Multifunctional bioenergy systems

In pace with the ever-growing complexity of environmental problems, new types of measures based on a holistic perspective are needed. Focusing on only one problem at a time is impossible, as this can at worst make another environmental problem even more serious, or at best prevent taking advantage of potential synergy effects. Biomass production for energy purposes is a good example of where a holistic perspective must be adopted. The present report deals with such so-called multifunctional bioenergy systems. These are bioenergy systems which – through well-chosen localisation, design, management and system integration – offer extra environmental services that, in turn, create added value for the systems.

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The project has the overall aim to evaluate and propose robust pathways towards a sustainable energy system with respect to environmental, technical, economic and social issues. Here the focus is on the stationary energy system (power and heat) in the European setting.

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Multifunctional bioenergy systems

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PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS

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Multifunctional bioenergy systems

AGS Pathways report 2007:EU1

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PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS
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Table of content

Introduction

In pace with the ever-growing complexity of environmental problems, new types of measures based on a holistic perspective are needed. Focusing on only one problem at a time is impossible, as this can at worst make another environmental problem even more serious, or at best prevent taking advantage of potential synergy effects.

Biomass production for energy purposes is a good example of where a holistic perspective must be adopted. The primary aim with greater use of renewable energy sources such as biomass is to reduce society's influence on the climate by replacing fossil fuels. But the production of biomass for energy can also yield significant further environmental effects in connection with changing how land is used in forestry and agriculture. Several of Sweden's fifteen environmental goals can be associated with land use. These must be taken into account, therefore, when designing strategies to increase the use of bioenergy, which is regarded as an important element in the reorientation of Sweden's energy system to become more environment-friendly.

It is essential to avoid, as far as possible, negative environmental effects of increased bioenergy use. This is done by setting up rules and guidelines concerning how biomass production for energy purposes should be carried out. However, an additional step can be taken: based upon general and local knowledge of possible feedback and integration between technical and biological systems, one may find different ways of producing biomass for energy and provide further environmental services, at the same time as replacing fossil fuel. Given mechanisms that enable the delivery of such services to generate extra income, this can be a means of improving the competitive power of bioenergy and lowering the cost of climate measures.

The present report deals with such so-called multifunctional bioenergy systems. These are bioenergy systems which – through well-chosen localisation, design, management and system integration – offer extra environmental services that, in turn, create added value for the systems. Focusing on the case of multifunctional Salix production in Sweden, research projects funded by the Swedish Energy Agency have been accomplished with the purposes to:

- Investigate which environmental services could be obtained from multifunctional bioenergy systems.
- Estimate how much biomass could be produced in multifunctional bioenergy systems in Sweden, based on an inventory of demand for the environmental services that can be provided with such systems.
- Estimate the economic value of the environmental services that can be offered with multifunctional bioenergy systems, as well as the production costs for biomass from such systems.
- Identify market- and structure-determining barriers to different multifunctional bioenergy systems, and propose solutions that overcome barriers and strengthen present driving forces for increasing the production of bioenergy.

A correct assessment of different bioenergy systems' total environmental impact requires that the entire systems be considered. Moreover, it is from a holistic perspective that potential synergy effects can be identified. The holistic perspective has thus been the point of departure in this study. However, the focus has been on biomass production itself, and the possibility of combining it with the delivery of environmental services. The analysis has also been confined to biomass production on agricultural land, with Salix as the energy crop. This does not mean Salix is the only conceivable energy crop in multifunctional bioenergy systems. The focus is explained by the facts that, in Sweden, most research has been done on Salix as an energy crop, and that it is also the most widely cultivated crop. Hence, the best foundation for evaluating multifunctional bioenergy systems has been with those based on Salix. The following chapters briefly describe the properties of multifunctional bioenergy systems and their domains of use, as well as how the possibility of providing environmental services can influence their economic prospects. To be discussed thereafter are the possible area extent for different Salix-based systems, and various important factors that affect the future scope of multifunctional Salix cultivation in Sweden.

Multifunctional bioenergy systems

Multifunctional bioenergy systems with well-chosen localisation, design, management and system integration can offer numerous environmental services, which in turn create added value for the bioenergy system.

Multifunctional bioenergy systems can be exploited to attain several of Sweden's national environmental goals, namely – besides the carbon dioxide objective – goals such as avoiding over-fertilisation and maintaining a rich cultivation landscape and an unpolluted environment. The systems treated in this report can be divided roughly into two categories. Some are exploited for directed environmental services, an example being the cultivation of Salix as a vegetation filter for water purification and handling of sludge, or as a protective zone against nitrogen leakage. Others are systems that provide environmental services of more general nature, for instance greater carbon fixation and land fertility, cadmium unloading and improved hunting potential.

Below, possible applications based on Salix cultivation are described. This account is divided according to the environmental services' contributions in the areas of water, land, and biotope.

Figure 1. Salix being harvested during the harvest season in 2002/03. At present, Salix is produced on ca. 15,000 hectares of arable land, and the season's harvest comprised about 3% of the wood fuel produced in Sweden. The energy crop production is thus small in terms of both agriculture and energy supply. But in the long run bioenergy from agriculture is expected to grow substantially. (Photo: Stig Larsson, Agrobränsle AB.)

Water

Salix plantations can be utilised as vegetation filters to purify different types of nutrient-bearing water, such as wastewater from households, run-off water from farmland, and leachate from landfills. Moreover, sewage sludge from treatment plants can be used as fertiliser in Salix cultivation. Salix has an extensive root system, is a perennial crop with a long growth season and needs much water, which contribute to high removal efficiency. Compared with alternative methods of treatment, such as conventional nitrogen removal, vegetation filters are an economically attractive solution. Irrigation with nutrient-rich water also results in higher biomass harvests and less need to buy fertiliser, which means that the cultivator receives further advantages from growing Salix in the form of irrigated vegetation filters.

Already today these forms of multifunctional bioenergy systems have become rather widespread. In about ten facilities, Salix is irrigated with pre-treated wastewater, around 25 facilities treat landfill leachate in Salix filters, and some 10% of all sewage sludge is fed to Salix plantations where it replaces fertiliser and takes part in a functioning system for recirculation of nutrients back to farmland. The ability of Salix to accumulate heavy metals means that these are removed with the harvest, which avoids their accumulation in farmland (this is discussed further in later sections).

