerering. Mer än halva värmeproduktionen i Sverige är baserad på biomassa, medan ungefär 5% av elproduktionen är biomassabaserad. Biodrivmedelsanvändningen utgör ca 2% av den totala svenska transportbränsleanvändningen, och biodrivmedel förekommer till övervägande delen som låginblandad etanol i bensin.

Sverige ligger långt framme internationellt vad gäller produktion och användning av biomassa för energiändamål. Samtidigt kan konstateras att trots tillräckliga inhemska resurser (i förhållande till det nuvarande behovet) så förekommer import av biomassa för energiändamål pga att nuvarande skatter och regelverk i Sverige och andra länder resulterat i att detta är ekonomiskt fördelaktigt. På längre sikt kan skillnader mellan länder (framförallt inom EU) vad gäller styrmedel och regelverk förväntas minska och därmed bör en del av drivkraften bakom nuvarande import försvinna. Den framtida omfattningen av biobränsleimporten som idag förekommer pga att produktions-kostnaderna i andra delar av världen är lägre än i Sverige (t ex brasiliansk etanol) avgörs av prisutvecklingen för sådana bränslen internationellt samt av utformningen av specifika instrument (t ex tullar) för att värna den inhemska produktionen. Sannolikt kommer man eftersträva en balans mellan import och inhemsk produktion för att så långt möjligt förena kostnadseffektiv introduktion av biobränslen och stimulans av den inhemska produktionen.

Därefter behandlas förutsättningarna för en ökad biomassaanvändning i Sverige, både vad gäller framtida efterfrågan och möjlig inhemsk tillförsel

Baserat på detta konstateras att i Sverige finns en ännu outnyttjad potential som möjliggör en omfattande expansion av bioenergitillförseln baserat på inhemsk råvara. Det är också så att det både inom värmeproduktion och t ex kraftvärme finns stora möjligheter att öka biomassaanvändningen. Likaså kommer en utvecklad satsning på alternativa drivmedel leda till en ökad biomassaanvändning för energiändamål. Samtidigt konstateras att om det inom hela EU sker en utveckling mot en relativ hög andel biodrivmedel i transportsektorn (säg 20%) – och om Sverige genom storskalig produktion skulle bidra på ett signifikant sätt till biodrivmedelsförsörjningen inom EU– så skulle sannolikt biomassa behöva importeras för att tillgodose råvarubehovet.

Möjligheterna för en storskalig import av biomassa och biodrivmedel behandlas.

En beskrivning ges av de globala biomassaflödena inom skogs- och jordbruk och dessa jämförs med den nuvarande energianvändningen i världen. Det konstateras att för att bioenergianvändningen skall kunna öka till en nivå av betydelse i ett klimatperspektiv, så krävs det en omfattande produktion av energigrödor. Restproduktflödena inom skogs- och jordbruket är inte tillräckligt stora för att kunna tillgodose en sådan biomassaefterfrågan. När det gäller petroleumbaserade produkter är det annorlunda. Här utgör sannolikt inte (fysiska) råvarubegränsningar ett hinder.

Baserat på en kort genomgång av två studier av framtida globala biomassatillgångar ges en bild av vilka regioner som kan tänkas växa fram som nettoexportörer respektive – importörer av biomassa i en framtid med stor efterfrågan på biomassa för energi- och materialändamål. EU är en av de regioner som förväntas behöva importera biomassa för att tillgodose behovet vid en omfattande användning av biomassa för transport, el och värme. Bland de regioner som kan komma att exportera stora mängder finns länderna i det forna Sovjetunionen, Oceanien och Sydamerika.

Mot bakgrund av en möjlig framtid med omfattande global biomassaanvändning för energiändamål och också storskalig internationell bioenergihandel, pekas några viktiga områden ut.

Dessa innefattar risken för att biomassaefterfrågan skall leda till konkurrens om befintlig jordbruksmark och också omfattande omvandling av naturliga ekosystem till bioenergiplantager. I regioner med begränsad vattentillgång kan omfattande biomassaproduktion leda till ökad konkurrens om vatten och konflikter mellan uppströms och nedströms parter kring vilka prioriteringar som skall gälla vid allokeringen av tillgängliga vattenresurser. Om exempelvis EU planerar att i betydande omfattning tillåta att importerade biobränslen (eller biomassa) utnyttjas för att uppfylla utfästa målnivåer för regionens bioenergianvändning, bör man etablera kriterier och regelsystem som säkerställer att detta inte leder till oacceptabla miljömässiga och socioekonomiska konsekvenser i exporterande länder.

Det finns också möjligheter att tillgodose en växande biomassaefterfrågan genom att etablera produktionssystem som tillhandahåller betydande mervärden. Ett exempel på detta är så kallade multifunktionella biomassaodlingar som exempelvis kan minska erosionsproblem, rena åkerjord från kadmium och skydda vattendrag från övergödning genom att fånga upp näringsrikt vatten från områden med intensiv odling. Det är angeläget att finna former för att stimulera framväxten av sådana odlingssystem.

Biomassaanvändning för andra ändamål än energi och hållningen till bioenergi och biomaterial inom internationell politik och forskning diskuteras.

Bioråvaror från skogen för olika materialanvändningar har en mycket stor ekonomisk betydelse i många länder. Historiskt hade skogsindustrin även en stor roll som leverantör av kemikalier innan petroleumråvara tog över före mitten av förra seklet. Tidigare oljekriser samt jordbruksöverskott har i industriländerna under de senaste decennierna lett till ett ökat intresse för att utveckla olika materialanvändningar för skogs- och jordbruksråvaror, för att tillverka förnybara plaster och kompositer, smörjmedel, lösningsmedel m.m. ”Gröna” material har dock haft svårt att konkurrera med etablerade petroleumbaserade produkter, främst av kostnadsskäl, och det är endast inom några få tillämpningar de har fått fotfäste på marknaden.

Förutsättningarna för biobaserade material har förbättrats starkt de senaste åren. Ett högt oljepris fördyrar petroleumbaserade material, jordbrukspolitiken i EU och USA söker alternativ till livsmedelsproduktion för jordbruket, och USA och EU söker av säkerhetsskäl aktivt minska oljeberoendet både när det gäller energi och material. Inom energipolitik och forskningspolitik riktas stort intresse mot ”bioraffinaderier”. Ett exempel på bioraffinaderi med koppling till skogsindustrin är svartlutsförgasning, där luten från sulfatmassatillverkning förgasas och där gasen kan användas för tillverkning av drivmedel eller användas för elproduktion. Ett annat är alternativa processer för massatillverkning där lignin och hemicellulosa fälls ut och kan användas som kemikalie- eller energiråvara. Andra typer av bioraffinaderier bygger på biotekniska processer, som jäsning av sockerarter för tillverkning av etanol, eller omvandling till mjölksyra för tillverkning av polylaktatplast (PLA). En grundtanke är att i bioraffinaderiet tillvarata mer ur bioråvarorna – material och energi – än enbart en typ av material, för att förbättra utbyte och lönsamhet.
Utvecklingen för bioråvarorna och dess olika användningar för material, energi – och livsmedel – påverkas starkt av politiken och av flera starka aktörsgrupper: jordbruket, skogsindustrin, oljeindustrin, energiföretag och fordonsindustri. I Norden har politiska styrmedel gynnat en stor användning av bioråvaror från skogen för uppvärmning. I USA, men även Sverige, har etanol för drivmedel fått subventioner och ökat starkt. Det finns inte tillräckligt med råvara för att möta de anspråk på råvaran som blir följden av den expansion som från olika håll skisserats. Den fortsatta utvecklingen avgörs i hög grad av politiska beslut inom jordbruks-, handels- och energipolitik, men även av den starka satsning på forskning och utveckling som görs inom i synnerhet fordons- och drivmedelsområdet. För Sverige är värmeproduktion etablerad och ekonomiskt konkurrenskraftig med

dagens regler – men i Europa som helhet kanske drivmedelsanvändningen får högst prioritet?

EU har formulerat mål för en ökad användning av biodrivmedel och för el- och värmeproduktion med bioenergi, men implementeringen i många länder släpar efter. Inom forskningen har bioenergi, bioraffinaderier och nya material från bio-råvaror lyfts fram i det sjunde ramprogrammet. I USA finns flera program som lyfter fram bioråvaror för energi och material, och även en konkret satsning där myndigheter åläggs att välja biobaserade material och energi i sin upphandling. Men det finns många hinder och svårigheter som hämmar en introduktion, både svår konkurrens från etablerade produkter och system och tekniska hinder i form av marknader och lagstiftning.

Avslutningsvis pekas några viktiga områden ut där det finns behov av ytterligare analys.

En kvantitativ översikt över svenska, regionala och globala biomassapotentialer behöver kompletteras med kunskaper kring möjliga konsekvenser av att sådana potentialer realiseras.

Dels handlar det om att bättre förstå hur olika miljö- och resursrelaterade faktorer styr möjlig omfattning och former för biomassaproduktion och uttag inom både skogsekosystem och inom ramen för jordbruk (inklusive biomassaplantager). En omfattande biomassaproduktion för energi och nya material kan komma att påverka flera centrala områden såsom biodiversitet, vattenförsörjning, och markvård. Genom att Sverige deltar i en växande internationell biomassahandel leder politiska ambitioner och utformning av styrmedel till effekter utanför Sveriges gränser. Därför bör man i Sverige inte inskränka sig till att endast fokusera på svenska förhållanden utan aktivt bidra i internationell samverkan till en vid kunskapsuppbyggnad, speciellt med avseende på effekter i utvecklingsländer.

I detta sammanhang är det angeläget att delta i arbetet med att etablera och utveckla kriteriesystem för biomassaproduktion och därigenom verka för att minska omfattningen av oönskade miljö- och socioekonomiska konsekvenser pga en expanderande biomassaproduktion. Utifrån ett betraktande av hittillsvarande konsekvenser av expanderande jordbruk och skoglig produktion i olika delar av världen måste det konstateras att risken för negativa effekter är stor. En viktig fråga i detta sammanhang är hur man uppnår lokal förankring och acceptans för regler och kriteriesystem i länder med otydligt reglerat markägande, begränsad institutionell kapacitet och problem med korruption.
Utöver att hitta former för att begränsa negativa effekter av en växande biomassaproduktion bör man utveckla pro-aktiva strategier som fokuserar på positiva möjligheter. En lovande väg är att utveckla system för biomassaproduktion som även genererar andra miljötjänster (eller ekosystemtjänster) än den skördade biomassan. Svenska erfarenheter av salixproduktion i multifunktionella odlingssystem är

ett exempel på hur sådana produktionssystem kan etableras. Inom detta område ligger Sverige väl framme internationellt.

