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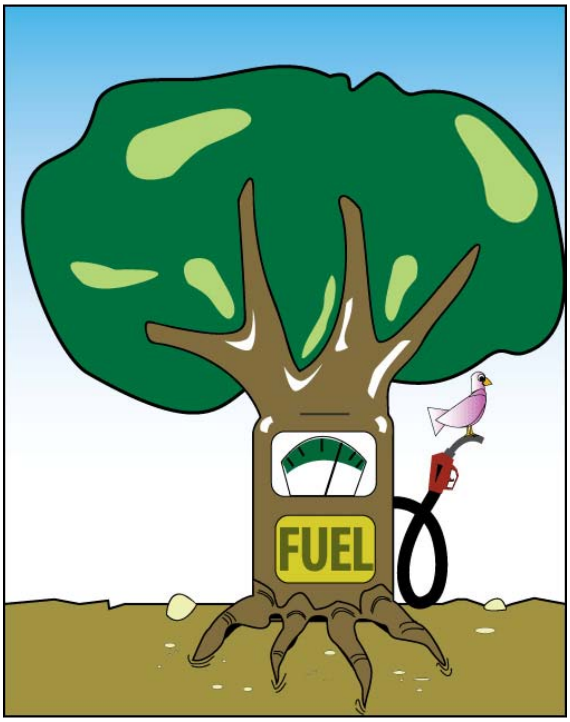
Planted Forests and Trees Working Papers

Planted Forests and Second-generation Biofuels



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The purpose of these papers is to provide early information on on-going activities and programmes, and to stimulate discussion.

Comments and feedback are welcome.

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1. Introduction

Today the world's electric, heat, transportation and industry sector are almost fully dependent on fossil fuels (oil, natural gas and coal) as an energy source (Metzger, *et al*., 2008). Liquid biofuel for the transportation sector represents only approximately 1 % of the sectors' total fuel consumption (FAO, 2008). In many parts of the world expectations are high for liquid biofuels, a fuel produced from raw materials existing in abundant amounts in most countries in contrast to oil that is very unequally distributed over the planet. A number of recent concerns have increased the interest in biofuel. The most important of these concerns are linked to 1) climate change, 2) high energy prices, 3) energy security, 4) and economic development opportunities.

Until now the feedstock for the production of liquid biofuels is mainly derived from agricultural products such as sugar cane, corn, wheat, oilseed and palm oil. Biofuel derived from agriculture crops are called conventional or "first-generation biofuels". Intensive research is now ongoing to develop new commercially viable techniques to derive liquid biofuels from the more complex lignocellulosic materials. Wood will likely become a key raw material for the production of liquid biofuels given that the lignocellulosic "second-generation biofuels" technology will be commercially viable. Second-generation biofuels can also be produced from crop residues such as wheat straw and corn stove, and from purpose-grown material such as switchgrass and short rotation woody crops.

Currently, the production of second-generation bioenergy using lignocellulosic biomass is limited to a few production plants. There is a wide variety of opinions on how soon the technology will become more common. The biofuel sector is, however, fast moving and intensive research on development of second-generation biofuels is ongoing in many parts of the world with the USA, China, Brazil and Canada leading the way.

First-generation biofuels using sugar, maize, cassava, oilseeds and palm oil as raw material for the production of biofuels have lately been criticised for weakening food security. Using food crops to produce energy can contribute to augmenting food prices. Most available rain-fed agricultural land is already in use, which offers marginal opportunities to expand production of crops in order to provide enough feedstock for a growing biofuel sector in a world where already approx. 850 million persons are food insecure. Lignocellulosic biomass for second-generation biofuels does not compete directly with food and is more land-use efficient and less carbon positive than first-generation biofuels, which argues for a shift from first- to second-generation biofuels.

The biofuel sector is driven by major political, economic, environmental and security interests. Energy has immediate impacts on global markets. Commercialising second-generation biofuels will have a major and complex interconnected impact on many different fields. Increased demand for bioenergy and biofuels may increase pressure to convert natural forests or adopt management practices which reduce biodiversity, food security, or other forest benefits. Increased biofuels demand may also provide positive outcomes such as improved forest management, increased employment opportunities and increased reforestation and afforestation on marginal land. Whether the impacts are positive or negative depends on practices, systems, and policies and how they are implemented. Large scale second-generation biofuels production would likely spur the planted forests sector to expand to meet the growing demand of lignocellulose (Bingham *et al*, 2008). FAO should be prepared to give neutral, science-based, professional technical advice on how a growing planted forest sector can balance the economic, social and environmental trade-offs and synergies. This Working Paper gives an introduction to areas connected to the planted forest sector affected by an evolution of commercialising second-generation biofuels that should be considered in developing a sustainable biofuels sector.

2. Purpose

The purpose of this Working Paper is to review the status of second-generation biofuel technology and its potential implications for planted forests. These implications need to be considered by decision makers, academics, industry and the international community. The paper discusses potential concerns and opportunities related to the large scale commercialization of second-generation biofuels, including issues of food security, land use, livelihoods, environmental considerations and trade. In particular, issues are raised that need to be addressed in order to achieve sustainable management of planted forests when used for liquid biofuel production as this sector expands rapidly in future.

3. Scope

This Working Paper is focusing on the implications and possibilities for the planted forests sector of commercializing second-generation biofuels. The Paper also describes the use of forest and processing residues as a feedstock for generating second-generation biofuels. Second-generation biofuels can also be derived from short rotation woody crops, agriculture crops such as switchgrass (*Panicum vergatum*) or elephant grass (*Pennisetum purpureum*) and from agriculture residues such as straw from cereal crops or bagasse from sugar cane. These feedstock sources are, however, excluded from this Working Paper. This Working Paper is restricted to considering the impact of commercializing second-generation biofuels on the planted forest sector. It should be recognized that any expansion of heat and electricity generated from lignocellulosic material will also have trade-offs and synergies that should be explored.

4. Background

4.1. Planted forests

Planted forest is the definition of planted trees in 1) semi-natural forests and 2) in plantations, productive and protective, that form a larger unified area of more than 0,5 ha. Figure 1. visualizes the classification of forests highlighting the planted forests.

Planted forests account for about seven percent of the global forest area or about two percent of the global land area i.e. about 271 million hectares. At the same time, planted forests provide more than half of the industrial wood produced in the world, and the extent and productivity and area of planted forests are increasing. Compared to naturally regenerating forests, planted forests represent a higher investment per unit area and normally require higher values from their products and services to provide an acceptable return on investment. Planted forests are also diverse, ranging from small holdings to industrial estates and from primarily provision of ecological or social services on one end of the scale to provision of wood and non-wood forest products on the other. They stretch from boreal to tropical zones, and are established using native or introduced tree species. They are also sometimes controversial and balancing the trade offs between socio-cultural, environmental and economic benefits can be a challenge (FAO, 2006).