Treatment of municipal wastewater

The municipal sewage treatment plants have long concentrated on reducing the discharge of phosphorus and of oxygen-depleting substances. This purification, which uses a combination of biological and chemical methods, is effective: on average, both phosphorus and BOD are reduced by over 90%. In contrast, the reduction of nitrogen discharges has been much lower (ca. 30%). Along with the growing attention to nitrogen discharges, especially in coastal regions, the coast-based purification plants have been increasingly complemented with systems for greater nitrogen purification. Still, a substantial part of Sweden's population is not yet connected to facilities of the latter type, particularly in small and medium-sized communities inland.

Vegetation filters with Salix are useful to complement conventional treatment plants, since the discharge primarily of nitrogen can be decreased. A precondition, of course, is the availability of suitable arable land. One hectare of Salix can receive sewage from about 30 people, so that a community of, for example, 10,000 requires just over 300 hectares of Salix. However, the arable land does not need to lie very near the purification plant, as sewage can be transported for relatively long distances (around 5–10 km) at tolerable cost.

If all wastewater is to be treated in Salix plantations, storage ponds are required that hold the winter half-year's volume until the growth season. A cheaper alternative is to treat only sewage that is produced during the summer half-year with the help of Salix, and to utilise conventional purification (including phosphorus precipitation) during the winter. The nitrogen removal is then half as great, but so is the land area needed. Hence, this may be a solution if limited arable land is available.

Figure 2. A Salix field irrigated with pre-treated municipal sewage in Enköping. The inset picture shows measurement equipment used to chart the nitrogen flows in the field. An important question is how much of the nitrogen input is transformed to nitrogen oxide, a powerful greenhouse gas. The investigations until now indicate that the climatic impact of these discharges is small in relation to the climatic benefit of the produced biomass in replacing, for example, fossil fuels in municipal heating plants. Also important are the hygienic aspects of sewage-irrigated Salix production. Experiments show that the risk of spreading infection is low, but that unsuitable locations should be avoided, such as nearness to waterways. (Photo: Pär Aronsson, SLU.)

Treatment of nitrogen-rich water in agriculture

Today, agriculture is estimated to be responsible for, on average, 45% of society's total output of nitrogen that reaches the sea through Swedish waterways. In strongly agricultural regions such as Halland and Skåne, ground leakage from arable land can account for up to 75% of this nitrogen supply. Several measures for decreasing the nitrogen leakage are employed today – such as more efficient spreading of farmyard manure, creation of edge zones, and restoration of wetlands. Another possible measure, proposed for instance by the Environmental Protection Agency, is to establish perennial bioenergy plantations in especially pollutant-sensitive regions such as south-western Sweden.

Salix plantations can be exploited in different ways to purify run-off water. On the one hand, run-off water is usable for irrigating Salix in the same manner as when treating municipal sewage.

This method is suitable if the arable land has a system of covered drains, since the run-off water can be collected in storage ponds to be used for irrigation. Run-off water has a high nitrogen content in proportion to its phosphorus content, but sewage sludge has an opposite proportion and, if added to supplement the irrigation, thus balances the nutrient supply.

If the arable land lacks a covered-drain system, Salix can instead be planted in protective zones along open waterways, where nutrient-loaded surface and ground waters are purified. About 70% of the water's nitrogen content is estimated to be removable in zones 25–50 metres wide, provided that the Salix plantation is harvested regularly to maintain the nutrient uptake.

Treatment of landfill leachate

The interest in local treatment of leachate from landfills has grown during recent years. One reason is that the majority of municipal sewage treatment plants are no longer willing to accept leachate, for fear that the sewage sludge's quality will be worsened. Another is that the collection and purification of leach water are required increasingly. The main environmental problem for older landfills with household waste is usually the nitrogen leakage, since leachate has a low content of, for instance, heavy metals.

Besides the roughly 300 municipal landfills which operate today, older abandoned landfill sites (around 4,000 in total) may eventually need to establish systems for leachate management in order to deal with diffuse discharges, and this is an ever more salient problem. The degradation in deposits can continue for up to a century or so, which means that leachate treatment may be required for a long time.

For these types of landfills, vegetation filters with Salix can be a cost-effective alternative. In addition to capturing nitrogen, Salix has a high transpiration rate that contributes to decreasing the amount of water.

Leachate from industrial deposits often contains lower levels of nutrients such as nitrogen, whereas the content of diverse organic and inorganic impurities may be higher. In such cases, vegetation filters with Salix can function as a complement to other treatment methods, and then primarily to reduce the amount of leachate. When the polluted water contains heavy metals such as cadmium, and to some extent zinc, Salix can be used to capture these metals.

Treatment of sewage sludge

Today 10-15% of the municipal sewage sludge, is used in agriculture (food crops) and about 10% in Salix plantations. The rest is used in the production of engineering soils, for covering or deposits, or used in other ways. The use in agriculture has decreased considerably since 1999, due to the sludge boycott that is conducted by the Federation of Swedish Farmers (LRF) and various farming and food companies, which are motivated by uncertainty about the sludge's content of heavy metals and organic poisons. The average heavy-metal content, however, has gradually diminished during the 1990s, and is well below the limit and guideline values stated by law, as well as by the agreement on sludge use in agriculture that was made between the parties concerned. The levels vary, though, and it happens at several treatment plants that limit values are exceeded.

Sludge fertilisation of Salix plantations is an opportunity to increase the recycling of sludge in agriculture. The sludge can be spread with conventional techniques for spreading manure during establishment and after harvesting. Experience of using sludge as a nitrogen source shows that the growth is comparable to plantations using fertiliser, that the leakage of metals and nutrients is negligible, and that the heavy-metal content in the topsoil remains almost unchanged.

Land

Modern techniques of cultivation, with intensive working of the land and a larger share of annual crops in the growth sequence, have led to loss of humus and lower soil fertility. Another negative trend is that the cadmium content of topsoil in Swedish farmland has risen by about 30% during the twentieth century. Almost 10% of Swedish farmland has such high cadmium content that it is placed in the class of land which is considered to present health risks from consumption of crops grown there (see Table 1). Historically, phosphorus fertiliser has been the dominant cause of increased cadmium content in the farmland, but today more cadmium is added through atmospheric deposition.