De erfarenheter som finns i Sverige och också utomlands inom detta område bör tas tillvara och utgöra utgångspunkt för samverkan kring strategier för etablering av multifunktionella odlingssystem för tillhandahållande av ekosystemtjänster i olika delar av världen. Utöver ökade kunskaper kring utformning av specifika odlingssystem behöver också utvecklas incitament och system som möjliggör att leverantörer av ekosystemtjänster belönas. Detta kan t ex vara riktade miljöstöd som belönar leverans av specifika ekosystemtjänster (exempelvis biomassaodling i buffertzoner som fångar upp växtnäringsämnen på samma sätt som våtmarker) eller kontrakt som kan användas av aktörer som samverkar kring multifunktionella produktionssystem (exempelvis biomassaodling i vegetationsfilter som renar förbehandlat kommunalt avloppsvatten).

De av IEA Bioenergy etablerade Task 30, 31 och 40 är exempel på samverkansformer inom ovan nämnda områden där Sverige redan deltar.

En central frågeställning med implikationer för hur man bör utnyttja biomassa som ett led i strävan mot klimat- och energipolitiska mål, är effektiviteten hos olika bioenergisystem. Främst med avseende på nettoenergitillförsel och klimatnytta men också bidraget till att minska oljeberoendet. Flera studier har på senare tid genomförts med målsättningen att bringa klarhet kring olika biobränslens företräden. Det är dock svårt att direkt utläsa om det råder samstämmighet kring vilka bioenergistrategier som är att föredra eftersom metodansatser, data och utgångspunkter skiljer sig åt. Här behövs insatser för att öka kunskaperna inom området och också ge en översiktlig och lättöverskådlig redogörelse för effektiviteten hos olika biobränslen och också hur olika bioenergistrategier bidrar till uppfyllandet av specifika mål.

Det behövs också mer kunskap kring kombinationen energi och material i ett nationellt och internationellt perspektiv. Det behövs kunskap i ett systemperspektiv om resurseffektivitet, klimat- och miljöpåverkan, liksom ekonomi och betydelse för industrins råvaruförsörjning för olika alternativa kombinat för skogliga och agrara råvaror.

Avslutningsvis efterlyses också bredare ansatser till analys av bioenergistrategier, mot bakgrund av möjligheten att energisystemtekniska och andra förutsättningar dramatiskt kan förändras. Det kan t ex handla om en storskalig etablering av fossil- och biomassabaserad kraft med infångning och lagring av koldioxid som minskar kravet på icke-fossil energitillförsel, eller förändringar av transportsystemet mot en dominans av elbaserade urbana transportsystem (inkl elbilar) i kombination med flexifuel/plug-in hybrider som leder till ett dramatiskt minskat behov av vätskebränslen.

3 Preface

This report is intended to give a background to discussions about the future of bioenergy in Sweden. The study has been financed by the Swedish Energy Agency as a basis for their planning of future efforts in the biofuel supply chain. Starting out from the present situation and trends, the prospects for increased use of bioenergy in Sweden is assessed. Both sources of increased bioenergy demand and possibilities for increased domestic supply are treated. Also additional use of biomass as raw material for the production of renewable materials and chemicals is treated. The prospects for large scale import of biofuels and biomass to Sweden is discussed based on assessments of the future global and regional bioenergy demand and supply potential. Possible logistic bottlenecks related to global sea transport capacity as well as characteristics and capacity of Swedish ports are assessed. Finally, outstanding issues are outlined and proposals for further studies are given.

Note: Energy quantities are mostly given in Watt-hours (Wh) in this report, since this is the unit commonly used in Sweden. The quantities can easily be recalculated to the SI unit Joule based on the relation 1 Watt-hour = 3600 Joule.

4 The present supply and use of biomass in Sweden

Presently, biomass contributes about 110 TWh, or one fifth of the Swedish energy supply (see Table 1). Biomass is mainly used for energy within the forest industry, in district heating plants, in the residential sector and for electricity production. More than 50% of the heat comes from biomass today. The contribution in other sectors is smaller: roughly 5% of electricity is biomass-based and about 2 % of the transport fuels used in Sweden is produced from biomass (Energimyndigheten 2005). The main strategy for the introduction of renewable transport fuels in Sweden has been low-level blending of biofuels in gasoline. Today, most of the gasoline in Sweden contains up to 5 percent of ethanol (Energimyndigheten 2004).

The major part of the biomass that is used for energy is produced domestically and the main sources are byproducts and residue flows in the forest sector. Some of these sources have competing uses within the forest industry. Thinning wood can be used for pulp production and sawmill residues can be used for fiberboard production. Other sources, such as felling residues have energetic uses as the only end use. At present, the view is that there is no severe competition between the energetic and other uses of forest biomass. Rather, energetic demand for inferior quality wood from silvicultural operations is regarded beneficial, since it provides incentives for improved forest management leading to increased long term supply of higher quality wood.

In addition to forestry, agriculture contributes to the bioenergy supply, but to a much less extent. Presently, about 1 TWh is provided, mainly in the form of straw, energy cereals, and lignocellulosic energy crops (mainly Salix). Cereals obviously have alternative uses as food or feed, but also the energetic uses of straw have to face competition, primarily from animal production and bedding in stables. A certain share of the straw production also has to be left on the cropland in order to preserve the soil quality. Some energy crops have alternative uses as industrial feedstock, but the major competition is for the cropland rather than the crop.

Salix has been cultivated and delivered to heating plants in Sweden since the early 1990s. Despite this significant time period, Salix production is still an emergent agricultural activity with a small land claim (presently about 15,000 hectares, or 0.5 percent of Swedish arable land). In the mid 1990s, there was stagnation in the establishment of new cultivations in Sweden, leading to a reduced number of enterprises and reduced technology development. However, due to several factors, willow establishment has gained momentum again. In fact, thanks to persistent investment in research in the area of energy crop cultivation, Sweden has taken a lead internationally in research and development of dedicated energy crops such as Salix. In the breeding program run by the company Agrobränsle AB, the emphasis is on increasing the yield, resistance to pests and diseases, and tolerance to frost.

Sweden is also at the forefront internationally what regards so-called multifunctional biomass plantations (MPS). Research and practical implementation of MSPs in Sweden have resulted in the accumulation of valuable knowledge into how Salix cultivation can be located, designed and managed in order to provide additional environmental services. Specific applications of MSPs are becoming established land use practices, and MSPs are increasingly being referred to as a promising option for improving the environmental performance of agriculture. Presently, about 10 % of the municipal wastewater sludge in Sweden is recycled in Salix plantations, and about 25 facilities treat landfill leachate in Salix plantations. A number of municipalities and small villages have established Salix/wastewater treatment systems already. The experiences from these treatment systems are very positive: the Salix plantations deliver high treatment efficiency at low costs and less use of chemicals and energy resources compared with conventional treatment technologies. At Agrobränsle AB, specific varieties for treatment of wastewater and remediation of soils polluted by heavy metals are under development.

Biofuels are also imported from abroad. In the year 2000, Sweden imported 4.5 TWh of biofuels (corresponding to about 4 percent of the present domestic bioenergy use), mainly in the form of solid biomass for heat and power production. In addition, 2.5 TWh of imported pulpwood and timber ended up as fuel (Ericsson and Nilsson 2004). The main import sources were other Nordic countries, the Baltic countries, Russia, The Netherlands and Germany. But significant amounts of tall oil and pellets are also imported from North America.

The Swedish import of solid biofuels has principally been driven by a high domestic demand -induced by carbon taxes- in the district heating system, combined with differences among European countries in energy and waste regulations, taxes and policies, which made export to Sweden the most attractive option (Ericsson and Nilsson 2004). However, due to a gradual harmonization of national policies, and also due to an expected increasing demand for solid biofuels in other member states of the European Union (EU), Swedish import of solid biofuels is projected to decrease (Ericsson and Nilsson 2004, Alakangas et al. 2002). It has even been suggested that Sweden may instead export these fuels in the future (Nikolaisen 2001).

Most of the biofuels for transport that are used in Sweden today is imported. Biodiesel is imported mainly from Denmark and Germany, while the Swedish ethanol is imported from Brazil, France, Spain, Italy and Norway (Sandebring 2004). The import of liquid biofuels has increased rapidly due to recent policy initiatives. The so-called biofuel directive proposes that biofuels should constitute 2 percent (energy content basis) of the total amount of transportation fuels sold in the individual EU countries in 2005, increasing to 5.75 percent in the year 2010 (European Parliament and Council 2003).

Table 1 Swedish biofuel use and import of biofuels during the last five years.

TWh	2000	2001	2002	2003	2004
Biofuel use					
Total[1]	97	97	98	103	110
Transport fuels[2]		0.3	0.6	1.1	1.8
Biofuel import					
Direct import, excl. transport fuels[3]	4.6				
Indirect import[4]	2.6				
Transport fuels[5]			0.14	0.5	

1. Data for 2000-2003 (Energimyndigheten 2001-2004). Data for 2004 (Energimyndigheten 2005). Total biofuel use includes municipal waste and peat, which amounted to about 10% of total biofuel use in 2004 (Energimyndigheten 2005).
2. Calculated from the compilation in Energimyndigheten (2005).
3. Talloil (1.3 TWh), refined solid fuels (pellets etc. 1.2 TWh), chemically treated used wood and mixed solid recovered fuels (0.9 TWh), firewood (0.5 TWh), chemically untreated used wood and separate fractions of paper (0.4 TWh), wood chips (0.2 TWh) and municipal waste (0.1 TWh) (Ericsson & Nilsson 2004).
4. Sawmill by-products (0.8 TWh), pulp mill by-products except black liquor (0.7 TWh), bark and sawdust from other sectors than the forest industry (0.7 TWh) and refined solid fuels (0.3 TWh) (Ericsson & Nilsson 2004).
5. The import of biodiesel was about 0.1 TWh in 2002 and the import of ethanol about 0.1 TWh (SPI 2003, Energimyndigheten 2003). In 2003, about 0.5 TWh of ethanol was imported (Energimyndigheten 2004) and the import of biodiesel was about 0.1 TWh (Sandebring 2004). However, it is difficult to depict the exact amount and origin of the ethanol import since ethanol mixed with a certain amount of petrol is classified as a chemical mixture and thus faces a different (lower) duty (Sandebring 2004, SPI 2003).

5 Expectations for the future

5.1 Swedish bioenergy strategy

Bioenergy is central in the Swedish strategy for the transition to a sustainable energy system and the use of biofuels in Sweden is projected to increase due to carbon abatement policies and other tools established to achieve energy policy targets. The future Swedish demand for biofuels can be met by production based on domestic resources, import of solid and liquid biofuels, and import of biomass feedstocks for subsequent conversion to refined fuels in Sweden. There are many factors influencing the balance between these supply options. Besides physical (e.g., domestic supply potentials) and economical conditions (e.g., cost of imported biofuels), political decisions strongly influence the future bioenergy trade situation.

There are hopes that Sweden, by taking early steps, will gain a strong international position in the future bioenergy field and that large scale biofuels production based on domestic resources –for domestic consumption and also export– can generate substantial employment and export revenues. In addition to biofuels, also Swedish know-how, technology and equipment in the field of bioenergy are considered to have export potential.