Figure 1. The continuum of forest characteristics from primary forests to and trees outside forests in which the scope of planted forests is highlighted (Adopted from the Global Forest Resources Assessment 2005).

Primary	**Modified natural**	**Semi-natural**		**Plantation**		**Trees outside forests**
				Productive	Protective	
Forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed	Forest of naturally regenerated native species where there are clearly visible indications of human activities	Assisted natural regeneration through silvicultural practices for intensive management • weeding • fertilizing • thinning • selective logging	Planted component Forest of native species, established through planting, seeding or coppice of planted trees	Forest of introduced species and in some cases native species, established through planting or seeding mainly for *production of wood or non-wood goods*	Forest of native or introduced species, established through planting or seeding mainly for *provision of services*	Stands smaller than 0.5 ha; trees in agricultural land (agroforestry systems, homegardens, orchards); trees in urban environments; and scattered along roads and in landscapes
			PLANTED FORESTS SUB-GROUP			

Forests, including planted forests supply wood, fibre, fuelwood and non-wood forest products and services for industrial and non-industrial uses. The added benefits of wood products over competing products (cement, plastics, metal products) are that they are renewable and are energy efficient and environmentally friendly. Well-managed planted forests can also contribute positively towards provision of environmental services (soil and water protection, rehabilitation of degraded or marginal lands, restoration of landscapes, habitat development and carbon sequestration) and provision of social services and livelihood support (regional development, income generation, employment and recreation). Planted forests may also offset pressure for wood production from primary forests and valuable forest ecosystems (FAO, 2006).

4.2. Bioenergy

Bioenergy refers to energy obtained from biomass, which is the biodegradable fraction of products, purpose-grown or waste and residues from agriculture (of vegetable and animal origin), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste (FAO, 2008b). Bioenergy can be in many forms such as electricity, heat, gas or liquid biofuels.

Traditional biomass materials, including fuelwood, charcoal and animal dung, continue to be important sources of bioenergy. Today woodfuel is still the primary source of energy for cooking and heating in less developed countries, where about 75 percent of energy is based on burning biomass (IEA, 2004).

Modern bioenergy relies on efficient conversion technologies for applications at the household, small business and industrial scale. Solid or liquid biomass inputs can be processed to be more convenient energy carriers. These include solid biofuels (e.g. firewood, wood chips, pellets, charcoal, briquettes), gaseous biofuels (biogas, synthesis gas, hydrogen) and liquid biofuels (e.g. bioethanol, biodiesel) (GBEP, 2007). Among the different segments of the bioenergy sector, the largest and most rapid growth has been seen in liquid biofuels (FAO, 2008b).

4.3. Biofuels

The term biofuel includes solid, liquid or gas fuels derived from biomass. Biomass is derived from a recently living organism; a plant or an animal or their by-products. The term biofuel is increasingly used to refer specifically to liquid or gas fuel derived from biomass and used for transportation or to generate heat and electricity. Liquid biofuels can be classified into "first-generation" and "second-generation" biofuels where the distinction between them is the biomass (feedstock) used.

First-generation biofuel is generally made from sugars, grains or seeds using only a specific often edible part of the above ground biomass. The conversion of these products into biofuels is relatively simple (Larson, 2008). The two main first-generation liquid biofuels are bioethanol and biodiesel. Bioethanol is the dominant liquid biofuel at the moment representing approximately 85% of the global production while biodiesel accounts for the other 15%.

Second-generation biofuel is generally made from non-edible lignocellulosic biomass. The biomass can be crop, forest, and food production residues, as well as material such as switchgrass or trees. The biomass can also consist of a whole plant, for instance switchgrass or a tree. Lignocellulosic biomass, also called cellulosic biomass, is a complex composite material consisting primarily of cellulose and hemicellulose bonded with lignin in plant cell walls (USDOE, 2006). Conversion technologies for second-generation biofuels are presently under development and will be described in more in-depth in the following chapter.

5. Second-generation biofuels

The second-generation biofuel technology enables the decomposition of lignocellulosic biomass to liquid biofuels. Recently a major interest in moving from the current fist-generation liquid biofuels to second-generation biofuels has appeared. There are a number of benefits of using second-generation biofuels compared to first-generation biofuels. Firstly, the production of the lignocellulosic biomass does not compete as immediately with food production as the first-generation biofuels may. Secondly, the conversion technology enables the use of the whole above ground plant material and thereby can increase land-use efficiency, when yield per unit area is greater than a crop for first-generation biofuel (Larson *et al*., 2008). The sugars and seeds needed for first-generation biofuels form only a fraction of the total plant material as cellulose is in fact the most abundant biological material on earth. Thirdly, second-generation biofuels have the potential to be carbon neutral and even carbon negative. Fourthly, agriculture and forestry residues can be used, which may increase land use efficiency and may provide an affordable feedstock.

If large scale production of second-generation biofuels is to become a reality important breakthroughs in conversion technologies need to take place. Major investment in research and development is being done and the investments are expected to increase worldwide during the coming years (Kamis and Joshi, 2008). In 2007 the United States invested some 2,9 billion dollars for the development of second-generation biofuel technologies. In June 2007 the oil giant British Petroleum (BP) announced the funding of a five-year cellulosic fuel programme that is to be executed by Mendel Biotechnology. Other oil corporations that are contributing to research in second-generation biofuels are the Brazilian Petrobras, Chevron, Shell and Conoco-Phillips.

5.1. Biomass production

The biomass needed to produce second-generation biofuels can be either from residues or dedicated crops. A dedicated crop is a source of biomass intended for a specific purpose, in this instance for the production of liquid biofuels. The residues may originate from biomass left after harvesting an agricultural crop or trees or from the processing residues of these.

5.1.1. Residues

The annual global use of wood is approximately 4 billion cubic meters. It is estimated that approx. 55% of this volume is used as fuelwood mainly in less developed countries. The remaining 45% is used as industrial raw material. Of these 45% only approximately 60% is actually used as an industrial raw material, the remaining part (40%) ends up as residues. The residues form a significant potential raw material resource for the production of second-generation biofuels (Richardson *et al*., 2002). In addition, creating more economic value from traditional timber production forests may encourage reforestation, afforestation, and improved forest management, reducing pressure to convert forests to other uses and encouraging replanting of degraded land areas.

Residues occur both from logging and from the processing of the round wood. Residues from logging, which can constitute up to 60% and more of the total harvested trees, are often left in the forest (Parikka, 2004).

The use of harvest residues is generally an inexpensive source of biomass and can hence be an economical choice. Harvesting costs of a full recovery may, however, be high and make the practise economically unsustainable even though there are significant energetic resources already invested in unused harvest residues. There are also environmental concerns considering an extensive long term use of harvest residues. Leaving appropriate levels of residues protects soil quality and decreases or eliminates the need for the use of fertilizers. Extensive long term use of harvest residues may increase erosion and diminish wildlife. The use of residues may however, when managed to conserve soil resources, be ecologically sustainable as it increases land use efficiency by applying multifunctional uses of the land.