By increasing the proportion of perennial crops in the growth sequence, one can counteract the trend of declining soil fertility, partly through increase in the supply of organic material (leaves, roots etc.), and partly because the working of land is decreasing, which otherwise stimulates the breakdown of organic material. A transition from cultivation of annual plants, for instance to Salix cultivation, can have several positive effects in this case. There is a climatic benefit due to the fact that atmospheric carbon dioxide becomes bound in land and standing biomass, and there is an increase in soil fertility which means that the harvests may grow in future.

If the Salix is cultivated on farmland with high cadmium content, the cultivator can also count on a higher land value in the future, once the cadmium level has gone down to levels where it is again possible to produce, for instance, cereals that meet certain requirements on cadmium content and thus have a higher value. In the same way, Salix plantations that are established to reduce wind in areas exposed to wind erosion

Table 1. The division of Swedish farmland into condition classes with regard to cadmium. In the highest class 5, health risks are considered to exist for consumption of the crops being cultivated. Crops that are cultivated on lands belonging to class 4 are not currently specified as unsuitable for human consumption, but the cultivator's economy can nonetheless be worsened. For instance, analyses of cadmium content are required if the cultivator wants to sell crops from such land within the quality-marking system Svenskt Sigill.

Class	Designation	Cadmium content (mg /kg soil)	Distribution in topsoil (% of total farmland)
1	Very low content	<0.1	7
2	Low content	0.1 - 0.2	47
3	Moderate content	0.2 - 0.3	29
4	High content	0.3 - 0,4	9
5	Very high content	>0.4	8

can reap the profit from harvest increases that are obtained in surrounding cultivation of other farm crops.

Salix cultivation as a carbon sink

When Salix is cultivated instead of annual plants, the working of land decreases greatly. The supply of organic material is also relatively large in energy plantations. An established Salix plantation recirculates 5–10 tons dry organic material per hectare annually, of which about 2/3 consist of the leaf stems and 1/3 of root stems. A small portion is transformed and accumulated as humus, while the rest is broken down and emitted as carbon dioxide. The accumulation, however, declines with time and a new equilibrium is reached after some decades, where the supply and breakdown of organic material balance each other.

A transition from annual crops such as cereals to energy crops that are grown for several years before harvest, such as Salix, also results in an increase of the average amount of standing biomass. The size of this carbon sink depends on the rotation time, since the time and the growth determine the average volume of the standing biomass. At the level of the field, the carbon content in standing biomass obviously reflects the production cycle: it increases with the biomass growth and is reduced almost to zero by harvesting. But if the carbon content in standing biomass is instead considered over larger areas, the production cycle of individual fields is not reflected so strongly in the total amount of carbon in standing biomass, since different fields are harvested at different times. Losses of standing biomass by harvesting of certain fields are compensated by growth in other fields.

Figure 3 illustrates the contribution from carbon binding to the total climatic benefit, when energy crops are cultivated and used to substitute for fossil fuels. An important distinction between carbon binding and fossil substitution is that while the climatic benefit of fossil substitution is "eternal", the benefit of carbon sinks will last only as long as the bound carbon is retained in soil and biomass.

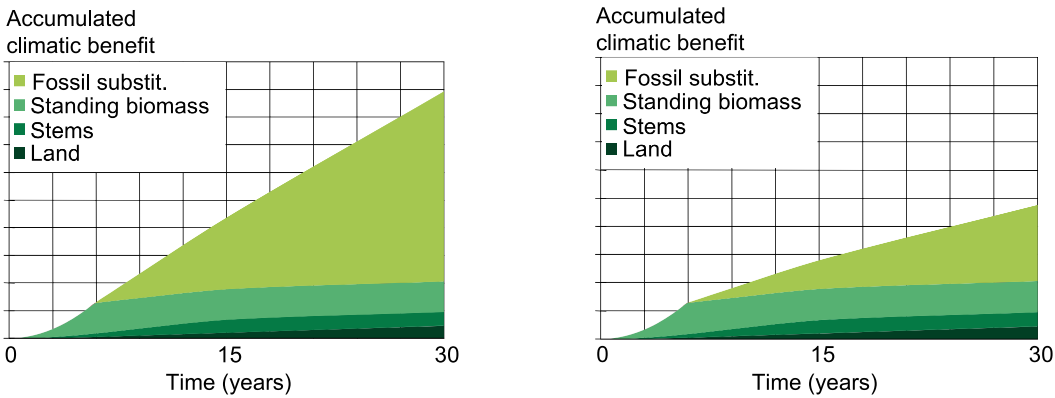

Figure 3. Illustration of the accumulated climatic benefit when energy crops are cultivated on previous cereal lands and are used as fuel instead of (left) carbon in heat production and (right) natural gas in electricity production. The scale on the y-axis is not stated, but is the same in both pictures. As can be seen, the climatic benefit is greater when biomass replaces coal for heat production, than when natural gas is replaced for electricity production. One also sees that the climatic benefit of fossil-fuel substitution dominates in the long run, but the contribution from carbon binding in land, stems, and standing biomass is substantial, especially at the beginning. The figures have been created with an analytical tool called GORCAM , which can be used to study the climatic benefit of different land-use strategies for climate measures.

Salix cultivation for cadmium unloading of agricultural land

The supply of cadmium to Swedish farmland has decreased since the 1970s. We have come a long way in Sweden regarding reduction of the cadmium supply that occurs through phosphorus fertilisation, and since the 1970s this supply has decreased by a factor of 15. The cadmium supply via atmospheric deposition has also declined, but not to the same extent. The total cadmium inflow to farmland is still greater than the outflow via harvesting and leaching, which means that cadmium accumulation in Sweden's farmland continues.