Sweden already is at the forefront internationally when it comes to wood supply systems (especially forest biomass but also willow produced on cropland) and also the use of wood for process energy in the forest industry, district heating and combined heat and power generation. There are also initiatives in the field of liquid biofuels. Sweden has two ethanol plants today. The plant in Norrköping produces ethanol based on cereals and in Örnsköldsvik ethanol is produced from a sugar solution obtained by processing paper pulp with atmospheric oxygen. There are discussions about building a new cereal ethanol plant, twice the size in Norrköping (which produces about 50 000 m^3 ethanol per year). Sweden also have three plants for research and demonstration of technologies for so-called second generation biofuels, i.e., lignocellulose based ethanol and also other biofuels based on the gasification of black liquor or other biomass resources. Recently, the consortium *Biofuel Industries* involving, among others, three municipal energy companies in northern Sweden, initiated a study to find a suitable location for the first of three large plants for the production of ethanol based on wood. Also biogas and biodiesel (RME) are domestically produced, but in rather small quantities.

It is acknowledged that cheap imports may stimulate development on the end use level and contribute to reaching policy targets in a cost effective way. At the same time, there are worries that cheap imports may also pose a barrier to the local production of biofuels or biofuel feedstocks[1]. It can be expected that also in the future, the ambition will be to keep biofuels import at a level where it does not become detrimental to the development of domestic supply, technology and know-how in the field of bioenergy. However, in a prospective situation where an early establishment of a Swedish industry for lignocellulose based biofuels production has placed Sweden in a strong position internationally, large scale import of biofuels feedstocks may become a prerequisite for the competitiveness of this industry. Especially, in a situation where Sweden exports large volumes of refined biofuels, domestic resources may not be sufficient, or at least not available at the cost defined by global feedstock markets.

It could be argued that many other European countries could support their own biofuel industry based on the same biomass feedstock import sources. A counter-argument could be that this is true also for, e.g., pulp production for paper, but still Sweden and Finland dominates, presently representing almost one third each of the total pulp production in EU25 (FAOSTAT 2005). Indeed, the forest industry developed within a different historical context, were close availability to the resource base was crucial. But it is a fact that, thanks to know-how in relevant technology and logistics, strong organization and global networks, Finland and Sweden maintain their dominant position as pulp producers, (despite that any country with a coastline could import cheap wood for pulp production). Given that Sweden takes early steps and gains a strong position in the field of liquid biofuels, a similar situation can arise here.

5.2 Prospects for increased domestic biomass supplies

The availability of forest biomass for energy largely depends on the activities in the forest industry: an increased forest product demand may lead to increased availability of forest biomass in the form of felling residues and by-products in the forest industry. However, there is scope for a substantial increase, even if the production of sawn wood, pulp etc. does not increase, since only a relatively small share of the potentially available logging residues is used today (see Table 3). However, the prospective demands sources may require a higher quality than that of forest residues.

[1] The revision of regulations is illustrative of this dual situation; By mixing the ethanol with more than 20% gasoline ethanol, importers have been able to declare the product as chemical products. This leads to much lower customs duty than that for pure ethanol. However, the tax exemption for imported ethanol is suggested to be conditioned on that the ethanol is declared as pure ethanol. This leads to increased market prices, which improves the prospects for Swedish cereal ethanol production to become competitive. However, the new rule only applies for the imported ethanol that goes into low-level gasoline blends (where also Swedish cereal ethanol is used). E85 and pure ethanol for bus fleets can still be produced based on ethanol imports benefiting from both tax exemption and the lower customs duty. The reason is that ethanol buses need cheap ethanol to stay attractive, and also that this segment is not targeted by the Swedish cereal ethanol producer.

Also the supply of biomass for energy in agriculture can increase (Table 3). For example, LRF (2005) suggests that by 2020, it might be possible to supply about 22 TWh/yr based on a range of sources, including straw, food industry waste and different energy crops. The potential further into the future may be even larger, and will primarily depend on how much land that can be dedicated to energy crops production. A selection of studies of the future availability of land for such production is given in Table 2. The areas given in the table can be compared with the present area used for Salix production, at about 15 000 hectare: clearly, if the energy crop production in Sweden expands to a scale similar to that indicated in Table 2, the contribution to the Swedish energy supply would become substantial.

Thus, in the near to medium term, physical restrictions on domestic feedstock availability will not constrain increased biofuel use in Sweden. Instead, biofuels import will be driven by cost competitiveness rather than by Swedish need to overcome resource constraints on further expansion. But in the longer term, with a substantial increase of Swedish bioenergy use and with a Swedish export of refined biofuels, e.g., to the European market, the situation might be different.

Table 2 Results from a selection of studies of the future availability of Swedish cropland for energy crop production.

Reference	Land available for bioenergy production (ha)	Comments
Biobränslekommissionen 1992	800 000	Estimate for 2005
SNV 1997, “Stigfinnare”	553 000 (1 953 000)	475 000 ha energy forests and 75 000 ha energy grasses. The higher number includes 1.4 Mha of land used for extensive production of broad-leaf trees or reed canary grass.
SNV 1997, “Vägvinnare”	458 000 (807 000)	458 000 ha energy grasses. Sensitivity analyses including higher yields in production of cereals and other crops indicate slightly above 800 000 ha of available land.
SNV 1997, ”Målbild”	650 000	384 000 ha energy forests and 266 000 ha energy grasses.
LRF 1995	400 000	Estimate for 2020. 300 000 ha Salix and 100 000 ha wheat and rape seed.
LRF 2005	500 000-600 00	Refers to the area presently used for export crops and unused fallow land.

5.3 Comparing domestic biomass supply potentials with prospective demand

In Table 3, one estimate of the domestic bioenergy potential is compared to demand for biofuels related to scenarios for increased diffusion of bioenergy in domestic energy applications. Also, the biomass feedstock demand arising from a predefined biofuels export is given. Note that the numbers in Table 3 are not intended as projections of the most likely development in the bioenergy field in Sweden up to any specific year. The purpose of Table 3 is solely to provide perspectives on the scale of Swedish supply potentials in relation to that of different possible demand sources. Both the supply and the demand could be made both larger and smaller by adjusting crucial parameters whose future level cannot be narrowly defined. Additional demand sources could arise from, e.g., substitution of oil for heat in industry. Increased supply could come from, e.g., increased utilization of demolition wood and municipal organic waste.

Several conclusions can be made from the above comparison. First of all: if the domestic biomass use for energy expands in line with what is given in Table 3, the Swedish bioenergy use would essentially double. At the same time, it appears from Table 3 that the Swedish bioenergy potential is large enough to accommodate such a substantial increase in the Swedish biofuel use. Note though, increasing the biomass supply for energy to such an amount implies both new forest management practices (optimized fertilization) and a re-orientation of agriculture to comprise biomass production for energy as one of the major activities.

However, it is also clear that Sweden to a significant extent will need to rely on imported biofuels (biomass feedstock at the magnitude 100 TWh) in order to be able to also support a prospective biofuels industry capable of exporting substantial volumes of liquid biofuels to Europe (substantial in the perspective of transport fuel demand in EU25). If ambitious EU targets for alternative transport fuels become realized while also complying with requirements for a certain level of internal production –and if Sweden succeeds in establishing a competitive biofuels industry– Sweden could become a major European supplier of liquid biofuels. Even if such a scenario implies import of very large volumes of biomass as feedstock for the biofuels production, it might still be the case if the biofuels can be imported to Sweden at low enough costs.

The cost of biofuel imports will of course be crucial. In the next Section, selected issues that are judged crucial for the costs of imported biomass are discussed.

Table 3 Assessed possible domestic increase in biofuel supply and a comparison with the scale of possible sources of increased demand.

Sources of increased demand	*(TWh/year)*
High level of utilization of biofuels in the district heating system and 80% substitution of oil for heating of individual homes, mainly by wood pellets [1]	24
Electricity production in the Swedish district heating systems (DHS) and forest industries by combined heat and power production. Gasification- & combined cycle technologies in large DHS's and steam turbines in small DHS's. Maximum integration within the forest industry to increase heat sinks [2]	50
Domestic production of liquid biofuels corresponding to 20% of the projected final energy demand in the Swedish transport sector year 2020 [3]	41
Export of liquid biofuels to Europe: Sweden supplies 10% of the biofuels required if EU25 uses biofuels for transport corresponding to 20% of the projected final transport energy demand in 2020 [3]	199
Sources of increased domestic supply	*(TWh/year)*
Forest fuels – conventional forestry [4]	50
Forest fuels – optimized fertilization on 20% forest land [5]	25
Energy crops [7]	33
Straw [8]	7

1. Based on projected extension of district heating system to 2020 (Börjesson et al. 2002, Börjesson 2001).
2. (Börjesson et al. 2002, Börjesson 2001).
3. (EC DG-TREN 2003). Based on that liquid biofuels are produced from biomass at an efficiency of 50%.
4. The Swedish Bioenergy Association estimates the total forest fuel potential at 136 TWh/yr (Svebio 2003), which minus current use of domestic forest fuels of 86 TWh/yr (Energimyndigheten 2004) is equivalent to a potential increase of 50 TWh/yr. Other estimates indicate that additional volumes could become available from new silvicultural practices.
5. Additional amounts of forest fuels based on the judgment that optimized fertilization on 20% of Swedish forest land could be feasible due to economical, geographical and technical conditions (Börjesson 2001, Andersson et al. 2001).
6. (Svebio 2003).
7. Based on energy crop production on 600 000 hectares (equivalent to about 20% of current arable land) and an average yield level corresponding to 56 MWh/ha/year. For a selection of estimates of future land availability, see Table 2.
8. (LRF 2005). Restrictions due to competing uses (feed and bedding), soil conservation requirements and climate, leads to a theoretical potential given present cultivation practices at about 15-19 TWh/year. Of this, about 7 TWh/year is considered a feasible target.

6 Prospects for large scale Swedish biomass and bioenergy import from abroad

The existing situation, where Sweden imports biofuels from other continents, is proof of that international bioenergy trade is feasible at least on the present scale and under the present policy regime (including, e.g., customs duties). But what volumes could become available for trade between world regions in the future?

6.1 The global and regional bioenergy supply potential

Some analysts dismiss biomass as an important future renewable resource, especially in the context of energy system transformation and climate stabilization (Hoffert et al. 2002). Others take the opposite view and propose biomass as one of the major future renewable resources (see, e.g., Berndes et al. (2003) for a review of 17 studies of the global bioenergy potential). There is no way to narrowly determine the potential contribution of biomass in a future global industrial society. The aim of this chapter is instead to provide some perspectives on the global potential of bioenergy and point out a few possibly important issues likely to come into focus in a future of extensive use of biomass for energy and as a renewable feedstock in industry.