The second type of forest residues potentially available for bioenergy and biofuel use is excess biomass remaining after pulp or saw mill processing. Bark can be a very important by-product from a saw mill. The bark content of round wood can be between 10-22% of the total volume of debarked wood, depending on the size and the species (FAO, 1990). In addition to bark, chips and sawdust appear as a residue or by-product from the saw mill industry. These residues or by-products are often sold to the pulp, or energy industry and can improve the economic situation of the sawmill (Peksa-Blanchard *et al.*, 2007). Black liqor is currently the most important by-product in energy production at forest inductry mills. Black liquor is the byproduct formed during chemical pulping of wood. In this process lignin is separated from cellulose fibres, that are used for several purposes, but mainly for paper making. Black liquor is the combination of the lignin residue with water and chemicals used for the extraction. In the chemical pulping process, a chipped wood material is cooked in a lye solution, which dissolves the lignin and leaves behind the cellulose. The lignin is burned in a recovery boiler for gathering the cooking chemicals and for utilising the energy of the dissolved wood material (Peksa-Blanchard *et al*., 2007). In fact, many of the primary mill residues are already utilized in the forest products industry for thermal and electrical energy generation. If excess is available, these residues could form an important feedstock for energy production.

Whether the residues will be a financially reliable biomass source depends on logistics and whether the quantities are large enough. The low bulk density poses a problem as it augments the transportation costs. Transportation costs of the low-value commodity can consist of half of the total costs. Optimizing the production using residues can mean minimizing transportation costs. An option is to make wood chips or pellets of the residues to augment and unify the biomass to a more easily transportable form.

Today wood pellets are used for heating but also for generating electricity. Wood pellets are usually made from compacted sawdust and is a byproduct of sawmilling or other wood transformation activities. The raw material is dried, mechanically fractioned to size and extruded under intense pressure into pellets. The pellets are extremely dense and can be produced with a low humidity content (below 10%). During the process, the raw material is densified approximately 3.7 times. This allows the pellets to be burned with a high combustion efficiency. Compact storage and lower transportation cost are also possible because of their high density. Their regular form and small size automatic feeding with very fine calibration.

5.1.2. Dedicated crops

Biomass produced for second-generation biofuels can apart from residues also be produced from dedicated crops. A dedicated crop is a source of biomass intended for a specific purpose, in this instance for the production of liquid biofuels. The dedicated crop for the production of biomass intended for second-generation biofuels can consist of perennial grasses such as switchgrass (*Panicum virgatum*) or short rotation woody crops such as willow (*Salix spp*.), poplar (*Populus spp*.), eucalypts (*Eucalyptus spp*.) and other species (Tuskan, 2007). Dedicated energy crops are however not demanding crops and can be grown on marginal or degraded land and would potentially not be competing for the more fertile lands required for food crop production (Sims *et al*., 2008).

In 2006 black cottonwood (*Populus trichocarpa*) became the first tree genome that was sequenced. The fact that the poplar genome is sequenced is crucial for further breeding programmes focusing on traits relevant for biofuel production. Also the eucalyptus genome is very close to be totally sequenced. Eucalypt is the most widely planted hardwood in the world and holds promise to be one of the main dedicated crops for the production of biomass intended for second-generation biofuels. Depending on site, genetic material and management, the yields of eucalypts and acacia (*Acacia spp*.) can reach 40 m^3/yr and be harvested only after some 3-4 years in some regions. Features that especially need to be taken into consideration in genetic improvement are rapid growth rate of the crop, and low lignin content. The decomposition of lignin is one of the main bottle necks in the biochemical conversion (please see Chapter 2.5.). Both poplar and eucalypts with lower lignin content have already been developed (Li *et al*., 2008). Lignin is not, however, a problem in the thermochemical conversion. Research and development of trees intended for second-generation biofuels is only starting and a lot is yet to be done.

Some species allow a different management system based on their ability to coppice. Short-rotation coppice is a tree plantation that is harvested every 2-6 years. The cutting stimulates stump sprouting and new growth. The coppiced tree has many stems. A wide range of species are used for short-rotation coppice such as willows, poplars, eucalypts, acacias and casuarinas (*Casuarina spp.*). Short-rotation coppice is used in many parts of the world but no reliable statistics concerning production area and productivity are however maintained.

5.2. Conversion

Lignocellulosic biomass is more complex than the biomass used in first-generation technologies and hence more sophisticated conversion technology is needed. Cellulose consists of polysaccharides and makes up about 40-50% of the weight of dry wood. Hemicellulose is also constructed of polysaccharides and accounts for 25-35% of the dry wood. Lignin, on the other hand, is not a polysaccharide and is strongly resistant to biological and chemical degradation. The relative proportion of these three materials varies depending on the species (USDOE, 2006).

Lignocellulosic biomass can be converted into liquid biofuels using two main techniques; biochemical or thermochemical processing (Larson *et al*., 2008). Other conversion techniques also exist and more are being developed. Using biochemical processing results in a petroleum-gasoline substitute in the form of ethanol or butanol derived by enzymatic hydrolysis. Using thermochemical processing results in petroleum-gasoline substitutes in the form of methanol, Ficher-Tropsch gasoline or mixed alcohols, petroleum-diesel substitutes in the form of Ficher-Tropsch diesel, dimethyl ether (also a propane substitute) or green diesel, and other chemical and biofuel products. Depending on the feedstock available the conversion can follow a number of pathways, which of the main steps are described below.

Enzyme hydrolysis (biochemical conversion) could be expected to produce 300 litres ethanol of one tonne of biomass whereas thermochemical could produce 200 litres of BTL diesel from the same amount of biomass. The yield in energy terms would however be approximately similar as synthetic diesel has a higher energy density by volume than ethanol (Sims *et al.*, 2008). As the research of these technologies is constantly on-going it is hard to tell what the future will hold concerning yields both in energy and quantity terms.

5.2.1. Biochemical conversion

The basic steps of the production of ethanol or buthanol using biochemical conversion are pre-treatment, saccharification, fermentation and distillation. It is also possible combine the saccharification and fermentation phase.

1. **Pre-treatment** is designed to separate the cellulose, the hemicellulose and the lignin. Pre-treatment can be carried out in a number of ways e.g. using dilute acids (sulphuric or hydrochlorid), alkalines (calcium hydroxide), liquid ammonia or steam explosion (Balat *et al.*, 2008).

2. **Saccharification** through hydrolysis, using acid or enzymes, is to brake down polysaccharides to simple sugars. The use of enzymes seems to be more probable in the future than the use of acids as the yields tends to be higher using enzymes than when using acids and acids additionally have negative environmental impacts, which leads to high wastewater treatment requirements for the industry (FAO, 2008).