Since the cadmium from atmospheric deposition comes mainly from discharges elsewhere in Europe, this supply source is harder to influence through domestic measures. However, there is a possibility of reducing the cadmium accumulation by increasing the outflow of cadmium. It is here that Salix enters as an alternative. Certain Salix clones are very efficient at accumulating heavy metals – notably cadmium but also, to some degree, zinc – which are then removed from the field with the harvest. The cadmium uptake in Salix can be up to 40 times higher than in cereal crops (see Figure 4). With a well-chosen Salix clone that accumulates cadmium in the shoots, it would take a time on the order of 20–25 years (corresponding to the normal lifetime for a Salix stand) to transport the same amount of cadmium from the farmland as has been added, on average, during the entire twentieth century.

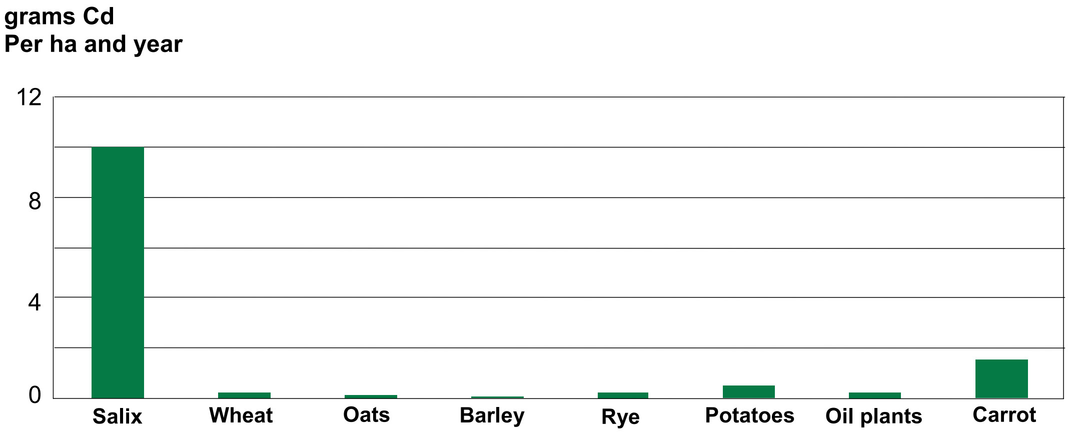

Figure 4. Uptake of cadmium in Salix and seven other farm crops. As can be seen, the uptake is many times greater in Salix than in the other crops. The high specific uptake of cadmium makes Salix suitable as a crop for cadmium unloading of soils with excessive cadmium content.
(Data: Kenth Hasselgren, SWECO VIAK AB.)

Biotope

A larger component of Salix in the cultivated landscape promotes more animal life in the area. This applies to cervids such as elk and roe deer, but also foxes, hares, and wild fowl like pheasants. This phenomenon has long been exploited in England, for example, where Salix is planted to raise the land's hunting value. The positive effect on opportunities for hunting is now also beginning to be noticed in Sweden. An investigation shows, for instance, that about 40% of the Swedish cultivators would consider growing Salix partly or solely for the wild game's sake. Salix can have a positive effect on the game in flat agricultural, mixed or forested landscape areas, the latter type being where the effect is judged smallest.

The cervids utilise Salix as food, and grazing occurs mainly in edge zones, but sometimes also within the plantations if these are sparse. This grazing is normally of marginal importance for the harvest yield. Wild fowl utilise Salix plantations for protection, and therefore the occurrence of fowl also depends on access to suitable food in the plantations, particularly weed seeds in the ground flora. Thus, one can design and manage the plantations in diverse ways to make them optimal from the standpoint of hunting – such as harvesting different sections on different occasions, leaving streets and open areas that entail more edge zones and more ground vegetation, etc. One estimate is that a component of 10–20% Salix plantations in the open agricultural landscape is optimal for fauna, especially if different parts are harvested at different times.

Besides an increase of bigger game, there is also a rise in the occurrence of small birds, insects, and other small animals when Salix replaces annual cereal crops – thanks to the roles of Salix plantations as refuges, circulation corridors and protection. The biodiversity among the ground fauna is promoted, too, by the greater supply of stems, less working of the land, and less use of chemical insecticides. However, viewed over a larger geographical area, such as a region containing many types of landscape, higher biodiversity in the open farming landscape does not necessarily mean that the region's total diversity increases. Most of the mammals, insects and so on that occur in Salix plantations are often common in other biotopes outside the agricultural landscape.

Figure 5. Multifunctional bioenergy system

System integration

As already mentioned, the multifunctional bioenergy systems presuppose a well-executed system integration, where the energy crop plantation is linked with the activities that demand a specific environmental service, and frequently also with the end-use stage in the bioenergy chain (such as a local heating plant). Salix cultivation for cadmium unloading on farmland with high cadmium content in the soil can be taken as an example. Due to the unusually high cadmium content in the harvested biomass, special requirements are placed on the end-user. After the cadmium is concentrated in the Salix chips, it must be separated from the fly ash upon incineration. Most suitable, for reasons of cost, is judged to be the use of large incinerator facilities, with combined burnout of the ash's carbon content and, finally, burning in a waste heat boiler where cadmium is separated in a barrier filter after cooling. The cadmium content is judged to decrease by more than 90% by this method, which means that the remaining ash fraction is so pure it can be returned to farmland as fertiliser. The fly ash fraction, in which the cadmium is concentrated, can then be disposed of, for example in a controlled deposit for permanent storage.

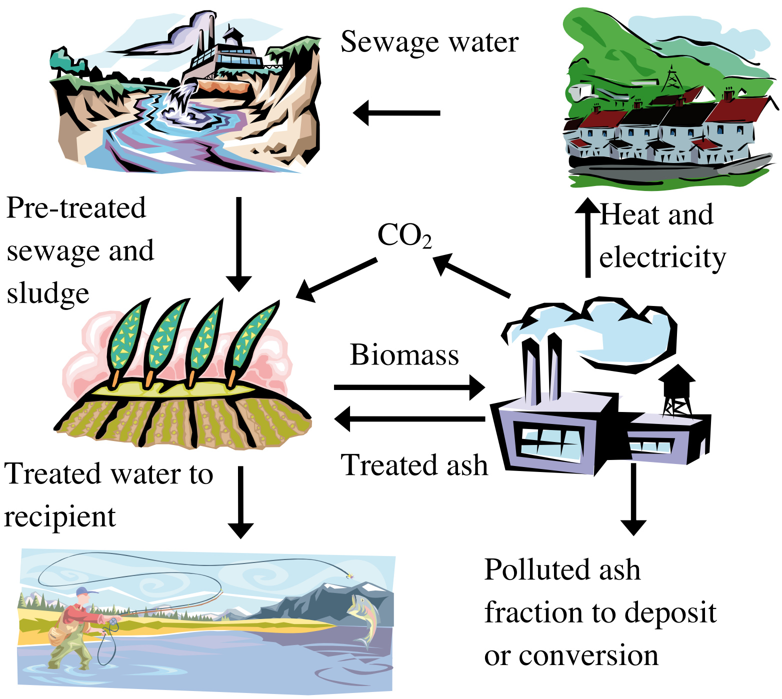

Figure 6. Illustration of how Salix cultivation can be linked with energy and sewage plants, thus satisfying the need for both biomass for energy and recirculation of nutrients which would otherwise require different handling, or else go to a deposit or a surrounding recipient.