6.1.1 A comparison of major resource/product flows

Table 4 presents a quantification of the biomass production for food, energy and materials. Other major product and resource flows are included for comparison. Table 4 provides some insights in relation to the discussion of the prospects for biomass to substitute for non-renewable resources in the future. It is evident from the table that the quantitative production of fossil resources is much larger than the biomass production in agriculture and forestry, implying that a far-reaching substitution of fossil resources with biomass would require a dramatic increase in the output from agriculture and forestry.

The situation is different when looking at materials that are presently primarily produced based on petroleum and fossil gas, e.g., plastics, rubber and various bulk chemicals. This production presently uses 5-10 percent of total annual petroleum and gas production and is small compared to the agricultural output. It is also evident from Table 4 that crop production for non-food/feed uses presently occupies a very small part of agricultural land use: the major part of society’s biomass production for material purposes takes place in forestry. However, as will be shown below, agriculture can play a major future role as supplier of renewable feedstocks to industry, substituting for non-renewable fossil resources, both by expanding dedicated production of non-food crops and by utilizing organic waste and residues.

The forest sector generates large amounts of biomass residues, both in the forests and at industrial sites such as sawmills and pulp/ paper plants. Over the years, the forest industry has improved the wood utilization efficiency by cascading residue flows to energetic or lower value material uses. But the potential for increased residue utilization in forestry is large: increased wood extraction in connection to thinning operations and final logging may yield substantial increases in biomass output. The prospects for increased stemwood extraction by extending and/or intensifying conventional forestry operations is an issue where standpoints diverge, depending on different views regarding environmental, technical, legal and economic restrictions (see, e.g., Nilsson 1996).

So far, biomass supply for energy has primarily been based on the utilization of residue flows in agriculture and forestry. An increased bioenergy use will likely involve an expansion of such uses, but will in the longer term require large scale energy crop production and/or forest stemwood extraction if a large contribution should be made (Table 4).

Table 4 Global production of major biomass types in agriculture and forestry, and of selected major products and basic resources[1].

Global product/resource flows	Estimated quantity year 2000 (billion ton dry matter)
Coal production, biomass equivalents[2]	5.0
Fossil gas production, biomass equivalents[2]	5.1
Crude oil production, biomass equivalents[2]	8.5
Cereal production	2.1
Sugar beet and sugar cane	0.4
Pasture and forage (eaten by grazing animals)	4.0
Food crop residues	3.0
Industrial roundwood production	0.8
Forest residues[3]	0.5
Wood fuel production[4]	0.9
Paper and paperboard production	0.3
World plastics production	0.2
Primary fiber crops	0.02

1. Data sources: (Marland et al. 2003, FAOSTAT 2005, RIVM 2004)
2. The fossil resources are given on a biomass equivalent basis (tbe) in order to facilitate a comparison with the different biomass types (conversion based on 1 ton oil equivalent = 2.3 tbe).
3. Indicative of forest biomass availability linked to industrial roundwood production, estimated based on forest sector characteristics given in (Johansson et al. 1993).
4. The fuelwood production data (from FAO) does not include all biomass uses for energy. For example, the FAO fuelwood data for year 2000 corresponds to 25-40% of the global biomass use for energy as estimated by (Turkenburg 2000).

Two recent studies of future bioenergy potentials

Below, some results from two recent studies of the future global and regional bioenergy potentials are presented. The studies are selected since they represent approaches that are based on comprehensive data inventories and modeling that allow for consistency over world regions. They are also useful in the sense that they together illustrate the sensitivity of results for possible variation of some parameters.

The first study, by Wirsenius et al. (2004), is based on a model based assessment[2] of how the global biomass potential is influenced by different long-term development paths in the food and agriculture system. The starting point for the analysis is the recent projections of global agriculture up to 2030 (WA 2015/30) made by the Food and Agriculture Organization of the United Nations (FAO) (Bruinsma 2003). In addition to one "Reference" scenario, depicting the FAO projection of the global food and agriculture system in 2030, three explorative scenarios were developed: "Increased livestock productivity" (IP); "Ruminant meat substitution" (RS); and "More vegetarian food & less food wastage" (VE). Selected major characteristics of the four scenarios are presented in Table 5.

Based on the scenarios, it was examined to what extent increases in livestock and crop productivity, and changes in human diets, may expand the bioenergy potential. In the IP scenario, annual increases of livestock productivity are assumed to be higher than in the FAO study. The assumed productivity growth rates in this scenario are only slightly above the historical rates of the productivity increases since 1960 (see Wirsenius et al. (2004) for more details). The RS scenario has the same productivity growth as the IP scenario, plus a substitution of 20% of the beef, sheep and goat meat end-use with pig and poultry meat. The VE scenario is the same as the RS scenario, but includes also a somewhat increased efficiency in the end-use (i.e. less food wasted) and a shift in the structure of diets towards more vegetable and less animal food in four of the regions (East & West Europe, Latin America & Caribbean, N. America & Oceania). However, in both East Europe and Latin America & Caribbean animal food consumption per capita 2030 is higher than presently.

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[2] Mass- and energy balanced bottom-up modeling of the flows of biomass in the global food and agriculture system, from production on cropland and grassland to intake as food. For eight world regions, the model calculates the necessary production of crops and other terrestrial phytomass from a prescribed end use of food, efficiency in animal food production and vegetable food processing, and use of by-products and residues generated within the system. The total number of individual model flows is roughly 140, and the total number of variables and parameters amounts to about 1,500 (for each region). See Wirsenius (2003) for further information.

Table 5 Major characteristics of scenarios of the food and agriculture system in 2030 (abbreviated scenario names in brackets). Based on Wirsenius et al. (2004).

Scenario	Total food end-use and intake	Share of vegetable and animal foods in diet	Livestock productivity	Livestock feeding base	Crop and pasture yields
"Reference" (Ref)[1]	As in WA 2015/30	As in WA 2015/30	As in WA 2015/30	Adapted to WA 2015/30 as far as possible	As in WA 2015/30 (where applicable)
"Increased livestock productivity" (IP)	As in the scenario "Reference"	As in the scenario "Reference"	More rapid increases in productivity	Adjusted for increased livest. productivity	As in the scenario "Reference"
"Ruminant meat substitution" (RS)	As in the scenario "Reference"	20% ruminant meat substituted with pig and chicken meat	As in the scenario "IP"	As in the scenario "IP"	As in the scenario "Reference"
"More vegetarian food & less food wastage" (VE)	Food end-use efficiency[2] increased by 10% (to maximally 70%).	Pulses, vegetables & fruits increased, and animal food decreased, esp. meat. Total meat decrease no greater than 25% (compared with Ref).	As in the scenario "IP"	As in the scenario "IP"	As in the scenario "Reference"

1. The "Reference" scenario refers to the recent projections of global agriculture up to 2030 made by the Food and Agriculture Organization of the United Nations (FAO) (Bruinsma 2003).
2. "Food end-use" basically refers to the amount of the food supplied on the wholesale level, and is normally referred to as food "consumption" in national statistics. This concept of end-use is used along with the concept "food intake", which represents the amount of food actually eaten. "Food end-use efficiency" is defined as "intake" divided by "end-use". "Feed conversion efficiency" is defined as the amount of carcass (or milk or egg) produced, divided by the amount of feed eaten by the animals; the numerator and denominator are both in gross energy. Data for 1992/94 are from (Wirsenius 2000), and those for 1997/99 are from the FAO study.

The results from the scenarios indicate that if the projections made by the FAO come true, the prospects for non-food crop production will be less favorable. In the scenario depicting the FAO projection, it is estimated that total agricultural land area globally will expand from current 5.1 billion ha to approximately 5.4 billion ha in 2030. This means that a major expansion of non-food crops would require an even further conversion of natural to cultivated land.

However, based on the alternative scenarios it was concluded that if livestock productivity increases faster than projected by the FAO –but still only slightly above the historical rates since 1960– global land requirement may actually decrease to 2030. In a situation where the higher livestock productivity is combined with changes in diets (including a 20 percent substitution of ruminant meat with pig/poultry meat), global agricultural land demand may decrease to 4.2-4.4 billion ha. If the surplus agricultural land was targeted for non-food crop cultivation, a considerable amount of biomass could be produced without claiming land beyond what has already been appropriated.

In the alternative scenarios, also the amount of food-system residues and by-products available for non-food purposes will be higher than in the FAO projection, mainly due to a lower use of crop residues as feed in those scenarios. In the European regions, agricultural land demand decreases also in the Reference scenario, due to decreasing population (-8% from 1998 to 2030) and continuing raises in crop and livestock productivity. This is in contrast to the developing regions, where growing population and increasing food consumption per capita adds to rising land demand. Figure 1 illustrates the development in Europe and Latin America.

The study by Wirsenius et al. (2004) indicates that biomass from surplus cropland and from food sector residues may indeed play a large role as a renewable feedstock and help reduce the present dependence on nonrenewable energy and materials. The scope for establishment of bioenergy plantations on surplus cropland may be considerable: if the food sector development follows a path similar to the RS/VE scenarios, a global biomass supply from plantations in the order of 3-6 billion tonnes per year does not seem to be impossible with regard to the land requirements of food production. Also the potential supply of biomass residues from the food system is impressive, being on the order of 3-4 billion tonnes per year. 10 billion tonnes of biomass, having an average energy content of, say 5 MWh per tonne, equals 50 thousand TWh of primary energy, or about 40 percent of the global primary energy supply. Clearly a substantial contribution. However, it is also clear that food sector development –and especially dietary preferences and the development of animal production efficiency– strongly influence the potential. Also, reductions in post harvest losses (e.g., during storage, processing and retailing) could lead to substantially reduced land demand for food production.