3. **Fermentation**, using yeasts or bacteria, breaks down the sugars into bioethanol. The fermentation is more complex than the fermentation process of the first-generation sugar and starchy crops as the lignocellulosic material requires a mixed-sugar fermentation. Only the cellulose and hemicellulose parts are possible to derive to ethanol. Lignin is not fermented but can instead be collected and used to generate heat and/or electricity (Hahn-Hägerdal *et al.*, 2006).

4. **Distillation**, is the last step of the process and separates the bioethanol from the water and liquid mixture containing the lignin Hahn-Hägerdal *et al.*, 2006).

Currently, there are only a few operational facilities producing bioethanol using second-generation biochemical conversion technology but a number of demonstration and pilot projects exist. The International Energy Agency is maintaining a site with the existing second-generation facilities on the following URL:
http://biofuels.abc-energy.at/demoplants/

The main areas that need to be improved in order to achieve a commercially viable conversion process are:

- developing biomass feedstock with physical and chemical structures that facilitate the conversion to ethanol for instance a lower lignin content or a higher cellulose content;

- improving enzymes used for the saccharification;
- develop new micro-organisms that are high-temperature tolerant, ethanol-tolerant and able to ferment multiple types of sugars.

During the past years great cost reduction has been achieved and research and development are constantly on-going (Sims *et al*., 2008). Achieving these goals could be facilitated by using genetic engineering. Great care is to be taken especially considering feedstock production because of the risk of cross-pollination with natural species or spreading and out-competing natural species, in both cases threatening biodiversity. Less risk is however involved in using genetically modified micro-organisms to improve the fermentation process as these organisms are in a controlled environment.

5.2.2. Thermochemical conversion

Thermochemical conversion is the second type of second-generation biofuel conversion technology. Thermochemical conversion involves much higher temperatures and pressure than the biochemical conversion. Using the thermochemical conversion technology it is possible to derive a number of different liquid biofuels. These are:

- a petroleum-gasoline substitute in the form of 1) methanol, 2) Ficher-Tropsch gasoline or 3) mixed alcohols;
- a petroleum-diesel substitute in the form of 1) Ficher-Tropsch diesel, 2) dimethyl ether (also a propane substitute) or 3) green diesel.

The thermochemical conversion begins with either gasification where the biomass is converted into synthetic gas (syngas) or with pyrolysis where the organic matter is heated in the absence of oxygen. The next steps of the process depend on which the final product will be (Sims *et al*., 2008). If the thermochemical conversion process could be made commercially viable it would be valuable as it permits to transform also the lignin into liquid fuels, which is not possible in the biochemical conversion.

The thermochemical conversion technology has already been used for years and is well known and includes much less technical hurdles than the biochemical conversion technology. On the other hand the technology seems to hold fewer possibilities for cost reduction (Sims *et al*., 2008).

6. Planted forest management

This chapter outlines issues related to the silvicultural management and harvesting of planted forests that need to be taken into consideration when planning the establishment of planted forests intended for second-generation biofuel production.

6.1. Site selection and establishment

Land-use and site selection for planted forest are most important issues for a number of reasons. The ambitious biofuel targets set up by USA and the EU, among others, may trigger a need for additional land to produce the feedstock. Rain fed land suitable for fibre, feed and food production is scarce in the world. Site selection for planted forest for a productive purpose is usually chosen based on topography, soil quality, water resources (sufficient rainfall or possibility for irrigation), infrastructure available, labour costs and closeness to processing facilities and markets. Biomass production for second-generation biofuels may provoke additional deforestation, threaten biodiversity and compete for land used for food production and consequently weaken food security. Trees are, however, generally less demanding concerning soil quality than food crops and forest is hence possible to establish on more marginal lands than most food crops, and may allow restoration of previously degraded areas. Using degraded land for biomass production would avoid the competition of land between food and energy production. Afforestating degraded land would also contribute to combating climate change by sequestrating carbon through the established forest. Afforestation of degraded lands will restore the organic matter in the soil and hence restore also the water storage capacity. Species like *Albizia lebbeck* gave 20 tons of wood per hectare and *Dendrocalamus strictus* 32 tons per hectare on a mine spoil in a dry tropical region of India (Singh and Singh, 2006). Establishing planted forest on lands under the threat of desertification has been done widely in China with encouraging results. The annual expansion of desertification has declined from 1,04 million ha in the 1990's to 0,76 million ha in 1999-2004 (China National Committee for the Implementation of the UNCCD, 2006). The productivity will obviously be limited during the first years but will improve with restoration of the soil organic matter and water storage capacity. To facilitate growth it is possible to use hydrogels able to store up to 400 times their own weight. The hydrogels also protect trees against salt, soil acidity and heavy metals (Frank, 2007).

Integrated planning and management approaches are crucial in planted forest site selection and establishment as planted forests interact with and impact upon local land uses, livelihoods and the environment. Site establishment should be avoided on biodiversity hotspots and where ecological corridors should be established throughout the landscape. It is not advisable to establish planted forest on peat lands as it may provoke carbon emissions. Sites should furthermore avoid interference with local communities. Further information on biodiversity, greenhouse gas (GHG) emissions and land use efficiency is to be found in Chapter 7.

6.2. Germplasm and species selection

Ideally a tree produced for feedstock to derive liquid biofuels using second-generation technologies would have the following properties:

- accumulate greater carbon allocations in the stem;
- minimal perennial branch formation and growth;
- large stem diameter;
- high growth rate MAI;
- drought and stress resistant;
- good nutrient- and water-use efficiency.

One of the main challenges that second-generation is facing is the conversion of the lignocellulosic polymers into biofuels. Efforts are being made to gain a better understanding of the cell walls. A milestone in these attempts was made when the first complete DNA sequence of a tree, the black cottonwood *(Populus trichocarpa)*, was done in 2006. The completely identified genome laid the foundation that will help researchers to develop trees that are fast-growing and easily-converted to liquid biofuels. Poplar is considered to hold promise as a second-generation feedstock in boreal, temperate and sub-tropical climatic zones also because of it rapid growth rate. In tropical regions Eucalypts will probably be an important species (Tuskan, 2007). Major research efforts are also being made to map eucalypts' genome with the aim to improve the tree as an energy crop.

The on-going research is aiming to achieve both economic and environmental benefits. An example of research to develop trees suitable for second-generation biofuels is a project developed by the US's Department of Energy's Joint Genome Institute. The research group has developed a poplar with lower lignin content. Lignin forms the so-called "glue" that holds cellulose together and the lower lignin content hence facilitates the conversion of the feedstock into bioethanol and makes the conversion process more affordable. The Taiwan Forestry Research Institute together with Council of Agriculture and North Carolina State University in the USA carried out a gene modification project that created eucalypts with a higher than normal carbon dioxide absorption capacity. The eucalypts in question also produces less lignin and more cellulose, which facilitates conversion. Other relevant research is focusing on drought tolerance and tolerance towards acidic soils.