Obviously it is an advantage if multifunctional bioenergy systems are established in such a way that the end-user of the biomass is located near the bioenergy plantations, whose placement is governed by the local demand for specific environmental services. Such local solutions improve the conditions for creating local cycles for plant nutrients. It can also be an advantage in the sense that the actors involved share a common local vision, which constitutes a starting point for the collaboration (as will be discussed later when describing the case of Enköping). But it is not an absolute requirement that the end-user be a "neighbour" to the bioenergy plantation. Biomass can be transported for relatively long distances while maintaining good economy.

The environmental services' economic value

In Table 2 are shown the calculated net values (income minus cost) of environmental services that can be provided with the help of multifunctional bioenergy systems. The net value varies between counties, for instance due to their differences in precipitation since this influences the size of the harvest increase that is obtained by irrigation of Salix plantations.

Several of the environmental services that can be provided lead to direct business profits for those who produce biomass in multifunctional plantations. For example, when Salix is cultivated as a vegetation filter for treatment of sewage and sludge, the need for fertiliser decreases at the same time as the harvests increase. Other profits are not reflected as immediate income in business calculations. An instance is the establishment of buffer zones with Salix to reduce nitrogen leakage from farmland, where the environmental profit – in the form of decreased over-fertilisation of our waterways – does not automatically generate new income for the Salix cultivator. Similarly, when Salix is cultivated for cadmium unloading of farmland, the profit accrues in the future when it becomes possible again to produce, for example, cereal that meets specific requirements on cadmium content and thus has higher value.

It may also happen that design and maintenance demands for multifunctional plantations lead to higher costs. For instance, the harvest cost is judged to increase when Salix plantations are utilised as buffer zones, since the harvested area on each occasion can be expected to be smaller than in conventional Salix cultivation. When the Salix plantation is to be used for treating sewage, irrigation facilities are needed, entailing investments that normally do not arise in Salix cultivation. An important question in this context is who will pay for the extra investments that may be required for specific multifunctional systems. Shall the farmer, who provides the environmental service, stand for the cost? Or is it the actor who demands the service – and who otherwise would have had to invest in different treatment methods – that should pay?

Figure 7. View over Kågeröd in Svalöv municipality, where Salix plantations are irrigated with pre-treated sewage water from the local purification plant. The inset picture shows a detail of the drop-irrigation hoses that are used in the facility. (Photo: Kenth Hasselgren, SWECO VIAK AB.)

It is important to understand how the total economy for the bioenergy system (plantation, harvest, and final use) is changed when Salix is produced in multifunctional bioenergy systems – how costs, and incomes or cost savings, are distributed between the actors involved, and to what extent farmers can earn direct business profits by establishing specific multifunctional plantations. In a later section, we will discuss the design of mechanisms to ensure that environmental profits which are primarily shown by a social-economic evaluation (such as decreased over-fertilisation of our waterway) will also generate income for those farmers who provide environmental services through biomass production in multifunctional plantations. We describe, too, the "Enköping model" as an example of how several actors can collaborate in the establishment of multifunctional bioenergy systems, and thus distribute incomes, costs and possible risks between themselves.

Table 2. Summary of direct business-economic, and indirect social-economic, costs (+) and profits (-) with multifunctional Salix plantations. The calculations are made on the basis of specific regional conditions.

	Direct costs/profits[a]		Indirect costs profits[b]	Sum
	Cultivation (kr/ha/yr)	Residual product handling (kr/ha/yr)	(kr/ha/yr)	(kr/ha/yr)
Water				
Sewage water				
Summer half-year	-900 to -1900	-5500 to -6100		-6400 to -8000
Full year	-900 to -1900	-3400 to -4000		-4300 to -5900
Leach water	-1200	-3700		-4900
Run-off water				
Protective zones			-2800	-2800
Irrigation *100% purified	+2900 to +10000		-4000	-1100 to +6000
*33% purified	+800 to +3400		-4000	-3200 to +600
Sludge	-300	-2500		-2800
Ground				
Cadmium[c]	-240 to -350	+20		-220 to-330
Carbon binding				
Higher soil fertility	-65			-65
Climate-related effects[d]				
Erosion control				
Water erosion	-700			-700
Wind erosion	-1200			-1200
Biotope				
Hunting potential	-30 to -600			-30 to -600

[a] Based on business costs such as changed cultivation costs for the farmer and changed costs for residual product handling, waste treatment plants, heating plants etc.
[b] Based on substitutions costs of obtaining an environmental service corresponding to that of the given Salix plantation. Where established alternative methods are lacking, the calculations are based on estimates of the cost of avoiding specific environmental problems.
[c] The net value of cadmium unloading in a national-average harvest of 10 tons dry biomass/ha/yr has been set at 280 kr/ha/yr based on the interval 74-580 kr/ha/yr, which has been derived through different evaluation methods (see the fact-frame at the end of this section). The variation between counties is due to the expectation that the biomass harvest, and thus the amount of cadmium removed, will vary.

[d] Varies with land type and yield level. The calculated present value of the carbon binding that continues relatively long into the future is also dependent on what assumptions are made about the price of carbon, the credit design, and which discount rate is used. The interval stated here comprises the total income for carbon binding in mineral soils and standing biomass, at a carbon price interval of 20-100 €/tC and 6% discount rate. Humus soils have not been included here. The incentive to give up cultivation of annual crops on humus soils may, however, become strong if such cultivation is burdened with charges for resultant emission of carbon dioxide. Cultivation of energy crops is then one of several possible alternatives for avoiding carbon dioxide emissions from humus soils.