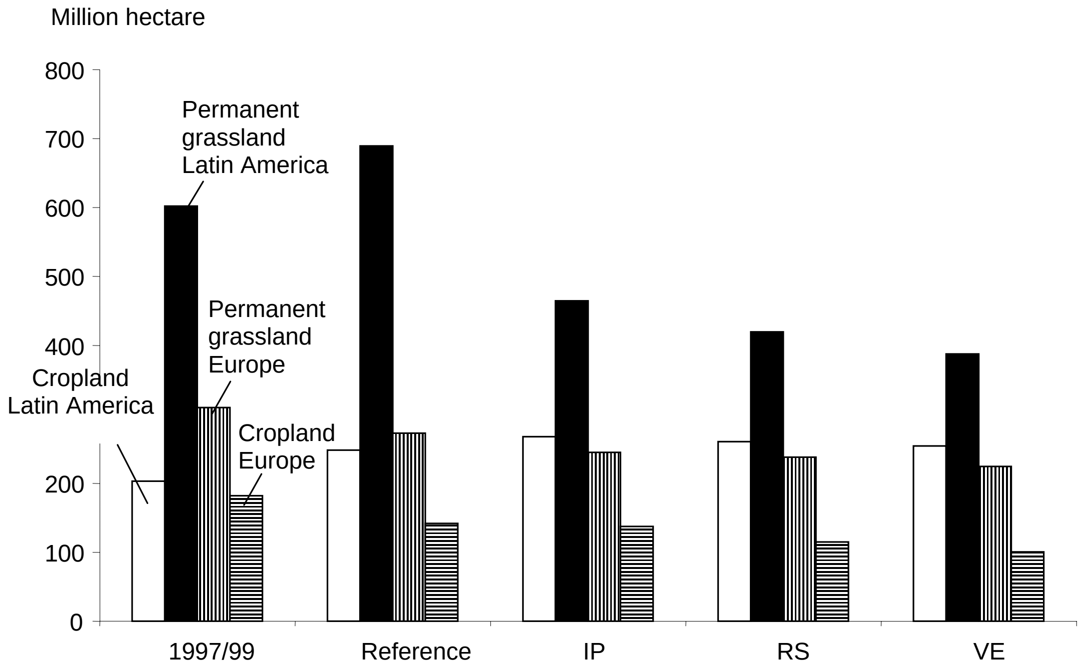

Figure 1 The present and future agricultural land use (four scenarios for 2030). The diagram shows results for W & E Europe (including whole Russia) and Latin America & Caribbean. See Table 5 for a characterization of the scenarios. Based on (Wirsenius et al. 20

The second study by Hoogwijk (2004) focuses solely on the potential future biomass supply from plantations. It is based on modeling studies of land use changes under the four so-called storylines for world development (including climate change) that was developed for the IPCC Special Report on Emission Scenarios[3] (SRES) (IPCC 2000). Energy crops are assumed to be produced on (i) cropland that is no longer required for food production in 2050 and (ii) a "rest land" category including mainly savannah, scrublands and grassland/steppe. Competing land claims (besides food and timber production) such as nature protection, urbanization, and animal grazing are considered through the use of scenario-specific land exclusion factors.

The bioenergy potentials are estimated for different cut off costs, and Figure 2 presents the potential biomass availability at costs below 4 USD/GJ (or about 14 USD/MWh). As can be seen, there are large differences in both global and regional biomass supply potentials between the different scenarios. At the production cost level given in Figure 2 (<14 USD/MWh), the global potential varies from about 50 to 120 thousand TWh/yr. In addition to the food system parameters found crucial in the first study by Wirsenius et al. (2004), also other parameters such as population growth, GDP development, trade patterns, and technological development influence the results.

[3] The storylines are shortly outlined in Appendix A.

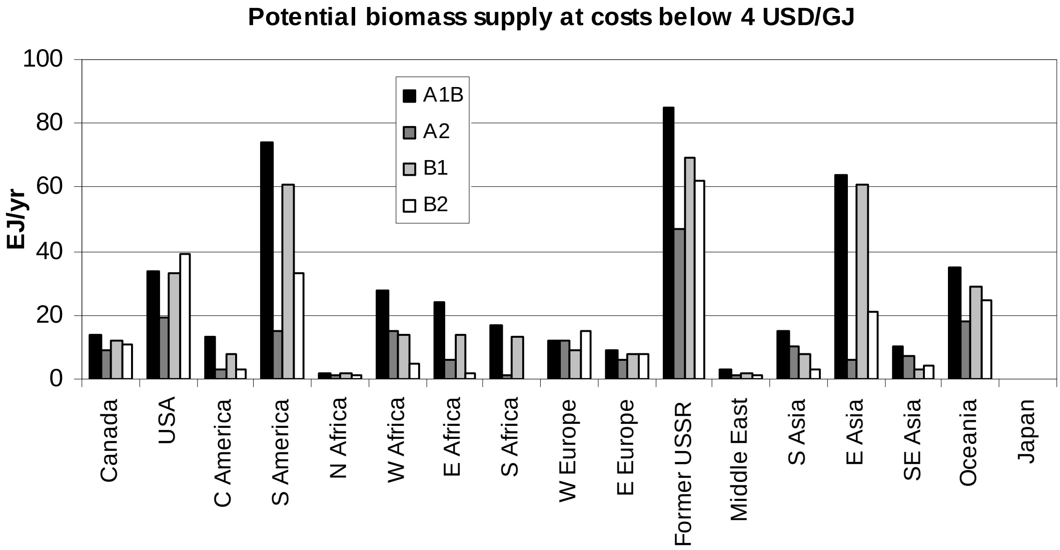

Figure 2 Assessed regional potential biofuel supply from energy crop production in 2050, at costs below 14 USD/MWh. The potential is given in the unit EJ/year, where 1 EJ is equal to about 278 TWh. Based on (Hoogwijk 2004). See Appendix A for a short outline of the four so-called storylines A1B, A2, B1 and B2.

6.2 A comparison of potential biomass supplies with possible future demand in different world regions

In order to obtain an indication of which regions that may have a future biomass supply potential that can outweighs the region's own demand, it is necessary to compare the regional potential biomass supplies with the future regional bio-energy demand level. Since the study by Hoogwijk (2004) is based on scenarios for world development that includes also modeled development of energy demand, it is here used to make a comparison of the future regional biomass supply potentials with possible demands.

The bioenergy demand is calculated assuming that each region uses plantation biomass to meet a specified share of the modeled regional energy demand in 2050 in the four SRES scenarios (IMAGE team 2001). *First*, it is assumed that half of the traditional bioenergy demand in a region is met by plantations. This would reduce the pressure on other supply sources (e.g., harvest residues, dung and wood in the agriculture landscape and forest boundary areas) and mitigate some of the impacts caused by too extensive use of these resources[4]. *Secondly*, biofuels are used to generate electricity corresponding to half the modeled thermal electricity production (which to a large extent is fossil fuel based) assuming a conversion efficiency at 50 percent. *Thirdly*, biomass feedstocks are used to produce transport

[4] Traditional biomass uses for energy (e.g., for cooking, heating and brick making) is still common in many developing countries. It is based on inefficient combustion, often leading to significant local and indoor air pollution and unsustainable use of biomass resources such as native vegetation.

fuels, corresponding to half the modeled transport fuel use (assuming the same efficiency as that of the primary energy supply mix in the transport fuel production in each SRES scenario in 2050).

The results are presented in Figure 3, which gives an indication of possible future exporting and importing regions. As can be seen, at the prescribed bioenergy use, many regions in the world would still be able to export large biofuels volumes (if using their full assessed potential), some even at productions costs below 2 USD/GJ (or about 7 USD/MWh). But there are also regions that would have to import biofuels in order to meet the demand (corresponding to a global level at about 22-42 thousand TWh, depending on scenario).

The aggregated biofuels import demand becomes larger than the aggregated biofuels export potential for several of the scenarios. Especially, the biofuels export potential at the cut off level 7 USD/MWh is lower than the aggregated biofuels import demand in three out of four scenarios. This implies higher biofuels prices on the international market (unless alternative energy technologies substitutes for bioenergy) leading to a very favorable economic situation in regions having a potential to produce large volumes of cheap biomass (<7 USD/MWh) for export.

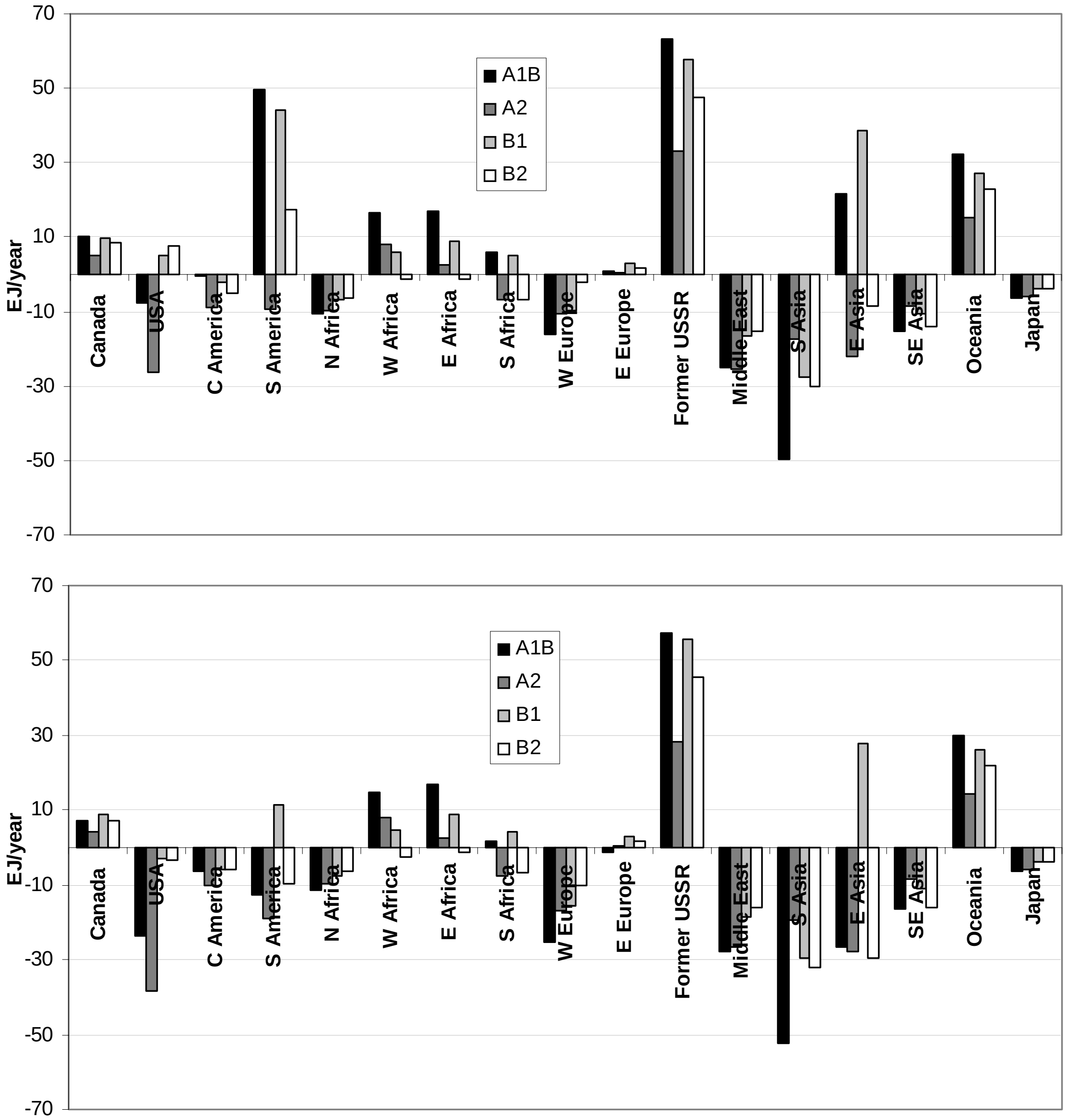

Figure 3 Regional biomass export potential, after that plantation biomass has been used internally in each region according to the specifications given in the text and assuming an energy crop production cost below 14 USD/MWh (upper chart) and 7 USD/MWh (lower chart). The potential is given in the unit EJ/year, where 1 EJ is equal to about 278 TWh. See Appendix A for a short outline of the four so-called storylines A1B, A2, B1 and B2.