6.3. Nutrient management

Planted forests have a nutrient cycle from foliage and branches to litter, which returns back into the soil. In long rotations and deep rooting systems of trees the weathering of minerals may contribute sufficient nutrients to compensate for their loss due to the harvesting of the biomass. However, artificial or biological fertilizers may be used in planted forests to provide healthy seedlings from nurseries, to replace soil nutrients removed in harvesting in short-rotation crops or lost through litter removal; to increase forest productivity when land is limited for new forest development; to provide nutrients on poor soils for the establishment of tree cover in site rehabilitation; and to provide one or more nutrients or trace elements that may be lacking or unavailable (FAO, 2006).

An environmental issue regarding fertilizers in nurseries or in forest planting is potential over-application of fertilizer, with subsequent nutrient leaching into streams and watercourses, contributing to the eutrophication of water courses and lakes or the accumulation of heavy metals in the environment (FAO, 2006). The input of artificial fertilizers to increase yields must be carefully managed to minimize or prevent greenhouse gas emissions and nutrient loss from the site. Trees demand less fertilizers than agriculture crops but fertilizer can still be necessary. A soil analysis provides information of which nutrients need to be applied and how much. Timing of fertilizing is additionally crucial in order to prevent run-offs of the added nutrients. In parallel, a greater understanding of the microbial activities in the soil and their interaction with the rhizospere is important for a more sustainable production.

The extensive use of agriculture and forest residues as a feedstock to produce second-generation biofuels may have negative implications on the nutrient balance in the soil. Stem only harvesting leaving the branches on the site contributes to enrichment of the soil and increased cation exchange capacity (Bélanger *et al*., 2003) and reduces erosion. It also enhances the existence of some types of wildlife especially small game and rodents. For large scale second-generation biofuel production vast amounts of feedstock is needed. A systematic removal of residues may lead to a need of replacement of the nutrients with biological and synthetic fertilizers. The decision to apply fertilizers, in the field or in the nursery, should be based on soil, foliar and/or mycoflora analysis, and fertilizer should be applied in an amount to meet the need only.

6.4. Water management

Water availability is a fundamental consideration for feedstock production. Water is required through the entire biofuel chain. Distribution of freshwater resource availability varies greatly. Globally pressure on water supplies is increasing from a growing population, per capita usage and climate change (UNESCA-WWAP, 2006). Increased production of liquid biofuels can further raise the demand for freshwater and will lead to less water availability for other uses (The Royal Society, 2008). This is an issue for careful consideration by decision makers.

Water use is crucial to include in life cycle assessments (LCA) for all stages of the production chain. Expanding production of biomass for biofuel production may increase the need for water, especially for crops with high water demand such as eucalypts. Some crops have higher water use efficiency (WUC) depending on several different factors such as precipitation, evaporation, transpiration, which in turn are dependent on climatic variables, including CO^2 levels, solar radiation absorption and wind speed (McNaugton & Jarvis, 1991).

Establishing planted forests in arid and semi-arid areas requires careful selection and evaluation of species. Inappropriate planting, particularly if using species with high water requirements, can deplete water resources, especially groundwater. The challenges are a mixture of both policy- and technology-related environmental and socio-economic considerations and options for integrated watershed management (FAO, 2006).

Planted forests may play a significant role in regulating water flows and improving water quality. They can be an important mechanism in rehabilitating catchments. As with naturally regenerating forests, they can regulate floods, reduce debris flows and stabilize land, thereby reducing soil erosion that would otherwise lead to excessive sedimentation in rivers and lakes. They can control soil and water salinity and improve soil stability to prevent landslides. Planted forests may also play an important role in urban and peri-urban localities, particularly in arid and semi-arid areas, by contributing to the recycling of waste water (phyto-remediation) from cities or from industrial activities, particularly where they enhance the functioning of wetlands (FAO, 2006).

Water availability is closely related to productivity due to the conservative nature of water use efficiency. More in-depth species and location specific studies are needed to have a better understanding of water use efficiency and implications to the hydrological cycle on the larger landscape (The Royal Society, 2008). Water pollution from the processing phase should also be considered. Effluent production linked to the processing phase to produce bioethanol may be substantial (Berndes, 2002).

6.5. Rotation lengths

The rotation length of a plantation is determined by the following factors:

- the species;
- management practices;
- profitability;
- growth rates;
- desired wood and fibre properties;
- site constraints (draught, wind etc.);
- socio-economic factors.

Profitability, the rate of return from roundwood production over rotation, tends to be the most important factor affecting the rotation length in economic terms. Economically optimal rotation lengths tend to be shorter where yields are higher and where the producer seeks to maximise the profitability of the planted forests (Brown & Whiteman, 2000). Therefore, second-generation feedstock production may encourage short rotations where possible in order to optimize profitability.

6.6. Protection

6.6.1. Pests and diseases

The control of weeds, insects, diseases and other pests is critical to maintaining planted forest health and productivity. Currently, chemicals are widely used for such control but involve environmental risks. Sound selection of species, provenances or hybrid materials with genetic traits tolerant to these biotic agents, timely tending, silvicultural operations and comprehensive protection monitoring and management can substantially reduce the risk of insect, disease and other pest outbreaks. Integrated-pest-management (IPM) relies primarily on environmentally benign processes, including the use of pest-tolerant varieties, improved silviculture, protection and management practices, the actions of natural enemies and cultural control (FAO, 2006).

Many introduced or exotic species may adapt to their new environment and regenerate prolifically. It is essential that the regeneration is monitored and when necessary controlled in order for the introduced species not to generate unanticipated negative impacts on native ecosystems or agricultural lands or causing increased fire risk. Introduction of new species should be based upon strict scientific testing and effective regulatory controls (FAO, 2006).

The use of species with the potential to become invasive may be considered in combating desertification or for rehabilitating severely degraded lands. Due to their resilience and high-growth rates, these species could be a possible choice for biomass production. However, their use should be based upon analysis of the risks and benefits and should be carefully monitored (FAO, 2006).

6.6.2. Forest fires

Fire can be a major threat to all forests, including planted forests, particularly where dry litter builds up or an inflammable shrub layer develops. Globally, damaging forest fires typically occur in areas modified by human use, like uncontrolled fires in and outside the forests for other land uses like hunting, agriculture or pasturing. Fire may contribute to the loss of tree products, nutrients and exposes the soil to erosion as well as the deterioration of other forest functions like the protection of biodiversity, watersheds and other. Smoke and other emissions from fires can be serious health hazards. While the release of greenhouse gases from fire is a natural phenomenon, the net release of carbon by unnaturally abundant or intense wildfires is contributing to the human-induced increase of the greenhouse effect and global warming.

Planned burning is often used in planted forests to reduce competing vegetation, improve wildlife habitat, avoid a catastrophic outbreak of wildfire and, in some instances, stimulate natural regeneration of fire-dependent species and maintain certain natural ecosystems. Fire is also used in land clearing before tree planting in some regions.