Calculation of the economic value of environmental services that can be provided with the help of multifunctional bioenergy systems

In cases where the environmental services do not lead to direct profits or cost savings for the cultivator, primary use has been made of the alternative cost method for calculating the economic value. The alternative cost is the cost of achieving a corresponding environmental service in an alternative way. One example is the cost of creating a wetland that provides the same kind of water-purification service as a buffer zone consisting of a Salix plantation.

Where established alternative ways of achieving an environmental service are lacking, the calculations are based on other indirect methods, such as estimates of the cost of avoiding harmful pollutants by using purification techniques or preventive measures like taxes and environmental control charges. Thus, for example, the value of cadmium unloading on farmland can be calculated in several alternative ways: based upon (i) the future added value of cleaner farmland, (ii) the charge on cadmium in phosphorus fertiliser, or (iii) the cost of purifying phosphorus fertiliser from cadmium. The present value of a future added value can, in turn, be calculated on the basis of different levels of the discount rate of interest, which influences the result. The choice of discount rate also affects the estimated present value of future increased harvests due to rising fertility and future income for carbon binding in the soil and the standing biomass.

The stated values are uncertain and the basis for the calculations can be changed. Innovations and technological development may lead to cheaper alternative methods. Environment-related charges or taxes based upon political or agency decisions reflect society's willingness to pay for avoiding environmental damage. This willingness to pay changes with time. There are also uncertainties regarding how well the environmental charges and taxes imposed by society correspond to the costs for reaching an environmental goal, or reflect the actual cost of environmental damage.

The potential extent of multifunctional bioenergy systems

Apart from the economic value of the environmental services that can be provided with multifunctional bioenergy systems, it is of course important to get an idea of what extent the different applications can attain. Further, the majority of environmental services are specific to a particular type of soil, localisation in the landscape, or geographical region, and therefore cannot be obtained simultaneously. For instance, Salix cultivation can be established for sewage water purification on both mineral soils and humus soils. But the possibility of combining this purification with cadmium unloading depends on whether mineral soils or humus soils are utilised, because cadmium unloading is assumed to be feasible only on mineral soils. Moreover, the possibility of combining these two environmental services is dependent on whether the farmland being used has so high a cadmium content that one can consider Salix cultivation for cadmium unloading (class 4 or 5 in our calculations: see Table 1).

Hence, in order to be able to calculate the total potential of multifunctional energy plantations in Sweden, an analysis is required of which combinations of environmental services can be obtained at the same place of cultivation. Based upon these possible combinations of services and the respective services' potential, the total practical potential is calculable.

Figure 8 shows the estimated practical potential (expressed in hectares of Salix cultivation) for multifunctional energy plantations in Sweden, together with the estimated production cost that results if the value of the provided environmental services is included as an extra income in the cultivation's calculation. The figure displays two graphs for different cases of the carbon price (20 and 100 €/ton C) and thus of income for carbon binding in soil and standing biomass.

As the figure demonstrates, it is judged possible to grow Salix at a negative production cost approaching 100,000 hectares, if diverse potential extra environmental services are fully utilised. For a further 200,000 hectares or more, Salix cultivation can be done at a production cost half that of conventional cultivation. This may be compared with the ca. 15,000 hectares of farmland which are used today for growing Salix.

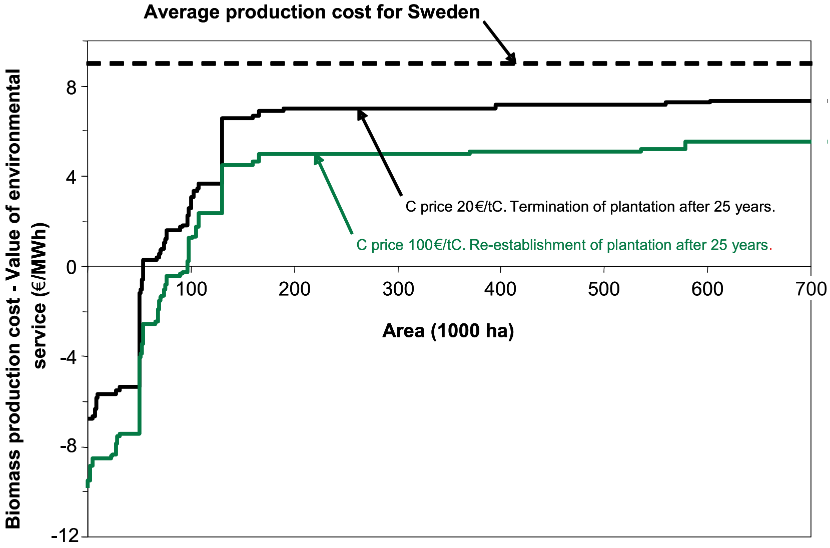

Figure 8. Practical potential and production cost for multifunctional energy plantations on a Sweden-wide level. The average production cost for the country (excluding land purchase and common business costs for the farmer) is given as a reference. Income that is attributable to soil carbon changes (increased fertility, carbon binding in mineral soils, and decreased emission of carbon dioxide from humus soils) is added to income from other environmental services in the cases where these combinations arise. Not included, however, are those areas where income related to soil carbon changes is the only income.

Barriers and incentives

The future extent of multifunctional bioenergy systems is dependent on several factors other than the purely economic ones. Investigations show that the willingness to cultivate Salix can be influenced by structural factors such as the farm's geographical location, the farmer's age, the farm's size and the orientation of its production. Barriers of technical/geographical and institutional kinds that hinder the new establishment of bioenergy plantations in general also hinder the establishment of multifunctional plantations. Moreover, there may be barriers specific to certain types of multifunctional plantations.