6.3 Some critical issues linked to the biomass supply potentials

Clearly, the above calculations are subject to many uncertainties. Still, it appears to be a robust conclusion that there is an imbalance between bioenergy supply potentials and prospective bioenergy demand in the world. It seems also that several regions may be able to supply large volumes of biomass at very competitive prices on the international market. Given that the world aims for ambitious greenhouse gas stabilization targets, it is likely that international biomass trade will take place between regions with surpluses and shortages in order to match supply with demand. If the bioenergy potentials presented above would become realized, biofuels trade flows corresponding to hundreds of exajoules may become traded between regions. Below, a few important issues connected to such a development are pointed out.

Plantation establishment rate

One critical issue for reaching a high bioenergy supply in 2050 relates to the energy plantation establishment rate required. For example, in order to realize the assessed regional potential biomass supply from energy crop production in scenario A1, about 1.3 and 2.3 billion hectares, respectively, of the land categories abandoned cropland and rest land would have to be planted with energy crops. Just planting energy crops on the abandoned cropland (i.e., planting on agricultural land as it is taken out of food production over time) would require that, on average, almost 30 million hectares would have to be planted each year during the coming 45 years. This can be compared to the global annual forest plantation establishment rate, year 2000, which was about 4.5 million hectares (FAO 2001). The total global forest plantation area the same year was estimated at slightly less than 190 million hectares (FAO 2001).

Thus, realizing the indicated potentials requires a large increase in the plantation establishment rate and consequently substantial investments. Funding sources and mechanisms for financing such investments –and the creation of framework and criteria to make sure that a large scale expansion of biomass use for energy complies with other urgent environmental and socioeconomic objectives– are issues that need more attention. Both the dedicated production of feedstock crops and the collection of residues can lead to undesired environmental impacts and it is crucial that practices are found that assures that reduction of one environmental impact does not increase another. However, if guided into sound directions, a growing biomass demand may be instrumental in promoting sustainable land management. This will be discussed further below, where it will be described how biomass plantations can be located, designed and managed so as to generate environmental benefits additional to those associated with the substitution of nonrenewable fuels or industrial feedstocks.

Environmental and socioeconomic consequences

Food and bioenergy interactions and competition for scarce land and biomass resources have been discussed in several studies (see, e.g., (Azar and Berndes 1999, Azar and Larson 2000, McCarl and Schneider 2001, Johansson and Azar 2003, Sands and Leimbach 2003)). Forest sector concerns about increasing energy sector demand for biomass are expressed in, e.g., (Dielen et al. 2000) and policies stimulating this development are even argued to induce developments towards less eco-efficient use of forest wood (Van Riet 2003).

Azar (2005) presents detailed modeling as well as some illustrative calculations of the willingness to pay for biomass in a world striving for low emissions. Based on a survey of future energy technology costs, and that the marginal energy price will be set by advanced technologies such as solar hydrogen, it is shown that farmers could sell biomass for energy at a price that is four to five times the estimated production cost. If such a situation would materialize, is estimated that land values might increase by an order of magnitude, and food prices may increase by a factor of two to five.

The environmental and socioeconomic consequences of higher land values, and food prices, are complex and there are different views about how a large biomass demand would influence development in agriculture. On the one hand, human demand for conquering more bioproductive lands might lead to the conversion of biodiversity rich ecosystems into monocultural biomass plantations, and poor people might be evicted from their lands. On the other hand, higher land vales will stimulate increased land conservation efforts on agricultural land and it might generate income to rural poor.

Biomass plantations can be established on degraded or otherwise marginal land, where production of food crops is not economically viable. It has been suggested that by targeting such land, farmers could restore soil organic matter and nutrient content, stabilize erosion and improve moisture conditions. This way an increasing biomass demand could become instrumental in the reclamation of land that has been degraded from earlier over-exploitation and improper management (see, e.g., Hall et al. 1993). However, studies indicate that biomass production on marginal/degraded land may not be the automatic outcome of increasing biomass demand (Azar and Larson 2000, Johansson and Azar 2003). If the allocation of land is done by profit maximizing farmers and forestry companies, prime cropland may be targeted in case the higher yields on the better soils outweigh the increased land costs. Biomass plantations may eventually be pushed to marginal/degraded land due to increasing land costs following increased competition for prime cropland, but this competition will likely also be reflected in increasing food commodity prices.

Besides land, competition for other resources, such as water, may also arise. For example, Berndes (2002) reports that a large-scale expansion of energy crop production would lead to a large increase in evapotranspiration appropriation for human uses, potentially as large as the present evapotranspiration from global cropland. More recently, Jackson *et al* (2005) report that the increased evapotranspiration resulting from establishment of plantations can lead to substantially reduced stream flow and also lead to increased soil salinization and acidification. Thus, in some countries, a large scale expansion of bioenergy plantations could lead to further enhancement of an already stressed water situation. But there are also countries where such impacts are less likely to occur.

In industrialized countries, rising food commodity prices may be less of a problem since food commodity prices only constitute a minor share of retail food prices, and the share of personal consumption expenditure spent on food is moderate. However, in developing countries where food often accounts for a very substantial part of total household consumption, the situation is different. An increase in prices of staple food crops might cause increased number of (or a worsened situation for) people chronically hungry and undernourished. Thus, the balance of distributional impacts is difficult to assess. Still, the risk that more people will be affected by hunger must not be disregarded. In a scenario with unequal economic development in the world, a large bioenergy demand with strong paying capacity in industrialized countries may out-compete demand for food in developing countries, creating a moral dilemma in the development of bioenergy strategies.

The potential impacts outlined above should not be taken as arguments against policies aimed at reducing CO_2 emissions. Rather, they imply that CO_2-abatement policies can not be assessed in the absence of distributional considerations and are a clear signal of the importance of global and national efforts to advance development and reduce poverty in the world, especially in developing countries. Synergies and joint action with other multilateral environmental conventions and agreements should be sought after, in order to ensure that CO_2-abatement policies do not aggravate the situation in relation to, e.g., food security, water resources and biodiversity.

Thus, in addition to the most often stated reasons –that energy crop production provides opportunities to make productive use of agricultural land and leads to reduced greenhouse gas emissions, more renewable energy, and reduced dependence on foreign fossil fuels– there are reasons for promoting certain types of energy crop systems that are linked to the systems' environmental performance. Below, multifunctional biomass production systems are briefly described and suggested a way to meet a growing biomass demand while at the same time promote environmental protection and sustainable land management, thus providing a possible strategy for addressing concerns about climate change and also many other of the most pressing environmental problems of today.

Multifunctional bioenergy production

Multifunctional biomass production systems can be defined as systems that, besides producing biomass for substitution of fossil resources, also provide additional environmental services[5]. Examples of environmental services that can be provided by include:

- Reduction of nutrient leaching and soil erosion.
- Carbon accumulation in biomass and soils leading to improved soil fertility.
- Cadmium removal from agricultural land.
- Increased nutrient recirculation and improved treatment efficiency of nutrient-rich drainage water and pre-treated municipal wastewater and sludge.
- Provision of habitats and contribution to enhanced biodiversity and game potential.

[5] Perennial crops can provide environmental advantages, also if no extra measures are taken (see, e.g., Volk et al. 2004). Here, we refer to MSPs as Salix plantations where the location, design and management is optimized for the very purpose of providing specific environmental services.

Research carried out in Sweden and elsewhere reveals that the environmental benefits from a large scale expansion of properly located, designed and managed biomass plantations could be substantial, as the negative environmental impacts from current agriculture practices and also municipal waste treatment could be significantly reduced.

The potential for multifunctional biomass production systems based on Salix (Multifunctional Salix Plantations, MSPs) in Sweden has been assessed in projects funded by the Swedish Energy Agency. Also, the economic values of the provided economic services have been estimated. The results are very encouraging (Börjesson et al. 2002): about 15 000 hectares are used for Salix production in Sweden today. An estimated 50 000 hectares could be dedicated to MSP systems providing environmental services having an estimated economic value exceeding the total cost of Salix production. On more than 100 000 hectares, the biomass could be produced in MSPs providing environmental services having an estimated value above, or roughly equal to, half the biomass production cost (see Figure 4).

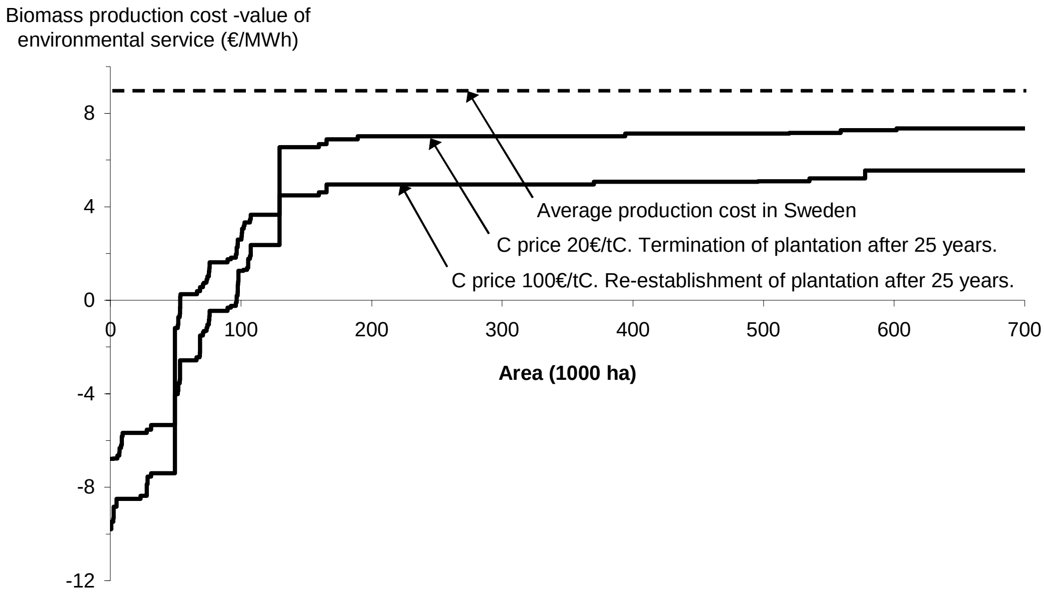

Figure 4 The practical potential for multifunctional bioenergy systems in Sweden, and an illustration of the estimated value of the additional environmental services provided, as they relate to the cost of Salix production. Assessed environmental services include: reduction of nutrient leaching and soil erosion; cadmium removal from agricultural land; increased nutrient recirculation and improved treatment efficiency of nutrient-rich drainage water and pre-treated municipal wastewater and sludge; and provision of habitats and contribution to enhanced biodiversity and game potential. Included is also the economic value (calculated for two different carbon prices) of the estimated carbon sequestration in soil and aboveground biomass stock. The magnitude of this carbon sequestration varies depending on soil type, land use history, and type of crops replaced by Salix. Based on Berndes and Börjesson (2004). See also Berndes et al. (2004).