Fire management in planted forests needs to be based on the management objectives, prediction, prevention and preparedness, supported by public awareness, monitoring, rapid response and community-based fire management. Fire weather prediction models have been developed in many industrialized countries, while less developed countries are improving their capacity and capability to predict, to prepare for and prevent destructive fires (FAO, 2007).

6.7 Harvesting, Transport and Processing

Planted forests for second-generation biofuels may consist of many and fast growing trees per hectare of relatively smaller diameters at breast height. With the increase in the number of established planted forests for such purpose there will also be a need to use specialized equipment for harvesting, transporting and processing smaller diameter trees and in the quantity predicted. Specialized equipment may be necessary to minimize unwanted impacts to the surroundings environment (mainly soil, water sources and remaining vegetation), and increase production per unit of time and per unit of raw feedstock. In addition, planning of these operations for smaller diameter trees may be different than when planning for harvesting, transporting and processing larger trees; thus specialized training will be necessary as well.

7. Environmental considerations

When developing a policy or legal framework or planted forests management plan for second-generation biofuels it is crucial to recognize certain environmental issues. Increased biofuel production may, when poorly planned and implemented, provoke greenhouse gas emissions from degraded carbon sinks, reduced biodiversity, water pollution and eutrophication, (UNEP/CBD/SBSTTA, 2007). In the following sub-chapters the most crucial environmental considerations are presented.

7.1. Land use efficiency

Land is ultimately the limiting resource in biofuel production. There is a wide variation of biomass growth potential and hence land-use efficiency depending on the species, climate conditions, soil type and management of the crop. Second-generation feedstocks become more land use efficient as the whole above ground biomass is used in contrast to the first-generation crops where only one fraction of the plant is used.

It is estimated that European Union, with its 10% biofuel blending target for the transportation sector by 2020, would need to convert 70 % of its arable land to feedstock production if using only first-generation biofuel technologies. The USDA examined the land required for the domestic production of biomass to meet a biofuel blending target of 30% by 2030 using both first and second-generation technologies. The study shows this amount could be derived domestically while still meeting food, feed and export demands. The biomass needed amounts to approximately 1.3 billion ton and the biomass would be derived from agriculture and forestry. All of the forest resources in the study are sustainably available. The biofuel blending targets require a large amount of biomass and the importance of sustainable natural resource management and land use efficiency is consequently fundamental.

7.2. Energy efficiency

When evaluating a new biofuel production system, one consideration is the energy efficiency of the biofuel compared to the equivalent fossil fuel. Energy efficiency describes the extractable amount of energy produced compared to the energy needed to produce and process the biofuel. When evaluating energy efficiency it is important to include the whole life cycle of the energy unit in question, including the energy needed for the biomass production, the conversion process, the transportation costs and the efficiency of using the fuel in the vehicle including all transportation during the life cycle.

7.3. Greenhouse gas emissions

The efficiency with which greenhouse gas (GHG) emissions, such as carbon dioxide, methane and nitrous oxide are reduced, can be avoided using a biofuel is among other things related to:

- the amount and carbon intensity of the fossil fuel inputs needed to produce the biofuel;
- the ability of the crop to fix carbon from the atmosphere;

- which fossil fuel the biofuel is substituting;
- the land use changes directly attributable to feedstock production;
- co-products produced as a consequence of the product stream.

A complete life cycle analysis (LCA) of the biofuel from ”field-to-wheels” is needed to get a proper understanding of the greenhouse gas emissions, energy and other environmental relationships. Cellulosic feedstocks can contribute to greenhouse gas emissions reduction because they have a relatively high carbon capture potential and their cultivation is less energy demanding than non-cellulosic feedstocks (Cook and Beyea, 2000).

Life cycle analysis of greenhouse gas emissions of different biofuel feedstocks shows that site selection is fundamental (Fargione *et al*., 2008). Soils and plant biomass are the two largest terrestrial carbon stores containing 2.7 times more carbon than the atmosphere. Converting native habitats to cropland releases CO^2 as a result of a reduction in biomass, burning (fire is often used to clear land) or microbial decomposition of organic carbon stored in plant biomass and soils. Over time the amount of greenhouse gas emissions can be recaptured by the cultivated biomass and by using it to produce biofuel to substitute fossil fuels, and the so-called carbon debt be paid, but only if the feedstock has less greenhouse gas emissions than the life-cycle emissions of the fossil fuels they displaced. Until the carbon debt is repaid biofuels from converted lands have greater greenhouse gas impacts than those of the fossil fuels that they displace (Fargione *et al*., 2008).

The amount of greenhouse gas emissions emerging from land conversion depends on the type of land that has been converted. Certain types of land store more carbon than others. Above all, peat lands store large amounts of carbon. If the peat lands are drained and converted to other uses, the carbon stored in the peat will be released to the atmosphere and this creates a large carbon debt. Converting peat land should hence be avoided. Likewise, the conversion of tropical rainforest to planted forests or agriculture crops may lead to a large carbon debt. However, the conversion of degraded agriculture land to planted forests does not lead to carbon emissions and hence not a carbon debt (Fargione *et al*., 2008). The quantification of the carbon debt that appears from land conversion of different types of land is recent and further research is necessary to gain a more in-depth understanding.

7.4. Biodiversity

Biological diversity refers to diversity of flora and fauna, including micro-organisms, and the habitats that support them. Over the past centuries human activities have resulted in fundamental and irreversible changes of biodiversity. These losses are accelerating particularly during the past 50 years (MEA, 2005). Globally human demand for agriculture and forest commodities has been a major driver of this loss. With recent ambitious biofuel policies around the world biodiversity degradation should be particularly closely considered. Large scale biofuel production can have adverse impacts on biodiversity. The use of wetlands and natural forest for biofuel production is considered an important threat to biodiversity through deforestation, loss, fragmentation and degradation of habitat.

Second-generation biofuels are considered to potentially have beneficial impacts on biodiversity if trees are planted for rehabilitating degraded lands, combating desertification or restoring landscapes (Tilman *et al*., 2006). In some instances, replacing agriculture crop lands with planted forest can have a positive impact on biodiversity due to reductions in the use of pesticides and fertilizers and lead to greater animal biodiversity as the habitat is improved and natural ecosystems functions are restored (Cook and Beyea, 2000). Particularly bird populations and under-story vegetation favouring habitat for small mammals could potentially benefit. An ecosystem-wide planning program including riparian reserves and naturally regenerating forest corridors should be integrated into planted forest planning and management.

Even when the production costs of second-generation biofuel technologies become more commercially viable, the production may still be capital intensive (Larson, 2008). Such concerns contribute to the doubts that the second-generation biofuel feedstock should be produced on marginal lands. Deforestation is a plausible threat that needs to be taken seriously in consideration. As the demand of wood for traditional purposes (pulp, paper and hard wood) is unlikely to diminish during the coming decades and the need of additional land for the production of biomass for biofuel emerges the pressure on natural forests may increase. Fast growing tree plantations may, however, diminish this pressure. Planted forests may never replace all the biodiversity value or benefits of natural primary forests, but may reduce harvesting pressure on ecologically significant forest ecosystems elsewhere.