Besides the fact that local and regional conditions govern the demand for environmental services that can be satisfied by multifunctional plantations, the demand for the produced biomass as fuel can vary between different parts of the country, due to differences in regional conditions. For example, if a region has good access to forest fuels as well as restricted possibilities for expanded use of biomass, the interest in energy crop cultivation may be limited. On the other hand, if there is a large regional demand for bioenergy and the access to forest fuels – or the possibility of receiving imported biofuels – is limited, the potential demand for energy crops can be great. Future supply and demand also depend on technical factors. These may, for instance, concern the development of new forestry methods (supply) and of techniques for manufacturing biofuels based on lignocellulosic feedstocks (demand).

Table 3 displays a division of Sweden's counties into categories with respect to the future potential need for energy crops (expressed as a proportion of the county's farmland which is needed for energy crop cultivation to meet the county's estimated bioenergy needs, after available forest fuel and straw have been fully utilised). The division is based upon a scenario study of how the regional balances between supply and demand of biomass – excluding energy crops – may evolve during a 10–20 year period, as well as of county-level demand for farm fuels. The table also gives an indication of the county-wise conditions for satisfying the bioenergy demand through importation of biofuel via boat transport. In the subsequent Table 4, a comparison is then made between this demand for farmland and the estimated potential for multifunctional plantations.

As Table 3 implies, there is a large need for utilising farmland for production of energy crops in densely populated agricultural counties, if these are to become self-sufficient in bioenergy (for densely populated urban areas at the coasts, biofuel imports can be a further alternative). Usually between 10 and 50% of the farmland is needed. The requirement is especially large in Stockholm County, whose farmland area would have to be 3–5 times greater and be utilised solely for cultivating energy crops in order to cover the potential biofuel need in the county. At the same time, there is a large need in these counties for environmental services that conserve water and soil resources, which means good preconditions for multifunctional energy plantations. The practical potential for such plantations for purifying water, recycling sludge, and controlling erosion is normally equivalent to at most a few percent of the farmland (Table 4). This is a lower proportion than the need for farmland that was described above, so the implementation of such multifunctional plantations in densely populated agricultural counties should not be hindered by a limited biofuel demand.

However, in forest rich counties with relatively low population density (e.g. Småland and parts of Norrland), the future demand can usually be fulfilled entirely by forest fuel, which limits the need for energy crops. In these counties, therefore, the implementation of multifunctional plantations may eventually be hindered by a limited demand. At the same time, the need for environmental services to conserve water and soil resources in these counties is normally smaller than in densely populated agricultural counties.

Also when considering the structural barriers mentioned above, it seems that the preconditions for establishment of multifunctional Salix plantations are best in agricultural regions dominated by large farms and crop production, i.e. mainly in Sweden's flat landscape areas. Smaller farms that are primarily oriented toward milk and livestock production (and which often need most of their farmland for producing fodder) occur chiefly in mixed and forested landscapes where the need for environmental services is lower. An exception is Halland County, which has a high density of livestock but also a large need for environmental services and for limiting plant-nutrient leakage.

Table 3. Division of Sweden's counties into categories with respect to potential future need for energy crops, expressed as a proportion of the total farmland area. Also shown is whether the conditions for biofuel import via boat transport are good or very good.

Category / need for energy crops	County	Conditions for biofuel import via boat transport
I. No need	Jönköping Kronoberg Kalmar Gotland Halland Värmland	
II. Need corresponding to Salix cultivation on up to 10% of the total farmland area	Östergötland Södermanland Västra Götaland	Very good
III. Need corresponding to Salix cultivation on up to 30% of the total farmland area	Blekinge Skåne Örebro Västmanland	Good Very good
IV. Need corresponding to Salix cultivation on up to 50% of the total farmland area	Uppsala Gävleborg	Good
V. Need corresponding to Salix cultivation on > 100% of the total farmland area	Stockholm	Very good

Table 4. Demand per county for a selection of environmental services judged to have highest economic value (see Table 2). Here the demand is expressed as a proportion of the county's farmland that would need to be used for establishing multifunctional Salix plantations to meet the demand.

Category[a]	**County**	**Demand per county for a selection of environemntal services with highest economic value in Table 2** (% of farmland)				
		Treatment of sewage water through Salix irrigation	Treatment of drainage water through Salix irrigation	Treatment of drainage water in protective zones with Salix plantations	Sludge recycling in Salix plantations	Limiting of wind and water erosion
I.	Jönköping	4.2	0.2	0.1	4.8	0.1
	Kronoberg	1.8	0.3	0.2	8.1	0.1
	Kalmar	0.7	0.4	0.4	1.3	0.2
	Gotland	0.9	0.8	0.4	0	0.2
	Halland	0.4	2.6	1.8	0	0.6
	Värmland	2.7	0.7	0.3	2.3	0.2
	Dalarna	6.1	0.1	0.7	0	0.2
II.	Östergötland	2.9	0.5	0.9	0.5	0.2
	Södermanland	1.0	0.1	0.2	0.6	0.2
	Västra Götaland	1.3	0.9	0.4	3.3	0.2
III.	Blekinge	3.0	0.5	0.4	3.2	1.1
	Skåne	1.4	1.2	2.0	0	0.6
	Örebro	3.3	0.4	0.8	3.3	0.2
	Västmanland	1.2	0.3	0.1	0	0.2
IV.	Uppsala	2.5	0.2	0.2	1.8	0.2
	Gävleborg	5.0	0.2	0.6	3.6	0.2
V.	Stockholm	1.6	0.2	0.2	11	0.2

[a] See Table 3.

In regard to institutional barriers that follow from how the EU agricultural policy is designed, these also influence multifunctional plantations to a very high degree. A coordination and clearer coupling between agricultural, environmental and energy policies could take concrete expression in the form of directed measures for stimulating multifunctional plantations. An example is long-term environmental and cultivation subsidy of, for instance, Salix cultivation in protective zones and vegetation filters for purification of drainage water, which gives higher cultivation costs for the farmer. To facilitate the use of biomass that is produced in multifunctional plantations, subsidy may be also needed for other actors in the biofuel chain (such as incineration facilities that accept biomass with high cadmium content). This could have the form of an environmental bonus which benefits entrepreneurs and end-users of the biomass.