Thus, given that additional revenues –corresponding to the economic value of the provided environmental services– can be linked to the MSP systems, the economic performance of such biomass production can improve dramatically. Biomass supply from MSPs could bring substantial improvements in the biomass supply cost and also in other aspects of competitiveness against conventional resources. Establishment and expansion of such plantation systems would also induce development and cost reductions along the whole biomass supply chain. Thus, MSPs could become prime movers and pave the way for an expansion of low cost perennial crop production for the supply of biomass as industrial feedstock and for the production of fuels and electricity.

A market for short-rotation forest (Salix) has been established in Sweden. Research in the area of energy crop cultivation has a long tradition and, as a result, Sweden has taken a lead internationally in research and development of dedicated energy crops such as Salix. Sweden is also at the forefront what regards multifunctional bioenergy production. Research and practical implementation of MSPs in Sweden have resulted in the accumulation of valuable knowledge into how Salix cultivation can be located, designed and managed in order to provide additional environmental services. Specific applications of MSPs are becoming established land use practices, and MSPs are increasingly being referred to as a promising option for improving the environmental performance of agriculture, while at the same time obtain additional revenues. Presently, about 10 % of the municipal wastewater sludge in Sweden is recycled in Salix plantations, and about 25 facilities treat landfill leachate in Salix plantations. A number of municipalities and small villages have established Salix/wastewater treatment systems already. The experiences from these treatment systems are very positive: the Salix plantations deliver high treatment efficiency at low costs and less use of chemicals and energy resources compared with conventional treatment technologies.

The production and use of biomass from multifunctional biomass production systems would not only contribute to the development towards more sustainable energy and industrial production, but also to development towards a more sustainable agriculture and to increased recirculation and efficiency in societal use of essential resources such as phosphorus and other nutrients. This way, multifunctional biomass production systems may become a valuable tool also for meeting additional great challenges such as getting the World’s water cleaner and preserving the long term quality of agricultural soils.

7 Additional uses for biomass: materials, chemicals, products

7.1 New industrial uses of biomass for materials and chemicals

All over the world the paper industry and sawmills have a strong position in the market for timber, sawn timber, pulpwood, and paper products. In Sweden as in many countries these industries have a long tradition in processing these materials to final products. Traditional uses of trees have well developed markets and logistic systems.

In addition to this, “new” energy uses of biomass for production of heat, power and liquid fuels have established new markets and new infrastructure, so far with only limited competition for the available biomass resources in general. In for instance Sweden and Finland, countries with a large biomass energy use, mainly byproducts from industry and forestry have been used.

However, the established forest industry in Sweden has been greatly concerned about competition for raw materials and higher costs as a consequence of favorable conditions for energy uses. For one branch, the board industry, the competition from fuel uses also has added to earlier difficulties with competition from countries with e.g. cheap byproducts from other forest industry. This industry has to a large extent been closed down, in a process starting before the expansion of bioenergy.

New uses of materials from trees and agricultural crops have been discussed, studied and also tried in many countries. This has been driven by a search for new markets for agricultural production in Europe and the United States, and by political initiatives to find renewable alternatives to oil-based products. Presently a limited share of crude oil is used for materials and chemicals.

There are many potential new applications of biobased materials:

- renewable plastic products: one example is corn-based PLA plastics in commercial production in the US (Nature Works LLC, developed by Cargill http://www.natureworksllc.com)
- renewable composites made from biobased fibers and plastics, to some extent introduced in the automotive industry
- carton-based packaging, with fossil-based barriers and coatings replaced by biobased
- solvents and detergents made from vegetable fats/oils, in Sweden from rapeseed or linseed, with applications in for instance paints, printing inks

- lubricants and hydraulic oil, in Sweden with successful commercial application in chainsaw lubricant, as additive to fuel for two-stroke engines and in hydraulic systems of forest machines.

The main arguments for biobased materials are sustainability, less dependence on imported oil, and potential industrial, economic and social benefits. Proponents of biobased materials also point to potentially superior structural properties, and to potential improvements in yields and material properties through genetic methods.

However, to date, renewable materials in general have not been able to compete with established fossil-based materials on the market in broad applications. The main obstacle has been higher costs, but also the general difficulty of competing with mature products in large-scale production with established supply chains. The expected or stated sustainability and environmental benefits have not been given a sufficient bonus in the markets to set aside these obstacles.

Recent changes in four areas have changed conditions to the advantage for biobased materials:

- The sharp increase in the price of oil has increased the cost of oil-based materials and chemicals
- An appreciation that global conventional oil production will peak during the coming decade has made it strategically important to find renewable alternatives
- Changes in the support to agriculture in Europe (and the US) have freed land to be used for “industrial” crops. New non-food markets are regarded crucial for addressing concerns about abandonment of cropland, increased unemployment, economic decline and depopulation in rural areas
- In a number of countries high priority has been given to development of domestic energy sources to replace the import of fuels, increasing the security of supply.

A successful development of biobased materials and products may in the long run lead to an increased competition for raw materials from agriculture and forestry. In the short run, the supply of raw materials or land is no limiting factor for production of biobased materials in for instance the US and Europe, considering the present levels of production and the early stage of development.

In particular, a more efficient use of residues in industry or agriculture will make substantial amounts of biomaterials available for processing to chemicals, plastics, solvents and other products. A large interest has therefore been directed to the development of paper mills into ”biorefineries” in Europe and North America. One type of biorefinery is based on gasification of black liquor in chemical pulp production, another on extraction of lignin, hemicelluloses and other chemicals at different locations in the processes (studied in the EU FP6 research project WaCheUp).

Studies for the former type show that there is a substantial potential production of transportation fuels using black liquor gasification. An example given at a biorefinery conference in 2005 indicated a potential production of 2,5 MWh of methanol per ton of pulp produced (with addition of biofuels from external sources to meet the energy needs of the paper process) (Axegård 2005). A hypothetical example to give the order of magnitude: For a production of the size of the Swedish production of chemical pulp (8 million tons) this would amount to 20 TWh of methanol, roughly equivalent to 20 % of the Swedish use of transportation fuels.

This type of biorefinery would be well suited for production of transportation fuels, and could also be used for conversion of organic waste to fuels, as an alternative to using waste as a fuel in district heating or power plants.

The other type of biorefinery, with extraction of lignin and other substances, would be suited for production of materials, chemicals, and fuels, using traditional pulp industry or new biotechnology processes. According to the presentation by Axegård the studies indicate that an amount of lignin corresponding to 2 MWh per ton of pulp could be produced, indicating a large potential production of lignin as solid fuel or as raw material for chemicals or materials. In addition to this a number of other substances/chemicals may be extracted.

A change of existing plants into biorefineries will require a long time, large investments, and political commitment to promote bioenergy and/or biomaterials.

For agricultural crops, the main potential source of biomass in many countries, interest is focused on other types of biorefineries, based on fermentation, bacteria or enzymes for conversion into or extraction of wanted chemicals or fuels. One example of this is the production of ethanol from crops rich in starch, another example is the processing of plant oils into chemicals, lubricants, solvents and fuels.

It can be argued that the production of materials represents a much lower share of the total use of oil than the use for energy. On the other hand, the materials and products represent large values and industrial production. The use of crops and forest resources for “green” materials may give a potential value and contribution of income to the producers – and increased sustainability in those value chains. Furthermore, the use for materials will yield wastes that can be reused as input in production of renewable energy products. The biorefinery concept is central in the discussion of a sustainable and economic use of biomass.

7.2 Markets, actors and potential alliances

The traditional uses and markets for crops and timber are controlled by farmers and forest owners on one side, and the food industry and forest industry on the other. New actors have entered the markets with the growing use of biomass for energy, stimulated by political measures, subsidies, and support to research and development of renewable energy technology.

The electric power industry and district heating industry are strong actors with an interest driven by energy, environment and climate policy. They have so far mainly acted as buyers of solid fuels, but have to some extent entered into cooperation with industry, for instance as heat producers or buyers of excess heat from process industry. Ideas of a more close cooperation with outsourcing of the total energy systems of paper mills to the power industry were discussed earlier, but have not occurred so far. The deregulation and establishment of a market for electric power in northern Europe has rather contributed to making the electric power industry concentrate on their core business.

One notable example of cooperation between interacting actors exists in Enköping, where one farmer and the operators of the municipal sewage plant and the heat and power plant have developed mutual agreements concerning the establishment and management of a willow vegetation filter system for municipal wastewater treatment, combined with delivery of willow chips to the heat and power plant (Börjesson and Berndes 2005). The power plant operator is now considering taking one further step by leasing land for extended willow production.

As for the international oil, coal and natural gas industry, there has been some, but limited activities into bioenergy. Biofuels are distributed through their network of filling stations and blended into gasoline and diesel fuels, and they are to some extent involved in research on biofuels. However, there is still great uncertainty on what the future transportation fuels will be, and the future role of the oil industry is not obvious.

A growth of new biorefineries of different types will open up for new business concepts, actors and alliances – or competition – between these branches of energy industry and the traditional forest, food and chemistry industries. The direction this will take is strongly dependent on the political measures taken to stimulate increased use of biomass for energy and material uses, but also on the future support to farmers in Europe and North America through subsidies and trade barriers.

8 Comments on bioenergy and biomaterials in international politics and research

Increased use of biomass for energy is a central issue in international policies for a sustainable and secure energy supply, and is also seen as an important factor for growth and employment outside industrial regions and cities, as well as in the industry of energy systems and technology. This is not the place for a general discussion on these matters, but some comments on political issues directly connected with the promotion of biomass for both energy and materials will be made.

Europe has set ambitious goals for bioenergy use in power production and in transportation fuels, and has established abatement policies increasing the cost of using fossil fuels. National policies are, however, lagging behind in many countries, for instance with respect to introduction of biofuels in transportation. The Biomass Action Plan (COM (2005) 628 final, 7.12.2005) is a part of an ongoing effort to increase and coordinate national legislation and policies. The action plan ”…sets out measures to increase the development of biomass energy from wood, wastes and agricultural crops by creating market-based incentives to its use and removing barriers to the development of the market”. These measures concern increased use of bioenergy in heating, power production and for transportation, as well as increased efficiency in all applications.

In appendix II of the plan a preliminary assessment of the EU biomass production potential is given, stating that an increase by a factor 2.5 is possible to 2010 compared to the use of 2003, and an increase by a factor of 3.5 to 4.5 is possible to the year 2030. No effects on food production, biodiversity and environmental pressure are foreseen in this assessment, and potential contributions from future members Bulgaria and Romania is not included.