Indigenous species are to be preferred for planted forests where they meet required growing rates for liquid biofuels. Introduced species should be selected in relation to specific management objectives, market conditions and ecological site conditions. Caution should be observed in using genetically modified trees, as their long-term impacts may not be known despite the fact that there are signs of large scale interest in the use of genetically modified crops in the production of second-generation feedstocks. The emergence of genetically modified crops could result in cross-pollination of wild relatives, thereby affecting biodiversity. By using crops that have the characteristics of a weed, such as jatropha, may become invasive (UNEP/CBD/SBSTTA, 2007).

8. Food security and sustainable livelihoods

Energy policies may have vast cross-sectoral impacts on the lives of people far away from the country where the policies are adopted since the market for liquid fuels is highly global. In the following chapter the threats and opportunities linked to the commercialization of second-generation biofuels and food security and sustainable livelihoods are outlined.

Food security exists when all people, at all times, have physical and economical access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 1996). According to FAO some 850 million people are undernourished (FAO, 2006). The majority of these people live in South and East Asia but by far the greatest proportion of undernourished people of a population is found in Sub-Saharan Africa.

The concept *livelihood* is a broad and normative concept responsive to people's own interpretation and priorities. People from different economic, cultural and social backgrounds may experience sustainable livelihoods very differently depending on their needs and priorities. Sustainable livelihoods can though be explained by the following definition: *A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base* (Chambers & Conway, 1992). Even if the concept of sustainable livelihoods is given an exact definition it is still not an absolute measurable parameter but a state of wellbeing that each individual experience from a personal point of view in relations to both his or hers needs, priorities and values in life.

8.1. Commodity price impacts

One of the sharpest criticisms towards first-generation biofuels is the possible negative impact on food security. Food prices are increasing partly as a consequence of the increased production of first-generation crops such as sugar, maize, cassava, oilseeds and palm oil as feedstock (CFS, 2008). This can create stress on urban or import reliant communities who must divert larger proportions of their income to food needs. Rising food prices are however not entirely due to biofuel production. Increasing consumption of meat and climate change are also contributing to higher food and feed prices (FAO, 2008).

Confidence is now increasingly put in second-generation biofuels. Lignocellulose is not a food crop which decreases the competition of arable land between the food and biofuels that appears in the production of first-generation biofuels. If, however, the cellulosic biomass comes from a dedicated plantation the feedstock still uses land that potentially could have been used for food production. In this case second-generation biofuels could also have a negative impact on food security. In the case where the second-generation feedstock consists of agriculture or forestry residues the competition does not appear.

Second-generation biofuel feedstock can theoretically be produced on marginal land. There is however no guarantee that the second-generation feedstock crop will be established on marginal land, and land tenure security is likely critical to realizing the benefits of any shifts away from subsistence production of food crops. This is an issue to be recognized in future bioenergy related regulations and policies.

Biofuel feedstock production may provide higher incomes for small-scale farmers. This is the case concerning first-generation biofuels through augmenting food prices (FAO, 2008).

8.2. Employment opportunities

Biofuel production can provide employment opportunities (Brown, 2006). Local biofuel production can foster the local economy by increasing business opportunities and income for farmers. In this context, biofuel production may lead to poverty alleviation and food security in rural areas (Coelho, 2005).

What kind, how profitable and how many jobs will be created depend on the production system and tenure rights. Due to the major technology involved in second-generation systems economies of scale is likely to be more significant than in fist-generation biofuels, especially concerning thermochemical conversion. Second-generation technologies generally are developed in industrialized countries to suit their own needs; capital-intensive, labour-minimizing, and designed for a large-scale installation to achieve best economics. In addition biomass technologies are designed for biomass in industrialized countries. These facts raise the question how less developed countries may be able to capitalize and adapt second-generation biofuels technologies. In order for second-generation biofuel industries to be competitive with industrialized countries it is crucial to adapt conversion technologies to reduce capital intensities and increase labour intensities in order to create greater employment opportunities.

Large scale, industrial, intensively managed planted forest where owned and managed by the industry offer limited job opportunities. Employment opportunities are usually connected specially to planting and harvesting periods, with marginal opportunities in between. There are examples of plantations where plantation and harvesting practises are carried out throughout the year (Cossalter and Pye-Smith, 2003).

There are, however, other issues than the number of jobs opportunities that need to be addressed. For example, how much the jobs pay? Which job has more stability? Which job is safer to do? Larger firms tend to pay their workers higher salaries than small-medium enterprises – some 35% more in developed countries and as much as 50% more in less developed countries is one estimate of the differential across a range of sectors (Biggs, 2002).

Whether or not planted forests increase or decrease employment and benefit to local people depends on the activities they replace and in the way the wood is processed. If planted forests are established on fertile agricultural land, the chances are that the number of jobs is reduced, especially in less developed countries. However, when planted forests are established on land that has either been abandoned or has previously been in little use to farmers or others, then the plantation activities may bring in new jobs to the area. Where planted forests are established on degraded or unused land, or where alternative agricultural employment is low, or where rotation cycles require continuous replanting, maintenance and harvesting – there may be high employment benefits. Employment in timber production generally, however, tends to be less labour intensive than agriculture – thus forestry's employment creation and general success has been greatest where agricultural potential is lower (Angelsen and Wunder, 2003; TFD, 2006).

Forest industries in many parts of the world draw a large part of their wood and fibre raw material from small growers, generally farmers. The potential advantages of such arrangements include the benefit to industry of limiting the need to invest in land, labour and the other costs of managing and harvesting a forest resource, and the benefit to growers of an assured market and access to technical services. There is a wide range of partnership between companies and communities with different arrangements between the growers and processors, such as:

- partnerships in which growers are largely responsible for production, with the company guarantee that it will purchase the product at harvest time;
- partnerships in which the company is largely responsible for production, paying landholders market prices for their wood allocation;
- land lease agreements in which landholders are not greatly involved in the plantation management;
- arrangements where the forestry company and the landholder share the production and the market responsibilities and the risks, dividing the returns in proportion to the level of inputs.

These kind of collaboration is called outgrowing schemes. The outgrowing schemes may have both a positive and a negative impact on sustainable livelihoods and land-use. It offers an additional income and employment possibilities for local communities. The outgrowing schemes diversify the farm production and offer a production opportunity of using underutilized land. The environmental risks are being diminished when the planted forests are spread to many smaller sites. There is generally increased community support towards the company when developing forestry that provides a broader social and economic enrichment for the individuals and communities. However, a partnership may also be negative for the producer in case that the price offer is too low and the contract period long.

8.3. Tenure rights

The increased need of land to produce sufficient biomass to meet the demands of new bioenergy markets raises the need for secure land tenure. Security of land tenure is important to the effective, sustainable development of planted forest programmes. Private investors, large or small, corporate, smallholder or community, require the security not only of good governance but also of legal tenure to the land and the crops they own or rent. A rapid evolvement of the bioenergy sector puts pressure on the often slowly adapting land policies and the governance of these.