A concluding example: the purification of pre-treated sewage in Enköping

In Enköping a farmer has established a Salix plantation of 80 hectares, irrigated with pre-treated sewage from the nearby municipal waste water plant (see Figure 9 below, and Figure 2 which gives a view over the field). The farmer himself has financed the Salix plantation and is responsible for managing it, while the waste water plant's owners have paid for and are responsible for the irrigation facility and the water-storage ponds that are used in wintertime. The two parties have drawn up a 12-year contract which confirms the purification plant owners' right to irrigate the Salix plantations with pre-treated sewage, and also to spread sludge. The farmer receives an annual payment for making the Salix plantation available for these purposes.

The biomass produced is delivered to the local heating plant, which has an agreement with the farmer obligating the plant to buy the Salix chips at the prevailing market price. In return, it is allowed to spread the Salix incineration ash on the plantation.

No formal contact has been made between the purification plant and the heating plant. Instead, they cooperate on the basis of a mutual understanding about how the Salix plantation should be utilised optimally, for instance in regard to harvesting times and to a suitable combination of sewage water, sludge and ash that is supplied to the plantation.

Several factors have contributed to the establishment of the multifunctional bioenergy system in Enköping. One important precondition, of course, is that all three parties have been able to see attractive properties of the system which has been established. The purification plant's owners have found a cheaper solution than conventional nitrogen-purification technology, and have managed to perceive further profits in the fact that the sludge production has decreased when conventional phosphorus precipitation is stopped (the phosphorus is recirculated together with the nitrogen to the Salix plantations). The farmer has lower costs for fertiliser, and obtains large harvests due to the irrigation. And the heating plant gets a local supplier of fuel. It must be said that, without the openness to new solutions which all three parties have demonstrated, this collaboration on the Salix purification system might not have come about.

In this connection, the supportive information provided by Agrobränsle has been important. The positive attitude of the authorities concerned has also made a positive contribution.

Figure 9. Plan of the area with the heating plant, sewage purification plant, and adjacent Salix plantations which are utilised for sewage water treatment.

This report has briefly discussed how multifunctional bioenergy systems can overcome barriers that hinder new establishment of energy crop production, and strengthen incentives which may exist. The results presented in previous sections show clearly that, if farmers who produce Salix in multifunctional plantations could obtain extra income corresponding to the estimated value of the environmental services which the plantations provide, the economy would in many cases be dramatically improved. It is thus evident that multifunctional bioenergy systems could overcome barriers and pave the way for increased establishment of Salix cultivation in Sweden. This applies especially to those cases where the cultivators receive direct business-economic profits (via new income or reduced costs). In other cases where multifunctional bioenergy systems generate indirect social-economic profits, it may however be required that part of the social-economic profits be transferred to the cultivator and, in certain instances, also to subsequent actors in the fuel chain. The present study demonstrates that such a redistribution, for example through establishment subsidy, cultivation subsidy and environmental bonuses, can be a cost-effective way for the state to deal with current environmental problems. Investments in establishment of multifunctional bioenergy systems could also be carried out with funds that are available for landscape development.

The example of Enköping, described above, illustrates how actors can collaborate on a specific type of multifunctional bioenergy system and create functioning agreements that enable all the parties involve to reap advantages from the system. Moreover, it underlines the significance of "catalysers" such as Agrobränsle, and the fact that relevant local and regional authorities can play an important role in the establishment of multifunctional bioenergy systems.

Pathways to sustainable European energy systems

The European pathways project is a five year project with the overall aim to evaluate and propose robust pathways towards a sustainable energy system with respect to environmental, technical, economic and social issues. The focus is on the stationary energy system (power and heat) in the European setting. Evaluations will be based on a detailed description of the present energy system and follow how this can be developed into the future under a range of environmental, economic and infrastructure constraints. The proposed project is a response to the need for a large and long-term research project on European energy pathways, which can produce independent results to support decision makers in industry and in governmental organizations. Stakeholders for this project are: the European utility industry and other energy related industries, the European Commission, EU-Member State governments and their energy related boards and oil and gas companies. The overall question to be answered by the project is:

How can pathways to a sustainable energy system be characterized and visualized and what are the consequences of these pathways with respect to the characteristics of the energy system as such (types of technologies, technical and economic barriers) and for society in general (security of supply, competitiveness and required policies)?

This question is addressed on three levels; by means of energy systems analysis (technology assessment and technical-economic analysis), a multi-disciplinary analysis and an extended multi-disciplinary policy analysis. From a dialogue with stakeholders, the above question has been divided into sub-questions such as:

- What is the critical timing for decisions to ensure that a pathway to a sustainable energy system can be followed?
- What are ”key” technologies and systems for the identified ”pathways” - including identification of uncertainties and risks for technology lock-in effects?
- What requirements and consequences are imposed on the energy system in case of a high penetration of renewables?
- What are the consequences of a strong increase in the use of natural gas?
- What if efforts to develop CO2 capture and storage fail?
- Where should the biomass be used – in the transportation sector or in the stationary energy system?
- Are the deregulated energy markets suitable to facilitate a development towards a sustainable energy system?
- Will energy efficiency be achieved through free market forces or regulatory action?
- What are the requirements of financing the energy infrastructure for the different pathways identified?

In order to address the sub-questions in an efficient and focussed way the project is structured into 10 work packages addressing topics such as description of the energy infrastructure, energy systems modelling, technology assessment of best available and future technologies and international fuel markets. In planning of the project significant efforts have been put into ensuring that the project should not only be strong in research but also in management, communication and fundraising.

The global dimension will be ensured through integration with the other three regional AGS pathway projects in the Americas, East Asia, and India and Africa.

More information at Pathways website:

www.ags.chalmers.se/pathways

The Alliance for Global Sustainability

The Alliance for Global Sustainability (AGS) brings together four of the world's leading technical universities – the Massachusetts Institute of Technology, The University of Tokyo, Chalmers University of Technology and the Swiss Federal Institute of Technology – to conduct research in collaboration with government and industry on some of society´s greatest challenges.

The AGS represent a new synthesis of multidisciplinary and multi-geographical research that draws on the diverse and complementary skills of the AGS partners. In addition to academic collaborations each of the universities has extensive experience in working with stakeholders, particularly a growing number of visionary leaders from industry who recognise their fundamental role in achieving sustainable development.

More information at AGS website:

globalsustainability.org

Photo: Måns Ahnlund