Planned research in the Seventh Framework Program includes new efforts in research on bioenergy, biorefineries, on new materials and processes in the forest industry, and on industrial biotechnology.

As for the use of biomass for materials the political measures so far have been limited and mainly concerned with the promotion of research. Large research programs on ”green” materials in earlier framework programs have so far resulted in little industrial exploitation.

Some national efforts are being made, in for instance UK based on a Strategy for Non-Food Crops and Uses, (Defra 2004). Biobased plastics and composites have been developed in Germany, Italy and France, and a wide variety of industrial crops have been tested and grown in many countries. This also applies to products and chemicals from plant oils used as base for solvents, paints and hydraulic fluids. In especially Germany and France there is a growing use of RME, rapeseed methyl ester, as a diesel engine fuel and lubricant.

Also in Sweden there is and has been some research into new “green” materials and their application, driven by agricultural and environment policies and also by users caring for the environment. The introduction of biobased hydraulic fluids and other oils/lubricants was largely user-driven.

In the US a number of programs and support actions are promoting bioenergy and biomaterials, at both a national level and in many states. The Vision for Bioenergy and Biobased Products in the United States following the Biomass R&D Act of 2000 established far-reaching goals for increasing the role of biobased energy and products in the national economy to 2030.

Today, ethanol from corn is subsidized by taxes and is well established and growing quickly. Biodiesel made from soybean is also growing but from a much lower level. As already noted, biobased plastic made from corn is also manufactured commercially at a large scale. Federal research programs into bioenergy and biomaterials are substantial and coordinated between the departments of energy and agriculture (DOE and USDA). In addition, research is funded by the states. The introduction of biobased products and energy is also supported by The Federal Biobased Preference Procurement Program, with the goal to increase the government’s purchase and use of biobased products.

In spite of all efforts to promote biobased products, there are many obstacles to an introduction and growth of these. Some are commercial: it is difficult for new products to compete with established products not only with respect to costs. Other advantages or better performance in different aspects may be necessary for success in the market. Buyers are reluctant to become dependent on one supplier which might be the case for a new product. This hampered for instance the introduction of corn-based PLA plastics for a period of time.

There are also technical obstacles: standards, legislation, testing methods etc. have been developed for established products over a long period. New products may not fit into these standards and methods.

9 Proposed further studies

This report is only a survey of potential biomass resources in Sweden and globally. The focus is on potential energy use, but the interaction between different uses – traditional and new – and different stakeholders has also been commented in a very general way.

Policies currently put in place to stimulate the development of biofuels for transport –and to some extent also fuels derived from natural gas– (the biofuel directive, tax exemptions, free parking etc) will mainly stimulate ethanol imports from Brazil and the domestic production and use of fuels that are believed to have a limited potential, such as FAME (fatty methyl esters), biogas, and ethanol produced from traditional agricultural crops such as cereals.

A second generation of biofuels derived from gasification (or enzymatic fermentation) of lignocellulosic feedstocks (dedicated crops, forest wood and residues such as black liquor) can benefit from a much larger resource base. However, the competition from other uses, such as heat and electricity generation and the production of various material, is already evident and will become even more so, as the demand for carbon neutral alternatives grows in all sectors (likely, this is also the case for natural gas and its derivatives).

Besides availability of resources, different bioenergy options need to be evaluated based on their environmental performance and specific contribution to important energy policy objectives. Climate change and the mitigation potential of bioenergy is one of the central concerns. The contribution of different biofuels to climate change mitigation varies widely. One reason for this is that there is a large variation in the amount and type of energy (and greenhouse gas emissions) that is required for the production of different energy crops and also for the subsequent conversion to refined biofuels. There are also differences with respect to the amount of net energy (or net liquid fuels) that can be delivered per unit of land. There are many studies that have addressed these and also other socioeconomic (e.g., rural employment) and environmental (including aesthetic) aspects. However, a consensus view cannot readily be extracted from the multitude of studies due to differences in scope, methodological approach and data used. Studies can also come to different conclusions regarding the attractiveness of different bioenergy options due to that different weights are put to various aspects of their performance (e.g., depending on how climate change mitigation, liquid fuel replacement, and rural employment creation are valued relative each other). There is a need for updating based on recent data, but also critical reviews of the lasts year's studies –to point out the conclusions that seem to be robust and also to clarify the reasons behind diverging conclusions where such still exists.

One aspect of resource efficiency and environmental performance where little material has been found concerns the life cycle and overall environmental performance of the combined production of materials (fibers/paper, chemicals, composite materials) and energy products in forest based biorefineries. The basic idea is the efficient use of all components in the wood, but there is a need for development of methods and of studies on actual alternative solutions and product mixes.

As has already been noted, concerns about the geopolitical implications of oil resources distribution, and the insights that conventional oil resources may not be sufficient to meet the anticipated demand for many more decades, has also stimulated the search for alternative transport fuels. In lack of low cost and abundant carbon neutral alternatives, it is not unlikely that we will see a strong push for synthetic liquid fuels derived from coal and unconventional oil and gas. Such a development could possibly ease energy security concerns, but would not automatically solve the climate problem. On the contrary, due to the abundance of coal and unconventional oil resources, it would worsen the climate problem.

However, a successful development and implementation of carbon capture and sequestration (CCS) technologies could change the outlook. According to several analyses, CCS could be one important option for CO_2 emissions reduction (see, e.g., IPCC (2005) for a comprehensive overview of CCS). Generally, it is believed that economies of scale will make CCS applicable mainly for large point sources such as large energy plants and various industrial activities (e.g., cement production, refineries and petrochemical industry). The need for a CO_2 transport infrastructure further emphasizes the importance of scale. Thus, large coal condensing plants appear to be one main alternative for applying CCS technologies, while using CCS in combination with natural gas combined cycle plants appears to be a less attractive option. In the long term, the technology may be used cost-efficiently in biomass fuelled plants, due to the possibility of reaching negative CO_2 emissions (Azar et al. 2005). An eventual widespread deployment of CCS will certainly strongly influence the entire energy system, including the use of biomass for energy.

Given such prospects, a number of questions can be raised and additional studies into a number of areas would be of great value for a discussion of Swedish R&D and policymaking:

- International development and politics; future propulsion technology and transportation fuels, industrial development in for instance the forest and chemical industries with respect to the use of biomass. Special attention should be given to the situation in countries that can become large future biomass users, such as China and India.
- Markets and opportunities/threats for Sweden; can Sweden for instance compete with the new member states of EU in the production of biofuels for trans-

portation? In this context, what is the importance of possible synergies with the forest industry?

- The possible consequences of the focus on security of supply; will synthetic fuels from coal and other fossil resources become the main alternative in North America and China and how will this influence the conditions for biofuels?
- The implications of CCS offering abundant carbon neutral heat and power at competitive cost in the medium term; how are the incentives for introducing CO_2 neutral fuels in transport sector affected? Could the possibility to produce electricity in plants with CCS give biofuels a more important role in the transportation sector, or is the development of a hydrogen infrastructure desirable under any circumstances? Could large-scale power plants with CCS in northern Europe start competing for the Swedish biomass resources? Could in fact a large scale implementation of biomass based stationary CCS options – leading to negative emissions that can compensate for transport sector emissions – be preferable to biomass based transport fuels production?
- The implications of new transport patterns; could the 'compact city' with a different balance between transport modes and transport distances create room for other types of vehicles and in turn other types of fuels? For example, could electric city vehicles complemented with long distance biofuel (possibly hybrid/plug-in hybrid) cars be an alternative to the development of universal hydrogen cars?
- Biomass as an interims option; what role may bioenergy play in an intermediate transition period? In which sector should scarce biomass be used? How do different bioenergy options contribute to potentially conflicting goals such as cost efficient climate change mitigation, energy security and employment generation? How do they bridge to prospective "post-biomass" options?

There is a multitude of short term options, a possibility of drastically changed prerequisites induced by a large scale implementation of CCS, and many available transitions paths and links to the development of energy systems. These create a great challenge for industry, policy and politics in relation to biomass. This includes the implications of a future large scale international trade in biomass and biofuels:

- What would be a robust strategy for a region within Sweden? What policies and strategies are robust for a forest rich country like Sweden within Europe and for Europe within the world? How do local initiatives link to the development in larger regions? Could a development of flexible technology allow for regional fuels, varying from continent to continent?
- What risks and possible gains in terms of industrial renewal and competitiveness are related to being a first mover in a particular direction?
- How can a framework for sustainable international bioenergy trade look like? What can be learned from previous initiatives to establish and promote certification schemes, e.g., for industrial roundwood production?

Finally, linked to the Swedish experience of multifunctional plantations so far, several important issues need further investigation. Besides learning more about proper location, design and management of plantations for the provision of specific environmental services, efforts linked to incentives creations and the implementation process in general are important. The implementation will depend on how the costs and benefits are distributed among the different actors affected (e.g., farmers, municipalities and the society in general). Some MSP applications lead to direct economic benefits for the Salix producer. For example, when Salix plantations are used as vegetation filters for the treatment of nutrient-rich municipal wastewater, the irrigation will lead to reduced production costs due to increasing biomass yields and commercial fertilizer substitution. Payments from the municipality that uses the Salix vegetation filters will make it even more attractive for the Salix producer. In other cases, the Salix production cost increases and society in general benefits from the environmental service provided. One example of this is when farmers produce Salix in buffer strips to treat nutrient rich drainage water. In such situations, society may need to pay the farmer for the environmental service provided in order to provide incentives. Thus, one important task will be to develop and propose suitable mechanisms to put a premium on the provided environmental services (e.g., long-term contracts between counter parties and targeted environmental support schemes).

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11 Appendix A

The four storylines for world development, including climate change, that was developed for the IPCC Special Report on Emission Scenarios (SRES) are shortly presented in the box below. For full documentation, see (IPCC 2000). The development in the four SRES Illustrative Marker Scenarios[6] along selected crucial parameters is presented in graphs below. The SRES storylines do not include explicit policies to limit GHG emissions or to adapt to the expected global climate change. All four SRES "futures" represented by the distinct storylines are treated as equally possible and there are no "central," "business-as-usual,""surprise," or "disaster" futures. Each storyline takes a different direction of future developments so that they differ in an increasingly irreversible way. They describe divergent futures that reflect a significant portion of the underlying uncertainties in the main driving forces. The differences among the storylines cover a wide range of the key "future" characteristics, such as technology, governance, and behavioral patterns.

[6] According to information provided via the SRES homepage (http://sres.ciesin.org/): "For the purposes of the SRES for each scenario family (A1, A2, B1 or B2) one quantification governed by the associated template is provided as marker. These markers represent one quantified interpretation of the scenario family concerned, no more and no less. They cannot be viewed as the best or most likely outcome within the boundaries of the scenario families, but only as one representative example selected for illustrative reasons".

A1

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

A2

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

B1

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Development in the four SRES Illustrative Marker Scenarios along selected crucial parameters