Planted forests may be developed under different ownership mechanisms, with the increasing emergence of corporate/smallholder contracts or partnerships. Duration, assurance, robustness and excludability have been identified as being the main legal elements in secure tenure arrangements. While forest policy reforms may be introduced to encourage participation, the laws are often not changed to give clear, formal and long-term recognition of rights and responsibilities, or are not changed completely. The actual implementation and governance of policies and laws are furthermore a major challenge. Security of tenure may not be robust if all or certain rights are limited by time, or if decision-making power has not been properly devolved permitting stakeholders to exercise their rights, to participate and to take decisions. As with the issue of rights of access or use of land, trees or both, the development of secure land tenure for planted forests will require consultation, conflict resolution and shared decision-making in order to meet also the needs of the poorest, the landless and the marginalized. The acknowledgement and recognition of customary rights may be necessary. Consultation with other land users will also be necessary. The opportunity may have to be taken to develop a new land-use policy and/or to resolve and harmonize conflicting land-use legislation that may impact tenure. Even decentralization may lead to conflict in tenure, or to marginalized groups being disadvantaged.

9. Market, trade and development outlooks

The market dynamics of liquid transportation fuel are undergoing a fundamental transformation. Until recently approx. 20 nations provided the liquid fuels for the rest of the approx. 200 nations in the world. In the future more countries will be producing at least a part of their liquid fuels themselves and hence the dependence upon the fossil fuel exporting countries will decrease.

The rapidly increasing biofuel production is driven by rising fossil fuel prices and the ambitious blending targets in EU and the USA. The market and trade developments of second-generation biofuels will largely depend on political incentives for the development of the technology in question and the production of the biofuel. For the moment all first-generation biofuels in the world, with an exception of bioethanol from sugar cane in Brazil, are subsidised. The first-generation biofuels now existing on the market, outside Brazil, are not able to compete without subsidy unless oil price is above 50-70 US dollars per barrel (Larson *et al.*, 2008). Second-generation biofuels are still far from this target. Thermochemical systems with relatively modest further development and demonstration efforts could be commercially produced in a few years. This is because many of the equipment components needed for biofuel production are already established for the production of fossil fuel conversion. Where thermochemical biofuels production can be integrated with a facility producing biomass by-products, such as a pulp and paper industry, thermochemical biofuels can be competitive at a much lower fossil fuels price, approx. 50 US dollars per barrel oil in the United States (Larson *et al.*, 2008). In countries where biomass production is lower than in the United States due to better site conditions, and where construction and labour cost are lower, thermochemical biofuels will compete at oil prices lower than 50 US dollar per barrel oil.

There will be a need for a strong international feedstock and fuel trading system since relying on a domestic production alone would be risky because of weather and other market liabilities. New trade dynamics will appear between traditional fibre markets and second-generation fuel markets and it remains to be seen how flexible these are.

As mentioned in the previous chapter research and development of second-generation biofuel technologies are mainly done by industrialized countries and the transfer of knowledge to developing countries will be challenging, especially if it is done in a manner that it would contribute to poverty alleviation by creating job opportunities. It will be important to establish an innovation system involving a broad set of stakeholders such as:

- research centres transferring knowledge from the global community to local needs;
- industries with capacity and interest to form joint ventures with foreign companies;
- government agencies supporting activities and providing a necessary policy and legal framework.

This kind of well functioning innovation systems is a key reason of the success of the Brazilian ethanol program. Similar systems are also set in place in China and India.

It is difficult to project which role less developed countries will take in the production of second-generation biofuels. One possibility is that the less developed countries will only become providers of biomass. A more desirable development would be their becoming producers, users and exporters of finished biofuels in order to maximise the value added gains and can also be a possibility for existing forest industries to use the waste.

The evolving second-generation biofuel sector may provoke a new competition for wood products that may have an influence on the traditional wood market raising wood prices.

10. Conclusion

During the coming years the demand for energy will continue to increase. Climate change, high fossil fuel prices, energy security and rural poverty are issues pushing towards a change to renewable energy sources. In many parts of the world hope is now put on liquid biofuels, a fuel produced from raw materials existing in abundant amounts in most countries in contrast to oil that is very unequally distributed over the planet. Restructuring the energy market will have vast cross-sectoral impacts on both on a financial, social and environmental level. The implementation of policies and economic incentives needs to be thoroughly thought through in order to minimize the possible negative impacts.

The availability of land for the production of biomass and the competition between food and biofuel prevails as fundamental. Through the development of the second-generation biofuel sector a competition between traditional forestry commodities and biofuel is additionally likely to emerge. Fast growing planted forests can be an efficient way to produce biomass. In the search for a sustainable energy sector second-generation biofuel technology could be part of a larger solution as one of several components. Second-generation biofuels have clear advantages compared to first-generation biofuels. Planted forests produced as biomass for liquid biofuels have the potential of being land use efficient, and carbon neutral or even carbon negative. However, production on marginal land also means lower production levels, which increases the costs of biomass production. Appropriate planted forest management practises are needed such as choosing the right site, the right germplasm, species, protection, nutrient and water management, and silviculture and harvest practices.

More research needs to be conducted in order to remove the bottle necks that currently make the production of second-generation biofuels too expensive to compete with other fuels. The technological developments are already moving fast. For this reason it is crucial to act swiftly in order to establish sustainable policy supported by a legal framework. Second-generation biofuels can offer a sustainable energy production model. This is, if the production planning, execution and management are done in a thorough and sustainable manner, recognizing good planted forest management practices as well as taking in consideration social and cultural values. Sustainable planted forest management plans should be implemented on all levels; international, regional, national, provincial, local among governments, corporations and communities.

Information sharing and cooperation should be encouraged as well as cooperation between the different planted forest stakeholders in order to accelerate development of the sector and create poverty reduction opportunities.

11. Recommendations

Recommendation 1. Promote research on second-generation biofuels. Special emphasis is to be given to developing a commercially viable technology that provides an energy efficiency and carbon neutral or preferable carbon negative biofuel.

Recommendation 2. Promote international cooperation to find solutions to diminish the competition between food and biofuels.

Recommendation 3. Promote development of guidelines concerning site and species selection of the planted forests in order not to provoke green house gas emissions due to land use changes or threaten biodiversity hotspots.

Recommendation 4. Promote sustainable planted forest management practices on all levels; international, regional, national, provincial, local among governments, corporations and communities (biodiversity, water, nutrition, social issues, tenure rights).

Recommendation 5. Promote poverty reducing production scenarios that would offer employment opportunities for small-scale farmers.

Recommendation 6. Promote a participative approach of information sharing and cooperation between the planted forest stakeholders.

Recommendation 7. Promote more research on the use of residues on forest soil productivity.

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